A sequential mathematical modeling approach for estimating supply curves for energy crops under different policy scenarios: A Greek case study

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Abstract

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. The relevant policy mix is analysed, discussed and outlined as a nexus of interrelated incentives provided by policy makers and the market. Supply curves for different energy crops can be used as a decision-making tool by all interested 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. For the purpose of energy crops supply curves estimation a sequential linear programming model is developed, which takes into consideration the deployment of farms' decisions in time, illustrating crop mix and economic indicators in the medium term. As biomass price increases, arundo cultivation reveals significant possibility of expansion compared to miscanthus and poplar. On the other hand, durum wheat and set-aside are decreased significantly. Aggregate biomass supply curve moves upwards over the studied years.

Keywords: perennial energy crops; biomass supply curves; mathematical programming; sequential modeling; Greece

1. Introduction

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 (Mavridis, 2015; Toka, 2015). Demand for wood pellets has increased considerably and many households abandon their old, oil consuming heaters in favour of heating systems based on pellets (Ketikidis et al., 2013). Yet, Greece is a net importer of pellets and thus increased demand threatens to make trade deficit even higher than the current one (imports 20.9 thousand tons of pellets and exports only 0.67 thousand tons) (Mavridis, 2015; Toka, 2015). Thus it is extremely important to assess 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. The studied energy crops are miscanthus, arundo, and poplar and their dry matter, biomass, is mainly intended for the production of solid biofuels (e.g., pellets). Additionally, 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. Thus, the substitution of perennial energy crops for conventional crops can have a beneficial effect in Greek regions like Thessaly facing nitrate pollution issues. Supply curves for different energy crops can be used as a decision-making tool by all interested 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 (Mantziaris et al., 2017a).

2. Energy crops across Europe: overview and context

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 (AEBIOM, 2013). 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 (AEBIOM, 2013).

Biomass provides already the largest share of renewable source of energy globally (IEA, 2012). The role and contribution of energy crops to the bioenergy sector is gradually being recognised as an important one (e.g., Panoutsou et al., 2009). 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 (AEBIOM, 2013). 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% (AEBIOM, 2013). When considering energy for Heating and Cooling, biomass holds the lion's share as almost 90% of renewable heating uses a biomass-related source (AEBIOM, 2013).

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) (Mantziaris et al., 2017a).

Table 1.Energy crops cultivation in EU-27 (2010-2013)

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

Source: AEBIOM (2013); BioEnergyFarm (2011); ESEK (2014); European Commission (2012); Paragogi (2013)

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 (AEBIOM, 2014). Accordingly, European pellet production has been growing at a rate of more than 30% between 2009 and 2012 (AEBIOM, 2013). However, recent data reveal that Europe runs a high pellet deficit of more than six million tonnes (AEBIOM, 2014).

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 (AEBIOM, 2013). Consequently, there is a considerable margin for the development of the European pellet market, which creates increasing demand for lignocellulosic biomass.

The Greek context

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 (European Commission, 2013). 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.

Currently, in Greece, there is no government driven incentives structure in place that could lead to the adoption of energy crops by farmers. 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.

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 (Mitchel et al., 2006) (Table 2). So far, there have not been any commercial cultivations of miscanthus, arundo or poplar.

Table 2.Profile of commercially exploited energy crops in Greece (2013/14)

	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

Source: Imerisia (2014); ESEK (2014); Paragogi (2013)

3. **Methodology**

Concerning the analytical tools, a commonly employed methodology is the use of variants of mathematical programming for two main reasons: firstly, the inadequacy of econometric models due to the frequency and extent of policy reforms and secondly, the policy shift from market instruments to agri-environmental and multifunctional support, which requires more detailed focus than estimating average reactions (Huylenbroeck et al., 2006). Although mathematical programming is normative in nature, models used in agriculture can be identified as positive, as empirical information on farmers' behaviour as well as validation against actual decisions are most often used. Relevant literature includes the evaluation of energy crops for biofuell supply in France and Italy (Sourie and Rozakis, 2001; Kazakçi et al., 2007; Bartoli et al., 2016), perennial crop supply in Greece and the impact of the Common Agricultural Policy (CAP) 2003 reform (Lychnaras and Rozakis, 2006) as well as a growing body of literature focusing on miscanthus and short rotation coppice (Styles et al., 2008; Sherrington and Moran, 2010; Bauen et al., 2010; Van der Hilst et al., 2010; Mathiou et al.,2012; Mathiou et al., 2014). Focusing on Greek agriculture, a variety of mathematical programming sector models has been used in order to assess the impacts of CAP reform focusing on arable farming accommodating staple crops such as cotton, tobacco and wheat, partial equilibrium models incorporating downward sloping demand (Rozakis et al., 2008), multi-criteria methods with non-interactive elicitation of the utility function (Manos et al., 2009; Sintori et al.,2010; Mantziaris et al., 2017b), interval linear programming to deal with uncertainty (Rozakis, 2011) and risk programming along with increasing cost functions by means of Positive Mathematical Programming (Petsakos and Rozakis, 2015).

A bottom-up staircase model based on individual farm data is specified for arable agriculture to simulate the decision-making process at farm level. A modular structure allows for taking into account the diversity of the arable farm system and production technology to a large extent independent of time-series data thus appropriate for policy analysis in cases of substantial policy reforms (Rozakis and Sourie, 2001).

Each sub-model consists of objective function and a number of resource-, institutional- and agronomic constraints. The major interest of this modeling certainly lies on the possibility of the farms sample to evolve from year y to year y+1. In order to modify the nature of Multi-Criteria Linear Programming (MCLP) model from static to sequential, at the end of each annual optimization, simple rules are applied to simulate the evolution of the number of farms and their structure for the period 2015-2019[1]. Thus, the disappearance of a farm is due to relatively low level of farm viability index. On the contrary, farms with relatively high levels of farm viability index incorporate the arable land of less efficient farms.

For the purpose of energy crops supply curves estimation, a sequential linear programming model is developed, which takes into consideration the deployment of farms' decisions in time, illustrating crop mix and economic indicators in the medium term (Guinde et al., 2005; Gallan-Martin et al., 2015; Robert et al., 2016). Afterwards, we introduce in the decision system of the farmer the perennial crops option and we assume that cost and yield data on the studied energy crops correspond to annual equivalent values because of the perennial life cycles of these, thus we maximize their Net Present Value (NPV) of gross margins. Parametric optimization to generate supply curves can be implemented using any objective functional form in linear or nonlinear programming models (Mathiou et al., 2014). Parametric optimization consists of iterative solutions of the model, by increasing the value of energy crop price (Mathiou et al., 2012). Taking into consideration the price range for biomass of pellet industry we obtain the energy crop supply curve for every year that we optimize the model. Consequently, the sequential Linear Programming model, could provide us the opportunity to forecast energy crops supply curves in a more realistic way[2].

Static MCLP model architecture (CAP 2014-20)

Different objective functions correspond to different goals of farmers. The first goal is the gross margin maximization, considering that a business-oriented farm attempts to optimize its economic performance. Despite the business-orientation of farms, family labor covers almost 30% of total labor requirements. Thus, we assume that farmers attempt to maximize family labor through their crop-mix decision. Minimization of risk is an additional criterion found in

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[1] As study period was determined the period 2015-19, since the year 2015 (baseline year) corresponds to the first year of CAP 2014-20 implementation and the year 2019 corresponds to the last year of subsidies convergence for the specific CAP reform.

[2] The software GAMS has been used to run both the static and sequential linear programming models.

the literature review (Amador et al., 1998; Petsakos et al., 2009). However, this specific criterion is not studied in this paper because we assume that the expectations of the Greek farms about unknown values of parameters (e.g. prices of non-contracted crops, crop yields) are based on the most recent experience. More specifically, in the case of non-contracted crops (e.g. cotton, maize, alfalfa, durum wheat) the value of expected price is considered the received price of the t-1 period. Regarding crop yields, farmers consider that they don’t vary significantly from year to year, thus the data on yields for some preceding years could be used to calculate an average representative expected yield for each farm.

All crops cultivated are treated as alternative activities for every farm in the sample. For crops not present in a production plan, the average data of sample concerning yield and family labor are used. As regards the crop cost forecasting, in the case of agricultural inputs (e.g. fertilizers) and labor cost, the average cost of the sample is used, while in the case of mechanical operations costs, the degree of mechanization of the farm is taken into consideration in order to estimate the possible rental rate of machinery and fuel costs with precision (for detailed information concerning the static MCLP see also Mantziaris and Rozakis (2016)).

The goals and constraints used in this analysis and their mathematical expressions are given below (see also table A1 in the Appendix for the indices, parameters and decision variables)

:

Maximization of gross margin (in euros)

$$f(1) = \text{Max}[(lg\_land \ * pay) + (lg\_organic * orgpay) + (lg\_nitro\_A * nitropay\_A) + (lg\_nitro\_B * nitropay\_B) + \sum_{n=1}^{N} \left[\left(yield_n \ * \ price_n\right) + ls_n - var\_cost_n\right] X_n]$$

(1)

Maximization of family labor (in hours)

$$f(2) = \text{Max}\ [\ \sum_{n=1}^{N} \text{fl}_n X_n\ ] \qquad (2)$$

Available arable land :

$$\sum_{n=1}^{N} X_n = tot\_land \qquad (3)$$

The sum of cropping area equal to total land.

Available irrigated land:

$$\sum_{n=1}^{N} \ irr_n X_n \leq irr\_land \qquad (4)$$

The sum of irrigated crops area cannot exceed irrigated land available.

Available working capital:

$$\sum_{n=1}^{N} var\_cost_n \, X_n \leq working\ capital \qquad (5)$$

The sum of variable expenses cannot exceed working capital available.

Available family labor:

$$\sum_{n=1}^{N} \mathrm{fl}_n \, X_n \leq tot\_family\ labour \qquad (6)$$

The sum of family labor cannot exceed family labor available.

New CAP entitlements activation obligation for each farm:

$$X_{st} \leq 0.5\ \mathrm{lg\_land} \qquad (7)$$

The Set-aside area cannot exceed 50% of the new CAP land entitlements area in order to receive the Basic Payment (70% of new CAP decoupled payment).

Crop Diversification obligation for farms with new CAP land entitlements area > 10 hectares:

$$X_n \leq 0.75\ \mathrm{lg\_land} \quad , \quad n=1, 2, 3\ldots N \qquad (8)$$

Farmers should cultivate at least two different crops (set-aside included) and the cropping area of each crop cannot exceed 75% of the new CAP land entitlements area in order to receive the Greening Payment (30% of new CAP decoupled payment).

Ecologic Focus Area obligation for farms with new CAP land entitlements area > 15 hectares:

$$0.7 [\![\sum_{n=1}^{N} Legume_n \, X_n]\!] + X_{st} \geq 0.05\ lg\_land \qquad (9)$$

The 70% of the sum of legume crops area[3] plus set-aside area must be at least equal to 5% of the new CAP land entitlements area in order to receive the Greening Payment (30% of new CAP decoupled payment). Farms with new CAP land entitlements area larger than 15 hectares are also obligated to apply the constraint 2.

Crop Diversification obligation for farms with land entitlements area > 30 hectares:

$$X_{OPT\,L1} + X_{OPT\,L2} \leq 0.95\ \mathrm{lg\_}land \qquad (10)$$

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[3] 1 hectare of legume crop corresponds to 0.7 hectare in the Ecologic Focus Area.

Farmers should cultivate at least three different crops (set-aside included) and the sum of cropping area of the two largest crops cannot exceed 95% of the new CAP land entitlements area in order to receive the Greening Payment (30% of new CAP decoupled payment). In order to find the two largest crops (in terms of land coverage) for farms with land entitlements greater than 30 hectares, we optimize the model adding the three above constraints (equations 7, 8, 9). After optimization, we obtain the results concerning the two largest crops and we add the fourth constraint (10). Then we optimize the model once more.

It should be noted that farmers are not obligated to apply the greening requirements in the organic cropping area.

Nitrogen pollution reduction program – Methodology A:

$$\sum_{n=1}^{N} Irr\_Nitrogen_n X_n \geq 0.75 \text{ lg\_}nitro_A \qquad (11)$$

The sum of eligible crops area for irrigated rotation must be at least equal to 75% of land entitlements of nitrogen reduction pollution program for methodology A.

$$X_{st} \geq 0.25 \text{ lg\_}nitro\_A \qquad (12)$$

The set-aside area must be at least equal to 25% of land entitlements of nitrogen reduction pollution program for methodology A.

Nitrogen pollution reduction program – Methodology B:

$$\sum_{n=1}^{N} Irr\_Nitrogen_n X_n \geq 0.75 \text{ lg\_}nitro\_B \qquad (13)$$

The sum of eligible crops area for irrigated rotation must be at least equal to 75% of land entitlements of nitrogen reduction pollution program for methodology B.

$$\sum_{n=1}^{N} NIrr\_Nitrogen_n X_n \geq 0.2 \text{ lg\_}nitro_B \qquad (14)$$

The sum of eligible crops area for non-irrigated rotation must be at least equal to 20% of land entitlements of nitrogen reduction pollution program for methodology B.

$$X_{st} \geq 0.05 \text{ lg\_}nitro\_B \qquad (15)$$

The set-aside area must be at least equal to 5% of land entitlements of nitrogen reduction pollution program for methodology B.

Organic farming program:

$$\sum_{n=1}^{N} Organic_n X_n \geq \text{lg\_organic} \qquad (16)$$

The sum of eligible crops area for organic farming must be at least equal to land entitlements of organic farming program.

Sequential MCLP model architecture (CAP 2014-20)

As we mentioned above the disappearance of farms is due to relatively low levels of farm viability index. On the contrary, farms with relatively high viability levels incorporate the arable land of less efficient farms.

As viability index of farms we use the Return to Working Capital that has already been used in order to estimate the impacts of CAP reform 2003 to Greek cotton farmers (Rozakis et al., 2008). The formulation of the index is as follows:

$$Return\ to\ working\ capital_f = \frac{Farm\ Family\ Income^{4}{}_f - Decoupled\ payment_f + Depreciations_f}{Working\ capital_f}$$

(17)

In the case that Return to Working Capital (RWC) is equal or lower than interest rates for regular bank deposits[5] (viability threshold), farmers would not keep on cultivating. After each annual optimization of MCLP model the total land of non-viable farms of year t is incorporated from viable farms in the year t+1 and redistributed among them proportionally according to RWC efficiency. The specific rule is described by the formula below:

$$Abandoned\ land\ redistribution_{f,t+1}(or\ added\ land\ per\ viable\ farm) =$$

$$(Total\ land\ of\ farms\ with\ RWC_t \leq viability\ threshold\ ) * \frac{RWC\ of viable\ farm_t}{Total\ RWC\ of\ viable\ farms_t}$$

(18)

The working capital is adjusted from year to year according to the formula below:

$$Working\ capital_{f,t+1} = Gross\ Revenue_{f,t} * \frac{Working\ capital_{f,t=1(baseline\ year)}}{Gross\ Revenue_{f,t=1(baseline\ year)}}$$

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[4] Farm Family Income = Gross Revenue-Cash Expenses (variable expenses, farm land rental expenses)-Depreciations.

[5] The average interest rate for June 2018 of two-year term deposit of Greek banks corresponds to 0.62 % (Bank of Greece, 2018)

(19)

The relation $\frac{Working\ capital_{f,t=1}}{Gross\ Revenue_{f,t=1}}$ represents the percentage of gross revenue that is intended for the working capital needs in the baseline year. Thus, we assume that the percentage remains fixed for each annual optimization after the baseline year (2015).

The land rental expenses are adjusted annually according to the added land in the context of redistribution described above. We assume that viable farms they do not buy the added land but they prefer to rent it. Currently, the land rental rates per hectare are considered fixed and correspond to 650 and 350 euros for irrigated and non-irrigated land respectively. The annual rental expenses are estimated according to the formula below:

$$\begin{aligned} Land\ \ rental\ expenses_{f,t+1} &= Land\ rental\ expenses_{f,t} + Added\ irrigated\ land_f \\ &* irrigated\ land\ rental + Added\ non - irrigated\ land_f * non \\ &- irrigated\ land\ rental \end{aligned}$$

(20)

In our analysis, we take into consideration the crop price variance. For the purpose of price forecasting, we use logarithmic function as follows:

$$Price_{c,t} = c\ lnt + b \qquad (21)$$

In order to estimate the logarithmic function for each studied crop we use a combination of data that emanate from relevant institutions (FADN; Hellenic Ministry of Rural Development and Food). The time-series data cover the ten-year 2006 to 2015 timespan.

At this point it should be noted, that logarithmic function is considered suitable for our analysis since the increasing trend of crop prices is followed by stabilization. Additionally, we validated the forecasting ability of logarithmic function, comparing the observed prices with the forecasted prices of the last four years. The results of validation reveal limited deviation for all crops that is range from 0,42% to 12,47% (see also tables A2-A6 and figures A1-A4 in the Appendix). As regards the prices of contracted crops (tobacco, processed tomato, processed peppers) are considered fixed at baseline year levels.

We also take into consideration the variable cost variance. For the purposes of variable cost forecasting, we also use logarithmic function:

$$Variable\ cost\ index_t = c\ lnt + b \qquad (22)$$

The logarithmic function uses as input variable cost indices that emanate from the Hellenic Statistical Authority (2018). The applied time-series data correspond to twelve-year range (from 2006 to 2017). Logarithmic function is considered suitable for variable cost indices forecasting since the increasing trend is followed by stabilization of indices. The validation reveals limited deviation between observed values and forecasting model results (see also table A7 and figure A5 in the appendix).

Afterwards, we estimated the annual variable cost of each crop according to the formula below (see also table A8 in the Appendix):

$$Variable\ cost\ _{c,t} = Variable\ cost\ _{c,t=1(baseline\ year)} * \ Variable\ cost\ index\ _{t} \qquad (23)$$

Regarding the crop yields, they are considered invariable at baseline year levels since the observed yields of the study area (especially for tobacco, processed peppers and processed tomato) are considerably higher than the regional or national averages that emanate from institutional databases (FADN; Hellenic Ministry of Rural Development & Food). Additionally, according to the sample farmers, insignificant yield variations are observed over the years. Consequently, we assume that the observed yields could be more representative for the simulation of the specific farming system.

Payments adjustments in MCLP sequential model concerning CAP 2014-20 are described, in order to estimate the impacts of the reform, at the last year of subsidies convergence (2019). The Greek government has opted for the partial convergence scheme for direct payments between 2015 and 2019 (European Commission, 2015; Hellenic Ministry of Rural Development & Food, 2014). The entire UAA has been divided in three agronomic regions, namely arable farming, tree crops and pastures. Focusing on arable farming region, the average entitlement value per hectare for the period 2015-19 equals 420 euro/ha(Hellenic Ministry of Rural Development & Food, 2014). This value is compared to the initial value of decoupled payment per hectare of each farm for the purpose of the calculation of new CAP decoupled payment. The initial value of decoupled payment is detailed in formulation 24:

$$Initial\ value\ of\ decoupled\ payment/ha(2015)_f = \frac{(Decoupled\ payment(CAP\ 2007{-}13){*}0.85)_f}{New\ CAP\ land\ entitlements_f} \qquad (24)$$

The decoupled payment value of CAP 2007-13 was decreased by 15%, because of the transfer of economic resources to the Second Pillar of CAP. Additionally, each hectare receiving the decoupled area payment in the year 2015 can claim the new CAP land entitlement (Hellenic Ministry of Rural Development & Food, 2014). If a farm’s Initial value of decoupled payment is lower than 90% of average region entitlement value per hectare (420 euros/ha), then this Initial value will rise by 33% of the difference between Initial value and 90% of average entitlement value of the region, reaching at least the 60% of the average region entitlement value per hectare until 2019. If a farm’s Initial value of decoupled payment is higher than average region entitlement value per hectare, then this Initial value will decrease by 30% until 2019 (European Commission, 2015; Hellenic Ministry of Rural Development & Food, 2014). In all these cases, the convergence process is linear, thus, farms loose or gain a fixed amount each year (Hellenic Ministry of Rural Development & Food, 2014). In our analysis, we estimated the decoupled payments for each year of the period 2015-19 according to the conditions described above.

Coupled payments have been determined a priori by the Hellenic Ministry of Rural Development and Food (2014) as follows:

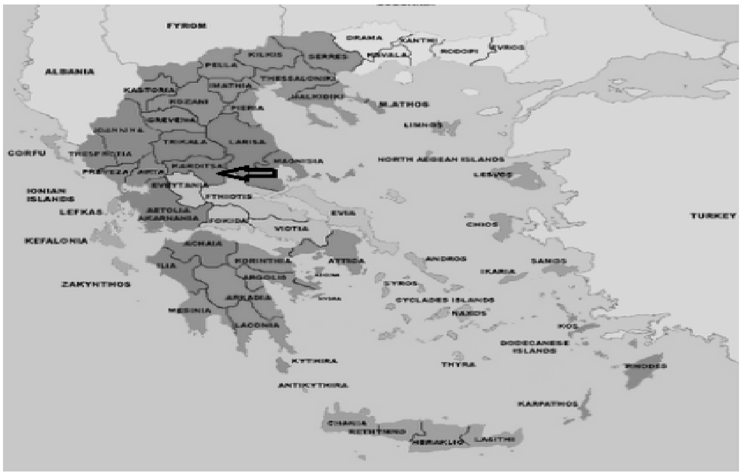
Table 3. Land subsidies €/ha (2015-19)

year	cotton	d.wheat	proc.tomato	alfalfa
2015	750	36	286.3	175
2016	750	47.4	348.2	173
2017	750	56.6	430.1	171
2018	750	56	425.4	169
2019	750	55.4	420.6	167

Agri-environmental payments of organic farming and nitrogen pollution reduction program are considered fixed at baseline year levels.

4. Case Study

The regional unit of Karditsa is located at the NUTS2 region of Thessaly, in Central Greece (Map 1). It covers 2,636 Km^2 and is populated by approximately 130,000 inhabitants (1.2% of the country's total population).



Map 1. *Greece: The regional unit of Karditsa*

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 4).

Table 4. Main Crops cultivated in the Regional Unit of Karditsa, Greece (2010)

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	5,986.56	5.44%
Other Cereals	5,568. 83	5.06%
Set-aside	5,208.00	4.74%
Maize	2,956.50	2.69%
Vegetables	1,755.99	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%

Source: Greek Payments Agency (2010)

Energy crops have been cultivated in 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 hectares of non-irrigated land. Since 2012, the existing pellet manufacturer in the area has been 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 tons of pellets from biomass with the plant operating in a single shift (ESEK, 2016). Biomass coming from cardoon cultivation (450 tn) is going to be used along with biomass from other sources (e.g. energy crops, crops residues, wood residues, forest residues).

Sample characteristics

Surveyed farms are located in the plain of Regional unit of Karditsa, one of the most important arable farming regions in Greece. Farm data concerning years 2005 and 2006, are derived from the database of research project PILOTEC (PILOTEC, 2009). Updated farm data, concerning the year 2012, were collected through personal interviews (Mantziaris, 2013), and correspond to 48 farms (out of 70 initially surveyed in 2005-06), specializing in arable farming. It has to be noted that between 2005/2006 and 2012, one-third of the initially surveyed 70 farms have gone out of business, as most of them retired and a few passed away without succession; their land has passed to the remaining 48 farms which have thus been enlarged (average farm area increased from about 12 ha to 17.6 ha) (see also table A9 in the Appendix). As we see at table 5, compared with the 'average farm' of the whole country, sample farms are much larger, in both physical and economic size, more intense as regards their irrigated land and more entrepreneurial, in terms of use of hired labour in their total human employment needs (Mantziaris et al.,2017c). Thus, we assume that the specific farmers would be willing to cultivate "innovative crops", as perennial energy crops.

Table 5. Sample farms compared to national averages

	Utilized Agricultural Area (Ha)	Economic Size (Euros)	Irrigated UAA (%)	Hired Labour (% of total Labour)	Total labour (hours per year)
Sample Farms (2012)	17.7	64,021	80%	70%	433
All Greek Farms (2013)	4.8	11,342	37%	19%	1152

Source: Sample data and Eurostat, Farm Structure Survey

On the other hand, sample farms are much less labour-intensive, since they use human labour for 433 hours per year, compared with 1152 hours of the respective national average. Also, 60% of gross revenue of sample farms is derived from the market, while the remaining 40% comes from subsidies (25% from decoupled payments, 11% from coupled payments and 4% from agri-environmental payments); this means that sample farms are more dependent on subsidies, as for 2012, on average, Greek farms derived 73% of their gross revenue from the market and 27% from subsidies (Eurostat, 2017).

Although the most important crop for the period 2005-2012, in terms of land coverage, is cotton, significant changes in the crop mix of sample farms have been recorded between 2005 and 2012 (figure 1).

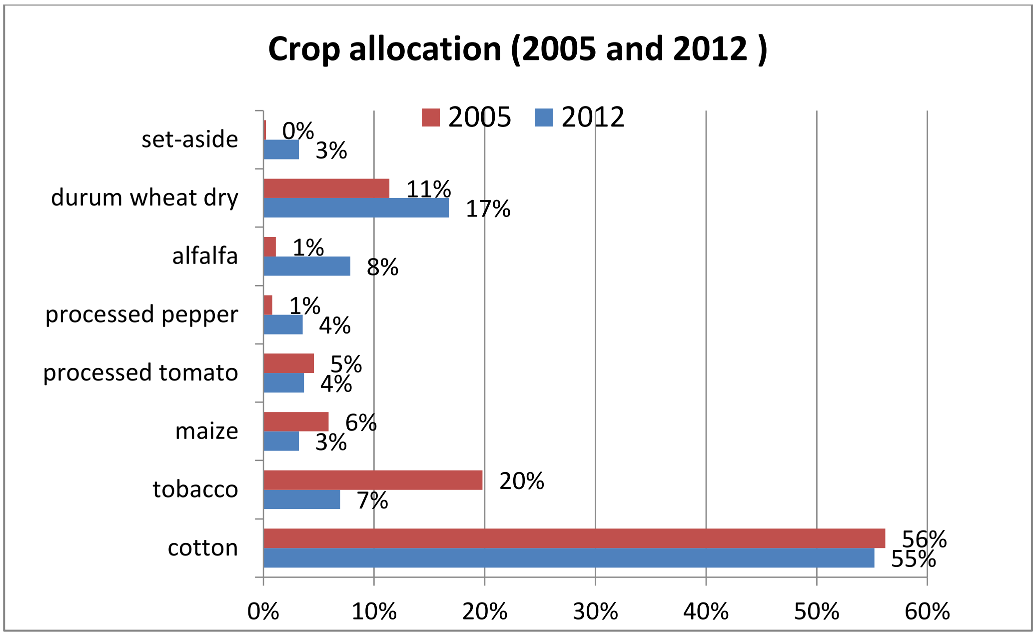


Figure 1: Average cultivated area per crop (2005-2012)

Up until 2005, tobacco (Virginia variety) held the lion's share in terms of revenue stream cultivated at a significant percentage of total land (20%). In 2006, with full decoupling of subsidies, tobacco cultivation was abandoned as the variable cost exceeded the farm gate market price of tobacco (almost 1 euros/kg and 0.3 euros/kg, respectively). However, in 2012, tobacco cultivation covered 6.7% of the total land (fig. 1) because of farm gate price that had increased since 2010 up to 2 euros/kg [6].

Another major evolution during the period 2005-2012, is the considerable increase of alfalfa cultivation due to the partial and full decoupling of subsidies for cotton and maize respectively, which resulted in a reduction of revenue for these two crops. Consequently, alfalfa cultivation became more competitive since it is characterized by similar variable costs compared to cotton and maize.

The increase of set-aside is mainly due to the fact that a significant number of farmers participate in the nitrogen reduction agri-environmental program in the context of Second Pillar of CAP for the 2007-13 programming period, whereby they are obligated to set-aside a part of irrigated arable land.

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[6] Virginia variety requires drying through kilns. Due to the significant increase of the diesel-oil cost during the period 2005-2012, farmers (that cultivate tobacco since 2010) have replaced the diesel boilers of drying kiln with biomass boilers in order to keep the drying cost at 2005 levels. Consequently, the tobacco cultivation is considered competitive (in terms of gross margin) compared to other crops, only for these farmers that have invested in biomass boilers.

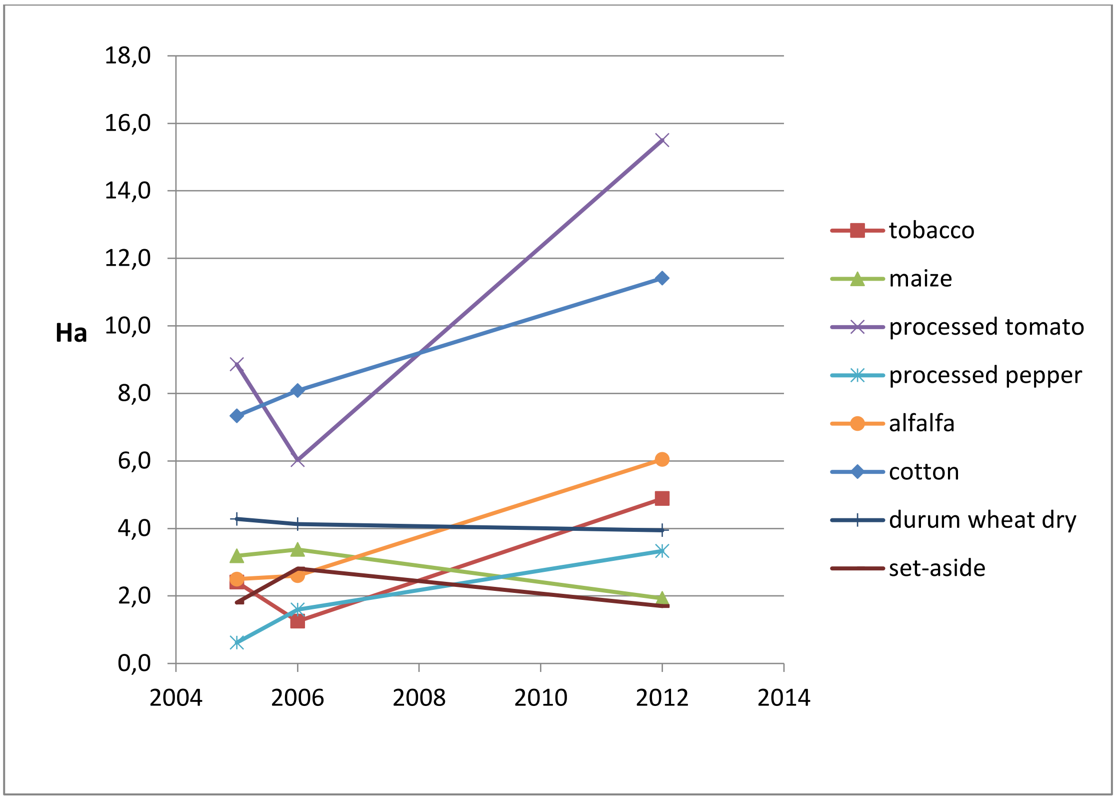


Figure 2. Average cultivated area per crop (2005-2012)

Figure 2 illustrates the average cultivated area per crop, indicating a noteworthy enlargement of scale and most probably the attainment of economies of scale for crops like processed tomato, cotton, alfalfa, tobacco and processed pepper. Additionally, more than 90% of farms own the machinery for all operations except for harvesting. The rate of harvesting equipment ownership varies widely, from 22% in cotton, to 45% in alfalfa and 100% in processed tomato. Also, 60% of total land is rented. Moreover, 31% of the sample farms participate in optional agri-environmental measures of the Second Pillar. More specifically 23% of farms participate in nitrogen pollution reduction program (Variant B), 4% in nitrogen reduction program (Variant A) and 4% in organic farming. The size of land that is intended for the application of agri-environmental measures corresponds to 30% of total land.

Convectional and energy crops basic techno-economic data

In the table 6 are presented some basic techno-economic data of studied crops. For additional information concerning the cost and yield estimation of energy crops see Mantziaris et al. (2017a).

Table 6. Basic techno-economic data of studied crops (2015)

Crop	Average variable costs per ha (euros)	Average yield per ha (tons)	Irrigation	Contract farming
Cotton	1.335	3.17	Annually	No
Tobacco	6.742	4.59	Annually	Yes

Maize	1.426	10.78	Annually	No
Processed Tomato	6.719	96.06	Annually	Yes
Processed Pepper	6.297	29.41	Annually	Yes
Alfalfa	1.476	10.12	Annually	No
Durum Wheat	630	3.53	No	No
Arundo	350.5	8.49	Only in the establishment	Yes
Miscanthus	347.2	7.07	Only in the establishment	Yes
Poplar	310	7.07	Annually	Yes

5. Results

After optimizing the sequential model described above, the overall crop mix for each studied year is revealed. Generally, the crop mix is characterized by a stabilization trend. A weak increasing trend is observed for the set-aside since 2017 that is correlated with a weak decreasing trend for the majority of crops (see also table 7 and figure 3). The number of farms decreases by 11% (i.e. 2.2% by year) and 28.7 hectares (71% correspond to irrigated land) redistributed to the rest of farms. It may be expected that a larger number of farms is going to be disappeared due to the austerity measures in the context of Third Memorandum Measures that stand since 2015 for the Greek economy and affect directly the agricultural sector (Mantziaris et al., 2017b).

Table 7. Optimal crop mix evolution in ha

Crop	2015	2016	2017	2018	2019
alfalfa	78,6	77,0	66,9	69,7	72,5
cotton	402,9	402,1	419,0	410,8	403,3
d. wheat	125,4	122,7	143,7	126,7	133,1
maize	19,2	18,8	9,2	9,7	8,4
Proc. peppers	36,4	34,5	30,3	28,6	26,5
Proc. tomato	29,7	28,7	27,3	23,1	20,9
setaside	110,3	120,1	110,3	141,1	147,2
Tobacco(Virginia)	45,0	43,6	40,9	37,9	35,7

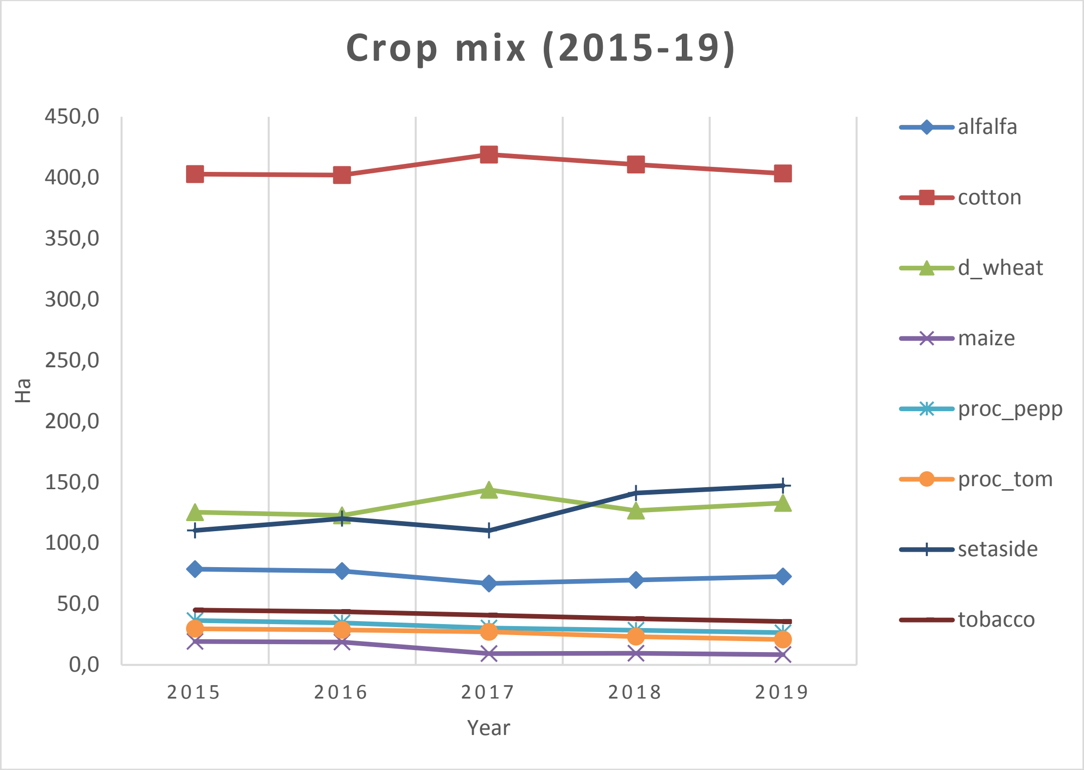


Figure 3. Optimal crop mix evolution

Concerning the basic economic results and parameters, gross revenue is decreased by 14%, gross margin by 16% and working capital by 12%. The specific results may be affected by the significant reduction of decoupled payments by 28%. The 90% of farms are going to lose significant part of their decoupled subsidies due to their high levels of entitlements value (948/ha) compared to the baseline entitlement value of 420/ha that stands for the agronomic region of arable farming.

Table 8. Basic economic results and parameters in euros (sample farms 2015-19)

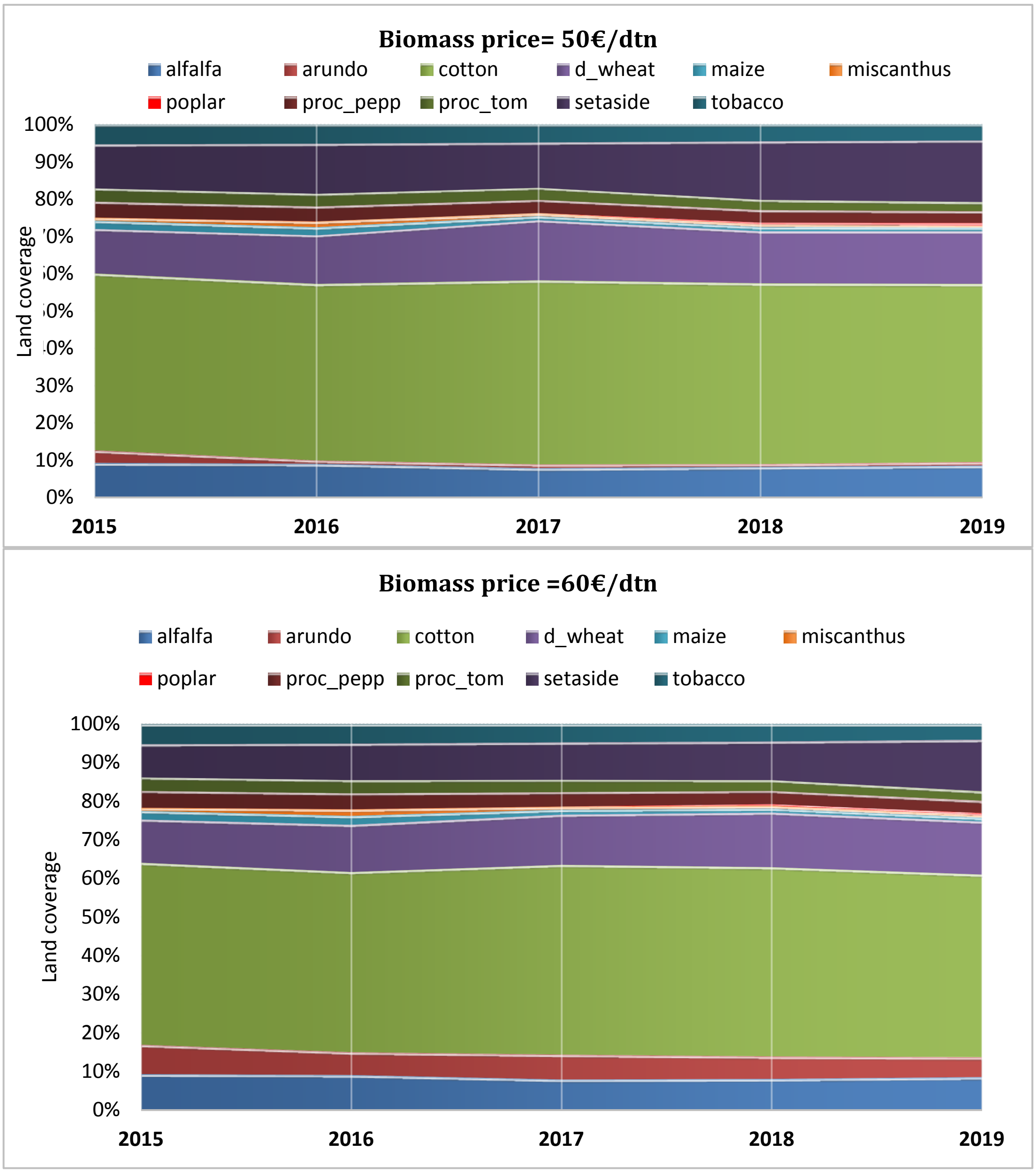
	2015	**2016**	**2017**	**2018**	**2019**
Gross Margin	1.700.840	1.642.493	1.583.388	1.488.239	1.430.951
Gross Revenue	2.988.321	2.913.872	2.828.009	2.668.813	2.577.047
Market sales	1.935.923	1.904.877	1.842.230	1.744.819	1.697.255
Working capital	1.348.574	1.318.425	1.291.078	1.228.730	1.184.846
Coupled payments	328.916	330.740	345.561	336.795	330.755
Decoupled payments	634.102	588.874	550.837	497.818	459.657
Agri-Environmental measures payments	89.381	89.381	89.381	89.381	89.381

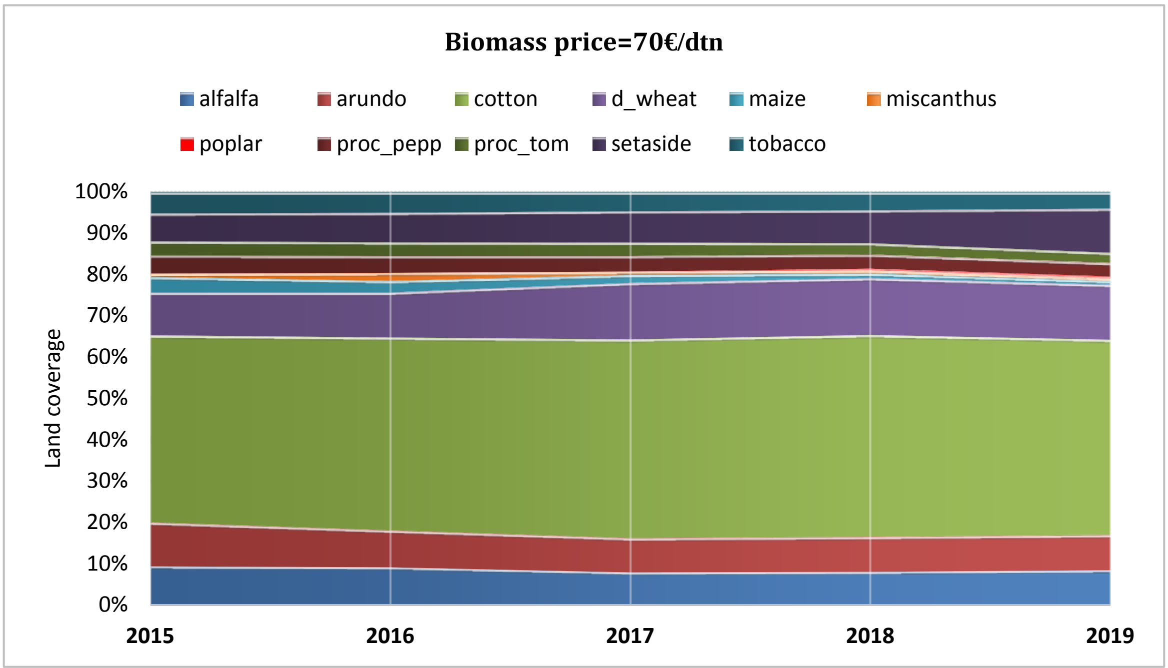
After introducing in the decision system of farms the perennial energy crops option we apply a realistic price range for biomass of pellet industry. Unfortunately, price data on the studied crops were not available due to the lack of an established market for these crops in Greece.

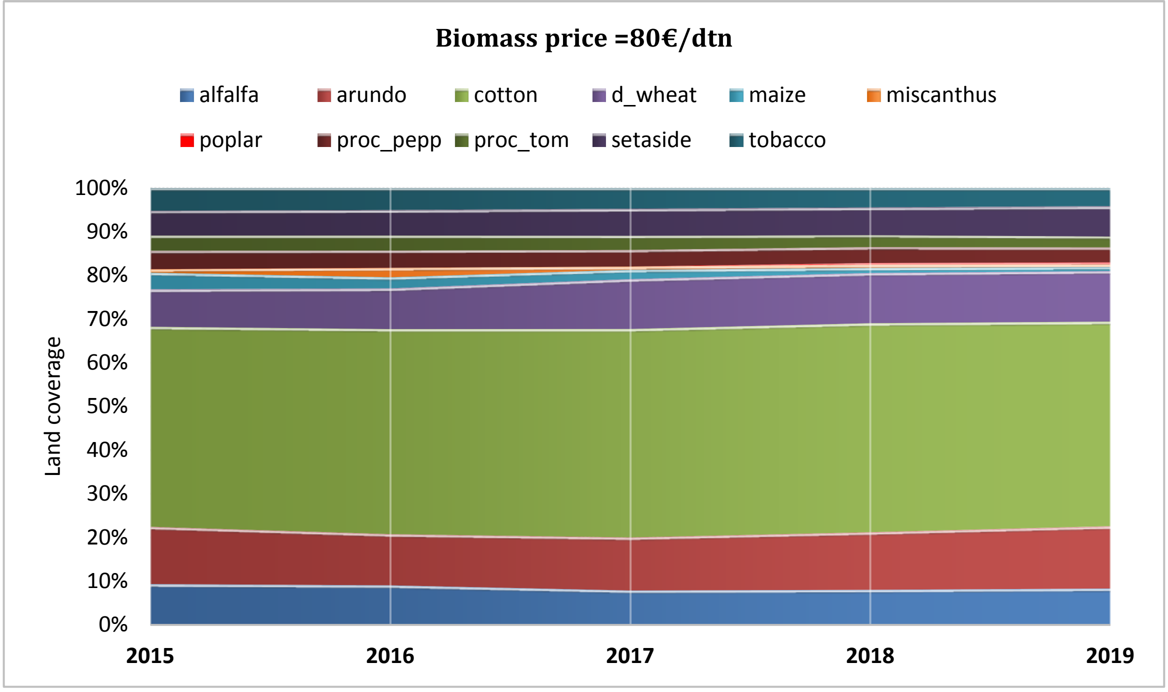
Instead, we use current contract prices for cardoon biomass in the areas of Karditsa and Central Macedonia which correspond to 50 €/dry tone (dtn) and 73 €/dry tone (dtn) at farm gate level respectively (Mantziaris et al., 2017a; Kathimerini 2011). Thus, the price range was determined from 50 €/dtn to 80 €/dtn.

Taking into consideration the specific price range we optimize the multi-annual model and obtain the crop mix for every year of the period 2015-19. In the following graphs is presented the multi-annual crop mix for each biomass price of studied range. As biomass price increases, Arundo cultivation reveals significant possibility of expansion compared to miscanthus and poplar. According to the multi-annual optimal crop mix, arundo is characterized as the most profitable cultivation among studied energy crops within the applied price range. On the other hand, durum wheat and set-aside are decreased significantly.

Figure 4. Optimal crop mix evolution for biomass price range 50-80 €/dtn

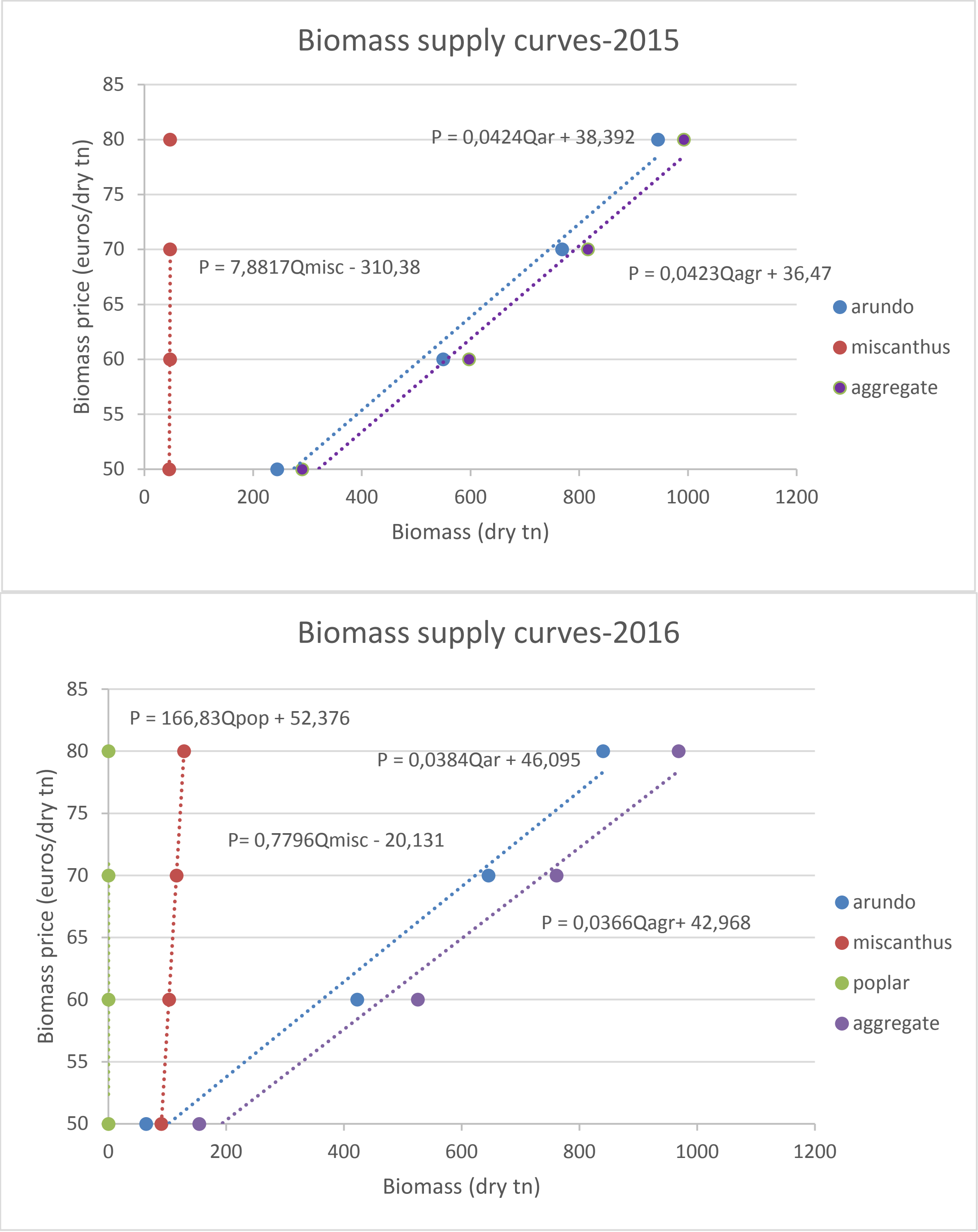


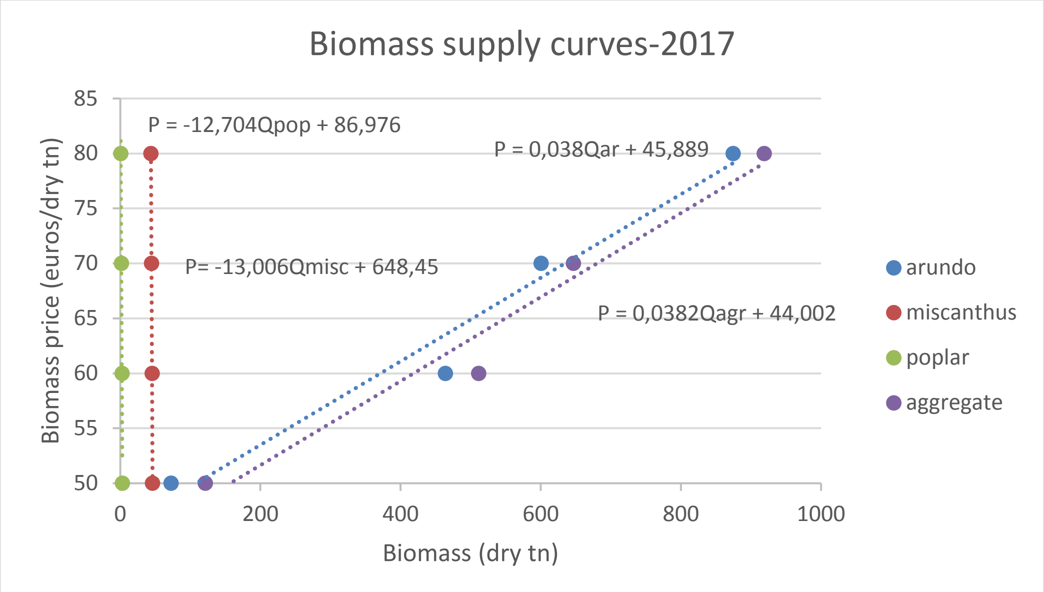


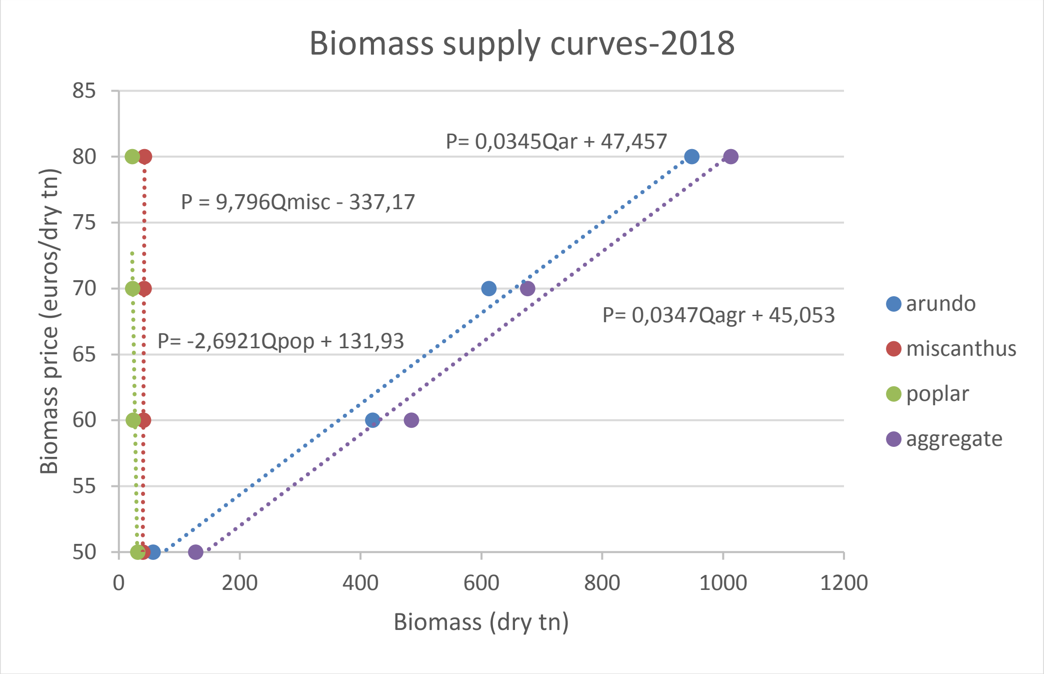


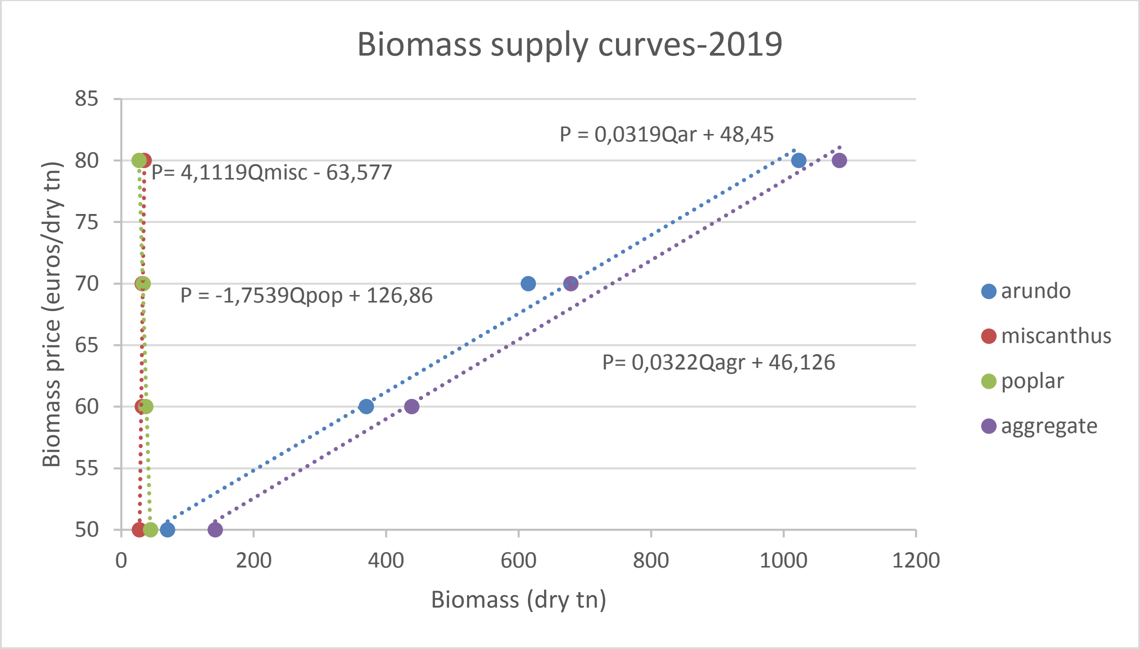
Then, we modified the energy crop cultivations from hectares to dry biomass tones in order to estimate the multi-annual biomass supply curve at energy crop level but also at aggregate level. More specifically, each energy crop hectare was multiplied with the biomass yield per hectare. Afterwards, annual optimal produced quantities of biomass for the studied price range were used in order to estimate the energy crops supply curves. Generally, arundo biomass supply is detected in considerably higher levels for the same price, compared to the other energy crops for each studied year. Thus, arundo is considered the most profitable option among energy crops for the majority of sample farms.

Figure 5. Biomass supply curves for the period 2015-19




Biomass supply curves-2017
P = -12,704Qpop + 86,976
P = 0,038Qar + 45,889
P= -13,006Qmisc + 648,45
P = 0,0382Qagr + 44,002
Biomass price (euros/dry tn)
85
80
75
70
65
60
55
50
0
200
400
600
800
1000
Biomass (dry tn)
arundo
miscanthus
poplar
aggregate


Biomass supply curves-2018
P= 0,0345Qar + 47,457
P = 9,796Qmisc - 337,17
P= 0,0347Qagr + 45,053
P= -2,6921Qpop + 131,93
Biomass price (euros/dry tn)
85
80
75
70
65
60
55
50
0
200
400
600
800
1000
1200
Biomass (dry tn)
arundo
miscanthus
poplar
aggregate



As we mentioned above, the initial target of the existing pellet manufacturer in the area is to produce 1100 tons of pellets from biomass with the plant operating in a single shift (ESEK, 2016), where 450 tons correspond to cardoon dry biomass and the rest (650 tons) could be covered by the combination of arundo, miscanthus and poplar dry biomass.

Table 9. Production level & required raw material

1,100 tons of pellets ≈ 1,100 tons of dry biomass[7]

Where: 450 tons correspond to cardoon dry biomass and the rest (650 tons) could be covered by the combination of arundo, miscanthus and poplar dry biomass.

(1 ha Cardoon = 4.5 dry tons)

(1 ha Arundo = 8.49 dry tons)

(1 ha Miscanthus = 7.07 dry tons)

(1 ha Poplar = 7.07 dry tons)

---

[7] 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.

Aggregate supply curve could be used in order to estimate the contract price under the multi-annual context. Thus, pellet manufacturer could design the medium-term or long-term price strategy in order to ensure the required raw material quantities. The estimated required contract price for biomass per dtn ranges from 64 euros to 67.6 euros (see also table 10). Aggregate biomass supply moves upwards over the studied years (see also figure 7). These results illustrate that payments convergence may has a negative effect on biomass production potentials. As regards the evolution of farm viability and economic results, remain almost at the same levels as before the introduction of energy crops in decision system. More specifically, 11% of farms disappear, 29.1 hectares are redistributed and the gross margin is increased by 1% in average terms compared to conventional farming system (see also table A10 in the Appendix). Concerning the crop mix, durum wheat and set-aside are decreased significantly due to the introduction of perennial energy crops in the conventional farming system (see also figure 8 and table A11 in the Appendix).

Table 10. Estimated contract prices for biomass 2015-19 (€/dtn)

2015	**2016**	**2017**	**2018**	**2019**
64,0	66,8	67,2	67,6	67,1

Figure 7. Biomass supply & demand (2015-19)

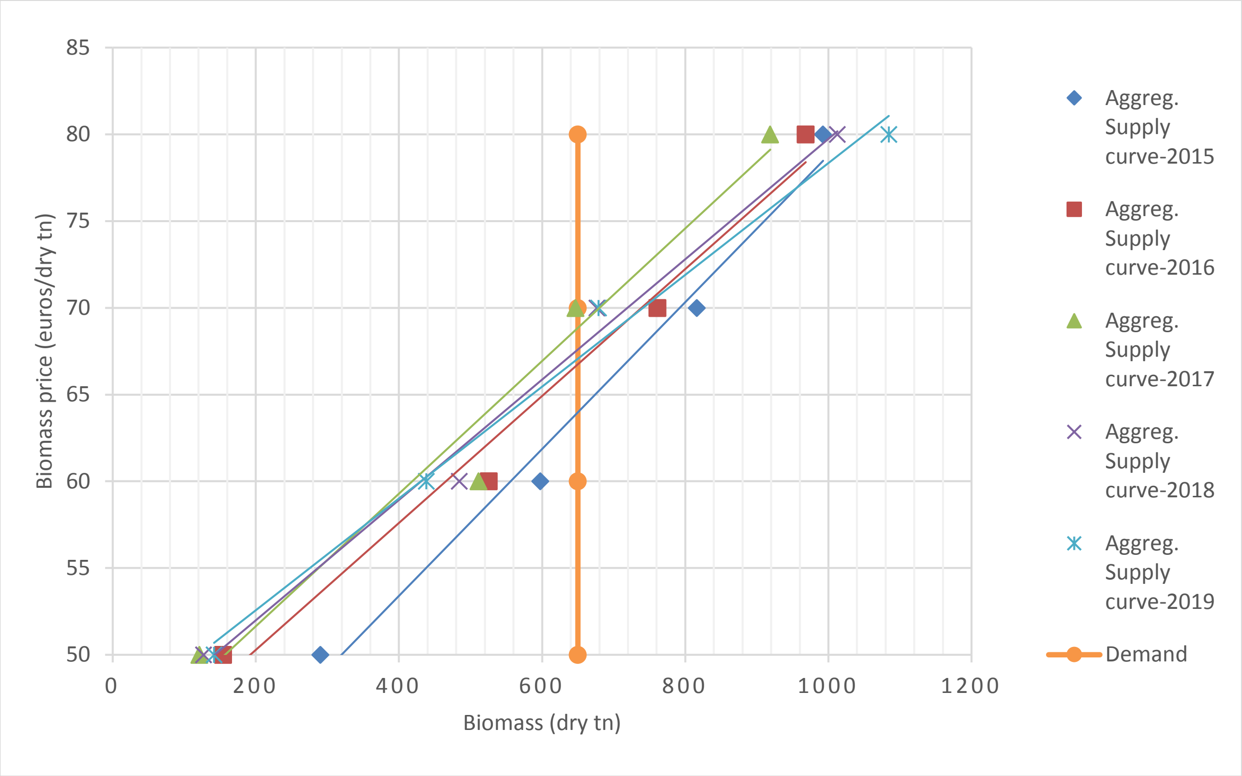
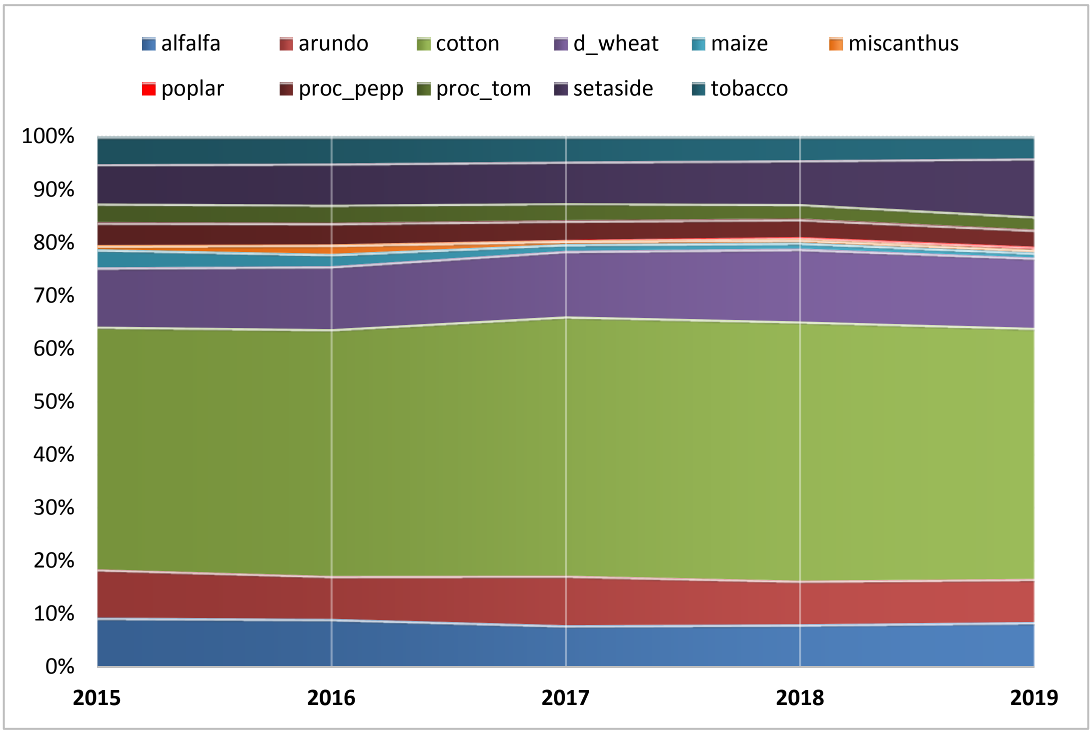


Figure 8. Optimal crop mix evolution according to biomass demand of local pellet manufacturer



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. Procuring biomass from farms 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 (Toka, 2015). 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, Miscanthus and Poplar.

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.

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). 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 (Mantziaris et al., 2017a).

6. Conclusions and policy implications

The energy debate in Greece, as in other European countries, has resulted into a number of different and often conflicting narratives. 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 (IEA, 2011). 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 (Savvanidou et al., 2010).

Within this context, 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 scope for the development of the biofuels supply chain[8].

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. 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. This argument can be exemplified by the Swedish case study as stated by Ostwald et al. (2013). The authors argue that although economic motivations for changing production systems are strong, factors such as values (e.g., aesthetic, environmental), knowledge (e.g., habits and knowledge of production methods), and legal conditions (e.g., cultivation licenses) are crucial for the change to energy crops. Also, as

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[8] The contribution of RES to the national energy balance in 2011 was approximately 11.6% of the gross final energy consumption (AEBIOM, 2013).

suggested by Paulrud and Laitila (2010), issues related to the visual impact on the landscape and the rotation period of the energy crop appear to have a significant impact on the utility derived from growing an energy crop.

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 (Mantziaris et al., 2017a). It may be expected that a larger number of farms will go out of business due to the austerity measures in the context of Third Memorandum Measures that stand since 2015 for the Greek economy and affect directly the agricultural sector. Apart from the above-mentioned changes in the CAP, the policy environment in which Greek agriculture operates is also determined by an extremely strict set of policy measures. These measures are part of the 'adjustment programs' of the Greek economy, since 2010, including: increases of taxation rates on household income, business profits and heating oil; increase of social insurance contributions and VAT (Value Added Tax) for specified products and services (e.g. food products and drinks, alcohol drinks, cigarettes, diesel oil, restaurants, tourism, etc.) as well as cuts of pensions, public sector salaries and handouts. Within this context, a series of measures have been in place since 2015, concerning the agricultural sector such as the abolishment of tax allowance of diesel oil used by farmers, doubling of the taxation on farm income which reached 26% in 2017, payment of this tax on an anticipatory basis, and a significant increase in social welfare contributions (Mantziaris et al., 2017c).

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.

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. 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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Appendix

Table A1.Indices, parameters and decision variables

Indices	
n	Crop
st	Set-aside
$OPTL1$	Largest crop in hectares after model optimization
$OPTL2$	Second largest crop in hectares after model optimization
Decision Variables	
X_n	cropping area of each crop in hectares
X_{st}	set-aside area in hectares
$X_{OPT\ L1}$	cropping area of largest crop in hectares after model optimization
$X_{OPT\ L2}$	cropping area of second largest crop in hectares after model optimization
$irr_n X_n$	cropping area of irrigated arable crop
$Irr\_Nitrogen_n X_n$	cropping area of eligible crop for irrigated rotation in the context of nitrogen reduction program
$NIrr\_Nitrogen_n X_n$	cropping area of eligible crop for non-irrigated rotation in the context of nitrogen reduction program
$Organic_n X_n$	cropping area of eligible crop for organic farming
$Legume_n X_n$	cropping area of Legume crop
Parameters	
$yield_n$	expected crop yield of each crop in tn/ha
$price_n$	expected crop price of each crop in euros/ha
ls_n	indicative coupled subsidy of each crop in euros/ha
var_cost_n	variable cost of each crop in euros/ha
fl_n	provided family labor for each crop in hours/ha
$\lg\_land$	land entitlements area in hectares
pay	single payment in euros/ha
$\lg\_organic$	land entitlements of organic program in hectares
$orgpay$	organic payment in euros/ha
$\lg\_nitro\_A$	land entitlements of nitrogen pollution reduction program in hectares- methodology A
$nitropay\_A$	nitrogen pollution reduction program methodology A payment in euros/ha
$\lg\_nitro\_B$	land entitlements of nitrogen pollution reduction program in hectares- methodology B

$nitropay\_B$	nitrogen pollution reduction program payment in euros/ha - methodology B
tot_land	Available arable land
irr_land	Available irrigated land
$working\ capital$	Available working capital
$family\ labour$	Available family labor

Table A2. Observed and forecasted prices according to logarithmic function (€/kg)

year(t)	**observed price-d. wheat**	**forecasted price-d. wheat**	**observed price-cotton**	**forecasted price-cotton**	**observed price-maize**	**forecasted price-maize**	**observed price-alfalfa**	**forecasted price-alfalfa**
1	0,12	0,150	0,31	0,298	0,14	0,162	0,15	0,162
2	0,21	0,175	0,42	0,350	0,22	0,170	0,16	0,164
3	0,25	0,190	0,2	0,381	0,18	0,176	0,19	0,165
4	0,18	0,200	0,32	0,403	0,13	0,179	0,17	0,166
5	0,13	0,209	0,6	0,419	0,18	0,182	0,16	0,166
6	0,24	0,215	0,5	0,433	0,19	0,185	0,17	0,167
7	0,22	0,221	0,41	0,445	0,21	0,187	0,17	0,167
8	0,22	0,226	0,51	0,455	0,18	0,188	0,17	0,168
9	0,25	0,230	0,42	0,464	0,21	0,190	0,16	0,168
10	0,23	0,234	0,43	0,472	0,17	0,191	0,16	0,168
11	-	0,237	-	0,479	-	0,192	-	0,169
12	-	0,241	-	0,485	-	0,194	-	0,169
13	-	0,244	-	0,491	-	0,195	-	0,169
14	-	0,246	-	0,497	-	0,196	-	0,169

Table A3. Price predictive capacity of ln function – durum wheat

year	D. Wheat-observed price(€/kg)	Forecast (ln function)	Deviation
2012	0,22	0,221	0,42%
2013	0,22	0,226	2,64%
2014	0,25	0,230	-7,95%
2015	0,23	0,234	1,73%

Figure A1. Price forecasting ln function-durum wheat

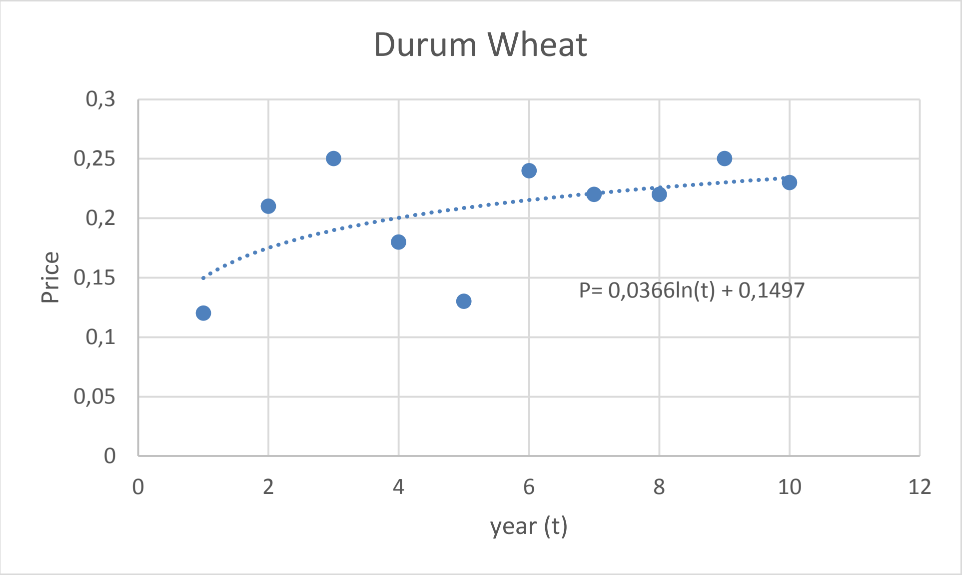

Table A4. Price predictive capacity of ln function – cotton

year	Cotton-observed price(€/kg)	Forecast (ln function)	Deviation
2012	0,41	0,445	8,47%
2013	0,51	0,455	-10,83%
2014	0,42	0,464	10,39%
2015	0,43	0,472	9,67%

Figure A2. Price forecasting ln function-cotton

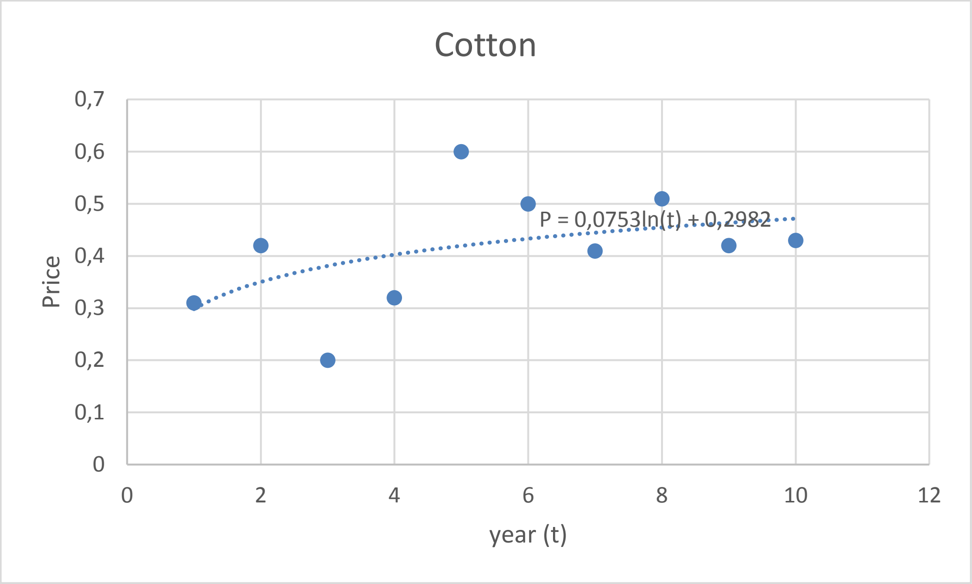

Table A5. Price predictive capacity of ln function – maize

year	Maize-observed price(€/kg)	Forecast (ln function)	Deviation
2012	0,21	0,187	-11,14%
2013	0,18	0,188	4,62%
2014	0,21	0,190	-9,60%
2015	0,17	0,191	12,47%

Figure A3.Price forecasting ln function-maize

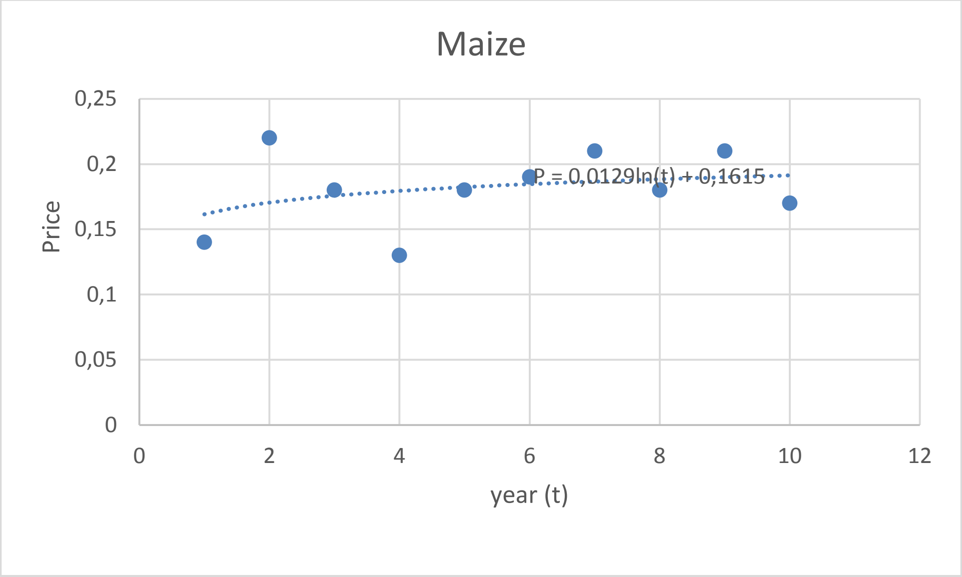

Table A6. Price predictive capacity of ln function – alfalfa

year	Alfalfa-observed price(€/kg)	Forecast (ln function)	Deviation
2012	0,17	0,167	-1,57%
2013	0,17	0,168	-1,33%
2014	0,16	0,168	5,06%
2015	0,16	0,168	5,25%

Figure A4. Price forecasting ln function-alfalfa

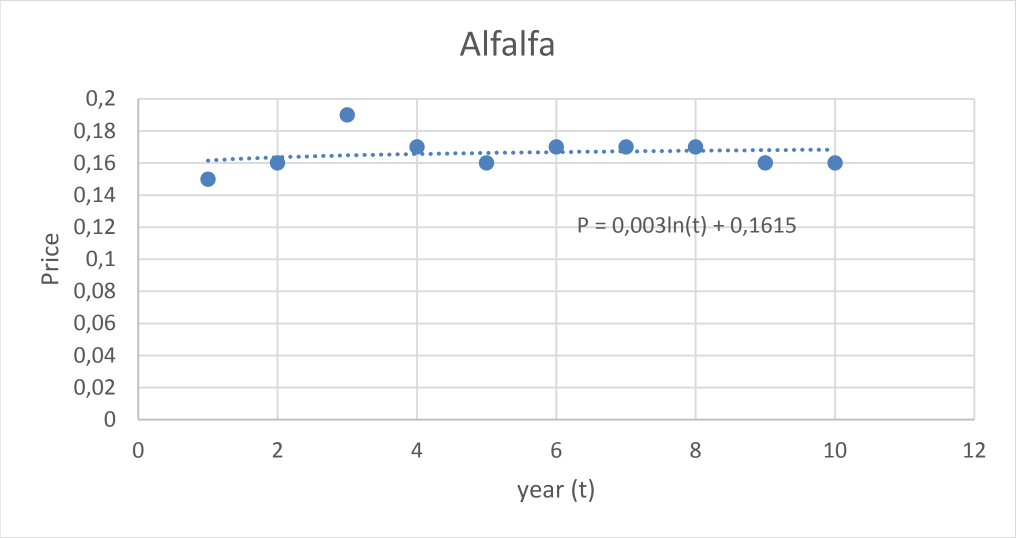

Table A7. Variable cost index predictive capacity of ln function

year	Variable cost index-Observed	ln function(forecast)	deviation
2014	1,33	1,32	-1%
2015	1,30	1,33	3%
2016	1,27	1,35	6%
2017	1,30	1,36	4%

Figure A5. Variable cost index forecasting ln function

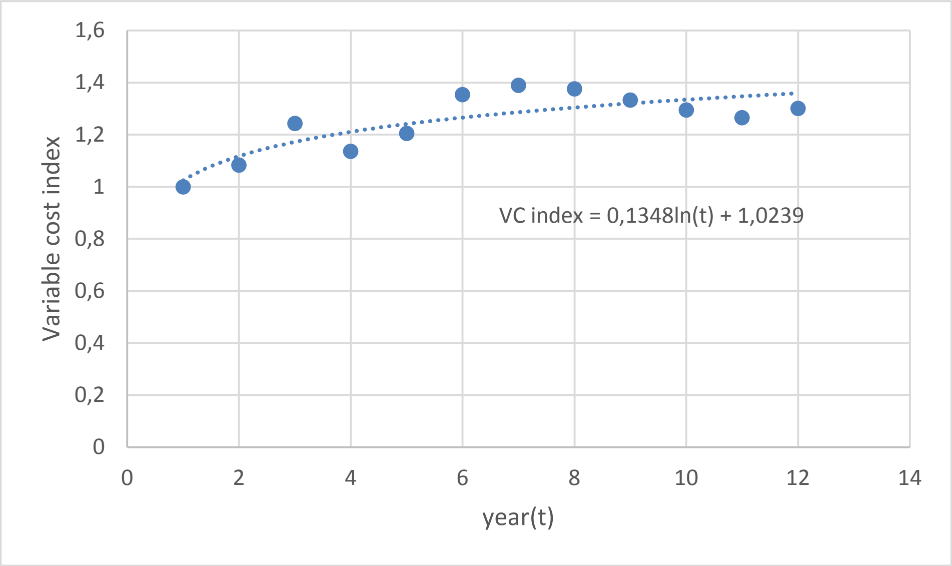

Table A8. Variable cost evolution according to forecasted indices (Baseline year = 2015)

year	**deviation**
2016	+1,0%
2017	+1,8%
2018	+2,7%
2019	+3,4%

Table A9 Crop patterns in the sample farms (2005-2012)

Year	**2005 (n=70)**		**2006 (n=70)**		**2005 (n=48)**		**2006 (n=48)**		**2012 (n=48)**	
Crop	**Area (Ha)**	**Number of farms**	**Area (Ha)**	**Number of farms**	**Area (Ha)**	**Number of farms**	**Area (Ha)**	**Number of farms**	**Area (Ha)**	**Number of farms**
Cotton (irrigated)	451.5	66	506.8	68	337.4	46	371.7	46	467.9	41
Tobacco (irrigated)	159.1	70	2.5	2	115.7	48	2. 5	2	58.6	12
Maize (irrigated)	47.4	24	48.8	18	44.7	14	40.5	12	27	14
Processed Tomato (irrigated)	36.6	4	34.1	4	26. 6	3	24.1	4	31	2

Processed Pepper (irrigated)	6.4	7	14.7	7	3.7	6	9.6	6	30	9
Alfalfa (irrigated)	9.0	4	11.6	4	5.0	2	7.8	3	66.5	11
Durum Wheat (non-irrigated)	91.5	28	168.4	49	68.5	16	119.6	29	142	36
Set-aside (non-irrigated)	1.8	1	27.8	10	1.8	1	25.3	9	27.2	16
Total	**803.4**	**70**	**814.9**	**70**	**603.5**	**48**	**601.2**	**48**	**847.5**	**48**
Average farm size(Ha)	**11.4**	**-**	**11.6**	**-**	**12.5**	**-**	**12.5**	**-**	**17.6**	**-**

Table A10. Gross margin evolution in euros (sample farms 2015-19)

Scenario	2015	2016	2017	2018	2019	Average (2015-19)
Status quo-conventional farming system	1.700.840	1.642.493	1.583.388	1.488.239	1.430.951	1.583.388
Perennial energy crops introduction in farming system	1.708.387	1.656.355	1.599.802	1.525.262	1.438.331	1.599.802

Table A11 .Optimal crop mix evolution according to biomass demand of local pellet manufacturer (in ha)

Crop	**2015**	**2016**	**2017**	**2018**	**2019**
alfalfa	79,1	77,1	66,9	68,4	71,7
arundo	77,3	68,6	79,2	69,7	69,4
cotton	387,5	394,1	414,1	414,0	400,6
d_wheat	94,6	100,5	104,8	116,4	112,8
maize	28,8	19,8	10,8	9,7	8,1
miscanthus	6,7	15,3	6,3	5,8	4,4
poplar	0,0	0,0	0,3	3,3	4,7
Processed peppers	36,8	34,5	31,8	29,3	27,5
Processed tomato	29,7	28,7	27,3	23,3	20,9
setaside	62,9	66,3	66,2	69,9	92,8
tobacco	44,0	42,6	39,9	37,7	34,6