Oper Res Int J (2017) 17:535–546
DOI 10.1007/s12351-016-0236-y

ORIGINAL PAPER

Planning of agro-energy districts for optimum farm income and biomass energy from crops residues

Emmanouil Tziolas[1] · Basil Manos[1] · Thomas Bournaris[1]

Received: 11 November 2015 / Revised: 28 January 2016 / Accepted: 15 February 2016 /
Published online: 3 March 2016

Abstract The objectives of the European Union 2014–2020 programming period include increase of energy production from renewable sources through the creation of agro-energy districts. The utilization of residues of annual and perennial crops in agro-energy districts as a combustion product of the exploitation of biomass industry to produce heat and electricity, create a new sustainable environment. This paper focuses on optimizing the agricultural income and the biomass energy potential from crop residues in agricultural districts and especially in a case study in municipality of Almopia in Northern Greece. For this purpose, the optimal plan of agricultural production of the case study area arising from the development of a multi-criteria mathematical programming model that combines more than one conflicting criteria to a utility function that interprets the behavior of farmers and better approaches the rational decision making. The objective of the proposed model is to combine two criteria, namely the maximization of the total gross margin of the case study area and the maximization of electric or thermal power from biomass of crop residues, based on a set of constraints for land, labor, capital, Common Agricultural Policy rules, etc. The optimal production plan of the case study area achieves higher gross margin (3.6 %) and higher level of bioenergy (7.7 %) than the existent production plan. The optimal plan also presents better results than those achieved by the linear programming model when the only goal is to maximize either the gross margin or the production of bioenergy.

Keywords Energy from biomass of crop residues · Farm planning · Multi-criteria model

✉ Basil Manos
manosb@agro.auth.gr

[1] Department of Agricultural Economics, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece

1 Introduction

An enhanced role in residue biomass production is rising and it is tightly connected to rural development (Rosillo-Calle 2003). The challenges for new sustainable forms of energy, independence from highly polluting non-renewable resources (e.g. coal, oil, gas) and abatement of CO_2 emissions are some of the greater targets of the EU environmental policy (EC 2005, 2010). Agro-energy districts could be the cornerstone in the successful accomplishment of these targets in rural areas by generating and distributing electrical and thermal energy, setting the tone for a new era.

In order to achieve coordination and solidarity between the new directives and farmers goals, proper decision making tools have to be applied. Although, decision-making in agriculture is complex, multiple objectives are considered so that many alternatives could lead to many solutions. In many cases, multicriteria mathematical programming was used in farmers' decision making process. Bournaris et al. (2014) used a multicriteria model for the assessment of rural development plans in Greece, while Manos et al. (2013) developed a model for farm households of three southern European countries, Greece, Bulgaria and Spain, for measuring the impact of CAP using different criteria. Valiakos and Siskos (2015) also evaluated agricultural units using multicriteria decision support for eliminating the "Sofa Farmers" phenomenon. On the other hand, Prišenk et al. (2014) used both linear programming (LP) and weighted goal programming (WGP) to optimize processes on farms through the development of the crop planning model. Their model is structured from two sub-models, where the first based on LP and the second on WGP.

This technique is used in the present paper. In pursuance of the golden mean a multi-criteria mathematical programming model is conducted, managing two conflicting goals for maximization of farmers' income and maximization of bioenergy through crops residues exploitation. Our research focuses on the optimization of agricultural income and biomass energy production from crop residues at the district of municipality of Almopia, a rural region in Northern Greece. At first, an analysis of the research is quoted along with the data for different crops. Next, an equation for defining the biomass energy in electrical and thermal power is used, in order to quantify the potential power created from the crop residues. In continuation, a LP model for each goal is applied and then a multi-criteria mathematical programming model that combines the two goals. Through, detailed analysis the final model approach is analyzed thoroughly and useful conclusions are elicited.

2 Study region and data

The municipality of Almopia is located in the prefecture of Pella in the north-west part of the region of Central Macedonia in Greece (Fig. 1). It covers an area of 985.8 km^2 with 27,556 inhabitants. The area is quite fertile, but there is significant altitude disparity, making agricultural production more difficult and unproductive. Mountain Voras creates a natural border with the neighbor country and enfolds a

Fig. 1 Prefecture of Pella

huge stretch of flatland. Furthermore, this field heterogeneity originates a great plant and animal diversity, giving the opportunity to the farmers to cultivate a variety of crops and trees. Only the 19.5 % of the total study area is cultivated.

The population distribution by occupation reveals the importance of the primary sector in our study area. A staggering percentage (45 %) of the active population is working at the agricultural production, making the whole area an agricultural-based region (National Statistical Service of Greece 2011). Therefore, the area is economically dependent on the production of food commodities and other crops.

The region is strongly connected with tree products, especially high quality peaches and cherries, thus creating an uneven comparison between arable crops. According to the existent production plan, 19,269.37 ha are cultivated with dominating cultivations the lucerne (17.2 %), maize (15.5 %), peach trees (17.1 %), cherry trees (11.4 %), soft wheat (9.3 %) and barley (6.6 %) (Table 1). The product of the existent plan in terms of gross margin (GM) amounted to 65.5 million euros, while spent 28.3 million euros of variable capital (Table 3). The labor used is around 4.4 million hours and the fertilizers used are 14.1 million kg (Table 3).

Table 1 Existent production plan

Crops	Cultivated land (ha)	Cultivated land (%)
Lucerne (alfalfa)	3312.1	17.19
Tobacco	30.5	0.16
Soft wheat	1799.4	9.34
Hard wheat	495.0	2.57
Barley	1273.0	6.61
Maize	2998.9	15.56
Potatoes	568.4	2.95
Pear trees	27.1	0.14
Apple trees	117.0	0.61
Apricot trees	96.5	0.50
Peach trees	3285.6	17.05
Cherry trees	2192.6	11.38
Plum trees	257.5	1.34
Walnut trees	71.9	0.37
Chestnut trees	266.0	1.38
Olive trees	154.8	0.80
Set aside with rights	2323.1	12.06
Total	19,269.4	100.00

The data were collected from the Municipal Authority of Almopia, the Union of Agricultural Cooperatives, the Ministry of Agriculture and individual farmers and are referred to the 2013 period. It is noted that the variable cost of each crop includes all variable cost and the labour cost required for each crop. The set aside agricultural land is connected with farmers' rights on specific subsidized crops according to the framework of environmental and agricultural directives targeting at a continuous rest for different fields so that the soil degradation to be avoided.

3 Heat and electricity production through biomass exploitation

One of the main goals for the Horizon 2020—Work Programme 2014–2020 is the creation of competitive bio-based industries (EC 2015). The contribution of a biomass industry based on agricultural residues is illustrated in Southern Europe through many papers (Fantozzi et al. 2014; Manos et al. 2014). In this way, the farmers are incentivized to retain agricultural residues, a new form of bio-energy is generated, agro-energy districts are created, the climate change effects are mitigated and a sustainable economy model is created.

In order to determine the thermal and electrical energy for all the crops, the Lower Heating Values (LHV) were considered (Di Blasi et al. 1997; Greek National Committee for Compating Desertification 2001, Menconi et al. 2015) and biomass factors as well (Jölli and Giljum 2005). With the available information for the rural area of Almopia, the following equations were determined:

Table 2 Thermal and electrical power (MWh) using the available biomass production from crops residues

Crops	Residue type	Biomass production (tonnes)	Electrical energy (MWh)	Thermal energy (MWh)
Lucerne (alfalfa)	Straw	8445.86	7508.03	33,786.12
Tobacco	Stalks	10.07	8.95	40.26
Soft wheat	Straw	3823.73	3399.14	15,296.12
Hard wheat	Straw	673.20	598.45	2693.02
Barley	Straw	2921.54	2759.45	12,417.52
Maize	Stalks and cobs	14,169.80	13,383.66	60,226.48
Potatoes	Stems and leaves	1636.99	1455.22	6548.49
Pear trees	Pruning	32.52	39.75	178.87
Apple trees	Pruning	168.48	205.94	926.71
Apricot trees	Pruning	92.64	113.24	509.56
Peach trees	Pruning	5716.94	6987.93	31,445.71
Cherry trees	Pruning	3288.90	4020.09	18,090.40
Plum trees	Pruning	309.00	377.70	1699.64
Walnut trees	Pruning and shells	94.91	116.01	522.04
Chestnut trees	Pruning and shells	255.36	312.13	1404.59
Olive trees	Pruning	157.90	193.00	868.50
Total		41,797.82	41,478.67	186,654.03

$$\textit{Thermal energy}\,(\text{MWh})\text{: } 0.9 \times \textit{Biomass}(\text{kg}) \times \textit{LHV}(\text{MJ/kg}) \times \textit{Transformation coefficientPresuming that the boiler efficiency is } 90\ \%$$

$$\textit{Electrical energy}\,(\text{MWh})\text{: } 0.2 \times \textit{Biomass}(\text{kg}) \times \textit{LHV}(\text{MJ/kg}) \times \textit{Transformation coefficientPresuming that the boiler efficiency is } 20\ \%$$

The transformation coefficient is interpreted as a mode of designation for conversion the MJ values to MWh (1 MJ = 0.0002778 MWh).

In Table 2 the available thermal and electrical energy production is presented via the use of crops residues for the existent plan of the study region. Clearly, stalks and cobs from maize, lucerne straw and pruning from peach and cherry trees could play an important role in the renewal of the power process and the creation of a sustainable economic and environmental system.

4 Model definition and results

Various optimization multicriteria mathematical programming (MCDA) models have been defined and used in farm planning. We applied in our research the utility MCDM approach, which in comparison with other approaches such as LP, cost benefit analysis, etc. can achieve optimum farm resource allocations (land, labour, capital, water, etc.) optimizing simultaneously several conflicting criteria (e.g. the maximization of GM, the minimization of labour used, the maximization of electrical energy production by crops residues etc.). At the MCDM approach a surrogate utility function is created assisting the decision-making process and clarifying the best solution for the MCDA model (Kienle et al. 2015; Manos et al. 2010, 2013, 2015). In our case the utility function combines the following two goals.

4.1 Maximization of total gross margin

The maximization of total GM, as a good estimator of profit, is defined in the objective function:

$$Max\,GM = \sum GMi \times Xi$$

4.2 Maximization of electrical energy production by crops residues

Furthermore, assuming that a biomass exploitation plant could transform crops residues into energy through combustion, the maximization of Electrical Energy Production (EEP) in MWh is also defined as in the objective function:

$$Max\,EEP = \sum EEPi \times Xi$$

The constraints of the model are referred to:

4.3 CAP production rights

The sum of production rights (PRi) for crops (Xi) according to CAP regulations should be minus-equal to the total PRi of the area (TPR):

$$\sum PRi \times Xi \leq TPR$$

4.4 CAP quotas

The sum of quotas (QPi) for all crops (Xi) according to CAP regulations should be minus-equal to the total quotas of the area (TQP):

$$\sum QPi \times Xi \leq TQP$$

4.5 Land total

The sum of total available land for all crops (Xi) must add up to 100. This constraint is only introduced in order to obtain the outcome of the model (decision variables Xi) as percentages

$$\sum Xi \leq 100.$$

4.6 Land irrigated

The sum of total land (ILi) for irrigated crops (Xi) cannot exceed the total irrigated land of the study area (TIL)

$$\sum ILi \times Xi \quad \sum \leq TIL.$$

4.7 Market constraints

They were defined according to market limitations and on the basis of the maximum historical cultivation during the planning period.

4.8 Available capital

Total variable capital (VC) needed for all crops (Xi) cannot exceed the total available capital (TVC). Variable costs are calculated as the sum of six categories of variable costs: Seeds, Fertilisers, Chemicals, Machinery, Labour, Irrigation water

$$\sum VCi \times Xi \quad \sum \leq TVC.$$

4.9 Total labour

Total labour used (L) for all farming activities (Xi) cannot exceed the total available labour (TLA)

$$\sum Li \times Xi \quad \sum \leq TL.$$

4.10 Total fertilizers

Total fertilizers (F) for all farming activities (Xi) cannot exceed the total fertilizers used by the existent plan (TF)

$$\sum FEi \times Xi \quad \sum \leq TF.$$

The MCDA model was solved by using the Weighting Goal Programming (WGP) technique that is recommended due to its high level of implementation in the decision-making analysis in agriculture (Bournaris et al. 2015; Sumpsi et al. 1997).

Initially, LP was implemented for each individual goal and two different optimal production plans were proposed and their results are presented in Table 3. Clearly, when setting the goal of total GM maximization there is a notable increase in GM (4.6 %) but a similar decrease in electrical power (−4.7 %). On the other hand, if our goal is electrical energy maximization there is very low a decrease in GM (−0.2 %) and a significant increase in electrical power (8.1 %). Presumably, the optimum model solutions have a significant divergence from the existent plan, introducing a developed model even in the early stages, without the extra income

Table 3 Linear programming for gross margin and electrical energy maximization

	Existent plan	Gross margin maximization		Electrical energy maximization	
		Optimum values	% deviation	Optimum values	% deviation
GM (€)	65,554,724	68,541,030	4.6	65,409,921	−0.2
Electrical energy (MWh)	41,479	39,545	−4.7	44,842	8.1
Thermal energy (MWh)	186,654	177,952	−4.7	201,787	8.1
Variable costs (€)	28,311,149	27,281,736	−3.6	27,528,432	−2.8
Labour (h)	4,445,479	4,445,479	0.0	4374,339	−1.6
Fertilizers (kg)	14,058,634	13,556,090	−3.6	14,058,634	0.0

calculation for the farmers from the crops residues exploitation. These two LP models illustrate the controversial character of the two goals and represent the different output of some important aspects.

Apparently, the GM maximization model except the increase on farmers' income, at the same time it saves more fertilizers (−3.6 %) and reduces the variable costs at a similar ratio. At the other end of the spectrum, there is a low decrease in GM for the farmers (−0.2 %), a significant increase in energy production (8.1 %), a decrease in variable costs (−2.8 %) and a decrease in labour hours (−1.6 %). For the purpose of achieving both goals and determine the weight ratio for each of them the MCDM model defined above is used further on.

5 Results of the multicriteria model

According to the WGP methodology a pay-off matrix is created, illustrating the two different goals optimized individually, such in LP (Table 3). In order to result in a set of weights, so that each objective could represent the exact degree of influence, a WGP technique with percentage deviational variables was expressed (Romero 1991). The achieved set of weights allocates to the maximization of GM a very high weight (63.5 %) and for the maximization of electrical energy production a considerable weight (36.5 %). Therefore, the utility function could be described as follows:

$$\mathbf{Uf = 63.5\,\%\,GM + 36.5\,\%\,EEP}$$

GM = GM, *EEP* = *Electrical Energy Production*

The estimated utility function is a predictor of farmers' behavior, thus meaning that GM maximization reflects the real preferences of farmers. Of course, the increase of income is the main concern for the farmers, but the influence of electrical energy production maximization is adequate and significant goal for the study area and the national economy in general. Certainly, a comparison between real values and the values of the MCDM model should be made in order to elicit conclusions.

Table 4 Comparison between observed values and MCDM model in the Municipality of Almopia

	Existent plan	MCDM model	
		Optimum values	% deviation
GM (€)	65,554,724	67,891,613	3.6
Electrical energy (MWh)	41,479	44,672	7.7
Thermal energy (MWh)	186,654	201,027	7.7
Variable costs (€)	28,311,149	27,702,978	−2.1
Labour (h)	4,445,479	4,445,479	0.0
Fertilizers (kg)	14,058,634	14,058,634	0.0
Lucerne (alfalfa)	3312.1	3974.5	20.0
Tobacco	30.5	0.0	−100.0
Soft wheat	1799.4	843.7	−53.1
Hard wheat	495.0	0.0	−100.0
Barley	1273.0	1527.6	20.0
Maize	2998.9	4011.6	33.8
Potatoes	568.4	0.0	−100.0
Pear trees	27.1	27.1	0.0
Apple trees	117.0	117.0	0.0
Apricot trees	96.5	96.5	0.0
Peach trees	3285.6	3285.6	0.0
Cherry trees	2192.6	2424.8	10.6
Plum trees	257.5	257.5	0.0
Walnut trees	71.9	71.9	0.0
Chestnut trees	266.0	319.2	20.0
Olive trees	154.8	154.8	0.0
Set aside with rights	2323.1	2157.6	−7.1
Total (ha)	19,269.4	19,269.4	

The production plan based on the MCDM model (Table 4) creates a better approximation. Therefore, the new methodology approach, utilizing the utility function, achieves 3.6 and 7.7 % higher GM and electrical power production respectively. The MCDM plan suggests a decrease in cultivated hectares for tobacco (−100 %), soft wheat (−53.1 %), hard wheat (−100 %), potatoes (−100 %) and set aside with rights (−7.1 %). It is also recommended that an increase should take place for lucerne (20 %), barley (20 %), maize (33.8 %), cherry trees (10.6 %) and chestnut trees (20 %).

The validation of the MCDM model is obviously the optimum solution for the two main goals. Simultaneously, MCDM generates higher electrical energy production and higher GM for the farmers, achieving at the same time the goals of the individual LP models. In Figs. 2 and 3 the percentage fluctuation of each goal is illustrated and definitely the MCDM model creates the better results. Hence, the LP model when maximizes the electrical energy production achieves higher electrical energy production by 0.4 % than the MCDM model, while there is a

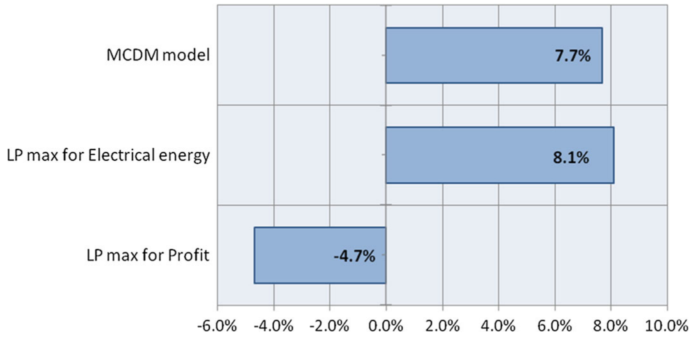

Fig. 2 Electrical energy production deviations in the different models

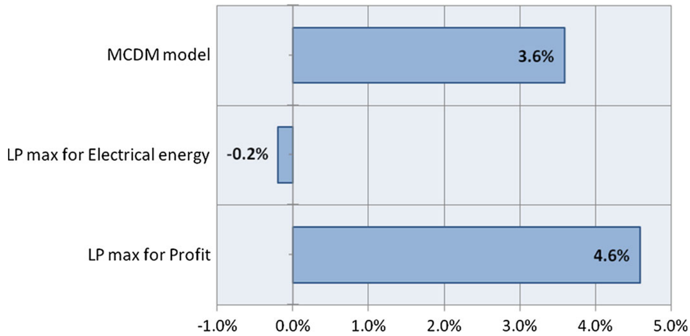

Fig. 3 Gross margin deviations in the different models

reduction in GM by 0.2 %. Furthermore, the LP model for the GM maximization achieves a significant increase (+1.0 %) in comparison with the MCDM model. As a complete contrast, the deviation of electrical energy productions is −4.7 % making this model a dispute cause. The only model achieving positive outputs for both goals, without a substantial divergence from the LP max solutions, is the MCDM model generating 7.7 % higher electrical energy production and 3.6 % higher GM for the farmers.

6 Conclusions

The creation of agro-energy districts based on the exploitation of local resources leads to an increase of the standard of living, lower prices for the public goods and a sustainable development for the regional economy and the environment (Frayssignes 2011; Shamsuzzoha et al. 2012). In order to simulate a similar type of economy, without displeasing the farmers, we investigated the optimization potential of electrical energy production from crop residues in the planning process of agricultural production in a region in Northern Greece, considering also the GM which is the basic criterion of farmers.

To support the decision making, an MCDM model was developed with two conflicting criteria, the maximization of GM and the maximization of electricity energy production from the crops residues. The results show that the MCDM model proposes a new crops plan that achieves both goals. Gross margin was increased by 3.6 % and electrical power by 7.7 % in comparison with the existent plan. The production plan based on the MCDM model creates a better approximation than the LP models when the maximization of GM or the maximization of electrical energy production consist single objectives.

The proposed MCDM model could be an important tool for the local and regional authorities, since it integrates new directives of the EU and local farmers' mentality so that new policies can be implemented gradually. With the use of new ideas and local volition, they can achieve in their regions an optimum solution for maximum income for the farmers and maximum power from agricultural residues in order to create a sustainable future. The model could be further improved in order to estimate the potential income for the farmers, from a biomass exploitation industry. In the near future, the electrical energy production through biomass will be one of the important competitive advantages for farmers in their crop selection decision making process. We could suggest that public and private sector should cooperate through investments, in order to create agro-energy districts, achieve better income for the rural population and achieve sustainable development for rural areas. The conceivable energy created from renewable resources is by itself the next step for sustainable development.

References

Bournaris T, Moulogianni C, Manos B (2014) A multicriteria model for the assessment of rural development plans in Greece. Land Use Policy 38:1–8

Bournaris T, Papathanasiou J, Manos B, Kazakis N, Voudouris K (2015) Support of irrigation water use and eco-friendly decision process in agricultural production planning. Oper Res 15(2):289–306

Di Blasi C, Tanzi V, Lanzetta M (1997) A study on the production of agricultural residues in Italy. Biomass Bioenergy 12:321–331

EC (2005) Biomass action plan European Commission, Brussels

EC (2010) Energy 2020. A strategy for competitive, sustainable and secure energy European Commission, Brussels

EC (2015) Horizon 2020. Work Programme 2016–2017. 9. Food security, sustainable agriculture and forestry, marine and maritime and inland water research and the bioeconomy. European Commision, Brussels

Fantozzi F, Bartocci P, D'Alessandro B, Arampatzis S, Manos B (2014) Public–private partnerships value in bioenergy projects: economic feasibility analysis based on two case studies. Biomass Bioenergy 66:387–397

Frayssignes J (2011) The concept of "agro-energy district": a pertinent tool for the sustainable development of rural areas, 51st Congress of the European Regional Science Association 30th August–3rd September 2011, Barcelona

Greek National Committee for Combating Desertification (2001) Greek National action plan for combating desertification, Athens

Jölli D, Giljum S (2005) Unused biomass extraction in agriculture, forestry and fishery Sustainable Europe Research Institute (SERI) Vienna

Kienle U, Manos B, Jungbluth T (2015) Alternatives to Tobacco cultivation—Towards an evidence based approach. Land Use Policy 45:199–203

Manos B, Bournaris T, Chatzinikolaou P (2010) Impact assessment of CAP policies on social sustainability in rural areas: an application in Northern Greece. Oper Res Int J 11:77–92
Manos B, Bournaris T, Chatzinikolaou P, Berbel J, Nikolov D (2013) Effects of CAP policy on farm household behaviour and social sustainability. Land Use Policy 31:166–181
Manos B, Partalidou M, Fantozzi F, Arampatzis S, Papadopoulou O (2014) Agro-energy districts contributing to environmental and social sustainability in rural areas: evaluation of a local public–private partnership scheme in Greece. Renew Sustain Energy Rev 29:85–95
Manos B, Chatzinikolaou P, Kiomourtzi F (2015) Sustainable planning of agricultural production. Int J Bus Innov Res 9(1):65–80
Menconi ME, Chiappini M, Grohmann D (2015) Optimisation of thermal performances in livestock housing design solutions using genetic algorithms. Int J Sustain Agric Manag Inform 1(2):142–162
National Statistical Service of Greece (2011) Agricultural structures survey, in: Greece, S.S.O. (Ed.), Athens
Prišenk J, Turk J, Rozman Č, Borec A, Zrakić M, Pažek K (2014) Advantages of combining linear programming and weighted goal programming for agriculture application. Oper Res Int J 14:253–260
Romero C (1991) Handbook of critical issues in goal programming. Pergamon Press, Oxford
Rosillo-Calle F (2003) The role of biomass energy in rural development, 3. Encontro de Energia no Meio Rural, 2000, Campinas (SP, Brazil)
Shamsuzzoha AHM, Grant A, Clarke J (2012) Implementation of renewable energy in Scottish rural area: a social study. Renew Sustain Energy Rev 16:185–191
Sumpsi MJ, Amador F, Romero C (1997) On farmers' objectives: a multi-criteria approach. Eur J Oper Res 96:64–71
Valiakos A, Siskos Y (2015) Multicriteria decision support for the evaluation of agricultural units in Greece. Oper Res Int Journal 15:379–393