Volume XIV Number 4, 2022

Optimal Farm Planning and Assessment of Conventional Agricultural Practices under Alternative Scenarios Integrating Life Cycle Analysis

Emmanouil Tziolas[1], Konstantina Ofridopoulou[1], Thomas Bournaris[2], Basil Manos[2]

[1] Department of Marine Fisheries, Fisheries Research Institute (FRI), Hellenic Agricultural Organization "DIMITRA", Greece

[2] Departement of Agricultural Economics, School of Agriculture, Aristotle University of Thessaloniki, Greece

Abstract

Agricultural production and farm management are inextricable, since managerial aspects for safe and of high-quality food products have led to the development of successful production plans but multifaceted controversies as well. These controversies arise from the focus of policymakers, especially in the EU, to the environmental aspects of agricultural production, creating conflicting objectives for farmers. Energy from biomass derivatives could play a significant role in the dispute for economic and environmental sustainability in agriculture, along with the formulation of agro-energy districts. In this context, an MCDM model was developed integrating LCA data for the assessment of economic, environmental and energy sustainability regarding thirteen major crops in the Region of Central Macedonia in Greece. The model's objectives consist of maximization of farmers' gross income, minimization of emissions coming from farming practices and maximization of energy potentially coming from biomass. Furthermore, three different scenario-based directions allocate different weights to the respective objectives, creating different managerial strategies. The optimal production plan was the scenario in which the weights were allocated by goal programming. The optimal plan proposes the cultivation expansion of energy crops, tree crops, alfalfa and hard wheat to a higher degree. Moreover, a significant reduction to the cultivated areas of tobacco, rice, barley and soft wheat could lead to a potentially viable production plan.

Keywords

Farm management, multi-criteria analysis, life cycle assessment, mathematical programming.

Tziolas, E., Ofridopoulou, K., Bournaris, T. and Manos, B. (2022) "Optimal Farm Planning and Assessment of Conventional Agricultural Practices under Alternative Scenarios Integrating Life Cycle Analysis", *AGRIS on-line Papers in Economics and Informatics*, Vol. 14, No. 4, pp. 121-135. ISSN 1804-1930. DOI 10.7160/aol.2022.140410.

Introduction

Farm management in the EU consists of manifold conflicting aspects, while there is a strong need to rethink and re-design current farming systems. Such re-design process involves multiple objectives and stakeholders raising awareness for environmental sustainability in agricultural production. The increasing food demand and the unavoidable carbon footprint of agriculture will be the two major obstacles to overcome in the future (Mueller et al., 2012). Although farmers tend to comply with the imposed measures in order to be subsidized by the EU, new emerging challenges complicate their decision-making process. Agri-environmental measures were implemented for the first time in 1992 (Freibauer et al., 2004) and have been evolving through time, achieving an average positive impact to the primary sector of the EU (Batáry et al., 2015). Agri-environmental schemes were designed to alleviate the impacts of poor strategic planning regarding farm management (e.g., reduction of fertilizer and pesticide use), to promote alternative agricultural practices (e.g., integrated production, organic farming) and to enhance biodiversity (Science for Environment Policy, 2017).

The current regulatory framework for agri-environmental measures (REGULATION (EU) No 1305/2013, 2013) has contributed significantly to the reformation of rural development in the EU (Batáry et al., 2015; Carvalheiro et al., 2013). Although this regulation has been in force for a long time now, there are several amendments which have changed manifold articles, while the two latest have been enforced in 2021 (EU 2021/399 and 2021/1017). Nevertheless, Batáry et al. (2015) highlight significant costs regarding the subsidiary character of these measures, whilst several studies outline limited measure efficiency on a regional level (Cortignani and Dono, 2019; Nunes et al., 2017; Schmidt and Hauck, 2018). In this context, the political agreement (European Commission, 2021) emphasize on the necessity of a versatile and agile framework with simpler rules, more fair and more "green", for the future of CAP. Furthermore, the proposed green architecture of the new CAP entails the idea of eco-schemes (Meredith and Hart, 2019), a regional support framework for farmers that will be implemented in the newest CAP, based on regional characteristics of the different areas in the EU. In this context, the Renewable Energy Directive (EU, 2018) which promotes local renewable energy communities, could play a significant role to sustainable management in farming along with eco-schemes.

Furthermore, the updated European Bioeconomy strategy (European Union and Directorate-General for Research and Innovation, 2018) focuses on sustainable plans that efficiently allocate energy resources and promote renewable forms of energy, such as biomass (Ronzon and Piotrowski, 2017). Biomass is considered as an efficient, reliable and environmentally friendly source of energy (Manzano-Agugliaro, 2007) and it has already been proven that specific biomass utilization pathways could enhance the socioeconomic development of rural areas as a whole (Nishiguchi and Tabata, 2016; Rincon et al., 2019). Furthermore, the exploitation of energy crops is a key aspect in a sustainable and continuous provision of energy scenario (White et al., 2013). However, biomass conversion systems consist of several bio-energy pathways (Tziolas, Bournaris, Nastis, and Manos, 2018), which complicate the formulation of bio-based industries, due to conflicting interests among policy makers, stakeholders and farmers. The exploitation of conversion technologies in order to create sustainable forms of energy from agricultural produce and byproducts defines the term "agro-energy" (Frayssignes, 2011). The idea of independent or semi-independent rural areas that could generate sustainable forms of energy while achieving environmental and economic goals is strongly connected to the development of agro-energy districts (Macrì et al., 2016).

This multifaceted infrastructure of rural areas exploiting biomass with lower emissions from agricultural practices creates confusion to farmers, since their goals are usually related to maximization of income or minimization of costs. The new described challenges should comply with the traditional goals of farmers, thus entailing that agricultural landscapes should integrate a multifunctional character (Fischer et al., 2017). The mitigation of climate change impacts is one of the most significant aspects regarding environmental sustainability and this is illustrated by the national adaptation strategies implemented by several countries in the EU (Biesbroek et al., 2010), while the European Commission's Green Paper (European Commission, 2009) constitutes a wider urban and rural environmental framework for the Union. Therefore, rural areas and agricultural production should integrate these new challenges and address numerous competing demands, taking into account spatial heterogeneity (Verhagen et al., 2018). More specifically, ecosystem services strongly correlated with agricultural production (such as biomass derivatives, carbon stocks in soil, biodiversity etc.) could form a multi-criteria decision-making (MCDM) model along with traditional goals of farmers.

In this context, multi-criteria techniques have been implemented in conjunction with life cycle tools in agriculture by several studies (De Luca et al., 2017; Tziolas, Bournaris, Manos, and Nastis, 2018). Apart from the tangible quantitative aspects such as costs, subsidies or labour hours, environmental impacts (direct or indirect) have been integrated into multicriteria models as well. Climate change in agriculture is transmuted to soil composition aspects (Mandryk et al., 2017; Seyedmohammadi et al., 2018) or GHG emissions (Baležentiene and Užupis, 2012; Nakashima, 2010; Yue et al., 2016), imported to multicriteria models. GHG emissions are usually derived from Life Cycle Assessment (LCA) indicators, namely Global Warming Potential (GWP), since LCA is considered as a great methodological approach for the environmental evaluation of agricultural systems (Ekvall and Finnveden, 2001; Foster et al., 2006; Roy et al., 2009).

The main aim of this paper is the assessment of agricultural production in Northern Greece and the direction of different production plans, considering emissions from agricultural practices in the field, biomass production and economic aspects. The current work is a continuation of Tziolas et al. (2017), in which an MCDM model was implemented for optimal farm planning in the smaller municipality of Almopia. The present study constitutes a part of a broader research in the Region of Central Macedonia (RCM) in Greece, highlighting the economic and environmental assessment of the agricultural production on the area. The assessment is enriched with primary data obtained from a survey conducted in every sub-district of the Region. Three scenarios with different set weights on each objective are optimized. The first scenario distributes the weights in equal terms, whilst the second scenario depends on primary data from the questionnaires. The third scenario is based on percentage deviational variables, as it is widely implemented in several agricultural systems (Bournaris, Papathanasiou, Manos, Kazakis, and Voudouris, 2015; Gómez-Limón and Berbel, 2000; Sumpsi, Amador, and Romero, 1997).

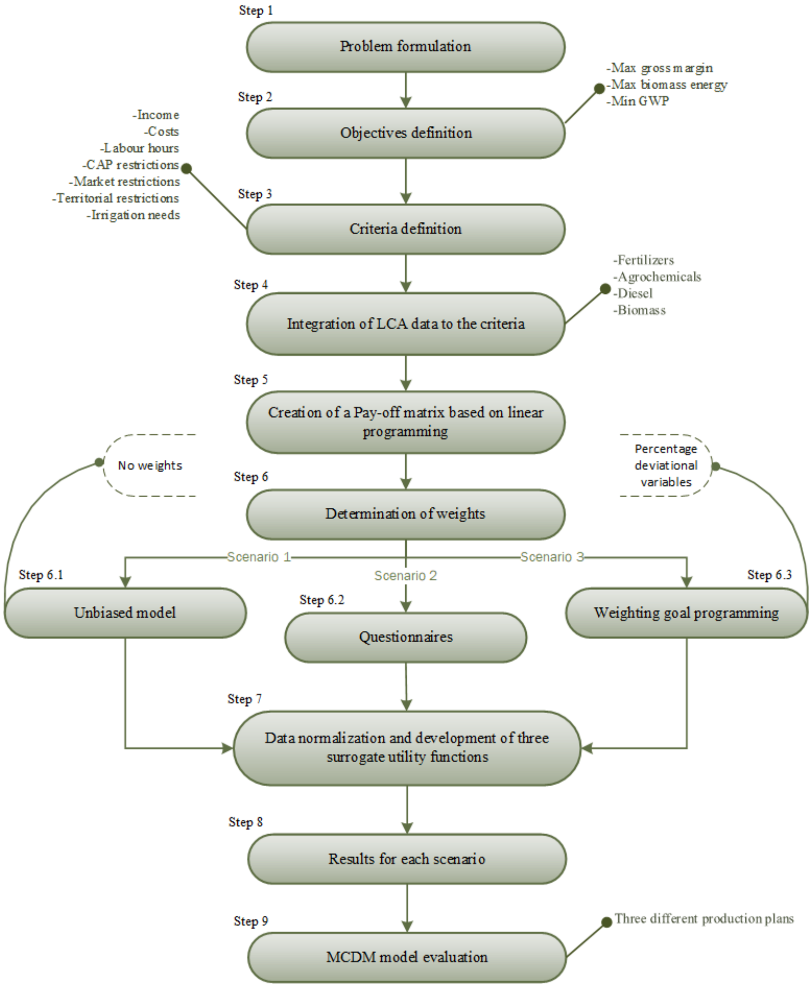
Materials and methods

In order to identify the optimum farm plan for the area of interest, an MCDM model with multiple scenarios was developed. The main objectives incorporate gross margin maximization, which is a traditional goal for farmers, energy maximization from biomass and minimization of the on-field GHG emissions. Emissions are measured in CO_2 equivalents, based on a unified LCA indicator (Global Warming Potential - GWP). The model outlines an assortment of managerial acts of agricultural production, regarding costs, labour hours, fertilizer application, income, irrigation needs, CAP obligations etc. Datasets for GWP indicators, potential energy from biomass, irrigation needs, fertilizer application, agrochemicals and diesel consumption have been derived from an LCA published research (Tziolas and Bournaris, 2019). All the relevant datasets regarding economic data were drawn from two private agricultural consulting firms located in the regional units of Thessaloniki and Pella. A sample of 502 farmers, meeting the research needs, was extracted from the firms' databases to create a reliable and representative sample for the entire region. The sample included only farmers who followed conventional agricultural practices and agriculture was their main source of income for the period 2016-2017. In addition to secondary data, we have also collected primary data (147 questionnaires out of the 502) from the farmers who accepted to cooperate via the mediation of the two private agricultural consulting firms. The main aim to acquire primary data was to capture useful factors for the LCA (e.g., kg of nitrogen fertilizers, working hours of an agricultural tractor per hectare, m^3 of irrigation per hectare, etc.) and to highlight the perspective of farmers in relation to the model's objectives.

Many producers appeared to be quite reluctant to provide information about their farms, despite the assurances of us and the two private agricultural consulting firms. This was the main reason for the cooperation with private firms, so that the results could be verified and up to date. Finally, the answers were cross-referenced with similar surveys carried out abroad in order to accurately depict the environmental data, since producers found it difficult to accurately estimate quantities of diesel used, hours of mechanical work per hectare, etc. The gist of the approach is the formulation of three scenarios, based on different weights for each objective. The model follows the methodological procedure designed and successfully implemented by Sumpsi et al. (1997) and Bartolini et al. (2007). The first scenario (SC1) allocates the weights equally to each objective. The second scenario (SC2) depicts the preferences of farmers based on questionnaires delivered in the sub-regions of the RCM, while the third scenario (SC3) is a weighted goal programming approach based on deviational variables. A surrogate utility function for each scenario should be introduced in pursuance of the simultaneous optimization of the three objectives simultaneously. The ideology behind this approach lies on the simulation methods of Sumpsi et al. (1997) and Amador et al. (1997), which have been implemented specifically on agricultural systems, allocating different weights to each goal. This approach has been successfully employed by several studies regarding water management in agriculture (Bartolini et al., 2007; Bournaris et al., 2015), farm planning (Bournaris, Moulogianni, and Manos, 2014; Manos, Papathanasiou, Bournaris and Voudouris, 2010) and environmental management (Manos, Papathanasiou, Bournaris and Voudouris, 2010). The MCDM model develops three different production plans for the area of interest, whilst a step-by-step procedure for the formulation of the MCDM model is depicted in Figure 1.

Model specification

The model specification section will provide an extensive overview of all the necessary information for the formulation of a linear programming model and, by extension, an MCDM model for the study area. In more detail, the decision



Source: Authors' elaboration

Figure 1: Step by step procedure for the MCDM model.

variables, the different goals, the constraints and useful features for the implementation of the model will be presented.

Decision variables

Each farmer manages a different mix of X_i variables (which are depicted as crops). The reorganization should be performed in a wider context, at the level of the entire study area. Thus, the decision variables will form an integrated production plan for the RCM, depicting the necessary fluctuations on the existent production plan, based on the examined objectives.

Objectives

The objectives of the MCDM model are outlined as necessary from the point of view of both farmers and policy makers and they also incorporate the rationale for investing in rural areas, through biomass industries. The mathematical expression of each objective is illustrated as follows:

- Maximization of gross margin, which is the main motivational factor in the decision-making process of farmers. Therefore, Gross Margin (GM) for each crop *i* is taken into account, whilst GM_i is calculated in euros per hectare:

$$max_{GM} = \sum_{i=1}^{n} GM_i \times X_i$$

- Maximization of the potential energy from biomass, which is a social and European goal for renewable energy sources. This objective has a social aspect, since apart from the autonomy, it can create energy communities and strengthen key elements of rural economic life (e.g., reduction of unemployment), while reducing burning of residues in open fields. The objective function to maximize energy (EN) from each crop i is defined as follows and the EN_i is calculated in Megajoules per hectare:

$$max_{EN} = \sum_{i=1}^{n} EN_i \times X_i$$

- Minimization of GWP from farming practices, which is expressed in CO_2 equivalents, is an aspect of the emission of harmful air pollutants into the atmosphere. This is a new objective, with multiple benefits for the local community, stimulating awareness for all the involved parties (farmers, political leadership, the EU). It is an environmental objective trying to minimize the total harmful emissions (GWP) of each crop $_i$, while GWP_i is depicted in kg of CO_2 equivalents per hectare:

$$min_{GWP} = \sum_{i=1}^{n} GWP_i \times X_i$$

Constraints

The data collected from the relevant sources (the Directorate-General for Agriculture and Veterinary, the Region of Central Macedonia's Directorate, the Hellenic Statistical Authority and the Ministry of Rural Development and Food of Greece), as well as those from the existing production plan, constitute specific constraints. For this model, the constraints concern multiple aspects of agricultural production and they are referring to: land availability, variable costs, fertilizers, labour, diesel, agrochemicals, CAP regulations and market constraints.

Land use and data analysis

The RCM covers an area of 18,811 km^2; it is divided into seven regional districts, namely Chalkidiki, Imathia, Kilkis, Pella, Pieria, Serres and Thessaloniki. The Region has a large number of protected areas (33.8% of its total area), though only half of the Natura 2000 sites have an organized management plan to provide a competent protection framework. Nevertheless, the energy from biomass derivatives is considered significant (Moulogianni & Bournaris, 2017), though the potential power plants' capacity is average (1-2 MW) due to the structure of the area (Bakos et al., 2008). Regarding the production plan of the RCM, hard wheat and soft wheat are the most widespread crops with 24.37% and 10.92% of the cultivated land (Table 1). On the other hand, rapeseed covers only 1.15% of the total cultivated area. However, it is a newly introduced crop, that gained more attention in recent years. Among the crops, there are also set-aside areas, which oblige farmers to apply tillage operations once per year according to Article 94 of the Regulation No 1306/2013 (EU), in order to be subsidized by the EU.

Apart from the production plan for the RCM, Table 1

Crops	Area (ha)	(%)	Gross margin (€/ha)	Biomass energy (MJ/ha)	GWP (kg CO_2 eq/ha)
Soft Wheat	57 431.60	10.92%	175.94	9 377.67	1 512.68
Hard Wheat	128 159.20	24.37%	274.67	8 540.38	1 512.68
Barley	29 700.10	5.65%	308.32	9 042.76	2 376.81
Maize	35 019.70	6.66%	442.68	22 162.80	5 096.92
Rice	27 508.60	5.23%	777.03	11 306.06	8 954.48
Tobacco	6 834.10	1.30%	1 450.85	2 740.13	4 715.80
Cotton	56 243.30	10.69%	1 030.00	8 731.80	4 405.36
Sunflower	22 515.60	4.28%	472.29	74 585.98	2 248.63
Rapeseed	6 049.70	1.15%	513.69	42 174.78	1 856.76
Alfalfa	23 793.10	4.52%	1 114.20	9 649.20	1 777.47
Peach trees	34 208.20	6.50%	2 947.86	18 673.32	4 510.86
Cherry trees	11 866.30	2.26%	6 006.32	11 099.09	2 767.24
Olive trees	40 253.30	7.65%	3 686.60	14 821.07	2 772.93
Set aside	46 398.30	8.82%	119.38	0	59.59
Total	525 981.10	100.00%			

Source: Data rerived from Tziolas and Bournaris (2019)

Table 1: Existent RCM production plan and relevant data.

depicts the figures of the three main objectives of the mathematical model for every crop. Tree crops pay the most significant amounts of gross margin (up to 6,006.32 €/ha for cherry trees), though there are area restrictions, based on the climatic conditions for each regional district, with low potential to the arboriculture's percentage fluctuation in the model. The two energy crops in the production plan (sunflower and rapeseed) are not cultivated in a large scale but generate high amounts of energy as expected, with 74,585.98 MJ/ha and 42,174.78 MJ/ha respectively. The biomass energy for the rest of the crops refers to the exploitation of agricultural residues. The large amounts of cobs and stalks from maize significantly increase the outcome of biomass energy by 22,162.80 MJ/ha. The final objective involves the on-farm emissions and it is depicted in kg of CO_2 equivalents per hectare. Rice emits the highest amounts of GHGs (8,954.48 kg CO_2 eq/ha), whilst hard and soft wheat produce only 1,512.68 kg CO_2 eq/ha. All the pertinent datasets have been derived from Tziolas & Bournaris (2019).

Scenario analysis

Multi-criteria mathematical programming is basically an extension of the mathematical programming theory and the gist of it is that there are multiple objective functions to optimize (Ehrgott, 2005). The main difference between the solution of mathematical programming problems with one goal or with multiple goals lies in the concept of the optimal solution. Solving a problem of multicriteria mathematical programming focuses on finding a compromise solution rather than the optimal one, since the latter does not exist. In this context, a surrogate utility function is calculated, integrating the three objective functions. The formulation of the surrogate utility function assigns different amounts of weights to each goal, according to the exposition of each scenario (Table 2).

The first scenario (SC1) is detached from any kind of bias, regarding allocation of weights to the goals. It is a scenario that integrates in equal terms all three objective functions. Scenario 2 (SC2) allocates weights to the goals, based on a broader research in all the sub-districts of the RCM. More specifically, 147 interviews were conducted, as described in the methodology section seeking farmers' preferences among the main objectives of the model, namely income, biomass exploitation and environmental impacts of farming practices. Farmers were asked which one of the three objectives was the major from their point of view and a set of weights from each goal was elicited. The third scenario (SC3) has its basis in weighted goal programming and is suitable for the analysis and simulation of agricultural systems (Amador et al., 1997; Bournaris et al., 2015; Manos et al., 2006; Sumpsi et al., 1997; Tziolas et al., 2017). Each one of the described scenarios will export a different production plan, based on the preferences introduced. The production plans integrate simultaneously all the given goals, with the same constraints, while allocating the crop mix differently. In order to determine the most efficient scenario, the Eco-Efficiency indicator was calculated (EE) (Bidwell and Verfaillie, 2000).

Eco-Efficiency relies on a simple ratio between economic outputs and emissions to highlight a key-aspect between economic and environmental sustainability for farm systems (Masuda, 2016b). Efficiency in farm-scale is usually measured with Data Envelopment Analysis (DEA) (B Manos and Psychoudakis, 1997; Nastis et al., 2012; Vlontzos et al., 2014), whilst DEA is also implemented with LCA datasets (Iribarren et al., 2010; Rebolledo-Leiva et al., 2017; Vázquez-Rowe et al., 2012). The huge disadvantage related to DEA efficiency is based on the high data requirements, while DEA can be implemented to assess separate farming practices (Nastis et al., 2012) or a group of regional aspects (Masuda, 2016a) and not whole regions. In this context, the authors employ Eco-Efficiency as an indicator for each scenario z which is presented below according to Masuda (2016b):

$$EE_z = \frac{TGM_z}{TGWP_z}$$

Where TGM_z is the total gross margin achieved and $TGWP_z$ is the total emissions from farming

	SC1	SC2	SC3
Weights	Equal	Farmers' preferences	Percentage deviational variables
Methodological approach	-	Interview based	Weighted goal programming
Normalization	✓	✓	✓

Source: Authors' elaboration

Table 2: Scenario aspects and approaches.

practices depicted in CO_2 equivalents from each scenario z. In this manner, EE_z is used as a managerial tool for the selection of the most efficient scenario in the study area.

Results and discussion

Pay-off matrix

The solution to each separate linear programming problem has exported three production plans and the Pay-off matrix is basically the depiction of these results. The Pay-off matrix essentially includes all the best values achieved for the goals' set (Table 3). The first column depicts the three main objectives (maximization of gross margin – GM, maximization of energy - EN, minimization of impacts – GWP), while the last column (real values) depicts the existing plan's results for each one of them. The rest of the columns represent the optimum results when linear programming is implemented for each objective. The results illustrate interesting extensions, since the three linear programming models achieve the defined objectives, but do not manage to achieve all three objectives at the same time.

The next step is to determine the weights for each scenario and assign them to the relevant goals.

Weight determination

The weights integrated in the model are illustrated in Table 4. SC1 is a scenario where all the weights are equally distributed, thus there is not any kind of moderation to the direction of the production plan. The SC2 is based on the broader research in the RCM. Questionnaires were distributed to farmers in each regional unit of the RCM in order to identify and document all the relevant inputs and outputs of agricultural practices in an LCA perspective (Tziolas and Bournaris, 2019). Apart from the primary findings, farmers' preferences were investigated, asking them to put a weight on each objective. From the results, it is obvious that the main goal of farmers in the region is maximization of income (69.4%). However, a significant percentage is allocated to the minimization of GWP and environmental protection consequently, which highlights the raising awareness regarding the mitigation of climate change impacts in agriculture.

Regarding SC3, the weighted goal programming model, which was based on percentage deviational variables, depicts the maximization of gross margin as the main objective (43%) once more, while sustainable development and the reduction of air pollutants generated by agricultural practices play an important, but secondary role. Optimization of biomass energy is an innovative goal that could be omitted for the other two scenarios, but it is less than a quarter of the weight preference (22.5%) for SC3. The analytical procedure for the weighted goal programming model is thoroughly described by Gómez-Limón and Berbel (2000).

Utility function

From the determination of weights, the utility function, which is essentially the unified form of the three objectives simultaneously, takes the form of one objective function for each scenario. The utility function should be integrated into the MCDM model, but the coefficients should be normalized first, since objectives are expressed in different units. In order to normalize weights, there is a need to find the difference between the ideal and the non-ideal value for each goal (Sumpsi et al., 1997). Each variation for the separate goals is divided by the corresponding weight given

Values	Optimum			Real values
	GM	EN	GWP	
GM (€)	544.773.004	502.313.301	484.342.000	514.351.918
EN (MJ)	6.889.808.721	7.684.419.705	6.778.164.351	7.029.814.718
GWP (kg CO_2 eq.)	1.356.666.577	1.274.523.714	1.002.569.986	1.463.794.051

Source: Authors´elaboration

Table 3: Pay-off matrix.

	GM	EN	GWP
SC1	-	-	-
SC2	69.4%	9.4%	21.2%
SC3	43.0%	22.5%	34.5%

Source: Authors´elaboration

Table 4: Scenario set of weights.

for the objective function. Thus, three different utility functions are formed as follows:

$U_{SC1} = 1.65 \times 10^{-8}\ GM + 1.10 \times 10^{-9}\ EN - 2.82 \times 10^{-9}\ GWP$

$U_{SC2} = 1.15 \times 10^{-8}\ GM + 1.04 \times 10^{-8}\ EN - 5.98 \times 10^{-10}\ GWP$

$U_{SC3} = 7.09 \times 10^{-9}\ GM + 2.47 \times 10^{-10}\ EN - 9.74 \times 10^{-10}\ GWP$

In this context, the depicted utility functions will be optimized under the same constraints, in order to elicit three optimal production plans for the region in discuss.

MCDM production plan

The output of each scenario develops different production plans, allocating inputs and cropland based on the set weights for every objective. Apart from the scenario outputs, Table 5 depicts the existing production plan as well. SC2 has a greater impact on inputs, especially for fertilizers (-10.84%) and agrochemicals (3.36%), though it is the only scenario that did not achieve all the objectives simultaneously, since biomass energy generation is reduced by 2.03%. On the other hand, SC1 and SC3 share a more rationalized perspective for the reorganization of agricultural production in the area, by achieving all the objectives simultaneously. The price to pay for this, is the little to none decrease of inputs. Figure 2 illustrates the percentage deviation of the output of the scenarios compared to the existing production plan.

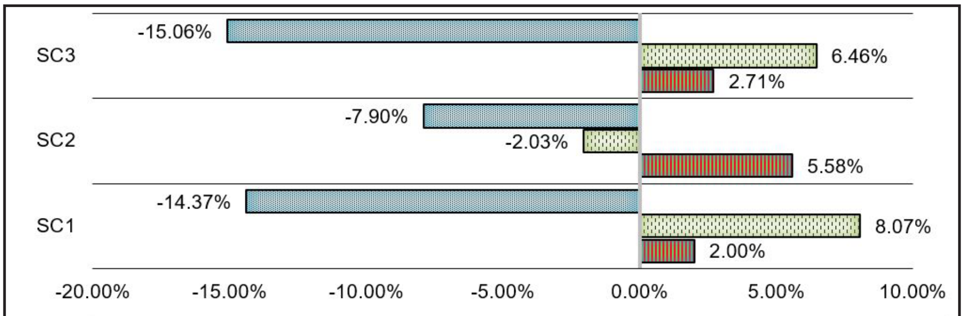
Under the current agricultural policies of the EU, a significant amount of greenhouse gas emissions could be mitigated if the relevant inputs were efficiently allocated. The fluctuation of the GWP indicator could reach a decrease between 7.90% and 15.06% depending on the selected scenario. The production plans of the scenarios have similarities in crop composition; hence, a main directive could be developed. The model proposes the augmentation of cultivated tree crops (+10% for cherry trees, peach trees and olive trees), energy crops (+30% for sunflower and rapeseed), hard wheat (+30%) and alfalfa (+10%) for all the scenarios. In this context, the expansion of arboriculture and energy crops could be the cornerstone for the RCM, to achieve a small step towards sustainable agricultural production.

Regarding annual crops, the crop plan is diversified significantly, based on the selected scenario. SC3

	Existing plan	SC1		SC2		SC3	
		Mod. Values	% deviation	Mod. Values	% deviation	Mod. Values	% deviation
GM (€)	5.10E+08	5.20E+08	2.00%	5.40E+08	5.58%	5.30E+08	2.71%
EN (MJ)	7.00E+09	7.60E+09	8.07%	6.90E+09	-2.03%	7.50E+09	6.46%
GWP (kg CO_2 eq)	1.50E+09	1.30E+09	-14.37%	1.40E+09	-7.90%	1.20E+09	-15.06%
Costs (€)	8.10E+08	8.00E+08	-0.57%	7.80E+08	-2.71%	8.00E+08	-1.32%
Labour (h)	4.00E+07	4.00E+07	0.00%	4.00E+07	0.00%	4.00E+07	0.00%
Diesel (l)	6.10E+07	6.10E+07	0.00%	6.00E+07	-1.27%	6.10E+07	0.00%
Agrochemicals (kg)	2.80E+06	2.80E+06	0.00%	2.70E+06	-3.36%	2.80E+06	0.00%
Fertilizers (kg)	1.20E+08	1.20E+08	-0.33%	1.10E+08	-10.84%	1.20E+08	-1.54%
Soft Wheat	57 431.60	49 954.50	-13.02%	0.0	-100.00%	52 912.10	-7.87%
Hard Wheat	128 159.20	166 606.70	30.00%	166 606.70	30.00%	166 606.70	30.00%
Barley	29 700.10	1 140.10	-96.16%	32 670.00	10.00%	11 585.40	-60.99%
Maize	35 019.70	42 024.00	20.00%	0.0	-100.00%	28 958.80	-17.31%
Rice	27 508.60	0.0	-100.00%	30 259.90	10.00%	0.0	-100.00%
Tobacco	6 834.10	0.0	-100.00%	3 923.10	-42.60%	0.0	-100.00%
Cotton	56 243.30	56 423.50	0.32%	62 691.60	11.47%	62 691.60	11.47%
Sunflower	22 515.60	29 270.80	30.00%	29 270.80	30.00%	29 270.80	30.00%
Rapeseed	6 049.70	7 865.00	30.00%	7 865.00	30.00%	7 865.00	30.00%
Alfalfa	23 793.10	26 172.30	10.00%	26 172.30	10.00%	26 172.30	10.00%
Peach trees	34 208.20	37 628.80	10.00%	37 628.80	10.00%	37 628.80	10.00%
Cherry trees	11 866.30	13 052.60	10.00%	13 052.60	10.00%	13 052.60	10.00%
Olive trees	40 253.30	44 278.30	10.00%	44 278.30	10.00%	44 278.30	10.00%
Set aside	46 398.30	51 564.60	11.13%	71 562.00	54.23%	44 958.70	-3.10%

Source: Authors´elaboration

Table 5: Model validation for the three scenarios.



	SC1	SC2	SC3
GWP	-14.37%	-7.90%	-15.06%
EN	8.07%	-2.03%	6.46%
GM	2.00%	5.58%	2.71%

Source: Authors´elaboration

Figure 2: Percentage deviation of the three scenarios' outputs.

is the only scenario which depicts a decrease in set aside areas (-3.10%), whilst SC1 and mainly SC2 present a significant raise. Cotton cultivation is encouraged by all scenarios, significantly by SC2 and SC3 (+11.47%), but to a lower extent by SC1 (+0.32%). Finally, barley cultivation is almost excluded in SC1 (-96.16%), while in SC2 it is increased by 10% and in SC3 by 60.99%. Finally, the only viable production plan that integrates tobacco cultivation is SC2, but requires a significant reduction in covered areas (-42.60%). It appears that tobacco and rice could be substituted by cotton and hard wheat, in order to adapt the production plan to the relevant constraints and objectives.

Eco-Efficiency indicator

Although farmers, policy makers and stakeholders may have different interests regarding the organization of agricultural production, weight allocation to specific goals develops an integrated approach. Therefore, to identify the optimal production plan for the area of interest, an eco-efficiency aspect of every scenario is presented. Eco-efficiency as an indicator of sustainable farm planning and it is based on the two aspects that were identified as the most important for farmers. Income is the one and emissions from agricultural practices in the field is the other. The eco-efficiency ratio is depicted in Table 6 for each of the scenarios analyzed.

SC1	SC2	SC3
0.4186	0.4016	0.4249

Source: Authors´elaboration

Table 6: Eco-efficiency ratio (€/kg CO_2 eq).

The results for the eco-efficiency ratio are quite similar among the three scenarios. SC2 is the most underachieving scenario, as it was in absolute numbers. It is obvious that the scenario based on the questionnaire answers from farmers is unbalanced resulting in the least efficient production plan. Thus, stakeholders and policy makers should be integrated to the decision-making process. The second most efficient scenario is SC1, while SC3, which allocates weights based on a weighted goal programming model, is the most efficient of all, achieving a ratio of 0.4249.

Discussion

In this paper, potential changes in agricultural production of the RCM are investigated, with the implementation of an MCDM model that allocates weights on three different objectives. The configured model is based on a linear programming rationale and these methodological frameworks feature a considerable amount of limitations (Viaggi et al., 2009). The objective of energy maximization, especially from agricultural residues, could be received as arbitrary, since the infrastructure for the incorporation of all residues in the area is limited. On top of that, risk and uncertainty of agricultural production are not considered in the model, similarly to Gómez-Limón et al. (2004) and Bournaris and Manos (2012), which are significant aspects of agricultural production. This is one of the major problems when large areas of land are considered, since each area faces different challenges. Therefore, the choice of the current methodological framework integrating multiple criteria in several agricultural systems is deliberate. It has been implemented several times to assess water directives (Bartolini et al., 2007; José A. Gómez-Limón et al., 2002), CAP policies (Basil Manos et al., 2011) and potential energy from agricultural residues (Tziolas et al., 2017) on farming systems.

Furthermore, the weight distribution of SC2 relies on the responses of farmers who implement conventional agricultural practices. Although most of the farmers in Northern Greece follow these types of practices, the weight percentages could develop a completely different strategy of crop production if other types (e.g. organic farming, reduced tillage) were included in the data sample. Regarding the set objectives, gross margin remains the main goal of farmers as demonstrated in other relevant studies (Manos et al., 2006; Tziolas et al., 2017). Environmental impacts in other studies could be illustrated as fertilizer application or water usage on the field (Bournaris et al., 2014), though the farmers' income remains the most relevant objective.

Farmers in the EU are highly dependent on subsidies (Falcone et al., 2016; Tziolas & Bournaris, 2019), thus the combination of LCA and MCDM could develop a solid policy framework, integrating economic and environmental impacts in order to find a compromise between the two aspects. The extension of tree crops is of utmost importance for the area, as suggested through the MCDM. The subsidiary framework could further focus on the costs for the establishment of tree crops, in order to promote their extension, though the budget proposal for the CAP after 2020 will decrease (European Commission, 2018a), leaving small to no hope for the investment provisions.

Conclusion

The main aim of this research is the identification of optimal agricultural production in the RCM, based on economic, environmental and energy generation parameters. Financing of the newest CAP will engage a more environmental friendly profile, contributing to climate change mitigation and to sustainable energy production (European Commission, 2018b). Based on the latest directives, farmers will be rewarded for undertaking commitments that go beyond the mandatory agri-environmental and/or climate policy requirements. This entails the major motivational aspect of farmers' preferences, which is maximization of gross margin in conjunction with environmental preservation. Therefore, the authors propose the extension of energy crops in the RCM, along with a decrease of tobacco and rice cultivation, based on the three main objectives of the MCDM. Annual crops of the production plan in the RCM, such as soft wheat, cotton, barley and maize should be handled differently, based on the outcome of each scenario.

The scenarios are designed to tackle regional economic and environmental problems, since local conditions may vary between different areas in the EU. Following the proposed new architecture of the CAP and the increased flexibility of eco-schemes, policy makers are considering regional needs to a higher degree. Future research should incorporate more environmental indicators (e.g., acidification, non-renewable energy etc.), though as stated by Falcone et al. (2016) the perspective of potential stakeholders should be taken into account, as well as regional characteristics. Finally, mid-point indicators (e.g. ionizing radiation, toxicity, etc.) could develop unified end-point indicators (e.g. human health, biodiversity, etc.), which could illustrate and draw conclusions on the social extension of agricultural production.

Corresponding authors
Emmanouil Tziolas, Research Associate
Department of Marine Fisheries, Fisheries Research Institute (FRI)
Hellenic Agricultural Organization "DIMITRA", Greece
64007 Nea Peramos, Kavála, Greece
Phone: +30 6955 998556, E-mail: tziolasm@inale.gr

References

[1] Amador, F., Sumpsi, J. M.and Romero, C. (1997) "A non-interactive methodology to assess farmers ' utility functions: An application to large farms in Andalusia , Spain", *European Review of Agricultural Economics*, Vol. 25, No. 1, pp. 92-102. E-ISSN 1464-3618, ISSN 0165-1587. DOI 10.1093/erae/25.1.92.

[2] Bakos, G. C., Tsioliaridou, E. and Potolias, C. (2008) "Technoeconomic assessment and strategic analysis of heat and power co-generation (CHP) from biomass in Greece", *Biomass and Bioenergy*, Vol. 32, No. 6, pp. 558-567. ISSN 0961-9534. DOI 10.1016/j.biombioe.2007.11.014.

[3] Baležentiene, L. and Užupis, A. (2012) "Multi-criteria optimization for mitigation model of greenhouse gas emissions from abandoned grassland", *Journal of Food, Agriculture and Environment*, Vol. 10, No. 1, pp. 859-865. ISSN 1459-0263.

[4] Bartolini, F., Bazzani, G. M., Gallerani, V., Raggi, M. and Viaggi, D. (2007) "The impact of water and agriculture policy scenarios on irrigated farming systems in Italy: An analysis based on farm level multi-attribute linear programming models", *Agricultural Systems*, No. 93, No. 1-3, pp. 90-114. ISSN 0308-521X. DOI 10.1016/j.agsy.2006.04.006.

[5] Batáry, P., Dicks, L. V., Kleijn, D. and Sutherland, W. J. (2015) "The role of agri-environment schemes in conservation and environmental management", *Conservation Biology*. E-ISSN 1523-1739. DOI 10.1111/cobi.12536.

[6] Biesbroek, G. R., Swart, R. J., Carter, T. R., Cowan, C., Henrichs, T., Mela, H., Morecroft, M. D. and Rey, D. (2010) "Europe adapts to climate change: Comparing National Adaptation Strategies", *Global Environmental Change,* Vol. 20, No. 3, pp. 440-450. ISSN 0959-3780. DOI 10.1016/j.gloenvcha.2010.03.005.

[7] Bournaris, T. and Manos, B. (2012) "European Union agricultural policy scenarios' impacts on social sustainability of agricultural holdings", *International Journal of Sustainable Development and World Ecology*, Vol. 19, No. 5, pp. 426-432. ISSN 13504509. DOI 10.1080/13504509.2012.670670.

[8] Bournaris, T., Moulogianni, C. and Manos, B. (2014) "A multicriteria model for the assessment of rural development plans in Greece", *Land Use Policy,* Vol. 38, No. 1-8. ISSN 0264-8377. DOI 10.1016/j.landusepol.2013.10.008.

[9] Bournaris, T., Papathanasiou, J., Manos, B., Kazakis, N. and Voudouris, K. (2015) "Support of irrigation water use and eco-friendly decision process in agricultural production planning", *Operational Research*, Vol. 15, No. 2, pp. 289-306. E-ISSN 1866-1505. DOI 10.1007/s12351-015-0178-9.

[10] Carvalheiro, L. G., Kunin, W. E., Keil, P., Aguirre-Gutiérrez, J., Ellis, W. N., Fox, R., Groom, Q., Hennekens, S., Van Landuyt, W., Maes, D., Van de Meutter, F., Michez, D., Rasmont, P., Ode, B., Potts, S. G., Reemer, M., Roberts, S. P. M., Schaminée, J., Wallisdevries, M. F. and Biesmeijer, J. C. (2013) "Species richness declines and biotic homogenisation have slowed down for NW-European pollinators and plants", *Ecology Letters*, Vol. No. 7, pp. 870-878. E-ISSN 1461-0248. DOI 10.1111/ele.12121.

[11] Cortignani, R.and Dono, G. (2019) "CAP's environmental policy and land use in arable farms: An impacts assessment of greening practices changes in Italy", *Science of the Total Environment*, Vol. 647, pp. 516-524. ISSN 0048-9697. DOI 10.1016/j.scitotenv.2018.07.443.

[12] De Luca, A. I., Iofrida, N., Leskinen, P., Stillitano, T., Falcone, G., Strano, A. and Gulisano, G. (2017) "Life cycle tools combined with multi-criteria and participatory methods for agricultural sustainability: Insights from a systematic and critical review", *Science of the Total Environment.* Vol. 595, pp. 352-370. ISSN 0048-9697. DOI 10.1016/j.scitotenv.2017.03.284.

[13] Ehrgott, M. (2005) "*Multicriteria optimization*", 2nd ed., 323 p. ISBN 978-3-540-27659-3. DOI 10.1007/3-540-27659-9.

[14] Ekvall, T. and Finnveden, G. (2001) "Allocation in ISO 14041 - a critical review", *Journal of Cleaner Production*, Vol. 9, No. 3, pp. 197-208. ISSN 0959-6526. DOI 10.1016/S0959-6526(00)00052-4.

[15] EU (2018) "Renewable energy directive (EU) 2018/2001", Official Journal of the European Union.

[16] European Commission (2009) "*White paper - Adapting to climate change: towards a European framework for action*, COM(2009) 147 final. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52009DC0147 [Accessed Feb 10, 2022].

[17] European Commission (2018a) "*Modernising and simplifying the Common Agricultural Policy"*, Consultations. [Online]. Available: https://ec.europa.eu/info/consultations/modernising-and-simplifying-common-agricultural-policy_en [Accessed Feb 10, 2022].

[18] European Commission (2018b) "*Proposal for a Regulation of the European Parliament and of the Council on the financing, management and monitoring of the common agricultural policy and repealing Regulation (EU) No. 1306/2013*", COM(2018) 393 final. [Online]. Available: https://eur-lex.europa.eu/resource.html?uri=cellar:6cb59a1e-6580-11e8-ab9c-01aa75ed71a1.0003.03/DOC_1&format=PDF [Accessed Feb 10, 2022].

[19] European Commission (2021) "Political agreement on new Common Agricultural Policy: fairer, greener, more flexible". [Online]. Available: https://ec.europa.eu/commission/presscorner/detail/en/IP_21_2711 [Accessed March 25, 2022].

[20] EU (2013) "*Regulation EU No. 1305/2013 of the European Parliament and of the Council*", 17th Dec. 2013, Official Journal of the European Union. [Online]. Available: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:347:0487:0548:en:PDF [Accessed March 25, 2022].

[21] European Union and Directorate-General for Research and Innovation. (2018) "A sustainable bioeconomy for Europe: strengthening the connection between economy, society and the environment", Publications Office. DOI 10.2777/478385.

[22] Falcone, G., De Luca, A. I., Stillitano, T., Strano, A., Romeo, G. and Gulisano, G. (2016) "Assessment of environmental and economic impacts of vine-growing combining life cycle assessment, life cycle costing and multicriterial analysis", *Sustainability*, Vol. 8, No. 8. ISSN 20711050. DOI 10.3390/su8080793.

[23] Fischer, J., Meacham, M. and Queiroz, C. (2017) "A plea for multifunctional landscapes", *Frontiers in Ecology and the Environment*. Vol. 15, No. 2, pp. 59-59. E- ISSN 1540-9309. DOI 10.1002/fee.1464.

[24] Foster, C., Green, K., Bleda, M., Dewick, P., Evans, B., Flynn.and Mylan, J. (2006) "Environmental impacts of food production and consumption: A report to the Department for Environment Food and Rural Affairs", London, Manchester Business School, Defra(December), 199.

[25] Frayssignes, J. (2011) "The concept of “agro-energy district”: apertinent tool for the susta inable development of rural areas", *51st Congress of the European Regional Science Association*, Barcelona, 30th August - 3rd September 2011. [Online]. Available: http://www-sre.wu.ac.at/ersa/ersaconfs/ersa11/e110830aFinal00318.pdf [Accessed March 15, 2022].

[26] Freibauer, A., Rounsevell, M. D. A., Smith, P. and Verhagen, J. (2004) "Carbon sequestration in the agricultural soils of Europe", Geoderma, Vol. 122, No. 1, pp. 1-23. ISSN 0016-7061. DOI 10.1016/j.geoderma.2004.01.021.

[27] Gómez-Limón, J. A. and Berbel, J. (2000) "Multicriteria analysis of derived water demand functions: A Spanish case study", *Agricultural Systems*, Vol. 63, No. 1, pp. 49-72. ISSN 0308-521X. DOI 10.1016/S0308-521X(99)00075-X.

[28] Gómez-Limón, J. A., Arriaza, M. and Berbel, J. (2002) "Conflicting Implementation of Agricultural and Water Policies in Irrigated Areas in the EU", *Journal of Agricultural Economics,* Vol. 53, No. 2, pp. 259-281. E-ISSN 1477-9552. DOI 10.1111/j.1477-9552.2002.tb00020.x.

[29] Gómez-Limón, J. A., Riesgo, L. and Arriaza, M. (2004) "Multi-criteria analysis of input use in agriculture", *Journal of Agricultural Economics*, Vol. 55, No. 3, pp. 541 - 564. E-ISSN 1477-9552. DOI 10.1111/j.1477-9552.2004.tb00114.x.

[30] Iribarren, D., Vázquez-Rowe, I., Moreira, M. T. and Feijoo, G. (2010) "Further potentials in the joint implementation of life cycle assessment and data envelopment analysis", *Science of the Total Environment*, Vol. 408, No. 22, pp. 5265-5272. DOI 10.1016/j.scitotenv.2010.07.078.

[31] Macrì, G., Delfanti, L. M. P., Tolli, M., Monarca, D., Proto, A. R. and Colantoni, A. (2016) "PPP Preliminary Analysis for an Agro-energy District Feasibility: TusciaRomana Area’s Case of Study", *Procedia - Social and Behavioral Sciences*, Vol. 223, pp. 791-798. ISSN 1877-0428. DOI 10.1016/j.sbspro.2016.05.271.

[32] Mandryk, M., Reidsma, P. and van Ittersum, M. K. (2017) "Crop and farm level adaptation under future climate challenges: An exploratory study considering multiple objectives for Flevoland, the Netherlands", *Agricultural Systems*, Vol. 152, pp. 154-164. ISSN 0308-521X. DOI 10.1016/j.agsy.2016.12.016.

[33] Manos, B. D., Papathanasiou, J., Bournaris, T. and Voudouris, K. (2010) "A DSS for sustainable development and environmental protection of agricultural regions", *Environmental Monitoring and Assessment*, Vol. 164, pp. 43-52. E-ISSN 1573-2959, ISSN 0167-6369. DOI 10.1007/s10661-009-0873-1.

[34] Manos, B., Papathanasiou, J., Bournaris, T. and Voudouris, K. (2010) "A multicriteria model for planning agricultural regions within a context of groundwater rational management", *Journal of Environmental Management*, Vol. 91, No. 7, pp. 1593-1600. ISSN 0301-4797. DOI 10.1016/j.jenvman.2010.03.002.

[35] Manos, B. and Psychoudakis, A. (1997) "Investigation of the relative efficiency of dairy farms using data envelopment analysis", *Quarterly Journal of International Agriculture*, Vol. 36, No. 2, pp. 188-197. ISSN 0049-8599. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-0031437846&partnerID=40&md5=6286b03f456680cddb65b72effd594aa [Accessed March 20, 2022].

[36] Manos, B., Bournaris, T. and Chatzinikolaou, P. (2011) "Impact assessment of CAP policies on social sustainability in rural areas: An application in Northern Greece", *Operational Research*, vol. 11, No. 1, pp. 77-92. ISSN 1866-1505. DOI 10.1007/s12351-010-0078-y.

[37] Manos, B., Bournaris, T., Kamruzzaman, M., Begum, M., Anjuman, A. and Papathanasiou, J. (2006) "Regional impact of irrigation water pricing in Greece under alternative scenarios of European policy: A multicriteria analysis", *Regional Studies*, Vol. 40, No. 9, pp. 1055-1068. ISSN 00343404. DOI 10.1080/00343400600928335.

[38] Manzano-Agugliaro, F. (2007) "Gasification of greenhouse residues for obtaining electrical energy in the south of Spain: Localization by GIS", *Interciencia*, Vol. 32, No. 2, pp. 131-136. ISSN 0378-1844.

[39] Masuda, K. (2016a) "Measuring eco-efficiency of wheat production in Japan: A combined application of life cycle assessment and data envelopment analysis", *Journal of Cleaner Production*, Vol. 126, pp. 373-381. ISSN 0959-6526. DOI 10.1016/j.jclepro.2016.03.090.

[40] Masuda, K. (2016b) "Optimization model for mitigating global warming at the farm scale: An application to Japanese rice farms", *Sustainability* (Switzerland), Vol. 8, No. 7. E-ISSN 2071-1050. DOI 10.3390/su8070593.

[41] Meredith, S. and Hart, K. (2019) "CAP 2021-27: Using the eco-scheme to maximise environmental and climate benefits", report for IFOAM EU by IEEP. [Online]. Available: https://ieep.eu/uploads/articles/attachments/4791a221-8525-4410-848f-8fb84f5a621a/IFOAM%20EU_Eco-scheme_Report_Final.pdf?v=63718564537 [Accessed Feb. 8, 2022].

[42] Moulogianni, C. and Bournaris, T. (2017) "Biomass Production from Crops Residues: Ranking of Agro-Energy Regions", *Energies*, Vol. 10, No. 7. E-ISSN 1996-1073. DOI 10.3390/en10071061.

[43] Mueller, N. D., Gerber, J. S., Johnston, M., Ray, D. K., Ramankutty, N. and Foley, J. A. (2012) "Closing yield gaps through nutrient and water management", *Nature*, Vol. 490, pp. 254-257. E-ISSN 1476-4687, ISSN 0028-0836. DOI 10.1038/nature11420.

[44] Nakashima, T. (2010) "Life cycle assessment integrated into positive mathematical programming: A conceptual model for analyzing area-based farming policy.", *Japan Agricultural Research Quarterly*, Vol. 44, No. 3, pp. 301-310. E-ISSN 2185-8896, ISSN 0021-3551. DOI 10.6090/jarq.44.301.

[45] Nastis, S. A., Papanagiotou, E. and Zamanidis, S. (2012) "Productive efficiency of subsidized organic alfalfa farms", *Journal of Agricultural and Resource Economics*, Vol. 37, No. 2, pp. 280-288. ISSN 1068 5502.

[46] Nishiguchi, S. and Tabata, T. (2016) "Assessment of social, economic, and environmental aspects of woody biomass energy utilization: Direct burning and wood pellets", *Renewable and Sustainable Energy Reviews*, Vol. 57, pp. 1279-1286. ISSN 1364-032. DOI 10.1016/j.rser.2015.12.213.

[47] Nunes, J. M. R., Bonito, A., Loures, L., Gama, J., López-Piñeiro, A., Peña, D.and Albarrán, Á. (2017) "Effects of the European Union Agricultural and Environmental Policies in the Sustainability of Most Common Mediterranean Soils, *Sustainability,* Vol. 9, No. 8. E-ISSN 2071-1050. DOI 10.3390/su9081404.

[48] Rebolledo-Leiva, R., Angulo-Meza, L., Iriarte, A.and González-Araya, M. C. (2017) "Joint carbon footprint assessment and data envelopment analysis for the reduction of greenhouse gas emissions in agriculture production", *Science of the Total Environment*, Vol. 593-594, pp. 36-46. ISSN 0048-9697. DOI 10.1016/j.scitotenv.2017.03.147.

[49] Rincon, L., Puri, M., Kojakovic, A. and Maltsoglou, I. (2019) "The contribution of sustainable bioenergy to renewable electricity generation in Turkey: Evidence based policy from an integrated energy and agriculture approach", *Energy Policy*, Vol. 130, pp. 69-88. ISSN 0301-4215. DOI 10.1016/j.enpol.2019.03.024.

[50] Ronzon, T. and Piotrowski, S. (2017) "Are Primary Agricultural Residues Promising Feedstock for the European Bioeconomy?", *Industrial Biotechnology*, Vol. 13, No. 3, pp. 113-127. E-ISSN 1931-8421, ISSN 1550-9087. DOI 10.1089/ind.2017.29078.tro.

[51] Roy, P., Nei, D., Orikasa, T., Xu, Q., Okadome, H., Nakamura, N. and Shiina, T. (2009) "A review of life cycle assessment (LCA) on some food products", *Journal of Food Engineering*, Vol. 90, No. 1, pp. 1-10. ISSN 0260-8774. DOI 10.1016/J.JFOODENG.2008.06.016.

[52] Schmidt, J. and Hauck, J. (2018) "Implementing green infrastructure policy in agricultural landscapes - scenarios for Saxony-Anhalt, Germany", *Regional Environmental Change*, Vol. 18, pp. 899-911. E-ISSN 1436-378X, ISSN 1436-3798. DOI 10.1007/s10113-017-1241-2.

[53] Science for Environment Policy (2017) "Agri-environmental schemes: how to enhance the agriculture-environment relationship, Thematic Issue 57", Issue produced for the European Commission DG Environment by the Science Communication Unit, UWE, Bristol. [Online]. Available: https://ec.europa.eu/environment/integration/research/newsalert/pdf/AES_impacts_on_agricultural_environment_57si_en.pdf [Accessed: Feb. 16, 2022].

[54] Seyedmohammadi, J., Sarmadian, F., Jafarzadeh, A. A., Ghorbani, M. A. and Shahbazi, F. (2018) "Application of SAW, TOPSIS and fuzzy TOPSIS models in cultivation priority planning for maize, rapeseed and soybean crops", *Geoderma*, Vol. 310, pp. 178-190. ISSN 0016-7061. DOI 10.1016/j.geoderma.2017.09.012.

[55] Sumpsi, J. M., Amador, F. and Romero, C. (1997) "On farmers' objectives: A multi-criteria approach", *European Journal of Operational Research,* Vol. 96, No. 1, pp. 64-71. ISSN 0377-2217. DOI 10.1016/0377-2217(95)00338-X.

[56] Tziolas, E, Bournaris, T., Nastis, S. A. and Manos, B. (2018) "Integrated impact assessment of biomass conversion systems with the method of life cycle assessment. A comprehensive review", *International Journal of Sustainable Agricultural Management and Informatics*, Vol. 4, No. 2, pp. 123-150. E-ISSN 2054-5827, ISSN 2054-5819. DOI 10.1504/IJSAMI.2018.094814.

[57] Tziolas, E. and Bournaris, T. (2019) "Economic and Environmental Assessment of Agro-Energy Districts in Northern Greece: a Life Cycle Assessment Approach", *BioEnergy Research*, Vol. 12, pp. 1145-1162. ISSN 1939-1234. DOI 10.1007/s12155-019-10020-x.

[58] Tziolas, E., Bournaris, T., Manos, B. and Nastis, S. (2018) "Life Cycle Assessment and Multi-criteria Analysis in Agriculture: Synergies and Insights", In Berbel, J., Bournaris, T., Manos, B., Matsatsinis, N., Viaggi, D. (eds) *Multicriteria Analysis in Agriculture. Multiple Criteria Decision Making*. Springer, Cham. E-ISBN 978-3-319-76929-5, ISBN 978-3-319-76928-8. DOI 10.1007/978-3-319-76929-5_12.

[59] Tziolas, E., Manos, B. and Bournaris, T. (2017) "Planning of agro-energy districts for optimum farm income and biomass energy from crops residues", *Operational Research*, Vol. 17, No. 2, pp. 535-546. ISSN 11092858. DOI 10.1007/s12351-016-0236-y.

[60] Vázquez-Rowe, I., Villanueva-Rey, P., Iribarren, D., Moreira, T. M. and Feijoo, G. (2012) "Joint life cycle assessment and data envelopment analysis of grape production for vinification in the Rías Baixas appellation (NW Spain)", *Journal of Cleaner Production*, Vol. 27, pp. 92-102. ISSN 0959-6526. DOI 10.1016/j.jclepro.2011.12.039.

[61] Verfaillie, H. A. and Bidwell, R. (2000) "*Measuring ecoefficiency: a guide to reporting company performance*", Coches-Gneva: World Business Council for Sustainable Development, 36 p. ISBN 2-940240-14-0.

[62] Verhagen, W., van der Zanden, E. H., Strauch, M., van Teeffelen, A. J. A. and Verburg, P. H. (2018) "Optimizing the allocation of agri-environment measures to navigate the trade-offs between ecosystem services, biodiversity and agricultural production", *Environmental Science and Policy*, Vol. 84, pp. 186-196. ISSN 1462-9011. DOI 10.1016/j.envsci.2018.03.013.

[63] Viaggi, D., Bartolini, F. and Raggi, M. (2009) "Combining linear programming and principal-agent models: An example from environmental regulation in agriculture", *Environmental Modelling and Software*, Vol. No. 6, pp. 703-710. ISSN 1364-8152. DOI 10.1016/j.envsoft.2008.10.014.

[64] Vlontzos, G., Niavis, S. and Manos, B. (2014) "A DEA approach for estimating the agricultural energy and environmental efficiency of EU countries", *Renewable and Sustainable Energy Reviews*, Vol. 40, pp. 91-96. ISSN 1364-0321. DOI 10.1016/j.rser.2014.07.153.

[65] White, E. M., Latta, G., Alig, R. J., Skog, K. E. and Adams, D. M. (2013) "Biomass production from the U.S. forest and agriculture sectors in support of a renewable electricity standard", *Energy Policy*, Vol. 587, pp. 64-74. ISSN 0301-4215. DOI 10.1016/j.enpol.2013.02.029.

[66] Yue, D., Pandya, S. and You, F. (2016) "Integrating Hybrid Life Cycle Assessment with Multiobjective Optimization: A Modeling Framework", *Environmental Science and Technology*. Vol. 50. No. 3, pp. 1501-1509. ISSN 0013936X. DOI 10.1021/acs.est.5b04279.