AUA Working Paper Series No. 2011-3
9/9/2011

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Abstract

The purpose of this study is to evaluate ethanol cost- effectiveness with regards to carbon dioxide emissions. Actually, bio-fuel production is only viable thanks to the tax credit policy resulting in economic 'deadweight' loss. The environmental performance is assessed under the Life Cycle Assessment (LCA) framework. Economic burden to society to support the activity divided by avoided CO2 equivalent emissions indicates the bio-ethanol cost effectiveness.

Agricultural feedstock supply that comprises of sugarbeets, grains and industrial processing sub-models are articulated in a regional sector model. The maximization of total welfare determines optimal crop mix for farmers and the best configurations for industry. This is illustrated for bio-ethanol produced by the ex-sugar industry in Thessaly, Greece. Life cycle activity analysis showed that, at the optimum, CO_2 emission is reduced between 1 and 1.5 t of carbon dioxide equivalent per ton of ethanol. The unitary cost falls in the range of 100 to 250 euro per ton of CO_2 and it is remarkably dependent on the agricultural policy scenario.

***Keywords*.** Cost effectiveness, ethanol, mathematical programming, life cycle assessment, greenhouse gases

Introduction

Recent changes in European policies concerning the sugar and the bio-fuel sector that completes the Common Agricultural Policy (CAP) reform in 2003, has created favourable environment conditions for ethanol production by ex-sugar factories in Europe, also in countries that had not participated in the first wave of biofuel production in the nineties. Biofuel activity had gained momentum when positive synergies with agricultural policy goals appeared thanks to a pivotal element of the 1992 CAP reform, namely the obligatory set aside measure not applied to energy and in general industrial crops. Governments starting from France followed by Germany and other countries proceeded to exempt biofuels from taxes on petroleum products so that they become competitive in the energy market. Complete or partial decoupling of subsidies from production, the basic feature of 2003 CAP reform, have been implemented since the cultivation period 2005-2006. As a result earmarked gross margins for particular crops are drastically reduced (i.e. previously heavily subsidised arable crops) decreasing the opportunity cost of introduction of energy or alternative crops in the cropping plan. Additionally, according to changes in the EU sugar regime and the WTO ruling, the Common

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Market Organisation in the EU has excluded the sugar quota restriction (EC, 2005) on sugar beet production for non-food use (chemical and pharmaceutical industries and for energy purposes). As a result, several studies have been quickly conducted to evaluate ethanol production projects and the sugar industry perspectives within the EU (Anonymous, 2006, Bzowska-Bakalarz & Ostroga, 2010) but also in other countries facing similar conditions (Icoz et al., 2009).

Almost two decades after the removal of the tax exemption program in Europe, bio-fuels are still more costly than fossil fuels, and the agro-energy industrial activity largely depends on government subsidies for its viability. Even if the recent rise in crude oil prices alleviates the budgetary burden that bio-fuels represents, 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. Environmental problems have become more acute and international commitments mean that the abatement of Greenhouse Gas (GHG) emissions requires intensified efforts. Assuming that the main positive environmental effect of biofuel is the reduction in GHG emissions, the question arises as to whether subsidies for bio-fuels can be justified on cost effectiveness grounds. Cost-effectiveness regarding GHG has recently been assessed for biodiesel alternative schemes in Greece (Iliopoulos and Rozakis, 2010). In this paper, industrial transformation integrated to an agricultural supply model simultaneously estimates optimal bio-ethanol activity and subsidy levels as well as life cycle greenhouse gas emissions. These elements are used to evaluate the GHG effectiveness of the conversion of a sugar factory to ethanol production in the region of Thessaly, Greece. Economic costs (budgetary burdens, minus agriculture and industry surpluses) are put in the numerator; in order to estimate the cost effectiveness ratio, it has to be divided by the environmental impact. It can be used for comparisons with alternative ways of GHG emissions reduction.

It is said that bioenergy is carbon neutral, because carbon sequestered from the atmosphere during biomass growth is released when this biomass is used as a solid or liquid fuel after its transformation. However, production, transport and processing of biomass require energy and material inputs, adding directly or indirectly to GHG emissions. Studies on bioethanol (Murphy and McCarthy, 2005) that detail agricultural production, transportation as well as industrial transformation phases conclude that crop production contributes significantly to the greenhouse effect. Beside fuel use for cultivation operations, emissions due to fertiliser application should be considered including fertiliser production, but also N_2O emissions from soils (Brentrup et al., 2000). Greenhouse gas emissions associated to agricultural production are measured based on the explicit assumptions of land use change[2] (LUC). One could mention pioneering works concerning miscanthus in fallow land (Lewandowski et al., 1995) or more recent ones regarding short rotation coppice, miscanthus and rapeseed replacing wheat in arable land, grassland or broadleaved forest (St. Clair et al., 2008), wheat on arable land or grass-covered mineral or peat soil (Börjesson, 2009), wheat monoculture (Scacchi et al., 2010) and rapeseed on set aside land (Malça and Freire, 2010). It is generally admitted that the greenhouse footprint of biofuels depends to a large extent on the benchmark situation that may render them good or bad according to Börjesson (2009).

[2] Direct LUC: conversion of a land (cultivated land or not) into biofuels production

Environmental impacts are further differentiated if indirect land use changes[3] (iLUC) are taken into account. According to several studies (Searchinger et al., 2008; Wicke et al., 2008) indirect land use change induced by increasing bioenergy demand may result in important environmental impacts concerning GHG emissions. Current life cycle assessments of GHG effects often fail to take account of indirect LUC (Malça and Freire, 2010; Kløverpris et al., 2008a). Relevant research recently published does not ignore the indirect LUC (Russi, 2008, Lechon et al, 2011), based though on direct LUC that is rather arbitrarily calculated. Nevertheless methodological guidelines are provided by Kløverpris et al. (2008b) to determine LUC with prospective or consequential LCA taking market mechanisms into account. On this track, the present study attempts to estimate GHG resulting from bio-ethanol production in the region of Thessaly with a special emphasis in land use change. Ethanol production triggered by the tax credit policy, the subsequent demand on raw material by the ethanol plant and farmers' response regarding cultivation decisions, are the outcome of supply models determining at the optimum crop mix and rotations.

For this purpose, the arable agriculture of Thessaly that provides raw material for the ethanol plant is modelled by means of a microeconomic partial equilibrium approach. The market equilibrium is derived from maximisation of agro-industry system welfare subject to agronomic, institutional, market and resource constraints. Various configurations of ethanol plant size and technology and regional land use plans may be generated within the context of alternative technical, market and especially policy assumptions. It is observed that different policy variants may result in different bio-ethanol activity levels, and consequently altered cost effectiveness regarding GHG emissions. As a matter of fact, this analysis proves that GHG emission savings due to ethanol are sensitive not only to energy policy but also to agricultural policy conditions at a large extent.

This paper is organised into six sections, including this introduction. Section 2 introduces the concept of Life Cycle Activity Analysis (LCAA) approach, which is mathematical programming adjoined to the environmental Life Cycle Assessment framework. Section 3 presents the integrated sector modelling methodology, and the following, section 4 details greenhouse gas emission estimation. The case study and the optimisation results are presented in section 5. Discussion and ideas for further research conclude the paper.

Integrating Activity models and LCA: Life Cycle Activity Analysis

Activity Analysis (AA) was developed in the early fifties, (Koopmans, 1951) and have been reformulated as a Linear Programming (LP) problem, accommodating any number of activities and any number of commodities (Charnes and Cooper, 1961). Activity Analysis can be viewed as a tool of partial economic analysis modelling for the representation of an industry or a sector of the economy, providing a mathematical format suitable for the representation of an entire vertical production chain (Thore, 1991). More recently, Heijungs, 1997 recognised the conceptual similarities between LCA and classical Activity Analysis (AA) and observed that Life Cycle Inventory is an extension of AA, both being "commodity-by-industry analysis", generally seen as

[3] Indirect land use change: an energy crop replaces a food crop. The food crop must be produced elsewhere (in a case of a constant food demand)

superior to other forms of inter-industry analysis, however no connection between mathematical programming and LCA was made. Such an integration of Activity Analysis with the environmental Life Cycle Assessment methodology, which aims to quantify the environmental impacts of a product from 'cradle' to 'grave', is known as Life Cycle Activity Analysis (Freire and Thore, 2002).

The classical formulation of AA distinguishes three classes of goods: primary goods (natural resources, materials or labour), intermediate goods (outputs which serve as inputs into subsequent activities) and final goods (outputs). LCAA extends the concept of economic activities to embrace mass and energy fluxes over the entire life cycle of products. In particular, the proposed LCAA model includes one additional category: "environmental goods", representing primary resources (material or energy drawn directly from the environment) and emissions of pollutants and the disposal of waste (discarded into the environment without subsequent human transformation).

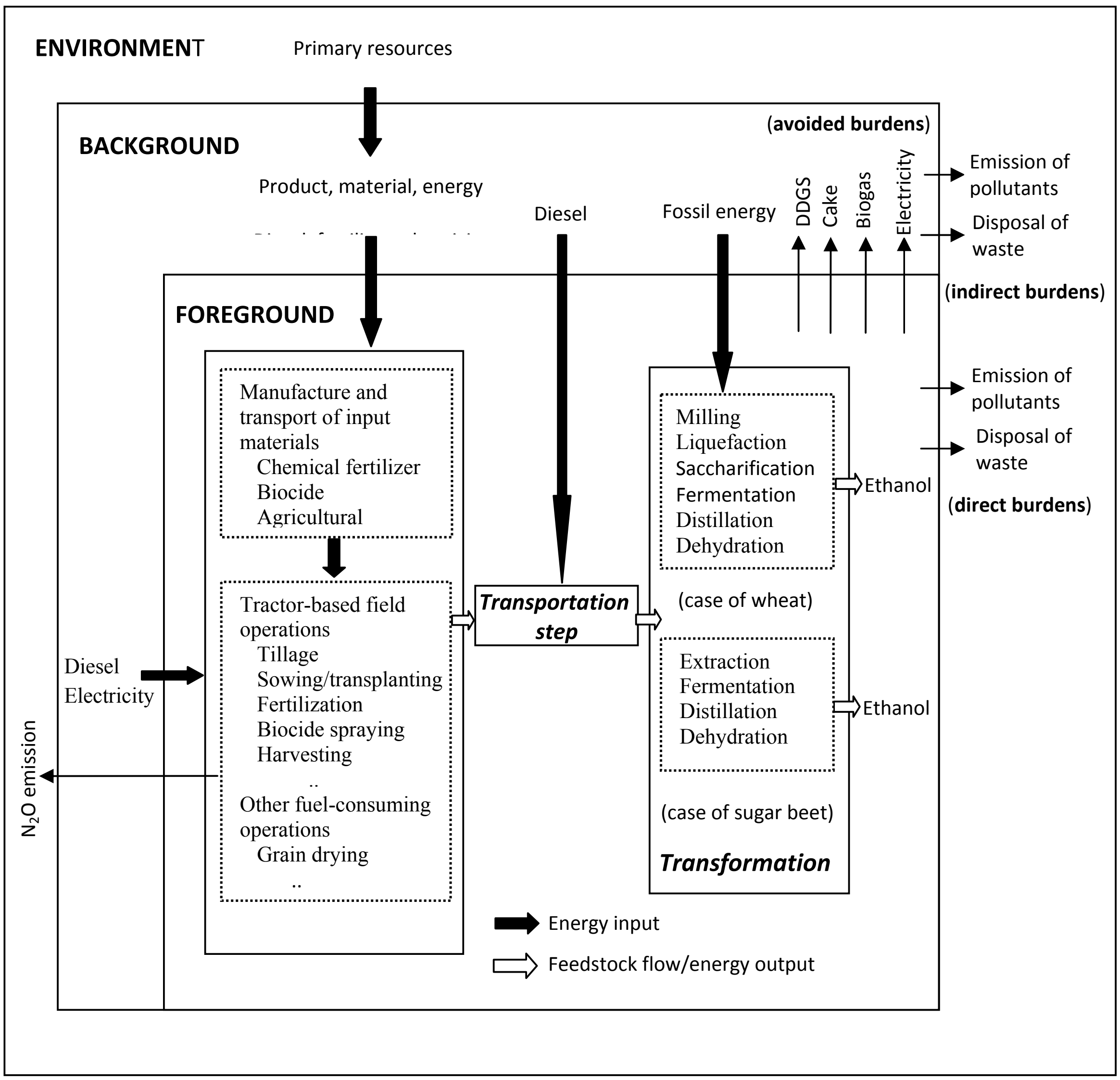


Figure 1. Foreground and background system for bioethanol production

The concepts of "foreground" and "background" proposed within the environmental systems analysis theory are very useful since they help to distinguish between unit processes of direct interest in the study, and other operations with which they exchange materials and energy, (Clift et al., 2000). The foreground may be defined as the endogenous part of the production chain, which includes the set of processes whose selection or mode of operation is affected directly by the decisions of the study. The background denotes the exogenous parts of the production chain, comprising all other processes that interact directly with the foreground system, usually by supplying material or energy to the foreground or receiving material and energy from it. These concepts are illustrated in Figure 1 adapted in the bio-ethanol production case. Adopting these concepts and terminology, a complete life cycle approach must pursue the production chains both upstream (all the way to their "cradle") and downstream (to their "grave"). Thus, the total environmental impacts are calculated over both the endogenous and the exogenous part of the life cycle.

In the case of bioenergy beside greenhouse gases, various environmental dimensions such as eutrophication, ecotoxicity, acidification, smog, human toxicity, ozone depletion are usually treated through LCA. Results can be analysed by using multicriteria methods (Rozakis et al., 2002) or by applying composite indices (Tsoutsos et al., 2010). This latter study compares biodiesel from different sources in Greece, namely sunflower, rapeseed and soya exploiting state-of-the-art LCA software that provides sophisticated information on various environmental impacts. However it is assumed that energy crops to be cultivated use not only the existing machinery but also similar inputs as existing cultivations, in other words land use change is not taken into account. On the contrary in the present paper, environmental considerations focus on impacts to the greenhouse effect only, nevertheless exploiting mathematical programming of the ethanol production much emphasis is put in land use change.

Modelling of the bio-fuel production system

The bio-ethanol integrated model consists of agricultural and industry components. Gross margin for farm is determined by total revenue earned from selling products and by-product deduced by variable cost. Industrial profit is determined by revenue earned from product and by-product in a year deduced by annualised total cost of the industry. The objective function represents total agents' surplus that is the sum of surplus (gross margin) generated from agriculture and profit earned by the industry. Welfare is maximised subject to constraints related to agricultural and industrial production. The model specification is detailed in Haque et al. (2009).

Industry model

Industrial models of bio-energy conversion seek to determine optimal plant size and appropriate technology. The main relationships shaping the feasible area deal with capacity, sugar-beet to wheat ratio to ensure maximal duration of operation during the year (330 days), and capital cost linked to size (average capital cost is decreasing for increasing ethanol capacities). Usually size determination is modelled by binary or integer variables, as in a bio-energy application (Mavrotas and Rozakis, 2002) that also mentions a number of studies of the same kind. In this study, since a continuous relationship is available (Soldatos and Kallivroussis, 2001) we preferred to introduce exponential terms (scale coefficients) in the objective function rendering the industrial module non-linear. Furthermore, feedstock supply i.e., wheat and sugar beet produced in farms, have to satisfy industry needs (raw material demand should be greater than supply). A number of balance constraints concerning by-products, material inputs and environmental balances complete the model structure. Detailed information is included on capital and administrative costs (which decrease with plant size), on variable conversion costs (proportional to the output), as well as on transport costs (increasing with plant size). Raw material costs are often assumed proportional to the output and biomass price is perfectly elastic thus constant no matter the quantity demanded by the plant. A typical example of this engineering approach for plant size optimisation is a model by Ngyen and Prince (1996) on bio-ethanol from sugarcane and sweet sorghum in Australia. However, we would expect that over a certain demand level, marginal increases in biomass quantity would result in higher price to pay to acquire it. This is determined through modelling of agricultural supply.

The agricultural sector model

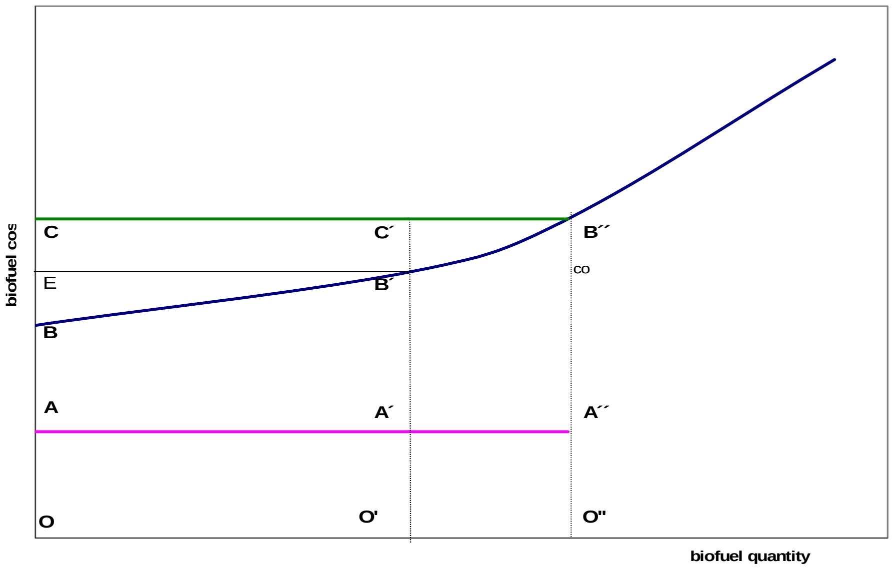
Partial equilibrium micro-economic models of the farm sector are coupled to agro-industry models to analyse the introduction of energy crops in the crop mix. For instance, (Treguer and Sourie, 2006) have estimated the agricultural surplus generated by the production of energy crops including sugar beet-to-ethanol in French arable areas, and assessed how these new crops can help to maintain farmers' income and farms' structure. A large number of individual farms are articulated so that to adequately represent regional arable agriculture. Each farm selects a set of activities (cropping plan) in order to maximize gross margin. The farm planning is governed by resource availability, technical and policy constraints. Main constraints are: available land (both total land area and area by land type such as irrigated, non-irrigated etc.), irrigation water availability, crop rotation, market quota and flexibility and policy (such as cross-compliance) constraints.

Biofuel economics and deadweight loss

Since biofuel production cost is normally higher than its market value, public policy to support biofuel take-off opted for tax exemptions from taxes imposed to fossil fuels. In this case, unitary tax credit along with eligible quantity needs to be determined. These values are based on critical parameters; budgetary expense earmarked for biofuels is the most important. Figure 2 illustrates the above process and displays surpluses and deadweight loss. Suppose that *CC´A´A* shows the budget available for biofuel support, then given that biofuel market value is equal to OA (fossil fuel market price), a tax credit of CA is required for the biofuel to become competitive. Then quantity eligible for tax exemption amounts at *OO´* that makes surplus for the agricultural sector equal to the area *EBB´* and for the industry to *ECC´B´*. The loss for the economy (deadweight loss) due to the voluntary policy supporting biofuel activity is the difference between the budgetary expenses and the agents' total surplus that is the area ABB´A´. The integrated model can minimize economic cost selecting the most efficient production system simultaneously determining tax exemption values per unit of biofuel volume given fixed amounts of government expenditure. To estimate the cost of CO_2 emissions saving per unit and subsequent cost effectiveness, net saving have first to be calculated in physical units.

Figure 2. Economic surpluses generated by biofuel production

BB´B´´: biofuel marginal cost curve =biomass opportunity cost + conversion cost - co product value
OA: biofuel market price (perfectly elastic demand)= equivalent gasoline value
OC: biofuel value=biofuel market price + tax exemption (AC)
CC´A´A: total budget earmarked to biofuel
OO´: biofuel quantity allowed to be produced (agreements approved by the government that depend on earmarked budget)
CA: tax exemption to biofuel (depends on budget and industry lobbies)
EBB´: producer (agricultural sector) surplus
ECC´B´: industry surplus



Estimation of GHG emission in ethanol production system: Methodology

Direct and indirect fossil energy used along the ethanol production chain is reported in primary energy sources terms. Fossil energy is calculated on the basis of amount of fuel and fertilizer used in the biomass production process. Soil carbon loss on conversion on land uses is significant in cases of forest and grass land converted to arable land. Also conversion from conventional to reduced tillage accumulates soil carbon. Crop conversion under the same tillage practice is assumed to have no effect. GHG costs related to the manufacture of the farm machinery and buildings are likely to be similar for the baseline land use (arable crops). Other substances such as pesticides and herbicides are not included in this analysis due to lack of data as relevant papers on these latter report minimal GHG impact (St Clair et al., 2008).

The energy used in the industrial processing is also calculated on the basis of primary energy. For example, steam power is used for industrial processing and steam is generated by fuel oil. Thus, amount of fuel oil used for steam generation is considered for steam energy. In addition GHG emissions from nitrous oxide are assessed.

Life cycle emission factor is used to calculate CO_2 emission from respective energy source. Both direct emission from combustion and indirect emission prior to combustion emitted for extraction, collection, refinement transportation to the consumer of the fuel (DEFRA, 2010) are considered including net CO_2, CH_4 and N_2O emissions.

GHG emission in agricultural production

To assess GHG emissions in agricultural production, all operational activities such as ploughing, sowing/transplantation, fertilisation, irrigation, harvesting etc. and input/material associated with crops cultivated in the region (both conventional and energy crops) have been taken into consideration. Carbon dioxide emission for machinery operation is calculated by the amount of fuel (diesel) used multiplied by emission factor. To calculate emission from fertilizer, the amount of fossil energy used to produce fertilizer is accounted for. Natural gas, coal and oil are used for the production of different fertilizers. Fossil energy requirement for fertilizer and associated CO_2 emission is presented in Table 1. Calculation of total GHG emission for different fertiliser contents (last row in table 1) can be presented with the following matrix notation.

GHGemiss(element) = unitGHGemiss(energy type) X energyContent(energy type, element) [1]

The row vector contains emission factors i.e., kg CO_2 emission per kg fossil energy (natural gas, oil, coal, respectively) whereas fertiliser ‘energy content’ matrix contains required amount (kg) of fossil energy (natural gas, oil, coal, respectively) for the production of 1 kg fertilizer (N, P_2O_5, K_2O) in column.

Table 1. Fossil energy requirement and CO_2 emission per kg fertilizer (Malça, 2002).

Energy type	LCA CO_2 coefficient	Elements in fertilisers	N	P_2O_5	K_2O
Nat gas	3.116		0.947	0.226	0.143
Oil	3.45		0.0546	0.188	0.0334
Coal	2.83		0.0254	0.0306	0.0316
Electricity	0.618*				
Gasoline	3.152				
Total emission			**3.211**	**1.44**	**0.65**

**in kg CO_2/kWh. Electricity factor depends on energy mix specific to the region*

N_2O emission from additions of nitrogenous fertilizer to land due to deposition and leaching is also estimated. Here, emissions of nitrous oxide from land are estimated from the latest IPCC model (IPCC, 2006). According to IPCC model, 1% of nitrogen fertilizer used is directly emitted as N_2O and 1% of direct emission is emitted indirectly. The greenhouse potentials of N_2O is 296 times of CO_2 (IPCC, 2006).

When the optimal crop mix is determined by whole-farm budgeting models, like linear programming ones, then due to the constraint structure, the cultivation of a new crop may result in combinations of cultivations replacements. Emissions are then calculated as differentials based on crop greenhouse gases coefficients and marginal changes in crop mix at the farm level, identifying to the substitution method. Thus depending on various energy intensities of different crops, introduction of energy crop in the plan could reduce overall emissions, provided that the new crop rotation is less intensive compare to the previous one.

CO_2 emission in subsequent phases

GHG emissions during transportation and industrial transformation are proportional to the ethanol produced. Emission during the industrial processing is largely dependent on what fuel is used to produce the heat, steam and electricity required for manufacture of bioethanol. Energy input for the transformation process assumed to be the highest part in bioethanol production system. Hence, bio-energy based efficient industrial processing system can drastically improve GHG balance (Koga, 2008).

To estimate GHG saving in the final stage (fuel combustion), life cycle GHG emissions of gasoline are considered as reference for comparison with ethanol. Hence, it is necessary to derive the fuel equivalency ratio between ethanol and gasoline. In terms of fuel efficiency, gasoline is found more fuel efficient but efficiency varies significantly on the types of vehicle engine. Warnock et al. (2005) mentioned that fuel efficiency of automobiles is reduced by 27 percent on E-85 compare to pure gasoline. Macedo et al. (2008) derived and adopted an equivalence of 1 l ethanol (anhydrous) to 0.8 l gasoline, that is also suggested by Nguyen et al. (2009). Considering all types of vehicle and findings of above mentioned writers, fuel efficiency of ethanol is considered 80% of gasoline.

Case study for the Thessaly region

Agricultural Sector to supply biomass for energy

Data on farm structure, costs and yields for farms which cultivated at least one stremma (one tenth of a hectare) of cotton or sugar beet for the cultivating period 2001-2002 were used in the case study. A group of 344 arable farms out of all farms monitored by the Farm Accountant Data Network (FADN) satisfy the above constraint, representing in total 22,845 farms of the region. Main crops cultivated by those farms are: Soft wheat, Durum wheat, Maize, Tobacco, Cotton, Dry cotton, Sugar beet, Tomato, Potato, Alfalfa, fodder maize and intercropped vetch to conform with the cross compliance term of the new CAP. Data items by crop and by agricultural farm in the sample were: output (kg/ha), prices (€), subsidy (€/kg and €/ha depending on the type of crop) and the variable costs (€/ha). Variable cost includes: Seeds and seedlings purchased, fertilizers and soil amelioratives, protection chemicals, fuels and lubricants, electrical energy, water, running maintenance of equipment, maintenance of buildings and landed improvements, salaries and social taxes, and wages of hired labour.

It is assumed that farms holding a sugar-beet quota in 2002 and possessing considerable experience on its cultivation (since they had multi-year contracts with the sugar industry) will be the first and presumably most efficient suppliers of the ethanol plant with beet. However ethanol exclusively from beet processing cannot last for more than three months due to its perishable nature with regard to sugars. In order to ensure profitability for the ethanol plant it is important to spread capital and administrative charges over a longer period. It points out to the attractiveness of using mixed crops, in this case beet and grains, to extend the processing season that can thus count 330 days per year. The cultivation of wheat in irrigated parcels is considered to supply ethanol plant by grains, first because output is much higher than that of non-irrigated wheat and secondly because it means extensive cotton cultivation replacing monoculture with cotton-wheat rotation (Rozakis et al., 2001) with beneficial effects on cropping system sustainability.

Sugar industry converted to ethanol production unit

Technical and economic data for the production process of ethanol and determination of various costs for the industry model are drilled by Soldatos and Kallivroussis (2001) adapted to the conditions of ex-sugar factory in Thessaly by Maki (2007). The base capacity of the unit (35000 t EtOH) determines the cost of investment, the cost of equipment, the requirements for the workforce and a line from costs (direct and indirect) that concerned the economic analysis as well as a pattern of the final cost of the first and auxiliary matters, the cost of electrical energy and steam, the cost of maintenance and other costs of operations that concern the production and the administrative support of the unit. A scale coefficient of 0.61 is used in an exponential function linking capital costs to plant capacity denoting increasing costs in decreasing growth rate. Allowable capacity sizes vary from 10000 to 120000 t. Furthermore transformation ratios for both chains are included namely wheat and sugar beet to ethanol, corresponding prices and required quantities (per produced quantity of ethanol) of additional and auxiliary matters e.g. chemical substances, the requirements in electrical energy and steam and the corresponding costs, production rate of by-products, the sale prices of produced ethanol and by-products.

Calculation of GHG emissions

Carbon dioxide equivalent emissions caused by fuel and fertiliser use (including fertiliser production and nitrogen oxide from soils) were calculated for all crops present in the crop mix of the region under study. Calculation of GHG emission for fertilizer for different crops can be presented with the following matrix notation.

$$\text{GHG\_fert(crop)} = \text{GHGemiss(element)} \times \text{input(element, crop)} \qquad [2]$$

'GHGemiss' vector values calculated via equation 1 (last line of Table 1) denote emissions per active element within fertilisers. The matrix of input requirements (elements × crops) identifies to Table 2 for the region of study comprising material and fuel inputs for cultivated crops.

Table 2: Average fossil input requirement for crop cultivation

Item	Crops										
	Soft wheat	Durum wheat	Irrigated wheat	maize	tobacco	cotton	potato	Sugar beet	tomato	Maize (fodder)	alfalfa
Diesel (lit./ha)	48.57	48.57	54.57	159.8	236.3	199	269.3	114.1	269.3	159.84	81.27
N (kg/ha)	123.8	123.8	123.8	334	180	206	164.5	110	180	334	55.28
P_2O_5 (kg/ha)	20	20	20	100	80	80	89	40	80	100	180
K_2O (kg/ha)	0	0	0	0	100	60	175	100	100	0	0

Aggregate greenhouse gases emissions from fuel and fertilizer (GHG_fert from equation 2) in kg ha^{-1} appear in the first part of table 3. Total nitrogen oxide emission for the cultivation of one hectare of land ranges from less than 1 kg to about 4 kg. Highest emission per ha is found in maize production and the lowest is in alfalfa cultivation (second part in Table 3).

Certainly GHG differentials when converting from grassland to intensive energy cropping are spectacular at the expense of energy crops, however even displacements and replacements among arable crops reveal significant differences in GHG costs or gains. For instance, if wheat substitutes for cotton in an irrigated parcel, overall CO_2 emissions are reduced by 1156 kg per ha (see last line of table 3: 1017 – 2173 = -1156 kg ha^{-1}). On the contrary, substitution of sugar beet for alfalfa results in emission increase. In a mathematical programming context when the marginal land use changes due to the introduction of energy cropping are determined by the regional agriculture supply model (income maximisation under constraints), GHG costs or gains are simultaneously calculated at the optimum. The aggregate results are then converted in an ethanol ton basis in order to calculate the total GHG emissions for bio-ethanol production.

Table 3. CO_2 emission for cultivation of 1 ha crops in the area

Sources of CO_2 emission	CO_{2eq} emission in cultivation stage (Kg/ha)										
	s.wheat	d.wheat	r.wheat	maize	tobacco	cotton	potato	s.beet	tomato	maize(f)	alfalfa
N, P_2O_5, K_2O	426.2	426.2	426.2	1216	758.2	815.6	770.1	475.8	758.2	1216.4	436.6
Diesel	167.6	167.6	188.3	551.4	815.2	686.5	929.1	393.5	929.1	551.4	280.4
CO_2 emissions (1)	**593.7**	**593.7**	**614.4**	**1767.9**	**1573.4**	**1502.1**	**1699.2**	**869.3**	**1687**	**1767.9**	**717**
Direct N_2O emissions	1.238	1.238	1.238	3.340	1.800	2.060	1.645	1.100	1.800	3.340	0.553
Indirect N_2O emissions	0.124	0.124	0.124	0.334	0.18	0.206	0.165	0.11	0.18	0.334	0.055
Total N_2O emission	1.361	1.361	1.361	3.674	1.98	2.266	1.810	1.21	1.98	3.674	0.608
total N_2O in Kg CO_2 equiv (2)	**402.9**	**402.9**	**402.9**	**1087**	**586.1**	**670.7**	**535.6**	**358.2**	**586.1**	**1087**	**180**
SUM (1)+(2)	**996.6**	**996.6**	**1017**	**2855**	**2160**	**2173**	**2235**	**1228**	**2273**	**2855**	**897**
CO2 transport (25km)	5.8	5.8	13.46	21.16	19.2	6.7	69.2	128.9	57.7	96.17	28.85

It should be noted at this point, that differentials in crop mix without and with the cultivation of the energy crop may be influenced by policy parameters. As a matter of fact, changes in the European Common Agricultural Policy altered the 'reference system' upon which the GHG emissions of the biomass to energy are measured. One can mention a study that estimates supply curves of solid biomass to electricity that points out a net displacement downwards due to the CAP reform in 2003 (Lychnaras and Rozakis, 2006). In 2008, because of serious concerns for the cotton sector viability, partial coupled subsidy is increased by 25 euro per ha resulting in significant increase of cotton cultivation and subsequent increase of opportunity cost for the energy crops. Table 4 shows optimal cultivated surfaces at the regional scale for selected scenarios, namely 'CAP 2006' (decoupling except cotton that enjoys area support of 55 euro ha^{-1}), 'CAP 2006 eth' (same agricultural policy plus demand for ethanol thank to the tax credits), CAP 2009 (decoupling except cotton that enjoys area support of 80 euro ha^{-1}), 'CAP 2006 eth' (same variant of agricultural policy plus demand for ethanol thank to the tax credits). Differential surfaces reveal that substitutions caused by energy crop demand by identical ethanol capacity present different patterns.

Biomass to supply a capacity of 120 kt of ethanol plant requires about 46 kha wheat-to-ethanol and 7 kha sugar beet. Energy crops replace soft and durum wheat, maize and last but not least cotton. Alfalfa cultivated area is increased in the crop plan with energy crops due to cross compliance constraints. Consequently to estimate GHG emissions, one should subtract the ones avoided thank to the substitution for cereals and cotton from those generated during the cultivation of energy crops and additional alfalfa areas. GHG emissions due to cultivation of energy crops approximately amount at 55 kt CO_{2eq}, whereas if substitutions are taken into account we observe emission savings amounting at 24.5 and 54.55 kt CO_{2eq} for scenarios CAP2006 and CAP2009 respectively. Savings are much higher in the second scenario because initial crop mix includes large areas of cotton, as one can verify in Table 4, which is more intensive than cereals.

Table 4. Policy dependent surfaces cultivated by arable crops

Optimal solution: aggregate crop mix (in k ha)	s.wheat	d.wheat	ir.wheat	maize	tobacco	cotton	potato	s.beet	tomato	maize(f)	alfalfa
CAP 2002	0.4	5.425	0	15.72	2.84	170.3	0.124	12.81	0.556	0.37	6.895
CAP 2006	28.43	59.39	0	42.29	0	82.64	0.124	0	0.413	0	51.07
CAP 2006 eth	21.61	45.39	46.22	31.03	0	59.93	0.124	6.98	0.413	0	52.66
differential 2006	-6.82	-14.0	46.22	-11.2	0	-22.71	0	6.98	0	0	1.581
CAP 2009	17.9	35.36	0	16.1	0	157.2	0.124	0	0.413	0	37.31
CAP 2009 eth	17.20	30.14	45.78	11.04	0	111.9	0.124	6.91	0.413	0	40.85
differential 2009	-.68	-5.22	45.78	-5.06	0	-45.3	0	6.91	0	0	3.54

The parametric optimisation of the integrated agro-industrial model, determined the optimal crop mix for farmers and technology configuration for the industry as well as the size of the plant. As expected, average biomass costs increase and transformation costs decrease with capacity in any case. Biomass costs are endogenously derived by the model (dual prices) resulting from changes in the crop mix to satisfy the increasing biomass demand from the industry. The feedstock supply curve, derived from dual prices of sugar beet and wheat demand-supply constraints, has a positive slope. The model maximises total profit, thus it proposes the highest possible capacity within the predetermined range. Key results of the model concerning the original configuration are presented in figure 3. One can observe that raw material cost is the major part of total cost increasing with plant size. Total average cost is minimised in capacity range of 50 kt ethanol. Explicitly, the average capital costs begin at 202 euro/t for small plants (10000 t) and decrease to 77 euro/t for maximal capacity (120000 t). Sugar-beet and wheat amount at almost 40% of total cost for small plants (10000 t) but this element increases to 60% for 120000 t plant.

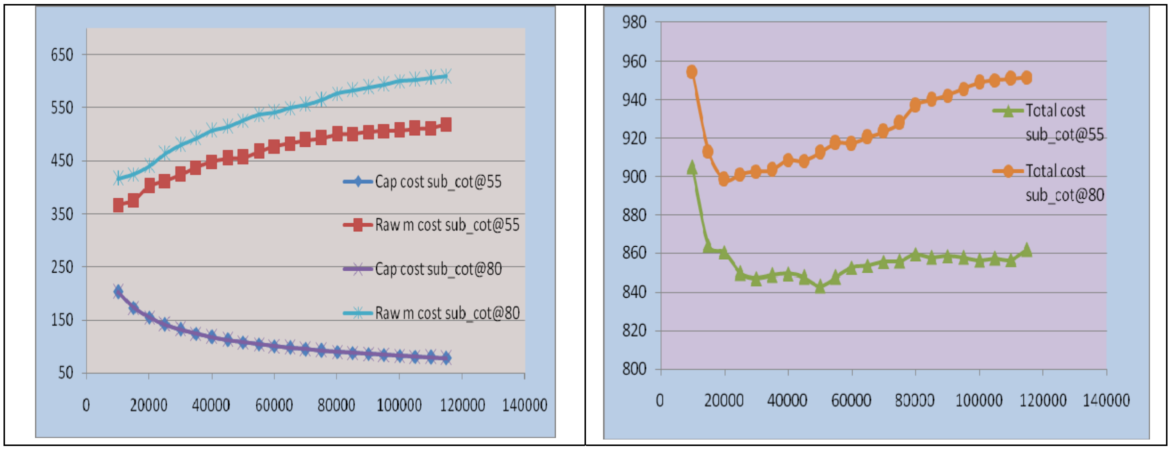


Figure 3 Cost and returns per ton of ethanol (for different agricultural policy schemes)

Emissions due to transport of raw material are estimated in a similar manner as those concerning cultivation taking into account substitutions among crops (unitary values in Table 3). The industrial processing stage is responsible for major part of emission followed by agriculture sector for biomass production and then transportation. CO_2 emission is proportional to plant size i.e. total CO_2 emission is increases as plant size increases. Steam and electricity requirement and CO_2 emission for industrial processing for 1 ton ethanol production from wheat and sugarbeet is shown in Table 5. To calculate overall emission one should weigh with wheat/beet ratio.

Table 5. CO_2 emission in the industry for the production of 1 ton ethanol

	Operation	Fuel ratio	Input ratio	Energy input (t or kWh)	Unit emission	Total emission (kg / t EtOH)
Wheat processing	Steam	0.072	5	0.36	3450	1242
	Electricity			503	0.618	310.85
Beet processing	Steam	0.072	4.42	0.32	3450	1097
	Electricity			228.7	0.618	141.34

Firstly the CO_2eq emissions are estimated considering direct land use change for feedstock production, plus emission for transportation and for industrial transformation. In this scenario (direct LUC), change in crop mix is taken into consideration and GHG differentials for without and with the cultivation of energy crop are evaluated within the regional boundary of Thessaly. In the second scenario, indirect land use change (iLUC) is considered taking into account: (a) reductions in cereal quantities leads to increase in imported cereals from Eastern Europe, (b) cotton quantity reduced results in local ginning industry downgrading with no additional imports, and (c) cake for feedstock by produced by the ethanol plant substitutes for soya cake currently imported.

The introduction of energy crops in the model, changes the crop mix that creates imbalances in the market demand and supply. For example, in the new cropping mix after introduction of energy crops, cotton, maize, soft wheat, durum wheat cultivation area is replaced by irrigated wheat and sugar beet that will be used for bioethanol production. A shortage of wheat and maize for food must be met by importing. Wheat and maize import from Eastern Europe would be the most suitable for Greece assuming availability of land for wheat and maize cultivation in Eastern Europe and moderate transportation cost. Life cycle GHG emission for wheat and maize production in Eastern Europe is different from Greece because fossil energy use and yield in agricultural production is different as calculated from BioGrace GHG calculation database (BioGrace, 2010). Moreover, bioethanol production activity produces DDGS a high value animal feed as by-product that is a substitute of soya cake. CO_2 avoided due to reduction of soya cake import is also incorporated. In terms of nutrient (protein) content, ratio for soya cake replace by DDGS is considered 0.78:1 (ADEME, 2006).

Table 6. GHG emission in the ethanol production system (in kt CO_2eq)

	CAP 2006 (subsidy on cotton @ 55 €/ha)				CAP2009 subs_cot 80 (€/ha)
Plant capacity (kt)	60	80	100	120	120
direct LUC (regional boundaries within Thessaly) (kt)					
Net CO_2 emission in agriculture	-20.5	-28.2	-37.5	-45.2	-32.7
Net CO_2 in transportation	0.47	0.65	0.86	1.05	1.2
regional direct LUC	**-20.1**	**-27.5**	**-36.6**	**-44.2**	**-31.4**
Indirect LUC (different crop mix and replaced food crops by imports) (kt)					
Net CO_2 emission in agriculture	22.8	32.8	40.3	47.5	18.2
Net CO_2 in transportation	7.3	10.5	12.9	15.1	5.9
CO_2 avoided_reduc_soya cake_imp	-31.7	-42.2	-52.8	-63.4	-63.4
indirect LUC	**-1.6**	**1.1**	**0.4**	**-0.8**	**-39.3**
CO_2 emission at the industrial transformation (kt)					
CO_2 for electricity	15.6	20.7	25.9	31.1	31.1
CO_2 for steam	71.9	95.8	119.8	143.8	143.8
Total CO_2 for industrial processing	**87.4**	**116.6**	**145.7**	**174.9**	**174.9**
CO_2 gasoline to be replace	**-151.3**	**-201.7**	**-252.2**	**-302.6**	**-302.6**
Total net CO_2 emission (kt)					
regional direct LUC	-84	-112.6	-143.1	-171.9	-159.1
indirect LUC	-65.5	-84	-106.1	-128.5	-167
Total net CO_2 emission per ton of ethanol (t)					
regional direct LUC	-1.400	-1.408	-1.431	-1.433	-1.326
indirect LUC	-1.092	-1.050	-1.061	-1.071	-1.392
Cost of CO_2 saving					
Total cost of CO_2 saving (M €)	**8.9**	**13**	**16**	**20.7**	**40.4**
Cost saving_direct_LUC(€/t)	105.95	115.45	111.81	120.42	253.93
Cost of CO2 or import indLUC (€/t)	135.88	154.76	150.80	161.09	241.92

Results on GHG emission in different scenarios are presented in Table 6. Under the scenario direct LUC, net CO_2 emission change in agriculture and transportation is estimated by the differences in CO_2 emission with and without ethanol production. Introduction of energy crops reduces CO_2 emission in the agriculture. One can observe that in absolute terms, on an average feedstock production contributes to 24% CO_2eq emissions, 75% emission is occurred in industrial processing whereas only 1% is dedicated for transportation. With the optimal plant size of 120kt ethanol per year 302.6kt CO_2 emission caused by gasoline can be avoided by replacing with ethanol. The total net CO_2 emission including emission saved due to replacement of gasoline by ethanol at the optimal plant size of 120kt is appeared 171.9kt that contributed 1.432 ton CO_2 saving per ton of ethanol production. Under the second scenario we consider indirect land use change including import and import substitution. Total CO_2 saving at the plant size of 120kt is only 128.4 kt that contributed 1.070 ton CO_2 saving per ton of ethanol.

In the case of direct land use change within the regional boundary of Thessaly, the cost of CO_2 saving varies from 106 to 120 euro per ton for capacities 60-120 kt. When considering indirect land use change and import and import substitution trend of CO_2 saving cost range moves from 136 to 163 euro per ton CO_2eq. This is explained as deadweight loss remaining at the same level, consideration of indirect land use change implies higher levels of GHG emissions. These values can be compared with alternative biofuel chains such as biodiesel, or other ways of reducing GHG emissions (alternative renewable energies or emissions rights price at the international marketplace). Comparing with biodiesel effectiveness estimated by Iliopoulos and Rozakis (2009), bio-ethanol performs better than current and proposed biodiesel production schemes that require for one t CO2 eq saved about 300 and 160-250 euro respectively.

When an agricultural policy is modified with regards to the area subsidies for cotton, that, as previously explained, alters regional crop mix and increases opportunity cost of land for energy crops, unitary emissions are lower than those under CAP2006 for the same capacity (120kt), but when we consider indirect LUC, unitary emissions become higher (last column in Table 6). Monetary cost per ton of CO2eq is also increased by 110% and 50% for direct and indirect land use respectively, amounting at about 250 euro per ton saved.

Conclusions

This paper attempts an evaluation of bio-ethanol production in the context of the ex-sugar industry in Thessaly taking into consideration recent changes in the Common Market Organisation for sugar in the E.U. We also intended to demonstrate the potential of mathematical programming for economic and environmental analysis of the material-product chains associated with the life cycle Analysis of products.

An integrated model articulating agricultural supply of biomass with ethanol processing maximizes total surplus under constraints to determine cost effectiveness for different production levels. Based on the detailed bottom up modelling of the agricultural sector, direct and indirect land use change, that represents a significant part of total emissions, is taken into account for the estimation of emission differential; indirect land use change always results in higher emission balance. Two policy variants of the current CAP are examined. Economic performance and environmental cost effectiveness of bioethanol are clearly affected by agricultural policy parameters, in this case, area subsidy to cotton. In order to reduce GHG by one ton of carbon dioxide equivalent by means of bioethanol production overall cost to the society varies between 100 and 250 euro.

Different technology configurations should be included in the integrated model to extend feasible area in the optimisation problem. A notable feasible alternative is co-generation with biogas within the bioethanol plant so that electricity requirement can be met. The biogas unit can use DDGS and pulp as raw material, by-product from ethanol production. In addition, additional technical configurations including recent research findings on promising crops such as sorghum (Maki. 2007) could increase farmers' gains.

Further research should be conducted to take into account uncertainty. Uncertainty issues concerning not only demand side (ethanol and by-products price volatility) but also supply side (changing policy contexts and competitive crop price volatility) need to be addressed in order to determine confidence levels of ethanol environmental cost-effectiveness.

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