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Energy Policy ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Environmental cost-effectiveness of bio diesel production in Greece: Current policies and alternative scenarios ☆

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ARTICLE INFO

Article history:
Received 30 June 2009
Accepted 29 October 2009

Keywords:
Bio diesel
Quota policy
Greece

ABSTRACT

Following European Directive 2003/30/EC, the Greek Government adapted legislation that introduces and regulates the bio diesel market. The implemented quota scheme allocates the country's annual, predetermined, tax exempt production of bio diesel to industries based on their ability to meet several criteria. A number of bio diesel supply chain stakeholders have criticized this policy for being efficiency-robbing and vague. This paper uses 2007 data from energy crop farms and three bio diesel-producing companies in order to assess these criticisms. We study the economic and environmental aspects of the currently adopted policy and compare them to three alternative scenarios. We conclude that such criticisms have a merit and that policy makers need to reconsider their alternative options regarding the promotion of bio diesel in transport. Permission of sales directly to local consumers and promotion of forward integration by farmers are efficiency enhancing and environment-friendly means of promoting the use of bio diesel in transport.

1. Introduction

Over the past two decades, environmental and energy concerns combined with overproduction of arable crops have led the official European Union bodies to propose concrete policies to member states. In the case of transport fuels a major leap is attempted, as the goal set is to replace 5.75% of the currently used non-renewable fuels by biofuels until 2010. Following European Directive 2003/30/EC on the promotion of the use of biofuels or other renewable fuels for transport, the Greek Government adapted legislation that introduces and regulates the bio diesel market with the aim of producing approximately 135 thousand tons in 2010.

In order to achieve the aforementioned goal, the government has implemented a dual policy. First, the Ministry of Development allocates an annual, predetermined quantity to the applying bio diesel-producing companies based on their ability to meet several criteria that are described in the relevant legislation. Second, the produced volume is tax exempt when sold to oil refineries or sellers in order to be mixed with regular automotive diesel.

Since the first year of the policy's implementation, industry stakeholders started criticizing the quota scheme. Particularly, concerns have been raised regarding the vague criteria that the Ministry of Development uses in allocating the tax exempt bio diesel quantity to applicant companies. The most important criticisms, however, have centred on the disparity between the volumes allocated to companies and their much higher productive capacities, which has resulted in severe constraints to efficiency. Low capacity producers, on the other hand, have been arguing that they would have been profitable only if they were allowed to sell bio diesel outside the quota scheme (e.g., to local gas stations). Concerns have also been expressed about the complexity of the highly bureaucratic and thus inefficient tax exempt policy. Finally, environmental NGOs and some political parties have doubted the expedience of the current bio diesel policy in minimizing CO_2 emissions.

This paper takes into consideration the above concerns and evaluates their soundness based on a comprehensive analysis of bio diesel chain organization in Greece. The questions we seek to address are: (1) does the quota allocation policy affect the efficiency and therefore competitiveness of bio diesel producers? Alternatively, what would happen if a single company produced all the tax exempt quantity? (2) Would a policy that permits the sale of pure bio diesel to local gas stations alter the profit-making ability of companies? (3) Should the government promote forward integration by farmers in the form of collective entrepreneurship firms that own oilseed crushing plants? (4) Is

☆This research was funded by the European Tobacco Fund [Commission Regulation (EC) No 2182/2002] through the Greek Paying Agency (OPEKEPE).
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doi:10.1016/j.enpol.2009.10.059

Table 1
Quantities of bio diesel and bio ethanol required so that Greece achieves EU goals (thousand tons).
Source: Ministry of Development (2006).

Year	Estimated consumption Diesel	% Bio diesel	Quantity	Estimated consumption Gasoline	% Bio ethanol	Quantity
2005	2.08	2	47	3.71	2	120
2007	2.17	4	98	3.89	4	190
2010	2.29	5.75	148	4.17	5.75	389

the current policy efficient in protecting the environment at a low cost for society?

We address these questions based on farm and industry surveys. Case study companies that provided detailed 2007 cost and revenue data represent various capacities. To the best of our knowledge no study based on actual industry data from Greece has been published. Thus far the estimation of production, transportation and operating costs has been based on small-scale laboratory or field experiments (Skarlis et al., 2008; Lychnaras et al., 2004; Diakoulaki and Kavadakis, 2002). A pre-feasibility study based on manufacturer's data is limited to a small size plant (e.g., Lychnaras, 2009). Furthermore, the crucial impact of the Greek regulatory framework on profitability has not been considered.

The paper is organized as follows. In the next section we present the institutional environment, policies adopted and the main bio diesel supply chain links in Greece. In Section 3 we describe methodology and the case study research design. Description of the case study farms and bio diesel-producing companies are provided in Section 4. Results are given in Section 5, while Section 6 presents the outcome of the sensitivity analysis and Section 7 assesses the environmental and societal costs of each alternative. The last section discusses the results, suggests avenues for future research and concludes the paper.

2. Bio diesel supply chains in Greece

2.1. Policy framework and implementation

Exceptionally high and increasingly volatile petroleum prices during the last years along with growing concerns over the impact of greenhouse gas emissions on climate have formed an environment favourable to the development of the biofuel industry (Gardner and Tyner, 2007). Despite the inconclusive controversies associated with biofuels' potential to address the aforementioned issues while avoiding the pitfalls of booming commodity prices (Russi, 2008; Doornbosch and Steenblik, 2007), the European Union has consistently encouraged their use. The promotion of energy crops[2] and biofuels in transport are key EU policies in this respect. Regarding the latter, the EU has set as an indicative target to achieve a 5.75% share of biofuels in total petrol and diesel consumed in transport by 2010 (COM 2003/30). Directive 2003/96/EC, which restructures the Community framework for the taxation of energy products and electricity is also intended to support achievement of this goal.

Table 1 shows the targets set by the EU against actual and projected diesel and gasoline consumption in Greece.

In order to realize its share of the pan-European target, the Greek Government adopted legislation that promotes the use of biofuels in transport (Greek Law 3423/2005). According to this law, priority is given to bio diesel since conversion of two plants of the Hellenic sugar industry to ethanol due to the new Common Market Organization (CMO) is expected to fulfil the ethanol obligation. Oil refineries are obliged to buy predetermined quantities each year from bio diesel producers or importers. Sale of pure bio diesel is not permitted since all production is to be mixed with regular diesel used in transport up to 5% by volume. The mandatory quality standards applied to bio diesel are described in Law 3340/2005 as ELOT EN 14214 standard.

[2] The McSharry reform of CAP in 1992 and the recent implementation of decoupling have both boosted energy crop farming.

Table 2
Sunflower in Greece: total acreage, annual oilseed production and percentage of non-food use (2003–2007).
Source: National Statistical Service of Greece (2009).

	2003	2004	2005	2006	2007
Farm land cultivated (ha)	8200	3700	4600	8600	14,000
Oilseed production (tons)	10,300	4600	5700	15,743	19,273
Non-food uses[a] (%)	0[b]	0[b]	0[b]	46.51	64.29

[a] Own estimations based on industry contracts with sunflower producers.
[b] Only pilot cultivations.

Bio diesel produced within the national quota scheme is totally exempted from the excise duty of €276/m^3 that applies to diesel. The 97,695 tons fully exempted in 2007 represent approximately €33 million. So far, bio diesel production is not directly subsidized.

The criteria used in allotting the tax exempt quantity to each company are described in Law 3423/05 and several ministerial decrees. These include the capacity of the applicant, the volumes delivered in previous years, and the number of production contracts signed with local farmers. While priority is given to bio diesel producers that use raw material from Greece this is not an obligatory provision.

In December 2005, the Ministry of Development invited for the first time bio diesel producers to supply 2500 tons of tax exempt bio diesel to refineries. Both producers and plain sellers could respond to this invitation. In subsequent years the Ministry gradually increased the volume of bio diesel that the industry could produce within the national quota scheme reaching 114 and 123 thousand tons in 2007 and 2008, respectively.

2.2. Main actors in bio diesel supply chains

A typical bio diesel supply chain comprises farmers, cooperatives, oil crushing entrepreneurs, bio diesel producers and refineries. Bio diesel in Greece is produced mainly from oilseeds and, particularly, sunflower, rapeseed, and cotton seeds. Sunflower is the most important energy crop. Table 2 summarizes the evolution of total farm land devoted to sunflower cultivation, the resulting seed production, and the percentage of non-food uses in the period 2003–2007. According to industry experts interviewed for this research, the cultivation of sunflower for energy production will become more popular in the near future due to the promotion activities funded by gigantic input manufacturers.

Raw material cost is an important part of bio-energy products reaching more than 50% of the total cost and thus a decrease in

Table 3
Bio diesel producers in Greece (2008) and allocation of bio diesel tax credit (2006–2007).
Source: Peitzika et al. (2007) and Ministry of Development (2008).

Company	Plant location	Annual capacity (tons)	Quota received (tons)	
			2006	2007
Bio diesel producers				
ELVI—Hellenic Biopetroleum Industrial and Commercial, S.A.	Stavrohori, Kilkis	90,000 (initially 45,000)	41,000	34,000
P.N. Pettas, S.A.	Patras	100,000 (initially 50,000)	24,000	31,000
VERT OIL, S.A.	St. Athanasios, Thessalonica	35,000 (initially 10,000)	8000	9000
ELIN BIOKAFSIMA, S.A.	Volos	40,000	5000	8000
AGROINVEST, S.A.	Ahladi, Fthiotida	250,000	5000	11,500
STAFF COLOUR ENERGY, S.A.	Larissa	15,000 (initially 10,000)	600	5000
EKKOKISTIRIA-KLOSTIRIA B. ELLADOS, S.A.	Vistonida, Xanthi	10,000	300	3000
BIO DIESEL, Ltd.	Assiros, Thessaloniki	20,000	1500	3500
BIOENERGY PAPANTONIOU, S.A.	Lakkoma, Chalkidiki	10,000		1200
MIL OIL, S.A.	Serres	5000	300	800
Trouloi Bros[b]	Crete	5000	100	0
B. K. Bio diesel Ltd.[b]		5000	400	0
Bioenergy Ltd.[b]		5000	300	0
Sub-total		*575,000*	*86,500*	*107,000*
Sellers/importers				
Miloi Sogias S.A.			4,000	0
Bioenergy-Biofuels S.A.			500	0
ETB Biofuels S.A.			0	4,000
Bio diesel S.A.			0	2,000
DP Lubricanti SRL			0	1,000
Sub-total			*4,500*	*7,000*
Total		575,000	91,000	114,000[a]

[a] By the end of 2007, 97,695 out of the 114,000 allocated tons have been produced.
[b] Not active in 2008.

energy crops' opportunity cost affects significantly the overall competitiveness of bio-energy. Thanks to the last Common Agricultural Policy (CAP) revision and the decoupling of subsidies from production, it is the first time that in Greece energy crops seem to become competitive against staple crops such as cotton and tobacco (Lychnaras and Rozakis, 2006).

Sunflower farms are concentrated in northern Greece due to previous experience in sunflower cultivation. Farmers procure sunflower seeds from two importers at around €5/kg. Depending on whether irrigation is used or not, yields range between 1.50 and 3.00 tons/ha while oil content ranges from 36% to 40% (Giannoulis et al., 2008; Kallivroussis et al., 2002). Preliminary calculations conclude that the opportunity cost of sunflower varies between €200 and €300/ton when cultivated in non-irrigated land, whereas it can range from €250 to €300/ton in case it replaces irrigated crops.[3]

In 2007, the bio diesel industry offered prices that ranged from €200 to €259/ton. On top of this, farmers receive a €45/ha subsidy for energy crops but only if they have signed production contracts with bio diesel plants (ministerial decree 36781/2007). However, the aggregate production of oilseeds represents only 12% of the quantity needed to achieve the national target. This explains why oil imports have increased rapidly from 19,000 tons in 2000 to 60,000 tons in 2005 (CRES, 2007).

Oilseed crushing plants represent another important link in the bio diesel supply chain. They are usually owned by companies with experience in the production of edible oils. With a few exceptions, such plants are not involved in oilseed crushing companies. Presumably in order to minimize transport costs, the latter prefer to contract with crushing plants located close to energy crop farms. The by-products of the seed crushing procedure (e.g., protein-rich animal feed) are sold by oilseed crushing companies to either farmers or animal meal manufacturers.

The first domestic bio diesel plant started production in 2005, with an annual capacity of 45,000 tons. Currently ten bio diesel plants are active (Table 3).

The glycerol by-product provides a secondary revenue stream to bio diesel producers or acts as an offset against the unit cost of bio diesel production. The Geek glycerol market follows international price patterns. However, local glycerol producers face a much smaller market whose geographic limits are largely determined by transport costs.

In the 1981–2001 period European glycerol prices have oscillated in roller-coaster fashion from approximately €1400/ton in 1981 to €2800/ton in 1986 to €1300/ton in 2001 (ABG, 2008). Among the factors that dictate glycerol prices the most cited include weather, regulatory costs, plant shut-downs and politics (Pagliaro and Rossi, 2008).

The post-2002 rapid expansion of bio diesel production coupled with a steadily increasing production of natural fatty alcohols in Asia since the mid-1990s have added to the glycerol surplus (Pagliaro and Rossi, 2008). Consequently the glycerol price has plunged fast and since the first quarter of 2005 it has been selling for €430–€450/ton (Oleoline, 2005). During 2006 the worldwide glut of glycerol created from bio diesel production drove the price below 2005 levels (Line, 2009; ABG, 2008).

In most recent years the consistently low price of glycerol resulted in expansion of glycerol usage, primarily by replacing the six-times more expensive propylene glycerol. This development reversed the downward price trend. In April 2009, purchasers of vegetable-based refined glycerol could obtain contracts in North Western Europe in the range €450–490/ton (ICIS, 2009). Whether this represents a more permanent trend or not remains to be seen.

According to the quota policy, bio diesel is sold to existing oil refineries and sellers in proportion to their shares in the

[3] Based on own calculations.

automotive diesel market during the previous year. In 2007, 114,000 tons of bio diesel were allotted to four companies.

2.3. Recent developments

Since 2006 bio diesel industry stakeholders have been criticizing the quota policy on the grounds of being too restrictive and mining market competition. Concerns have also been expressed about the vagueness of the criteria employed in allocating production quantities to the applicants and the complexity of the tax exemption system. As a partial response to these criticisms, in January 2008 the Ministry of development abandoned tax exemption of bio diesel.

The total 2008 production of bio diesel under the quota scheme increased to 123,000 tons. However, the scheme almost collapsed and the production of more than 60,000 tons had to be postponed until the first months of 2009. Subsequently the association of bio diesel industries sent a letter to the ministers for development, finance, and rural development in which they expressed their concerns regarding foreseen delays in the implementation of the quota plan in 2009. In May 2009, the Minister of Development announced the amendment of law 3054/2002. The new legal framework is intended to clarify the criteria used in allocating quantities to applicants, improve the evaluation procedure, reinforce tax exemption, and permit the sale of pure bio diesel directly to retailers and large-volume consumers.

On the industry's side, the number of companies dropped from 12 in 2006 to 10 in 2008 while the number of sellers increased from zero in 2006 to three in 2008. During the same period, the total annual production capacity increased from 425,000 tons in 2006 to 575,000 tons in 2008. This rise is mainly attributed to the decision of three industries to increase their capacity.

In interviews with industry representatives it was repeatedly mentioned that the aforementioned developments were primarily caused by the quota policy. Both the structure and the organization of the scheme are perceived as problematic. Besides high transaction costs associated with the vaguely defined evaluation procedure, efficiency may not be maximized due to the volume constraints imposed.

Considering the dramatic overtime increase in the average bio diesel plant size observed in other EU member states (Gubler, 2007), the quota policy may impose unnecessary constraints to efficiency. Scale is critical in minimizing bio diesel production costs. By imposing a low total upper limit but mainly by distributing this volume to many firms of diverse capacities, the plan may forfeit companies of their ability to maximize productive efficiency. Furthermore, low capacity companies argue that they have been incurring losses because they could not sell directly to final consumers (e.g., local farmers). In the following sections we use data from energy crop farms and three bio diesel-producing companies in order to assess the above criticisms.

3. Methodology and research design

Due to the nature of the research questions that we sought to address and the limited number of bio diesel producers in Greece we adopted the case study methodology (Yin, 2002). A holistic, multiple-case design was chosen, according to which the unit of analysis is the individual bio diesel-producing company while we focus on three such companies (Companies 1, 2, and 3[4]). These firms were chosen because they represent three distinct and potentially contrasting cases in terms of annual capacity (low, medium, and high) and plant location (upper central, central, and southern Greece, respectively).

A pilot study of a fourth bio diesel-producing company located in central Greece was conducted in October 2006 before designing the case study approach and instruments used in this research. Semi-structured interviews with key informants in each case study company were accomplished between December 2006 and March 2007. Following these interviews the research team asked key members of the personnel to provide detailed cost and revenue data for their companies.

In order to enhance construct validity we used multiple sources of evidence, including personal semi-structured interviews with board members, CEOs, production managers, chemical engineers and other key employees, the internet, power point presentation material, annual reports and other publicly available documents. Also, we asked key informants to review the draft case study results and, subsequently, incorporated their comments into the final report.

The internal validity of the design was improved by considering and addressing rival explanations for the case findings. Furthermore, by using replication logic we increased the external validity of the case study results (Miles and Huberman, 1994). Finally, the reliability of our results is significantly augmented through the use of a case study protocol and the development of a case study database. Both of these instruments were prepared during the data collection phase of the research.

Concerning the raw material cost, past experience shows that it represents the single most important determinant of bio diesel production cost. Due to high spatial dispersion of raw material in many productive units (i.e., farms) and competition among agricultural activities for the use of production factors such as land, estimating the cost of raw material encounters three principal difficulties (Sourie, 2002): (a) scattering of the resource, (b) competition between agricultural activities and non-food crops at the farm level, and (c) dependence of raw material costs on agricultural policy measures.

Application of the microeconomic concepts of supply curve and opportunity cost enables the amelioration of these difficulties. These concepts are elaborated by using mathematical programming models, called supply models, based on a representation of farming systems (i.e., sector models). The sector supply model developed is sufficiently detailed to reflect the diversity of arable agriculture in the study region. Numerous farm sub-models articulated in a block angular form, which are neither equally productive nor equally efficient, provide production costs that are variable in space.

A sector model is generally specified as follows: An individual farm (f) is supposed to choose a cropping plan (x^f) and input use among technically feasible activity plans $A^f x^f \leq b^f$ so as to maximize gross margin gm^f. The optimization problem for the farmer f appears as

$$\begin{cases} \max\limits_{x^f} gm^f(x^f, \theta^f, \kappa) \equiv g^f(\theta^f, \kappa) x^f \equiv \sum_c ((p_c^f + s_c) y_c^f + \text{sub}_c - v_c^f) x_c^f \\ \text{s.t.} \quad A^f(\theta^f, \kappa) x^f \leq b^f(\theta^f, \kappa) \quad A \in \Re^{m \times n} \quad \text{(I)} \\ \qquad x^f \geq 0 \quad x \in \Re^n \quad \text{(II)} \end{cases} \tag{1}$$

The sector model contains f elementary farm problems such as the one specified above. The basic farm problem is linear with respect to x^f, the primal $n \times 1$-vector of the n cropping activities. The $m \times n$-matrix A^f and the $m \times 1$-vector b^f represent, respectively, the technical coefficients and the capacities of the m constraints on production. The vector of parameters θ^f characterizes the fth representative farm (y_c^f yields, v_c^f variable costs, p_c^f

[4] The names of companies or individuals interviewed during this research are not disclosed due to a prior agreement with the participating firms.

Please cite this article as: Iliopoulos, C., Rozakis, S., Environmental cost-effectiveness of bio diesel production in Greece: Current policies and alternative scenarios. Energy Policy (2009), doi:10.1016/j.enpol.2009.10.059

prices dependent on quality, and s_c subsidy coupled to production volume for crop c) while κ stands for the vector of general economic parameters (p prices not dependent on farm, sub_c area subsidies specific to crops). The constraints can be distinguished in resource, agronomic, demand, and policy ones. A detailed algebraic specification appears in the Appendix. The model enables a comparative static analysis because it does not allow for farm expansion, as it takes as given land resource endowments and land rent of the base year. Different sets of parameters are applied to denote the policy context (i.e., CAP 2000 and the current CAP). To estimate the individual supply function for each farmer the above optimization problem can be solved for various levels of energy crop production volume. Moreover, the total supply function can be estimated by aggregating the individual supply functions, taking into account the total number of farms in the area under study represented by the individual farm models. Similar methodology has been used by Sourie (2002) for the estimation of supply of rapeseed for bio diesel in the French arable sector.

Supply chain models coupling agricultural production to transportation and the industrial transformation stage would undoubtedly be an ideal tool to assist policy makers (Rozakis and Sourie, 2002). Moreover, integrated multi-chain models have been implemented to evaluate policy efficiency (e.g., Rozakis and Sourie, 2005; Bernard and Prieur, 2007). Regarding bio diesel, a few supply chain models are recently reported in the literature (e.g., Rosa, 2008; Leduc et al., 2009; Espinosa-Diaz, 2009). These models use linear or mixed-integer linear programming aimed at determining the optimal configuration of supply chain at a national or regional level. However, all of them require more or less detailed technical description of the transport as well as of the transformation phase that is not available in our case. For this reason we opted for farm level modelling of the agricultural sector that generate supply curves to be exploited in cash flow and NPV calculations of predefined industry configurations.

4. Case study

4.1. Agricultural sector and energy crops

Mathematical modelling has been applied by implementing a farm-based approach in order to estimate sunflower supply at the national level. Due to various pedo-climatic and socioeconomic conditions prevailing in Greece the model drills data concerning representative farms from different regions, namely from north, central, and western Greece; about 70 farms were selected from each region using stratified sampling. Survey farm data have been used with 2005 as the base year upon which the model is calibrated, whereas policy parameters and constraints concern the revised CAP implemented in Greece from the period 2005–2006.

In western Greece, average farm size is relatively small (4 ha) with a large number of labour intensive cropping farms seeking alternatives after total decoupling the tobacco subsidies. Energy crops mainly compete against fodder crops depending on local demand conditions. In central Greece (Thessaly plains) where farm size is among the highest (12 ha in average) and parcels are the least fragmented, the main crops are cotton and cereals in non-irrigated soil. Cotton is the most profitable crop whereas under the revised CAP cotton enjoys partly coupled subsidies and thus remains an alternative, albeit less profitable than before. It is followed by maize, which is characterized by variable profitability due to highly volatile prices. In northern Greece, farmers own specialized equipment and have considerable experience in sunflower cultivation because during the last 20 years the region has been the main producer of sunflower for edible oils. Farm size reaches moderate levels (8 ha in average) while farms are less heterogeneous with respect to crop mix compared to the other two regions, which mainly cultivate durum wheat and to a lesser extent cotton.

4.2. Industry sector current situation: seed oil and bio diesel production

4.2.1. Company 1 (low capacity)

Located in upper central Greece, Company 1 is a family owned business that has a relatively low annual capacity of 15,000 tons. The bio diesel plant represents an investment of €3.5 million, 40% of which was given to the company as a government subsidy. The facility uses soy and cotton oil bought from local importers to produce bio diesel. Starting in 2007, the company signed contracts with sunflower producers in northern Greece in order to be eligible to participate in the national bio diesel quota scheme. In 2007 the company received a quota of 5000 tons of bio diesel.

The company's initial plan to construct an oilseed crushing plant was abandoned because local producer did not express an interest in supplying biomass to the mill. Furthermore, the plan was disregarded because the management took into account the high transaction costs associated with signing hundreds of contracts with individual farmers.

According to the owners of the firm, the initial business plan projections for a 3-year payback period were based on two assumptions; namely, that the company would supply local gas stations with pure bio diesel and that its annual production would be double the quota actually received from the Ministry. Both of these assumptions proved to be false and, consequently, the company did not deliver but a fraction of the quota it had received. Currently the owners consider disinvesting.

4.2.2. Company 2 (medium capacity)

Company 2 is also a family owned and run business. It has an annual capacity of 50,000 tons and is located in southern Greece. The company's bio diesel plant represents an investment of, approximately, €6 million.[5] It buys sunflower oil in the international market and sunflower seeds through contracts with farmers in northern Greece. Through informal agreements with crushing plants located in close proximity to the energy crop farms it contracts out the crushing of sunflower seeds and, subsequently, transports the seed oil to its facility in southern Greece. Due to high transportation and logistics costs the company seeks to sign contracts with biomass producers located closer to its bio diesel plant.

In 2007 the company produced 30,000 tons of bio diesel under the national quota scheme, which was transported with rented trucks or ships to oil refineries in the area of Korinthos.[6] The sunflower meal produced as a by-product of the oilseed crushing process is sold to the animal feed industry or to individual farmers.

The high production and transaction costs, partly resulting from limited access to inexpensive feedstock and the perceived vague institutional environment, have led Company 2's owners to consider three options. The first was to relocate their plant in Bulgaria in order to get access to inexpensive oilseeds and incur lower labour costs. The second alternative considered was to stop producing and focus on other industrial activities such as

[5] The company's initial estimate for the investment required was around €2.9 million.

[6] A town located around 80 km west of Athens.

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producing edible oils. The last option referred to increasing its production capacity in order to take advantage of scale economies in the form of reduced production costs. In 2008 the company decided to adopt the third option and doubled its capacity.

4.2.3. Company 3 (high capacity)

Company 3 is a large, family owned, vertically integrated company with an annual capacity of 250,000 tons of bio diesel. It represents a total investment of €17 million, €5 million of which were invested in the oilseed crushing facility. The bio diesel plant uses soy, sunflower, rapeseed, palm, palm kernel, and cotton seed oils as raw material. Seventy percent of the oilseeds are bought in the international markets while the remaining 30% are supplied through contracts signed with farmers in northern Greece. The company also owns a modern port adjacent to the bio diesel and crushing plants, all of them conveniently located in central Greece. Consequently, it enjoys significant scale economies and lower transportation costs relative to its competitors.

The company markets under its own label the protein-rich animal and fish meal produced as a by-product of the oilseed crushing process. The value captured in this way represents a significant, additional income.

Despite its high production capacity, in 2007 the company received a quota of 12,000 tons of bio diesel.[7] The resulting lost economies of scale do not seem to worry the owners who think that in the long run the company will survive and generate higher profits. One of the options the company considered in 2007 was to increase production levels and export bio diesel to other European countries. However, such a strategy is not without problems due to intense competition from Spanish, German, and French companies that enjoy lower transportation costs.

4.3. Industry sector alternative scenarios

4.3.1. Scenario #1: monopsony/monopoly

In this scenario we study the case where Company 3 becomes the sole bio diesel producer in Greece and receives 100% of the national quota. Consequently, the company will become both the sole national buyer of sunflower seeds used for energy production (monopsony) and the only seller of bio diesel to oil refineries (monopoly). This can occur through merger with or acquisition of other bio diesel companies, or in case smaller companies seize operation. Also, the Ministry could implement this option by allocating all the quota volume to Company 3. Due to its high annual production capacity Company 3 is a natural candidate for implementing this scenario.

4.3.2. Scenario #2: produce for a different market

This scenario focuses on the implications of a change in the regulatory framework for bio diesel. More specifically, we examine the case where bio diesel producers are permitted to sell directly to retailers and consumers of automotive fuels (e.g., public transportation organizations).

4.3.3. Scenario #3: farmer-owned oilseed crushing plant

This scenario implies a major organizational change in the Greek bio diesel supply chain. We study the implications for both farmers and case study companies when a group of sunflower producers integrates forward by forming a processing cooperative. The cooperative owns a crushing plant and sells sunflower oil to bio diesel industries. Also, it sells the produced sunflower meal directly to farmers and the animal feed industry.

[7] Given the low quantity it produced in 2007, it is assumed that all of the sunflower seeds it used were procured from Greek farmers.

5. Results

5.1. Biomass supply estimation

Applying parametric optimization onto aggregate regional models have resulted in a series of supply curves of sunflower seeds determining farmers' response and quantities offered to the market at different price levels. These quantities are calculated taking into account the crop mix change at the farm level as sunflower prices increase, ceteris paribus. Most efficient farmers are concentrated in central and northern Greece, able to supply sunflower at prices as low as €0.18–€0.20/kg. Aggregate results at the national level are illustrated in Fig. 1. It is a typical positive-sloped supply curve, with price on the vertical axis. On the horizontal axis the share of farms total cultivated land is presented in percentage, so we can read that at a sunflower seed price of €0.2/kg the farm in the sample are willing to cultivate about 20% of their cropping plan with sunflower. The reason of not giving quantities is that projections at the national level would be rather arbitrary, so we opted for showing land shares. In general terms, central Greece starts producing first even below €0.2/kg while the bulk of supply is produced by northern Greece between €0.20 and €0.25/kg with western regions providing the most expensive seeds. Nevertheless, one can say that at a price kept below €0.25, sample farms will cultivate more about 20% of their land with sunflower while at the same time they ask for prices over €0.30 to produce more. Rough projections on arable surface undertaken, one may conclude that in order to assure 30% of national raw material for the national bio diesel quota, seeds should be priced at €0.25/kg with oil crushing plants located in northern and central Greece having a competitive advantage.

Detailed model results are exploited in the development of alternative industry scenarios in subsequent sections in two ways:

(a) Prices of sunflower used in the subsequent cash flow models in different industry configuration scenarios are determined by the supply model depending on the quantity demanded by the industry, and
(b) the model can estimate aggregate farmers' surplus that corresponds to the sum of surpluses of all individual farms that supply sunflower. Mathematically the surplus is calculated as the difference between aggregate gross margin for sunflower-for-bio diesel price equal to p and equal to 0 (symbols in the following formula are the same as in (1)): $\int_{p=0}^{p} \sum_f gm^f(x^f, \theta^f, \kappa)$

5.2. Current situation and alternative scenarios

We build detailed cash flow models for each of the three case study companies. These include revenues, capital costs, operating

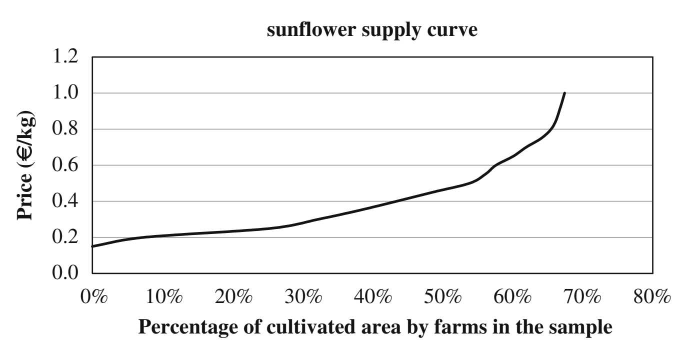

Fig. 1. Estimated sunflower supply curve (sample aggregate).

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Table 4
Summary of key parameters in the three scenarios.

Parameter	Company #1 (low capacity)	Company #2 (medium capacity)	Company # 3 (high capacity)
Scenario #1: monopsony/monopoly			
A. Unit costs (€/l of bio diesel)			
Raw materials	–	–	0.8582
Supplies and general works	–	–	0.0264
Depreciation[a] and interest	–	–	0.0218
B. Unit revenues (€/l of bio diesel)			
Sunflower meal	–	–	0.0800
C. Capacity (l)	–	–	250,000,000
Scenario #2: produce for a different market			
A. Unit costs (€/l of bio diesel)			
Raw materials[b]	0.9134	0.9126	0.8582
Supplies and general works[c]	0.0137	0.0116	0.0109
Depreciation and interest	0.0558	0.0370	0.0218
B. Unit revenues (€/l of bio diesel)			
Sunflower meal	0.0000	0.0500	0.0800
C. Capacity (l)	15,000,000	50,000,000	250,000,000
Scenario #3: farmer-owned crushing plant			
A. Unit costs (€/l of bio diesel)			
Raw materials[d]	0.8834	0.8551	0.8583
Supplies and general works	0.0477	0.3489	0.0264
Depreciation and interest	0.0558	0.0370	0.0218
B. Unit revenues (€/l of bio diesel)			
Sunflower meal	0.0000	0.0000	0.0800
C. Capacity (l)	15,000,000	50,000,000	250,000,000

[a] 10 year straight line depreciation.
[b] Company #1 uses soy oil and cotton oil (94% and 6%, respectively). Company #2 uses sunflower oil; 85% of this oil it buys from importers. The remaining 15% it buys in the form of oilseeds from sunflower farms in Greece. Company #3 uses as raw material only sunflower seeds that it buys from farmers in northern Greece.
[c] Transportation to local gas stations costs €0.0005/l.
[d] Storage, drying and transportation of seeds, and extraction of oil cost, respectively, 70% and 40% less than in current situation.

Table 5
Cost of seed oil procurement for case study companies (2007).

Cost Item	Company #1	Company #2	Company #3
Case #1: procurement of seeds and extraction of seed oil			
Sunflower seeds (€/kg)		0.2500	0.2500
Storage, drying, and transportation of seeds (€/kg)		0.0270	0.0100
Crushing and extraction of seed oil (€/kg)		0.0500	0.0300
Total cost of seed oil (€/kg)		0.3270	0.2900
Bio diesel produced (l) per kg of seed oil used		0.3800	0.3800
Total cost of seed oil (€/l of bio diesel)		0.8605	0.7632
Case #2: procurement of seed oil			
Sunflower oil (€/l of bio diesel)		0.8100	
Soy oil (€/l of bio diesel)	0.7850		
Cotton oil (€/l of bio diesel)	0.8680		
Total cost of seed oil used (€/l of bio diesel)	0.7900	0.8176	0.7632

costs and taxes, all in 2007 Euros. The values used in building the model were provided by the respective companies and compared in advance to estimates found in the literature (e.g., Lychnaras, 2009; Panoutsou et al., 2008; Kallivroussis et al., 2002; Diakoulaki and Kavadakis, 2002).

The key assumptions and parameter values used in the analysis are summarized in Table 4. We assume no external financing and a project life of 10 years.[8] All capital is straight line depreciated over the 10-year period.

The results of the financial analysis are summarized in Tables 5 and 6. Table 5 shows that the cost of seed oil procurement incurred by the three companies was €0.79, €0.82, and €0.76/l, respectively. In Table 6 we calculate the unit operating costs and revenues of each company. In 2007, the low capacity firm earned a gross unit profit of €−0.07/l. This might explain why the company did not deliver but a small percentage of the quantity it received under the quota scheme. Companies 2 and 3 earned a gross unit profit of €0.01 and €0.12/l, respectively.

Subsequently, we calculate the sensitivity of gross unit profits to changes in the procurement cost of sunflower oil (Fig. 2).

As shown in Fig. 2, ceteris paribus, Company 1 earns a zero gross unit profit when the cost of seed oil is €0.72/l of bio diesel produced. The respective costs for Companies 2 and 3 are €0.82/l and €0.88/l.

[8] The same assumption has been used in the business plans of the three companies. Also, the Ministry of Finance makes the same assumption in the estimation of investment costs and benefits before granting subsidies to applicant companies.

6. Analysis of alternative scenarios

In order to address the research questions posed above we estimate gross unit profits under the following three scenarios.

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Table 6
Unit operating costs and revenues of bio diesel production from sunflower oil (2007).

Description	Case study companies		
	Company #1 (low capacity)	Company #2 (medium capacity)	Company #3 (high capacity)
A. Unit costs (€/l of bio diesel)			
Raw materials			
Sunflower/other oil	0.7900	0.8176	0.7632
Catalyst	0.0131	0.0131	0.0131
Methanol	0.0894	0.0650	0.0650
Water	0.0020	0.0010	0.0010
Other additives	0.0190	0.0160	0.0160
Subtotal raw materials	0.9134	0.9126	0.8582
Utilities			
Electricity	0.0062	0.0062	0.0062
Wastewater treatment	0.0010	0.0010	0.0010
Subtotal utilities	0.0072	0.0072	0.0072
Labour			
Subtotal labour	0.0075	0.0075	0.0075
Supplies			
Operating supplies	0.0016	0.0016	0.0015
Maintenance supplies	0.0055	0.0053	0.0049
Subtotal supplies	0.0071	0.0069	0.0064
General works			
Transporation to refinery	0.0345	0.0300	0.0100
Maintenance	0.0030	0.0012	0.0010
Insurance	0.0011	0.0020	0.0080
Other costs	0.0020	0.0010	0.0010
Subtotal general works	0.0406	0.0342	0.0200
Depreciation and interest			
Depreciation	0.0233	0.0120	0.0068
Interest	0.0325	0.0250	0.0150
Subtotal depreciation and interest	0.0558	0.0370	0.0218
Gross operating cost	1.0316	1.0054	0.9211
B. Unit revenues (€/l of bio diesel)			
Bio diesel	0.9500	0.9500	0.9500
Glycerol	0.0113	0.0113	0.0113
Sunflower meal	0.0000	0.0500	0.0800
Gross unit revenues	0.9613	1.0113	1.0413
Gross unit profit	−0.0704	0.0058	0.1201
Capacity (l)	15,000,000	50,000,000	250,000,000
2007 Quota received (l)	5,000,000	30,000,000	12,000,000
Gross profit	−351,896.67	174,193.58	1,441,519.26
Volume delivered in 2007 (l)	*500,000*	*30,000,000*	*12,000,000*
Actual gross profit in 2007	−35,189.67	174,193.58	1,441,519.26

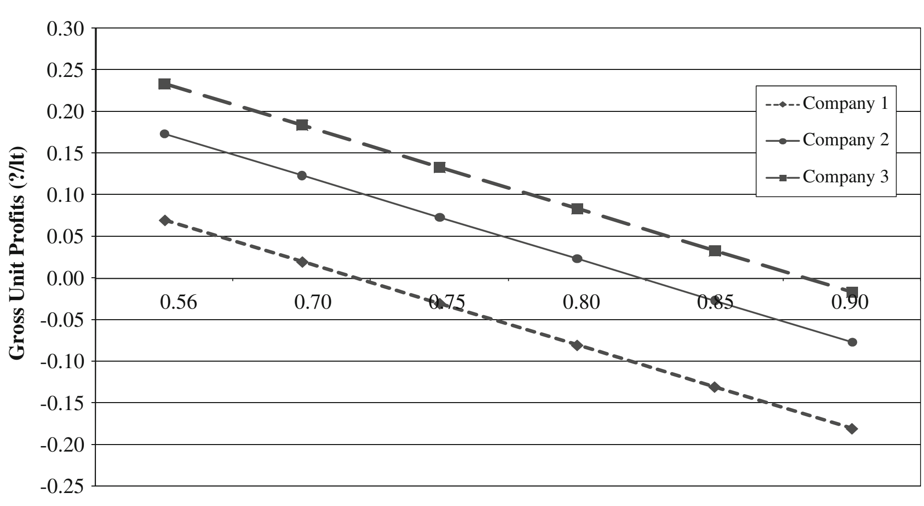

Fig. 2. Impact of sunflower oil cost on the gross unit profits of case study companies (2007).

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6.1. Scenario #1: monopsony/monopoly

Under this scenario, Company 3 earns the same gross unit profit of €0.12/l but maximizes its profits by producing 114,000 tons of bio diesel. However, the monopolist may also face significant problems. For example, assuring a reliable flow of feedstock for the high capacity plant may prevent the company from realizing the economies of scale related to higher production volumes. Furthermore, the logistics of sunflower production, harvest, storage, transport, and delivery will be taxing, due to the bulky nature of biomass, significant geographical variations in seed quality, limited harvest windows requiring storage to ensure steady supply, and product degradation in storage (Carolan et al., 2007).

Organizational issues are also critical in assessing the viability of the monopsony/monopoly scenario. Given the large number of sunflower producers and the relatively high costs of entry and exit for dedicated energy crop producers, the sole bio diesel producer might be able to exert anti-competitive market power. On the other hand, given the enormous capital requirements and the very high sunk cost for bio refineries, the bio diesel producer might not act in anti-competitive ways (e.g., hold-ups). This bilateral monopoly situation is caused by the existence of significant appropriable quasi-rents due to the high specificity of the assets involved. As a result, producers might not supply large enough quantities and investors are unlikely to invest in bio diesel production facilities. The formation of a producers' cooperative examined below provides a partial solution to these coordination and motivation problems.

Fig. 3 depicts the impact of changes in the price of sunflower seeds and bio diesel. We calculate this impact for the entire range of prices derived through the estimation of the biomass supply curve above. The company would earn a positive gross unit profit for sunflower seed prices below €0.30/kg, or for bio diesel prices above €0.83/l.

6.2. Scenario #2: produce for a different market

The medium and high capacity firms realize an even higher gross profit. However, the low capacity company still incurs losses (Table 7).

Also in this scenario the results are sensitive to changes in the price of bio diesel (Fig. 4).

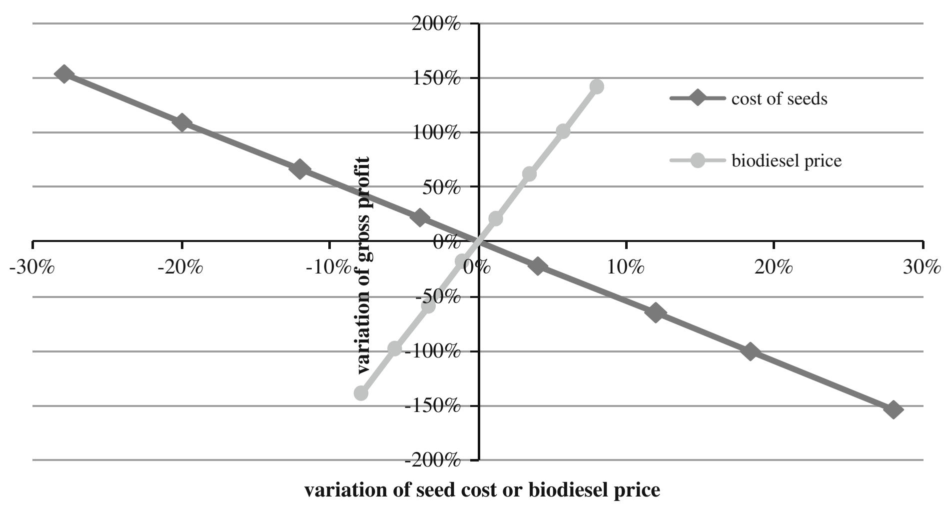

Fig. 3. Scenario #1 (monopoly): impact of changes in sunflower seed price and bio diesel price on gross unit profits.

Table 7
Scenario #2: produce for a different market.

Description	Case study companies		
	Company #1 (low capacity)	Company #2 (medium capacity)	Company #3 (high capacity)
A. Unit costs (€/l of bio diesel)			
Raw materials	0.9914	0.0951	0.8582
Utilities	0.0072	0.0072	0.0072
Labour	0.0075	0.0075	0.0075
Supplies	0.0071	0.0069	0.0064
General works			
Transportation to gas stations	0.0005	0.0005	0.0005
Maintenance	0.0030	0.0012	0.0010
Insurance	0.0011	0.0020	0.0020
Other costs	0.0020	0.0010	0.0010
Subtotal general works	0.0066	0.0047	0.0045
Gross operating cost	0.9977	0.9759	0.9056
B. Unit revenues			
Gross revenues	0.9613	1.0113	1.0413
Gross unit profit	−0.0364	0.0353	0.1356
Projected Volume of Sales, 2007 (l)	*10,000,000*	*40,000,000*	*100,000,000*
Scenario #2 Profit in 2007	−364,193.33	1,412,258.11	13,562,660.53

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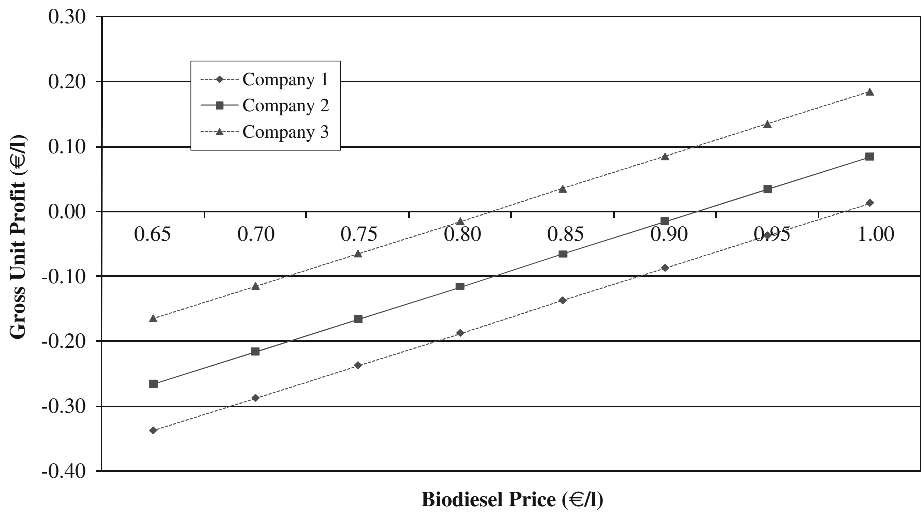

Fig. 4. Scenario #2: impact of bio diesel price on gross unit profit (2007).

Table 8
Cost of seed oil in scenario #3 (farmer-owned crushing plant).

Cost item	Farmer-owned crushing plant (cooperative)	Company #3
Sunflower seeds (€/kg)	0.2500	0.2500
Storage, drying, and transportation of seeds (€/kg)	0.0081	0.0100
Crushing and extraction of seed oil (€/kg)	0.0300	0.0300
Total cost of seed oil (€/kg)	0.2881	0.2900
Bio diesel produced (l) per kg of seed oil used	0.3800	0.3800
Total cost of seed oil (€/l of bio diesel)	0.7582	0.7632

Table 9
Gross profit of the cooperative in scenario #3 (€/l of bio diesel).

Sunflower or other oil	0.7600
Sunflower meal	0.0500
Total revenue of the cooperative	0.8100
Gross unit revenues of the cooperative	0.0518
Gross profit of the cooperative	1,814,473.68

6.3. Scenario #3: farmer-owned oilseed crushing plant

Due to lower operating and transport costs, the cooperatively owned crushing plant makes a profit (Tables 8 and 9) and still sells seed oil to companies 1 and 2 at a price of €0.76/l of bio diesel produced. However, while Company 2 increases its gross profit margins to €0.01/l, the low capacity Company 1 still earns a negative gross unit profit (Table 10).

7. Policy analysis and environmental cost-effectiveness

EU promotes biofuels as a means of environmental protection. The Greek government shares this objective but also views biofuels as a way to prevent the reduction of farm income caused by consecutive changes in the CAP. In order to assess both of these points of view, we estimate costs to taxpayers, benefits or surpluses to bio diesel chain participants, and environmental benefits for each of the scenarios examined in previous sections.

Many studies report greenhouse gases emissions measured in tons of CO_2 equivalent. Russi (2008) studies Italian bio diesel and makes the distinction between bio diesel imported from Eastern Europe and volume produced domestically. She finds that 1.045 tons of CO_2 equivalent are avoided per 1000 l of bio diesel produced domestically whereas each cubic meter (1000 l) of bio diesel imported contributes to avoiding 1.71 tons of CO_2 equivalent. More optimistic studies in France raise bio diesel's contribution to 2.10 tons of CO_2 equivalent per 1000 l of bio diesel (ADEME/DIREM, 2002). We use Russi's estimates because they are rather conservative and based on well-documented calculations.

Table 11 summarizes our calculations. It contains the surpluses accruing to each bio diesel chain actor in the current situation and for each of the scenarios examined. Also, it shows the budget burden to society as well as the deadweight loss and the environmental impact for each scenario. The last column presents the cost-effectiveness indicator, that is, the total economic cost to the society divided by the tons of CO_2 emissions saved.

In all three scenarios, bio diesel production is less efficient than other ways to reduce CO_2 emissions. For example, on the CO_2 stock exchange prices of CO_2 do not exceed €30–40/ton. Nevertheless, this price refers to all methods of emission reduction and not only those related to the transport sector. The examined scenarios differ in terms of the efficiency attained but all of them are more efficient than the current governmental allocation under the quota scheme. For example, note that in the current situation Greek taxpayers pay €311/ton of CO_2 instead of €161/ton under the most efficient scenario #2.

If efficiency is the only criterion employed, one could use the last column of Table 11 to rank the alternative scenarios and choose the most efficient. However, this would neglect other important information embedded in this table. For instance, scenario #2, which is ranked first, gives a higher surplus to importers whereas scenario #1 results in a higher surplus for farmers and local industries. Multi-criteria analysis is used in the literature in order to tackle similar problems of public decision making (e.g., Rozakis et al., 2001). Given the limited number of alternatives studied in this research, however, a thorough analysis of results appearing in Table 11 would suffice.

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Table 10
Unit operating costs and revenues of bio diesel production from sunflower oil in scenario #3.

Description	Case study companies		
	Company #1 (low capacity)	Company #2 (medium capacity)	Company #3 (high capacity)
A. Unit costs (€/l of bio diesel)			
Raw materials			
Sunflower oil	0.7600	0.7600	0.7632
Catalyst, methanol, water, other additives	0.1234	0.0951	0.0951
Subtotal raw materials	0.8834	0.8551	0.8583
Utilities	0.0072	0.0072	0.0072
Labour	0.0075	0.0075	0.0075
Supplies	0.0071	0.0069	0.0064
General works	0.0406	0.0342	0.0200
Depreciation and Interest	0.0558	0.0370	0.0218
Gross operating cost	1.0016	0.9479	0.9211
B. Unit revenues (€/l of bio diesel)			
Gross revenues	0.9613	0.9613	1.0413
Gross unit profit	−0.0403	0.0134	0.1201
Capacity (l)	15,000,000	50,000,000	250,000,000
2007 Quota Received (l)	*5,000,000*	*30,000,000*	*12,000,000*
Scenario #3 Gross Profit	−201,500.00	402,000.00	1,441,705.26

Table 11
Bio diesel policy and environmental cost-effectiveness in Greece (2007).

	Surplus							
	Farmers	Importers	Bio diesel producers	Total	Budget burden[a]	Deadweight loss	Environmental effects (CO_2eq)	Efficiency per € spent
Current situation (2007)	1,613.4	769.23	1,580	3,193.4	17,000	13,806	44,412	310.9
Scenario #1	5,923.3	0	13,691.4	19,614.7	45,600	25,985	119,130	218.1
Scenario #2	5,568.8	11,259.5	11,538	17,106.8	42,400	25,294	156,750	161.4
Scenario #3	5,503.9	0	1,022.8	6,526.7	18,800	12,274	49,115	249.9

[a] Suppose tax credit €0.40/l multiplied by quantity of bio fuel (Q).

8. Discussion and conclusions

The above analyses are subject to several caveats and limitations. First, calculations are based on the simplifying assumption that bio diesel plants operate at maximum efficiency and that they are constrained only by the maximum quantity they can produce under the national quota scheme. Clearly, this may not be true. However, the cost figures provided by the case study companies are very close to those reported in the literature (e.g., Demirbas, 2007; Haas et al., 2006). Thus operation at maximum efficiency is a plausible assumption.

In a democracy, the monopoly scenario is difficult to be implemented through a governmental policy. A state-owned bio diesel plant could bypass this problem. Yet, in this case other serious challenges would emerge.

Subject to the above limitations, the quota policy seems to create more problems than it solves. The production restrictions imposed on bio diesel plants do not allow them to realize the benefits associated with scale economies. This is particularly true for plants that receive a very small quota relative to their much higher capacity. Low volume producers are also seriously affected by the quota policy. Nonetheless, they would not be able to earn a positive return on their investment even in a non-regulated market environment.

Medium capacity firms that operate close to their maximum capacity enjoy a low gross profit margin whose magnitude depends on the quota they receive from the Ministry. Given their relatively high investment, one could reasonably assume that such companies would increase their capacity in order to minimize production costs and become less dependent on future policy changes. Actually this is what happened; in 2008, the medium capacity case study company doubled its capacity.

The case where a monopsonist/monopolist wins all allows for the maximum utilisation of scale economies. Yet, the resulting coordination and motivation problems and the difficulty of implementing it make this scenario relatively inapt.

A policy change so that bio diesel producers are granted permission to sell directly to local gas stations and/or public transport organizations seems to be a very promising scenario. Medium and high capacity companies would increase their profit margins; the first by 509% and the latter by 13%. Company 1 would keep losing money, albeit it would lower its loss by 48%.

The third scenario examined, according to which sunflower producers integrate forward and own an oilseed crushing plant, seems to be another promising case. Although the three case study companies do not increase their profit margins (or, in the case of company 1, lower their losses) as much as in scenario 2, they do enjoy better results relative to the current situation. What is more important though is that under this scenario many of the organizational issues threatening the bio diesel supply chain's viability are dealt within an efficiency maximizing way. Farmers' dedication to sunflower production becomes low risk and profitable. On the other hand, investors may be more willing to invest in bio diesel production because they secure a constant supply of oilseeds.

In all three scenarios, the total surplus produced is higher compared to the current situation. The current policy is also less efficient than the studied alternatives, with respect to CO_2 emission minimization. Thus, policy makers should consider abandoning the current quota scheme and turn into another bio

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diesel policy. In any case, a more in-depth study of all feasible alternatives is required before making a choice. For instance in France, the country that led in the first decade the European bio diesel production, the government implemented relevant policies based on the notorious Levy report (1993), a collective work of over 20 leading experts on all aspects of bio diesel chains. Eight years later, a new report incorporated updates on technical progress, the agricultural policy context, first and second level transformation industries, and refineries (Levy and Couveihnes, 2000). The proposed efficiency maximizing policy of a 20% decrease in the tax exempt volume was adopted by the government in 2002.

Future research should focus on examining in detail the economic, technical, and organizational implications of the three scenarios studied here. For example, it is critical to study how the incentives of the various stakeholders are altered in case the farmers' cooperative owns part of the bio diesel plant and/or the bio diesel producer owns part of the oilseed crushing facility. Another avenue for future research is to calculate additional indicators of economic, technical and environmental efficiency and use multi-criteria analysis methods to assess alternative policies in a comprehensive way.

Appendix A. Supplementary materials

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.enpol.2009.10.059.

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