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Perennial energy crops vs. durum wheat in low input lands: Economic analysis of a Greek case study

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ABSTRACT

A key challenge internationally is the design of policies that will result in the substitution of conventional energy sources with renewable energy sources. The European Union has set a legally binding target of 20% final energy consumption from renewable sources by 2020 but not all EU countries have been successful in meeting interim targets towards that goal. On the other hand, even if interim goals have been achieved, economic, social, and environmental considerations might threaten a country's ability to meet the 2020 goal without jeopardising other key economic goals. This is the case, among other countries, of Greece, where decision-making is governed by the economic recession and the austerity measures implemented to counter the debt crisis. This article studies the potential of three perennial energy crops, miscanthus, arundo and poplar, to play such a role in the region of Karditsa, Greece. According to our results and considering the option of farm gate delivery, sample farms generate on average positive gross profits from all three energy crops. The highest is generated by arundo, followed by poplar and at a much lower level miscanthus. The present study shows that Arundo, under certain conditions, can partially replace durum wheat in low input lands, without distorting the food trade balance of the country. While this research does not focus on environmental issues, results suggest that substituting arundo for durum wheat can have a beneficial effect in nitrate-polluted regions since arundo requires far less fertilizers. The relevant policy mix is analysed, discussed and outlined as a nexus of interrelated incentives provided by policy makers and the market.

1. Introduction

The Renewable Energy Sources (RES) Directive (Directive 2009/28/EC) of the European Union has set a legally binding target of 20% final energy consumption from renewable sources by 2020 [1]. To achieve this target, EU countries have committed to reaching their own national targets for renewable energy; these range from 10% in Malta to 49% in Sweden. Additionally, each of the EU countries is required to have at least 10% of their transport fuels come from renewable sources by 2020. All EU countries have adopted national renewable energy action plans stating what actions they intend to take to meet their renewables targets. These plans include sectorial targets for electricity, heating and cooling, and transport; planned policy measures; the different mix of renewable technologies they expect to employ; and the planned use of cooperation mechanisms. Nineteen EU countries have achieved their interim targets and are even projected to exceed the EU 2020 target (e.g., Austria, Estonia, Denmark, Germany, Italy, Lithuania, Romania, Sweden) [2]. Yet, other Member States, such as France, the Netherlands, and the United Kingdom have been less successful in meeting their national goals and, consequently, in moving towards the EU target of 20% [3]. A recent evaluation of the progress each country has made towards the RES goals reveals that the most important barriers in achieving these goals relate to the political, economic and environmental framework, the existence and reliability of a general RES support scheme, access to finance and the remuneration level of existing support schemes and land availability [4].

Most southern European countries are facing significant challenges. Spain, for example, did not meet its National Renewable Energy Action Plan (NREAP) 2012 and growth in the renewables heat and cooling sector needs to accelerate [4]. Portugal, although has met the less ambitious interim target 2011/2012, it has missed its NREAP 2012 target. Even more so, the renewables heat and cooling share has even decreased between 2010 and 2012 and this trend needs to be reversed. At the same time, Italy, while very successful in meeting its NREAP targets, still needs to accelerate the development of the renewables heat and cooling sector [4].

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Greece, the focus of this paper, has achieved both its national renewable energy action plan (NREAP) 2012 target and the interim target for 2011/2012. This positive outcome can be attributed partly to the rapid drop in economic growth that the country is currently experiencing as a result of rapidly contracting national consumption [4]. The economic crisis of Greece may indeed generate opportunities and challenges for the renewable energy. One such opportunity has been the increased demand for renewable, lower-cost energy, particularly from households which cannot meet their heating needs due to the very high price of electricity and oil used in conventional heating systems [5,6]. Demand for wood pellets has increased considerably and many households abandon their old, oil consuming heaters in favour of heating systems based on pellets [7]. Yet, Greece is a net importer of pellets and thus increased demand threatens to make trade deficit even higher than the current one [5,6]. Thus it is extremely important to assess whether there is room for developing a local bio energy supply chain that will be mainly based on locally grown, low-cost feedstock.

Although the Greek NREAP deploys a market incentive scheme, mainly based on feed-in tariffs and establishment subsidies for the bio fuels industry, the risk of the local industry being unresponsive to policy incentives is very high [8]. Equally challenging is the extremely limited access to risk capital for making required investments. Further, local communities in the country are highly concerned about land use and environmental issues perceived to be or actually emerging as a result of moving from food to energy crop production and the establishment of bio-power plants [9,10]. During times of severe economic crises one might expect to observe an attenuation of environmental concerns among local populations. Yet, recent empirical findings suggest that local societies in Greece are against investments in alternative forms of energy generation when it comes to their region or farm [e.g., [11]]. Although the services provided by the siting of such investments are widely considered beneficial, in practice, they are often strongly opposed by local communities. This phenomenon, also known as not-in-my-back-yard (NIMBY) behaviour poses great challenges for policy makers seeking to promote renewable energy sources [12]. Therefore, the recovery of the country's economy should not at any cost hinder society and the environment.

Moreover, diesel oil prices have increased substantially in Greece during the economic crisis, as a result of higher fuel taxes introduced by the government. Diesel oil is used as fuel in both central heating and transportation and, until recently, national social policies had kept the price of diesel oil used in heating much lower than that of oil used in transportation. However, under the second Greek Memorandum, the prices of diesel oil for heating and transportation were equalised. The higher diesel oil prices coupled with shrinking household budgets forced thousands of families across Greece to replace diesel with other energy sources for their heating needs during the winter of 2012–13. Among these alternative energy sources, old wood-burning stoves and fireplaces are seeing a revival, creating a profitable market for sellers of firewood. Forest managers fear that in the light of a weakening forest ranger service, illegal logging will be almost impossible to control, especially during the weekends, when most illegal logging takes place [13].

It should also be noted that, despite the significance of biofuels for reducing GHG emissions and the acquisition of energy efficiency in Greece, some biofuels might require more energy to produce than the energy they offer (e.g., the case of Germany). A recent report of the EC's Joint Research Centre reveals that green projects based on biofuels may have devastating impacts on the EU's biodiversity [14]. It is estimated that as a result of EU biofuel targets, about 85 per cent of biodiversity will be damaged across 17,000 square kilometres of natural habitats that risk being converted to farmland. Natural habitats will not be protected under current EU legislation for biofuels and it is likely to contradict EU's commitment to reverse biodiversity loss by 2020.

Therefore, policy makers are faced with a very challenging question: can they find the right policy mix that includes incentives for farmers and the industry and, at the same time, implement mitigation policies to address local community and environmental concerns, and promote the use of certified pellets? To make things even more perplexing, these goals should be achieved with scarce resources during an era of economic crisis.

This paper addresses these issues by studying the conditions, under which selected energy crops might become the basic input for local bio energy supply chains. We focus on the region of Karditsa, a promising agricultural area in central Greece, and on a representative sample of local farms. We study how attractive three perennial energy crops are for farmers, relative to durum wheat, the main crop cultivated in low input lands in the case study region. The selected energy crops are miscanthus, arundo, and poplar and their dry matter, biomass, is mainly intended for the production of solid biofuels (e.g., pellets[1]). These energy crops can be cultivated in low input land (e.g., arundo and miscanthus in non-irrigated land and poplar in land without fertilization). Perennials have lower pesticide and fertilizer requirements, so they can appear more attractive to farmers than annual crops.

We estimate energy crop supply curves as in Styles et al. [15]. Supply curves for different energy crops can be used as a decision-making tool by all interesting parties within a biomass-oriented supply chain; biomass producers can use them to decide on the economic feasibility and efficiency of a suggested energy crop, while industrial players may use them to determine contract prices that ensure long-term availability of inputs. However, we move one step further by also estimating the impact on trade balances associated with cultivating a biomass crop instead of a food crop. We calculate the net effect on the trade balances of both the food crop and the final energy product, namely, pellets.

This research informs energy and agricultural policy making by also taking into account and addressing undesirable side effects (e.g., trade deficit in wheat). It turns out that, under plausible assumptions, Arundo can potentially replace part of the durum wheat without jeopardising the country's positive trade balance in durum wheat. Our results are also of help to policy makers in other European regions with similar characteristics, as well as in countries going through turbulent economic times.

The remainder of the paper is structured as follows: Section 2 provides an overview of energy crop production and markets across Europe, with an emphasis on Greece. Section 3 presents information on the case study region while Section 4 describes the methods and data used, as well as the assumptions made. Section 5 focuses on the analysis of collected farm data and Section 6 presents and discusses the results. Section 7 concludes the paper.

2. Energy crops across Europe: overview and context

2.1. The EU context

The EU RES Directive, RED (2009/28/EC) lays out a roadmap for all member states to increase their share of renewable energy consumption to 20% of total energy consumption by 2020. According to 2011 data, the renewable energy sector contributes 13% to the total energy consumption in EU-27 [16]. Among EU-27 member states, Estonia is a good example of an achiever as regards the share of energy from renewable sources by 2020. On the contrary, the UK is the least efficient member-state in meeting the national target [16].

Biomass provides already the largest share of renewable source of energy globally [17]. The role and contribution of energy crops to the bioenergy sector is gradually being recognised as an important one

[1] These perennial energy crops can also be cultivated for the production of other types of biofuels. (e.g., bioethanol).

[e.g., 18]. Initial concerns over food supply and demand and the reduction of arable land dedicated to food production were mainly associated with first generation biofuels.

As far as bioenergy is concerned, 2011 statistics show that it represented 68% of the total gross inland consumption of renewables [16]. For the same year, biomass accounted for only 8.4% of the total final energy consumption in EU-27. However, for some countries such as Estonia, Latvia, Finland and Sweden biomass participation in the total energy consumption exceeded 25% [16]. When considering energy for Heating and Cooling, biomass holds the lion's share as almost 90% of renewable heating uses a biomass-related source [16].

Energy crops in EU-27 can be classified in oilseed (rapeseed, sunflower) and lignocellulosic energy crops (arundo, cardoon, hemp, miscanthus, poplar, reed canary grass, switch grass, willow). The area covered with lignocellulosic energy crops is rather limited when compared to that covered by oilseed crops: switch grass is cultivated in 50 thousand hectares, willow in 36.48 thousand hectares, miscanthus in 19.67 thousand hectares, reed canary grass in 19.48 thousand hectares, poplar in 15.62 thousand hectares, arundo in 4 thousand hectares, cardoon in 0.5 thousand hectares and hemp in 0.44 thousand hectares (Table 1).

The main producing countries of biomass from miscanthus are the UK (56%), France (15.2%), Germany (10.1%) and Ireland (10.1%), while biomass from poplar is produced mainly in Italy (35.1%) and Germany (32%). Poland (24.7%) and Denmark (15%) are the most important producers of biomass from willow. Switch grass, reed canary grass, hemp, arundo and cardoon biomass are mainly produced in Romania, Finland, Sweden, Italy and Greece respectively (Table 1).

Lignocellulosic energy crops are mainly intended for pellet production. Since 2001, pellet consumption in Europe has been growing at an average rate of 25% annually [23]. Accordingly, European pellet production has been growing at a rate of more than 30% between 2009 and 2012 [16]. However, recent data reveal that Europe runs a high pellet deficit of more than six million tonnes [23].

Current projections show that EU consumption will continue to expand. Some non-European countries, such as Japan and South Korea, are foreseen as potentially important pellet consumers [16]. Consequently, there is a considerable margin for the development of the European pellet market, which creates increasing demand for lignocellulosic biomass.

2.2. The Greek context

2.2.1. Policies

Up until 2009, energy crops cultivated in Greece for commercial exploitation were eligible for direct land subsidy in the context of the First Pillar of Common Agricultural Policy. The direct payment was 45 euros/ha. Since 2010, however, energy crops are excluded from the direct payment scheme. Further, the 2013 reform of the Common Agricultural Policy (CAP) moved toward decoupled payments partial convergence in combination with greening requirements [24]. As a result, the historical model no longer applies and thus subsidies received in the past do not determine subsidies received currently or in the future. Consequently, this policy may affect the gross income of various farms in different ways [e.g., 25–27]. Yet, we do not expect to have a major similar impact on the sample farms due to the high homogeneity characterizing them.

Currently, in Greece, there is no government driven incentives structure in place that could lead to the adoption of energy crops by farmers [28]. Nonetheless, market deployment policies involving establishment subsidies have been designed and implemented to influence investment decisions by the industrial partners. The main funding mechanism available in the time being is the Partnership Agreement for the Development Framework 2014–2020 (PA). PA seeks to mitigate the structural weaknesses that proliferated during the years of economic crisis.

2.2.2. Crops and the processing industry

Energy crops have been commercially cultivated in Greece since 2005. The planting rates of sunflower, rapeseed and cardoon—the most commonly cultivated crops—have increased significantly over these years also due to the implementation of contracting farming initiatives from the industry, which contribute in reducing the risk for farmers and provide long-term stability [29] (Table 2). So far, there have not been any commercial cultivations of miscanthus, arundo or poplar.

3. Case study: Karditsa, Greece

The regional unit of Karditsa is located in the southwest part of the Greek region of Thessaly (Map 1). It covers 2636 Km^2 and is populated by approximately 130,000 inhabitants (1.2% of the country's total population).

The Karditsa plain covers 22% of Thessaly's farmland, a fact that places it second, in terms of size, among the four regional units of Thessaly. Karditsa's agriculture contributes 2.6% to the National GDP. Half of its land is mountainous while the remaining represents farmland. Main crops cultivated are cotton and durum wheat, covering 37% and 25% of the region's cultivated land, respectively (Table 3).

Energy crops have been cultivated in the Karditsa area during the last fifteen years but predominantly at pilot and experimental farms participating in research projects. The only exception is Cardoon, which is currently cultivated on 100 ha of non-irrigated land. The harvested product feeds the local pellet producing plant, which operates under ten-year contracts with farmers [20]. However, the actual yields from the commercial cultivation of cardoon have been much lower than those reported in local pilot fields [20]. The resulting

Table 1
Energy crops cultivation in EU-27 (2010–2013).
Source: [16,19–22].

Energy Crops	Land Coverage (ha)	Main producing countries
Oil seed Crops		
Rapeseed	6.88 millions (2010)	Germany (21.4%), France (21.2%), Poland (11%), UK (9%)
Sunflower	3.68 millions (2010)	Romania (22%), France (19%), Spain (19%), Bulgaria (17.5%)
Lignocellulosic Crops		
Switch grass	50.00 thousands (2011)	Romania
Willow	36.48 thousands (2011)	Poland (24.7%), Denmark (15%)
Miscanthus	19.67 thousands (2011)	UK (56%), France (15.2%), Germany (10.1%), Ireland (10.1%)
Reed canary grass	19.48 thousands (2011)	Finland
Poplar	15.62 thousands (2011)	Italy (35.1%), Germany (32%),
Arundo	4.00 thousands (2011)	Italy
Cardoon	0.50 thousands (2013)	Greece
Hemp	0.44 thousands (2011)	Sweden

Table 2
Profile of commercially exploited energy crops in Greece (2013/14).
Source: [20,22,30].

	Sunflower	Rapeseed	Cardoon
Location	*Northern Greece*	*Northern Greece*	*Northern & Central Greece*
Cultivated Area (ha)	70,000 (2014)	15,000 (2014)	500 (2013)
Number of contracted biofuel industries	14	14	2
Final product	Biodiesel	Biodiesel	Solid biofuels

negative gross margins for cardoon have spread pessimism among local farmers who perceive these economic results as a harbinger of worst things to come for the whole local energy supply chain [11].

4. Methods, data and assumptions

4.1. Methods

Early literature on the economics of energy crops, focused on cost analysis using common budgeting methods like 'activity-based costing' [32]. In the absence of established markets for biofuels, these preliminary studies did not include any revenue data in their analysis.

In the ensuing years, a growing number of studies have used mainly partial budgeting methods to test the economic viability of energy crops, especially when compared to more conventional ones [e.g. 15]. Such studies provide information on costs (using activity-based costing methods) and revenues, albeit based on a rather limited sample of farms. The supply response of farmers with respect to energy crops is estimated in a number of studies. The most common methods used in estimating the energy crop supply curve are mathematical programming [e.g. 33] and break-even budgeting [e.g. 34]. In this paper, we apply both budgeting methods (partial and break-even budgeting) to perform an economic assessment of three specific energy crops, namely arundo, miscanthus and poplar, in Greece.

Table 3
Main Crops cultivated in Karditsa, Greece (2010).
Source: [31]

Crop	Land Cultivated (Ha)	Land Cultivated (as % of Total Cultivated Land)
Cotton	40,387.99	36.73%
Durum Wheat	27,515.24	25.02%
Animal Feeds	5986.56	5.44%
Other Cereals	5568. 83	5.06%
Set-aside	5208.00	4.74%
Maize	2956.50	2.69%
Vegetables	1755.99	1.60%
Vineyards	343. 49	0.31%
Tobacco (Virginia)	265.21	0.24%
Olives	137.45	0.12%
Other crops	19,834.84	18.03%
Total	109,960.1	100.00%

4.1.1. Partial and break-even budgeting

We analyse how attractive energy crops are to Karditsa sample farmers relative to feasible alternatives using the partial budgeting and break-even budgeting methods [35]. Partial budgeting allows us to calculate the difference between the average gross margin of energy crop *(en)* and conventional crop *(conv)* for a specific sample of farms.

Break-even budgeting enables us to estimate the minimum energy crop price that would provide incentives to farmers to cultivate. This price is referred to as critical price. Subsequently the critical price is used to estimate the energy crop supply curve, which provides information about the energy crop supply response of farms and the potential impacts on the balance of trade for the competitive conventional crop:

Map 1. Greece: The regional unit of Karditsa.

Table 4
Crop patterns in the sample farms (2012).
Source: [36]

Crop	Area (Ha)	% of area	% of farms
Cotton (irrigated)	467.9	55.2	85
Tobacco (irrigated)	58.6	6.7	25
Maize (irrigated)	27	3.1	29
Processed Tomato (irrigated)	31	3.6	4
Processed Pepper (irrigated)	30	3.5	19
Alfalfa (irrigated)	66.5	7.8	23
Durum Wheat (non-irrigated)	142	16.7	75
Set-aside (non-irrigated)	27.2	3.2	33
Total	847.2	100	

$$Pren = \frac{Prconv\ *\ Yieldconv + LSubconv - VCconv - LSuben + VCen}{Yielden}, \quad (1)$$

In Eq. (1), *Pr en* corresponds to the critical price of the energy crop, *Pr conv* to the producer price of conventional crop, *Yield conv* corresponds to the yield of conventional crop,*LSub conv* to the potential land subsidy of the conventional crop,*VC conv* to the variable cost of the conventional crop,*LSub en* to the potential land subsidy of the energy crop,*VC en* to the variable cost of the energy crop, and *Yield en* to the energy crop yield.

4.2. Data and assumptions

Estimation is based on data collected in January 2013 from farms in the Karditsa region through personal interviews [36]. The sample includes 48 farms specialising in arable farming. The most important crop, in terms of land coverage, is cotton, followed by durum wheat (Table 4).

The average farm in the sample is 17.65 ha; this represents a rather large size when compared to 7.2 ha of the average farm in Greece [2]. The same conclusion is reached when considering that 89% of the farms in Greece are equal or less than 10 ha while only 41.67% of the sample farms fall under this category (Table 5). In terms of economic size, 75% of the sample farms are relatively large, when almost 84.7% of the farms, at the country level, are classified as small [2].

This research focuses on Arundo, Miscanthus and Poplar cultivated on low input lands. Thus we assume that these energy crops compete only with durum wheat, since the latter is the crop that requires the lowest inputs in the Karditsa region. We also assume that cost and yield data on the studied energy crops correspond to annual equivalent values because of the perennial life cycles of these crops.

5. Analysis

5.1. Yield estimation

A major challenge of this research was the collection of yields data on energy crops. To address this problem we applied a yield-forecasting model for each farm [35]:

Table 5
Relative size of sample farms.
Source: own elaboration.

Utilised Agricultural Land (UAA) (Ha)			Economic Size Unit (ESU) (Ha)		
UAA ≤ 10	*10 < UAA≤30*	*UAA > 30*	*ESU < 16 (Small farms)*	*16≤ESU≤40 (Medium farms)*	*ESU > 40 (Large farms)*
41.67%	41.66%	16.66%	27.00%	37.50%	35.41%

Table 6
Yield per studied crop.
Source: [36–38]; own elaboration.

	Durum Wheat	Arundo	Miscanthus	Poplar
Max Yield (ton/ha)	5	12	10	10
Forecasted average annual Yield of the sample (ton/ha)[a]	3.58	8.49	7.07	7.07

[a] For energy crops yield corresponds to dry matter.

$$Yielden = \frac{max\ Yielden}{max\ Yieldconv} Yieldconv, \quad (2)$$

In Eq. (2), *Yielden* is the yield prediction of the energy crop, *maxYielden* the maximum observed yield of energy crop in surveyed area ,*maxYieldconv* the maximum observed yield of conventional crop in surveyed area, and *Yieldconv* the observed yield of the conventional crop. As *maxYielden* for each energy crop, we considered the mean yields that were recorded in South Europe [37,38] (Table 6).

5.2. Technical data, cost estimation and revenue streams

The studied energy crops are characterized by similar calorific values and economic life cycles (Table 7). Arundo and miscanthus require irrigation only during planting, while poplar needs to be irrigated on an annual basis, particularly under the weather conditions prevailing in Greece [37]. The reverse is true when it comes to fertilization and weed control; Poplar needs neither while arundo and miscanthus should be fertilized annually. For additional information

Table 7
Basic technical data of studied energy crops.
Source: [37–40].

	Arundo	Miscanthus	Poplar
High Heating Value (MJ/kg)	18.8 [39]	18.9 [39]	19.5 [39]
Low Heating Value (MJ/kg)	17.6 [39]	17.7 [39]	18.2 [39]
Economic Life cycle (years)	15 [38]	15 [38]	16 [37]
Plantation density (plants/ha)	15.000 [38]	15.000 [38]	10.000 [37]
Irrigation (frequency)	In the establishment year (1st year) [38]	In the establishment year (1st year) [38]	Annually [37]
Fertilization (frequency)	Annually [38]	Annually [38]	– [37]
Weed control (frequency)	In the establishment year and in the 2nd year [40]	In the establishment year and in the 2nd year [40]	– [37]
Harvesting (frequency)	Annual (after 1st year) [40]	Annual (after 1st year) [40]	Every 4 years [37]
Soil restoration (frequency)	15th year [38]	15th year [38]	16th year [37]

Table 8
Variable cost data sources per energy crop and operation.
Source: [37,38].

Operation	Arundo	Miscanthus	Poplar
Land preparation and crop establishment	[38]	[38]	[37]
Irrigation	[38]	[38]	[37]
Fertilization	[38]	[38]	[37]
Weed control	[38]	[38]	[37]
Harvesting	[38]	[38]	[37]
Farm Storage	[38]	[38]	[37,38]
Transportation	[38]	[38]	[37]
Soil restoration	[38]	[38]	[37]
Overheads[a]	[38]	[38]	[37]

[a] Overheads charged include administrative and general expenses, equipment insurance, maintenance and contingencies.

concerning the optimum climatic and soil conditions of the studied crops see Table A1 in Appendix A.

After installation of the crops, arundo and miscanthus are harvested annually after the first year while poplar every four years, primarily due to the slower development pace of the latter. At the end of the crops' economic life cycle the plantation is removed and the soil should be restored.

Another significant challenge of this research was the lack of variable cost data on energy crops. To ameliorate this constraint, we used representative cost data from the academic literature (Table 8). Given that energy crop prices refer to 2015, we adjusted durum wheat cost data to 2015 values by using relevant cost indices [41]. Harvesting, farm storage, transportation, and soil restoration costs were adjusted according to forecasted yields for each energy crop and for each farm. Due to the perennial life cycle of energy crops, variable cost corresponds to annual equivalent variable cost .[2]

The sample farms own the machinery used in all farm activities except for harvesting and transportation (Table 9).

We estimated production costs for the studied energy crops at both the farm gate and factory gate levels. This is in line with local reality as the only pellet producing facility in the region provides local energy crop producers with two options: they can either sell their produce at the farm gate or the factory gate. In the former option, the producer incurs all production costs prior to harvesting, while in the latter the farmer also incurs the costs of harvesting, storage, and transportation. Most local farmers, however, prefer the farm gate option since they do not have access to harvesting machines and transportation means.

After taking into account all relevant expenses, the highest cost per hectare of energy crop corresponds to Arundo. However, Arundo surfaces as the least-costly energy crop when we consider the average variable cost per ton of dry matter due to its higher yield (Table 10).

In calculating revenue streams, we assume that the farm gate price for durum wheat is the median price of the last four years (2011–2014). According to interviewed sample farmers, durum wheat prices range from 200 to 250 €/tn. Unfortunately, price data on the studied crops were not available due to the lack of an established market for these crops in Greece. Instead, we used the current contract price for cardoon biomass in the area of Karditsa which corresponds to 50 €/dtn at farm gate level and 70 €/dtn at factory gate level [20,43].

Among the studied crops, only durum wheat is eligible for a land subsidy of 90 €/ha. Based on the aforementioned data and assumptions, Table 11 depicts the revenue stream per crop.

[2] For the financial calculations, we used a discount rate (cost of funds) of 5% [38]. For additional information on the estimation methodology of annual equivalent cost, please see [42].

6. Results and discussion

6.1. Partial budgeting results

According to our partial budgeting results, under the farm gate delivery option, sample farms generate, on average, positive gross profits from all three energy crops (Table 12). The highest gross profit is generated by arundo, the second highest by poplar, while miscanthus follows, albeit at a much lower level. Despite these results, substituting durum wheat for one of these energy crops is not recommended as it results in lower total gross profit.

When farmers deliver biomass directly to the pellet plant, only arundo gives a positive gross profit. However, even in this case, substituting durum wheat with arundo is far from recommended; losses from the substitution under this scenario are even higher compared to the losses incurred under the farm gate delivery option.

Numerous studies have calculated the economic costs and benefits associated with the cultivation of the three energy crops of this research. Direct comparison of our results with those reported in the extant literature is not feasible because of the very different contexts, methodologies, and, in some cases, underlying assumptions. The research setting closest to this research is provided by Soldatos et al. [42] who report an annual total cost for Arundo equal to 1476.69 €/ha and 1475.46 €/ha for Miscanthus. In the UK, a 2007 study reports gross margins for Miscanthus ranging from 362.07 €/ha (baled) to 425.38 €/ha (chopped) [15]. In Canada, a similar study on Miscanthus reports annual costs of 2077.38 €/ha (year 1), 463.87 €/ha (year 2), 637.94 €/ha (years 3–20) and 886.67 €/ha (year 21) [44]. Wit et al. [45] calculate capital expenditures for Poplar and Miscanthus of 151.56 €/ha and 610.47 €/ha, respectively. Based solely on economic criteria, these results also suggest that farmers do not have a significant incentive to switch to the examined energy crops. We turn now to the results of our break-even budgeting exercise.

6.2. Break-even budgeting results

In order to derive the biomass supply curve, we calculated the critical price for each energy crop and farm, as described in Section 4.1.1. Previous research reports that the dry biomass supply curve can be derived from more than one crop. That is, one energy crop may be more profitable for a particular farm while other crops may be more profitable for other farms of the same sample. In the case of our sample, Arundo exhibits the lowest critical prices for every farm under both delivery options (Fig. 1 and Fig. 2).

So in our case the supply of biomass comes from a single energy plant, Arundo. Current producer prices for dry biomass in the area of Karditsa do not exceed 50 €/dtn at the farm gate and 70 €/dtn at the plant gate. Within this price range, Arundo is not an economically viable cultivation for any of the farms. Threshold prices for Arundo are calculated at over 55 €/dtn and 82 €/dtn, respectively.

At this point it should be noted, that biomass producers in the area of Karditsa, perceive biomass market prices as relatively low and thus have a disincentive to invest in energy plant cultivation. A higher price especially for Arundo may be feasible since its net calorific value is higher when compared to cardoon, the most popular energy cultivation in the area so far [39,46].

Land distribution of our sample farms is similar to the one of the main cultivated crops in the area (mainly cotton and durum wheat). Consequently we assume that biomass quantities produced from Arundo, cultivated in the sample farms, are representative of the entire area. Under these assumptions, we can estimate the impact on trade balance associated with cultivating Arundo instead of durum wheat. In this analysis we also consider demand as well as the impact on pellet trade balances from the anticipated increase in biomass and therefore pellet quantities.

Since 2012, the existing pellet manufacturer in the area has been

Table 9
Farmer owned[a] versus rented[b] machinery for durum wheat and energy crops.
Source: [36]

Crop	Machinery Type									
	Tractor	Plow	Spreader	Sprayer	Transplanting Machine	Seeding Machine	Combine Harvester and Lorry	Forage Harvester & Lorry	Modified Forage Harvester & Lorry	Mower, Baler & Lorry
Durum Wheat	O	O	O	–	–	O	R	–	–	–
Arundo	O	O	O	O	O	–	–	R	–	–
Miscanthus	O	O	O	O	O	–	–	–	–	R
Poplar	O	O	–	–	O	–	–	–	R	–

[a] . O: Owned.
[b] . R: Rented.

Table 10
Estimated sample average annual equivalent variable cost of studied crops.
Source: [37,38]; own elaboration.

Operation	Durum Wheat	Arundo	Miscanthus	Poplar
Land preparation and crop establishment (or seeding for durum wheat) (€/ha)	132.3	181.6	181.6	194.6
Irrigation (€/ha)	–	11.1	11.1	109.23
Fertilization (€/ha)	303.2	113.1	113.1	–
Weed control (€/ha)	–	16.4	16.4	3.19
Harvesting (€/ha)	123.9	135.8	99.9	134.4
Farm storage (€/ha)	–	–	16.9	
Transportation (€/ha)[a]		93.3	77.8	77.8
Soil restoration (€/ha)		6.5	3.2	1.91
Overheads (€/ha)		21.9	21.9	–
Factory gate cost[b](€/ha)	–	580	541	523
Farm gate cost (€/ha)	550	350.5	347.2	310
Factory gate cost (€/dtn)	–	68.3	76.5	73.9
Farm gate cost (€/dtn)	159.5	41.2	49.1	43.8

[a] Transport of biomass is the total cost of land transport to an average distance of 50 km with a medium size lorry (10 t) [38].
[b] Harvesting, storage and transportation costs are excluded.

Table 11
Revenue stream per studied crop.
Source: [20]; Personal communication.

	Durum Wheat	Arundo	Miscanthus	Poplar
Farm gate price (€/ton)	225	50	50	50
Factory gate price (€/ton)	–	70	70	70
Land subsidy (€/ha)	90	–	–	–

involved into selling dry biomass from cardoon to pellet makers abroad. Ten-year contracts with biomass producers ensure the required quantities. Starting in 2016 pellet production will be initiated in the plant's facilities. The initial target is to produce 1100 t of pellets from biomass with the plant operating in a single shift [43]. Biomass coming from cardoon cultivation (450 tn) is going to be used along with biomass from other sources. Assuming that the plant can reach its maximum capacity of producing 3300 t of biomass, operating in three shifts, we estimate the impact on national trade balances, associated with cultivating Arundo instead of a food crop (durum wheat) while at the same time we estimate the impact on the pellet trade balance due to the increase in pellet production. We call this Scenario-1 (Table 13). Furthermore, we estimate the impact on both pellet and durum wheat trade balances under the assumption that all pellet imports (currently 20.9 thousand tons)[3] can be substituted by national pellet production, which can entirely take place in Karditsa using Arundo as the main biomass source. This is Scenario-2 (Table 13).

According to 2010 data (see also Table 14), almost 40% of Greek durum wheat production is intended for exports and the balance of supply-demand can be considered significantly positive. The regional unit of Karditsa is considered one of the largest durum wheat producing regions, among the 74 regional units of Greece [31]. By taking the 4-year median world price[4] for durum wheat (225 euros/tone), we calculate a positive trade balance of approximately 95 million euros. On the other hand, Greece could be characterized as a net importer of pellets, since imports 20.9 thousand tons of pellets and exports only 0.67 thousand tons. Using the median European price of pellet (300 euros/tn) [6], we calculate a negative trade balance of approximately 6 millions euros.

According to Scenario-1, we estimate that 1.24% of durum wheat in the Karditsa area will be substituted by Arundo if the farm gate price offered is higher than 55.66 €/dtn. The same substitution effect will take place if the factory gate price is higher than 82.66 €/dtn (see also Fig. 3).

With respect to the impact on trade balances of pellets and durum wheat we estimated a significant increase for pellets (+16.1%) and a marginal decrease for durum wheat (−0.6%). However, the balance remains significantly negative for pellets (approximately 5 million euros) and positive for durum wheat (approximately 95 million euros).

According to Scenario-2, we estimate that 8.91% of durum wheat in the Karditsa area will be replaced by arundo if the farm gate price is higher than 59.39 €/dtn. The same substitution effect will take place if the factory gate price is higher than 86.37 €/dtn (see also Fig. 3).

With respect to the impact on trade balances of pellets and durum wheat we estimated a large increase for pellets (+103.3%) and a small decrease for durum wheat (−4%). Balance for pellet becomes marginally positive (approximately 0.2 million euros) while it remains significantly positive for durum wheat (approximately 91.8 million euros).

To access the impact of the above scenarios on national trade balances and the national economy, we calculated the values from imports and exports for durum wheat and pellets. Under both scenarios the impact on national economy is positive since the balance of trade for both products increases by 0.29% and 2.72%, respectively (Table 15).

The above analysis informs decision making at various levels. For example, pellet producers can use our results to design incentives to biomass producers through efficient pricing of biomass from each energy crop. This is a feasible, sensible pricing strategy since durum wheat-producing farms throughout Greece share similar technical, structural, and economic features. Procuring biomass from these farms

[3] This scenario can be feasible since there exists a pellet plant in Greece with a capacity of 60,000t of biomass.
[4] The domestic price of cereals is considered similar to the international price.

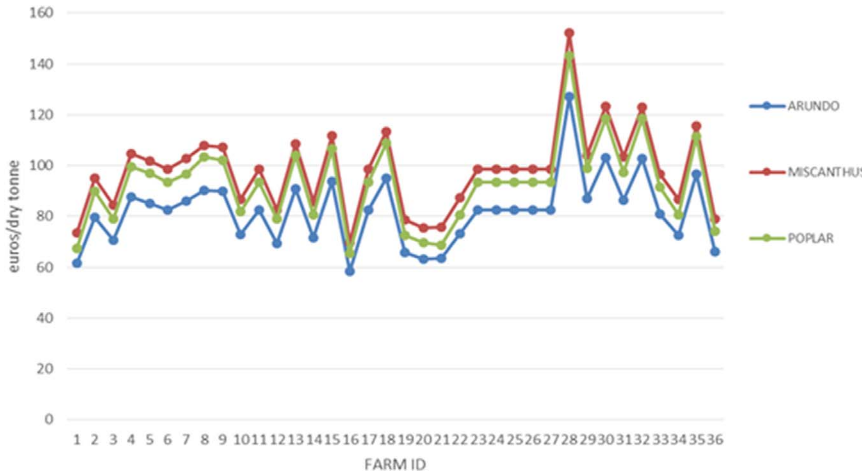

Fig. 1. Critical price per farm – Farm gate pricing.

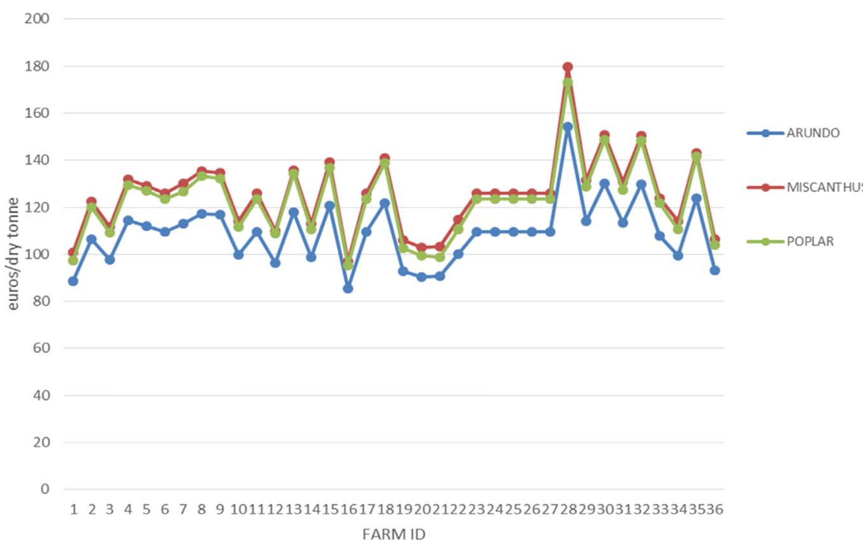

Fig. 2. Critical price per farm – Factory gate pricing.

Table 12
Partial budgeting results in the sample farms.
Source: own elaboration.

	Durum Wheat	Arundo	Miscanthus	Poplar
1) Variable cost (at farm gate) (€/ton)	550	350.5	347.2	310
2) Variable cost (at factory gate) (€/ton)	–	580	541	523
Avg. Yield (ton/ha)	3.58	8.49	7.07	7.07
1) Farm gate Price (€/ton)	225	50	50	50
2) Factory gate Price (€/ton)	–	70	70	70
Land subsidy (€/ha)	90	–	–	–
1) Farm gate Revenue (€/ha)	805.5	424.5	353.5	353.5
2) Factory gate Revenue (€/ha)	–	594.3	494.9	494.9
1) Farm gate Gross Margin (€/ha)	345.5	74	6.3	43.5
2) Factory gate Gross Margin (€/ha)	–	14.3	−46.1	−28.1
1) Farm gate Benefit/ Loss (€/ha)	–	−271.5	−339.2	−302
2) Factory gate Benefit/ Loss (€/ha)	–	−331.2	−391.6	−373.5

seems even more sensible since the existing 12 pellet producing factories in Greece currently utilize only 25% of their maximum total capacity of 130 thousand tons/year, using biomass from non-energy crops [6]. Thus it might be an efficient strategy for these factories to increase their production volume by using biomass from high calorific value crops such as Arundo.

Further, policy makers should take into account the fact that the biomass potential from forestry in Greece is limited and not sufficient to cover the needs of the Greek market for wood and its products [27,49]. Agriculture seems thus to be a key for the expansion of biomass supply [50].

Also, policy makers should consider the supply of and demand for biomass in nearby Balkan countries, as this may play a significant part in farmers' decision-making process towards biomass. Indeed the nearby Balkan countries could be seen either as biomass suppliers for Greek pellet businesses, or as potential markets for Greek biomass

Table 13
Potential first year production level and production scenarios of pellets in Karditsa.

Potential first year production level & required raw material	Assumed maximum production capacity & required raw material (Scenario-1)	Total substitution of pellets with the development of domestic production (Scenario-2)
1100 t of pellets ≈ 1100 t of dry biomass[a] Where: 450 t correspond to cardoon dry biomass and the rest (650 t) could be covered by arundo dry biomass. (1 ha Arundo – 8.49 dry tons) (1 ha Cardoon = 4.5 dry tons)	3300 t of pellets ≈ 3300 t of dry biomass Assumption: 450 t correspond to dry biomass of cardoon and the rest (2850 t) could be covered by arundo dry biomass.	20,900 t of pellets ≈ 20,900 t of dry biomass Assumption: 450 t correspond to dry biomass of cardoon and the rest (20,450 t) could be covered by arundo dry biomass.

[a] It may be expected that a larger amount of dry matter is required because of the relatively low net calorific value of cardoon and the loss of dry matter during pellet production process.

Table 14
Supply and demand of pellets and durum wheat in Greece.
Source: [5,47,48]

	Supply & Demand (S & D) for pellets (Current situation)	Supply & Demand (S & D) for durum wheat (Current situation)	Scenario-1 (impact in pellets S & D)	Scenario–1 (impact on d. wheat S & D)	Scenario-2 (impact on pellets S & D)	Scenario–2 (impact on d. wheat S & D)
Cultivation Area (thousand ha)	–	531.7 [47]	–	531.3		529.2
1) Production (thousand tons)	36.4 [5]	1292.2 [47]	39.7	1290.7	57.4	1283.7
2) Domestic consumption=(1+3)−4 (thousand tons)	57.4 (Own estimation)	866.9 (Own estimation)	57.4	866.9	57.4	866.9
3) Imports (thousand tons)	20.9 [5]	83.9 [48]	17.6	85.19	0	92.4
4) Exports (thousand tons)	0.67 [5]	509.1 [48]	0.67	507.81	0.67	500.6
5) Balance of supply-demand=4−3 (thousand tons)	−20.2 (Own estimation)	425.2 (Own estimation)	−16.93	422,6	0.67	408.2
Variation of supply-demand balance	–	–	+16.1%	−0.6%	+103.3%	−4%

producers [51]. Also of major importance for all decision makers along the biofuel supply chain, including regional and national policy makers are non-economic factors such as new technologies and methods for biomass production and harvesting, the level of environmental awareness of the rural population that can be enhanced by proper environmental education in the school system, and the overall public acceptance of biomass as a new energy source [52].

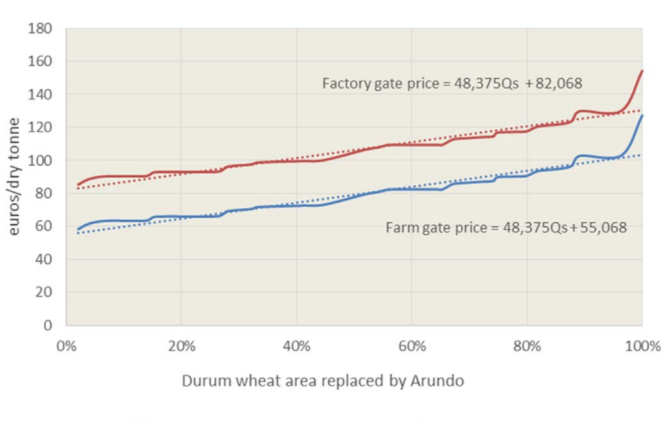

Fig. 3. Supply curves of energy crop for each delivery scenario.

Policy design is also informed by our results. Considering the overall positive impacts at the regional and national levels, policy makers might want to design adequate policies that would provide efficient and compatible incentives to farmers and energy producing plants.

While this research does not focus on environmental issues, nevertheless, the results reported also inform ongoing debates on the environmental impact of energy crops. These results suggest that substituting arundo for durum wheat can have a beneficial effect in regions like Karditsa facing nitrate pollution issues since, when

Table 15
Aggregate values of imports and exports for durum wheat and pellets (in million €).

	Total value of imports	Total value of exports	Trade balance	Difference in trade balance (%)
Current situation	25.14	114,7	89,56	
Scenario-1	24.38	114,2	89,82	0.29
Scenario-2	20.8	112,8	92	2.72

compared to durum wheat, arundo requires half the fertilizer quantity.

When adapted to individual grower and area conditions, the break-even budgeting presented here, for the specific energy crops, provides benchmarks for the evaluation of the profitability potential of converting conventional land to energy crops. However, a decision-making prerequisite for the farmer would be the development of a stable market for biomass. This would mean that significant investment is undertaken (e.g., in biomass power plants) and the mechanisms that build trust between the various actors of the biomass supply chain are in place (e.g., the availability of long-term contracting). Until the development of this market that may multiply farmers' options durum wheat remains a better choice. Once the market develops however, there should be many more issues that deserve careful consideration before a farmer engages in the production of these crops. Contract designs, and the way farmers are organized, communal and individual senses of landscape, the fluctuations of the oil market, as well as environmental considerations are, to mention a few, some of the issues that may influence farmers' but also investors' decision making [53].

7. Conclusions and policy implications

The European Commission considers biomass as a critical element of the fight against climate change and recognizes the prospects that energy crops can have for farmers and local communities as well as for national renewable energy plans [54]. On the other hand, there are several concerns raised within Greece on the potential effects of energy crops and biomass power plants on land use and the environment [55,56].

Within the context of different and often conflicting narratives on the energy debate in Greece, policy makers should undertake actions that provide incentives for the adoption of energy crops while, at the same time, counter balance possible environmental and economic risks and deal with the concerns of local communities. The appropriate policy mix and the subsequent implementation of a successful renewable energy strategy is a rather difficult puzzle for national and regional decision makers. This complexity partially explains the variety of national approaches as well as market shares of renewable energy across the EU.

In Greece, market deployment policies have been prioritized: feed-in tariffs, quotas and establishment incentives for the biofuels industry have been implemented mainly in order to support the development of the industry. Incentives to farmers are provided mainly by the industrial actors, through the application of contract farming schemes that reduce the risk for farmers and provide income stability in the longer run. Meeting the targets set by the RES roadmap until 2020—18% share of renewable energy in the gross final energy consumption—implies that in Greece there still exists a considerable margin for the development of the biofuels supply chain.[5]

When focusing on the Greek pellet market, an increased demand for pellets is forecasted mainly due to the considerably high cost of heating diesel, which has become a major issue for most Greek households during the years of economic crisis. Furthermore, starting at 2011 the use of biomass heating boilers in apartment buildings has been allowed in the two largest Greek cities, Athens and Thessaloniki. The increase in the household demand will probably trigger the demand for biomass feed stocks. As a result the motivations provided to the Greek bioenergy industry should be coupled by incentives for farmers to cultivate energy crops and thus reduce the risks of even larger national trade deficits from biomass imports.

A case study has been presented in this paper to demonstrate the potential of some energy crops to replace, under certain circumstances, conventional crops even in non-marginal lands, without significantly influencing the trade balance for grain. When looking at the economic criterion, results suggest that producing and using biomass from high calorific energy crops such as Arundo could potentially benefit several stakeholders along the biomass supply chain including consumers. However, there are more aspects that should be considered by policy makers before deciding on the final mix of appropriate bioenergy policies. A wider look should take into account not only economic but also social-cultural, political and environmental perspectives along the whole spectrum of the bioenergy supply chain. Future research should therefore also embody the impact of non-economic motivations on the utility derived from an energy crop, such as values (e.g., aesthetic, environmental), knowledge (e.g., habits and knowledge of production methods), issues related to the landscape and legal conditions (e.g., cultivation licenses).[6] Moreover, the economic recession enhances risk aversion, diminishes the availability of investment capital and may disable incentive mechanisms that have been introduced in former years. As a proposal for future research it would be wise to investigate through a wider and multidisciplinary study the factors involved in the decision making process at all levels of the bioenergy supply chain.

Another point of reference for future research should be the investigation of the level of acceptance of energy crops, since this can become a friction point between several social groups. The ethical dimension of how societies resolve or fail to resolve, the "energy issue' is noteworthy and deserves further exploration [57,58]. In the region of Karditsa, recent studies have demonstrated strong awareness of national and global economic and political trends shaping agricultural bioenergy and the ways in which their community and local economy might fit into or potentially clash with those developments [58].

To conclude, our results show the potential of local bioenergy supply chains that use locally grown perennial energy crops as their main input to provide a source of income to farmers, while addressing trade deficit issues. Yet, policy makers need to adopt a more systemic approach to designing and implementing energy policies. Other economic, environmental, and cultural concerns need to be addressed simultaneously. Depicting and studying all significant parts of the involved systems and subsystems as well as their interactions, associations and resulting impacts, can achieve this. Subsequently, policy makers need to facilitate changes that will help and enable the whole energy system to self-organize into a new desired state.

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[5] The contribution of RES to the national energy balance in 2011 was approximately 11.6% of the gross final energy consumption [16].

[6] For a similar discussion on a Swedish case see [59].

Appendix A

See Table A1.

Table A1
Optimum climatic and soil conditions of studied crops.
Source: [60–69].

	Durum Wheat	Arundo	Miscanthus	Poplar
Climatic zone	Temperate [60]	Mediterranean South & North, [61]	Mediterranean North, Atlantic central, Lusitanian, Continental, Atlantic North [61]	Atlantic central, Lusitanian, Continental, Nemoral, Atlantic North, Mediterranean North) [61]
Outdoor Temperature (°C)	20–25 [60]	10–28 [62]	7.5–17.5 [62]	15–25 [63]
Annual precipitation (mm)	450–650 mm [64]	300–400 mm [62]	400–500 mm [62]	600–1000 mm [65]
Soil type	Well drained, medium texture and clay Soils [66]	Soils with low sand content. [66]	Clay soils [67]	Sandy loamy soils with organic matter [63]
pH profile	7–8.5 [60]	5.0–8.7 [66]	5.5–7.5 [67]	6.5 Bassam [63]
Nutrients' chemical composition in P, N, K	150 kg/ha N, 35–45 kg/ha P ,25 –50 kg/ha K [64]	40–60 kg/ha N [62]	40–60 kg/ha N [62]	60–80 kg/ha N , 10–20 kg/ha P,35–70 kg/ha K [63]
Season of harvesting	April–September (Moisture content < 13.5%) [60,68]	October–March (Moisture content 45%) [66]	October–March (Moisture content 45%) [66]	October–March (Moisture content 59.2%) [65,69]

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