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Biomass Production from Crops Residues: Ranking of Agro-Energy Regions

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Abstract: The aim of the paper is to rank the agro-energy regions according to their potentials of biomass production in the Region of Central Macedonia (RCM). For this reason, a model of Multi-Criteria Analysis (MCDA) is developed with the ELimination and Et Choix Traduisant la REalite (ELECTRE) III method, with the construction of outranking relations. The aim is to compare in a comprehensive way each pair of action, in our case the agro-energy regions of the RCM, in order to satisfy the main goal which is to rank the seven regions as regards their biomass production. The final goal is to select the optimal crop plan as a pilot case for biomass production in the region. In the case of ELECTRE III multicriteria model, we used several conflicting criteria such as the farm income, the biomass production from crop residues, the variable costs, and the production of thermal energy and electrical energy. Alongside a technical and economic analysis of the study area is conducted for the existent crop plans of each agro-energy region. The results show that agro-energy regions with cereals and arable crops have better results than regions with fruit trees and other crops.

Keywords: biomass production; multicriteria model; ELECTRE III

1. Introduction

The E.U. Common Agricultural Policy (CAP) has set a series of environmental measures known as Agrienvironmental Schemes .Farmers must meet the conditions set by these measures in order to be eligible for subsidies for their cultivated crops. The new CAP framework for the 2014–2020 programming period reinforces the environmental conservation agenda [1]. According to Vlontzos et al. [1] these policy interventions impact both the energy and environmental efficiency of the primary sectors of E.U. member states. Also, one of the main objectives of the Horizon 2020 program is the creation of competitive industries based on sustainable technologies [2]. The contribution of biomass utilization industries from agricultural residues and in particular in Southern Europe has been presented in several research papers [3,4]. In this way farmers have an incentive to keep agricultural residues, a new form of bio-energy and agro-energy regions grow, diminishing the effects of climate change and creating a sustainable economic model [5].

According to the E.U. Biomass Policy and Action Plan [6] "biomass is essential for environmental and competitiveness reasons". On the other hand the European Parliament has adopted the statement that "biomass has many advantages over conventional energy sources, as well as over some other renewable energy forms". These advantages can be summarized, in the "low costs, less dependence on short-term weather changes, promotion of regional economic structures and provision of alternative sources of income for farmers". For these reasons Rosillo-Calle argues that biomass production is of high importance for rural areas and especially for overall rural development [7].

According to Best [8] "agro-energy refers to the energy function of agriculture, which can make significant contributions to achieving social and environmental sustainability at local, national, regional and global levels". This goal can be achieved by using agricultural and livestock resources worldwide and many new technologies in order to transform the traditional uses of these resources into modern forms of energy [8].

Based on the European energy policy axis [9] and the late development of renewable energy sources in Greece, the region of Macedonia is the best example to examine the creation of agro-energy regions. It is assumed that the exploitation of agricultural and forest residues has only positive impact in terms of jobs creation and the generated thermal and electrical energy [10]. Also, the utilization of energy crops and the production of biofuels, has an overall positive impact worldwide [11]. Greece depends heavily on imported forms of fossil fuels, but has high renewable energy production capacity and has set high goals. The objectives of Greece for producing final energy from renewable sources (any form) amount to 20% of total production by 2020 [12].

The main goal of this paper is to rank the agro-energy regions of the Region of Central Macedonia in Northern Greece. This can be achieved by calculating a number of indicators for biomass and bio-energy production from agricultural residues. By implementing an ELECTRE III multicriteria model, we will rank the seven agro-energy regions (Thessaloniki, Imathia, Kilkis, Pella, Pieria, Serres and Chalkidiki) with a set of criteria regarding economic and environmental aspects. In the next steps, ELECTRE III multicriteria model will compare in a comprehensive way each pair of indicators and will rank them with the use of the conflicting criteria. The three of them are economic criteria (gross margin, income and variable cost) and the rest are environmental criteria (biomass production, production of thermal energy, production of electrical energy). The final result will be the ranking of the seven agro-energy regions according to their potential production of biomass from agricultural crop residues.

First, the methodology of the ELECTRE III multicriteria model is presented with all the necessary mathematical equations. The section also includes the presentation of the case study area and the calculation of the main environmental and economic indicators that will be used as criteria for ranking the agro-energy regions of the Central Macedonia. The following section presents the results of the analysis from the implementation of the ELECTRE III multicriteria model. The final section contains the concluding remarks.

2. Methodology

2.1. Multicriteria Methods for Biomass Production

Many mathematical programming models of the decision-making process of farmers have been applied in several studies found in the literature. Examples are the multicriteria model for the assessment of rural development plans in Greece [13], the model for rural households to measure the effects of the Common Agricultural Policy (CAP) in three Southern European countries [14], and similar examples are the work of Xu et al. [15], Valiakos and Siskos [16] and Prišenk et al. [17]. The use of multicriteria models for ranking regions is also very common in the literature [18,19]. On the other hand, many methodologies have been successfully applied for the biomass production in farm level such as Haas et al. [20], Brentrup et al. [21], Pulighe et al. [22], Neri et al. [23], Blengini and Busto [24], Yu and Tao [25], Castillo-Villar et al. [26] and Fedele et al. [27].

This study will develop an ELECTRE III mathematical programming model for ranking the agro-energy regions of the region of Central Macedonia. The ELECTRE III multicriteria model will be used for the first time for ranking agro-energy regions focusing on biomass production. The great advantage of the methodology is that the results are presented clearly, facilitating the rational discussion of the results and the policy makers. The existent crop plans play a vital role in policy for biomass exploitation, especially in a sensitive environmental area since a large part of Central Macedonia consists of the Network areas Natura 2000. Therefore, this methodology is the most appropriate supportive tool for the ranking of the potentials of agro-energy regions and their combinations. Also, the ELECTRE III multicriteria model has not been implemented anywhere in Greece for the analysis of biomass production.

2.2. The ELimination and Et Choix Traduisant la REalite (ELECTRE III) Multicriteria Method

ELECTRE III is a well-known multicriteria method widely chosen in the international literature [28,29]. This method requires the determination of prices of three thresholds of the criteria which are used as the indifference threshold, preference threshold and the veto threshold [30]. These allow the uncertainties of the evaluation criteria, be integrated into a decision-making process [31]. The ELECTRE III multicriteria model is used in solving multi-criteria decision-making problems in order to determine the best alternative to a given problem using the multi-criteria analysis [32]. The only reason that this method could be meaningless is the lack of available weights of the criteria and/or the accurate and complete information in minimum preference limits [31]. In this study a number of g_j, criteria (indicators in our case), where $j = 1, 2, \ldots$ r and a group of alternative scenarios (agro-energy regions in our case) are considered. Between the two scenarios *a* and *b* there is a possibility to have the following relationships and opposite [30]:

- a**P**b: The *a* is strongly preferred to *b*, where $g(a) - g(b) > p$
- a**Q**b: The *a* is meager preferred to *b*, where $q < g(a) - g(b) \leq p$
- a**I**b: Indifference between *a* and *b*, when $|g(a) - g(b)| \leq q$

where *p* is the preference threshold and *q* the indifference threshold. The prices for *p* and *q* are set by the decision makers [30].

For the implementation of the ELECTRE III multicriteria model we introduce the relation with IPS = a**S**b symbolism, indicating that scenario *a*, is at least as good as *b*. In order to examine the a**S**b statement introduces the following principles according to Buchaman et al. [33]:

- Agreement Principle: Applies a**S**b for the majority of the criteria.
- Principle of non-discrepancy: From all the criteria under which it accepted the statement contains no criterion on which this statement is strongly rejected.

The a**S**jb symbol indicates that scenario *a* is at least as good as *b* relative to the j criterion. In order the criterion *j* to be considered in accordance with the a**S**b statement should apply a**S**jb, i.e., $g_j(a) \geq g_j(b) - q_j$. Respectively the criterion *j* is in disagreement with the statement a**S**b when applicable b$\mathbf{P}_j$a, i.e., $g_j(b) \geq g_j(a) - p_j$.

In general, the purpose of the method is defined as the ranking of alternative scenarios considering [34]:

- The indifference and preference thresholds for each criterion.
- The criteria weights.
- The difficulties that may arise from comparing two scenarios, the first is significantly better than the second relative to a subset of criteria but inferior compared with the total evaluation.

Multicriteria evaluation of the potentials of biomass production of the agro-energy regions of Central Macedonia consists a problem which is formulated by using a set of alternatives (a, b, c, d, e, f, g) and a set of criteria (c1, c2, c3, c4, c5, c6). The evaluation of criterion *j* for alternative A is described as c_j(A). The approach adopted in the framework of this analysis uses a ranking scheme following ELECTRE III principles, based on binary outranking relations in two major concepts; "Concordance" (c_j) when alternative *a* outranks alternative *b* if a sufficient majority of criteria are in favour of alternative a and "Non-Discordance" (d_j) when the concordance condition holds, none of the criteria in the minority should be opposed too strongly to the outranking of *b* by *a*. The assertion that *a* outranks *b* is characterized by a credibility index which permits knowing the true degree of this assertion [35]. To compare a pair of alternatives (*a*,*b*) for each criterion, the assertion "*a* outranks *b*" is evaluated with the help of pseudo-criteria. As already discussed, the pseudo-criterion is built with two thresholds, namely indifference (q_j) and preference (p_j), for which the following apply [30]:

- When $c_j(a) - c_j(b) \leq q_j$, the non-difference between alternatives *a* and *b* for the specific criterion *j* under study is identified. In this case $c_j(a,b) = 0$.
- When $c_j(a) - V_j(b) > p_j$, then a is strictly preferred to *b* for criterion *j*. In this case $c_j(a,b) = 1$.

For a criterion *j* and a pair of alternatives (*a*,*b*), the concordance index is defined as follows [30]:

$$c_j(a,b) = \begin{cases} 1 & g_j(b) - g_j(a) \leq q_j \\ 0 & g_j(b) - g_j(a) \geq p_j \\ \frac{p_j + g_j(a) - g_j(b)}{p_j - q_j} & q_j \leq g_j(b) - g_j(a) \leq p_j \end{cases}$$

A global concordance index $C_{a,b}$ for each pair of alternatives (*a*,*b*), is computed with the concordance index c_j (A, B) of each criterion *j* [30]:

$$c(a,b) = \frac{1}{\sum_{j=1}^{r} k_j} \sum_{j=1}^{r} k_j c_j(a,b)$$

where k_j is the weight of criterion *j*.

As already mentioned, a discordance index $d_j(a,b)$ is also taken into consideration for all pairs of alternatives and each criterion *j*. Discordance index (d_j) is evaluated with the help of pseudo-criteria with a veto threshold (v_j), which represents the maximum difference $c_j(a) - c_j(b)$ acceptable to not reject the assertion "*a* outranks *b*", as follows [30]:

$$d_j(a,b) = \begin{cases} 0 & g_j(b) - g_j(a) \leq p_j \\ 1 & g_j(b) - g_j(a) \geq v_j \\ \frac{g_j(b) - g_j(a) - p_j}{v_j - p_j} & p_j \leq g_j(b) - g_j(a) \leq v_j \end{cases}$$

The index of credibility $S(a,b)$ of the assertion "*a* outranks *b*" is defined as follows [30]:

$$S(a,b) = \begin{cases} C(a,b) & d_j(a,b) \leq C(a,b) \\ & \forall j \\ & d_j(a,b) \geq C(a,b) \\ C(a,b) \cdot \prod_{j \in J(a,b)} \frac{1 - d_j(a,b)}{1 - C(a,b)} & J(a,b) : d_j(a,b) > C(a,b) \end{cases}$$

In the case that a veto threshold is exceeded for at least one of the selected criteria, the credibility index is null. In other words, the assertion "*a* outranks *b*" is rejected. As regards the ranking procedure of all available location alternatives A_j, two complete pre-orders are constructed through a descending and an ascending distillation procedure [30]. In a nutshell, descending distillation refers to the ranking from the best available alternative to the worst, while ascending distillation refers to the ranking from the worst available alternative to the best [36,37]. As a last step of the developed methodology, sensitivity analysis is available, since parameter values in real life applications originate from estimations which are sometimes more or less reliable (weighting factors, thresholds, criteria qualitative values etc.) [30].

The next step is to rank the scenarios according to the reliability table. Originally there are formed two rankings Z1 and Z2, one ascending and one descending preference respectively and from their combination we end up in the final standings Z = Z1 ∩ Z2 [30].

At this point the constant λ is inserted, which is the highest reliability panel λ = max $S(a,b)$ and is defined as s reliability value (λ), such as to remain only the values $S(a,b)$ gene is greater than $\lambda - s(\lambda)$.The reliability value, like boundaries p_j, q_j, v_j above, determined by the decision-maker. We then apply [30]:

$$T(a,b) = \left\{ \begin{array}{ll} 1 & S(a,b) > \lambda - s(\lambda) \\ 0 & S(a.b) < \lambda - s(\lambda) \end{array} \right\}$$

From the implementation of the last function derived the final scoreboard under which rankings will be achieved. For the implementation of the ELECTRE III multicriteria model, the "demo" version of the software developed by the French university "LAMSADE Paris-Dauphine" was used [38]

2.3. Case Study Area and Criteria

2.3.1. Case Study Area

The case study area in this study is the Region of Central Macedonia (RCM). The RCM is divided into seven regional units, namely Chalkidiki, Imathia, Kilkis, Pella, Pieria, Serres and Thessaloniki. These regional units are considered as the agro-energy regions of the study. According to the biomass potential maps of the National Information System for Energy, the region of Central Macedonia has the largest reserves of biomass from agricultural residues of all Greece. All the appropriate technical and economic data of the total number of the agricultural holdings, collected from the General Directorate of Rural Economy and Veterinary and the Hellenic Statistical Authority. The data refers to the year of 2013. Crop plans of the agro-energy regions of the RCM are presented in Table 1.

Table 1. Crop plans of the agro-energy regions of the RCM.

Crops	Chalkidiki	Imathia	Kilkis	Pella	Pieria	Serres	Thessaloniki
Alfalfa		5548	4408.7	5518.7	3394.6	10,175.7	
Apples		2614					
Apricots				1628.7			
Barley	4265.8	1493.5	3549.8	4064	2425.4	7825	5324.8
Cherries				7825.1			
Cotton		16,354.4	6814.1	11,204.8	4614.8	14,816.2	10,348.6
Hard Wheat	16,218	4842	38,247.8	5933.5	9498.7	33,527	30,848.1
Kiwi					3218.4		
Maize		5998.3	3394.9	8498.7	1754.5	24,135	2994.8
Nectarines		3914		2948.5			
Oats	3214.2						
Olive Trees	30,847				3214.8	4623	2418.7
Peaches		18,235.7		15,898.7			
Rapeseed						2145	
Rice		1624			987.5	3104.5	17,994.5
Set Aside	11,922.9	2778.4	9909.9	4998.3	4358.4	8245.8	8494.5
Soft Wheat	3654.1	1598.4	22,246.3	4134.8	7914.8	11,924.5	21,911.2
Sunflower	1658.1		2158.9			10,748.5	5284.5
Tobacco					4888.8	2245	
Vetch	2549.1						
Total	30,847	65,000.7	90,730.4	72,653.8	46,270.7	133,515.2	105,619.7

2.3.2. Criteria

The selected criteria for the implementation of the ranking methodolody were three economic criteria (gross margin, income and variable cost) and three environmental criteria (biomass production, production of thermal energy, production of electrical energy). The criteria are calculated by multiplying the total land (ha) of each crop in the agro-energy district with the values of each indicator separately. A short description of the criteria is presented below.

Gross Margin

Gross margin is calculated by subtracting from income the variable cost of each crop of the agro energy region.

Income

It was computed by the simple combination of yields (kg/ha), and prices (€/ha), plus subsidies where applicable for each crop of the agro-energy region.

Variable Cost

In order to calculate variable cost all the agricultural inputs are summarized (seeds, fertilizers, chemicals, machinery, labour and the cost of water etc. (€/ha)).

Biomass Production

Based on the literature and taking into account newer research efforts [39] in the same direction [5] the agricultural residues from larger crops per area and yield in tons per hectare are calculated and are presented in Table 2.

Table 2. Biomass production (tn/ha) from crops residues for the main crops of the Region of Central Macedonia.

Crops	Residues Type	Output of Residues (tn/ha)	Humidity %	Biomass (tn/ha)
Alfalfa	Straw	3	0.15	2.6
Apples	Pruning	2.4	0.40	1.4
Apricots	Pruning	1.6	0.40	1
Barley	Straw	2.7	0.15	2.3
Cherries	Pruning	2.5	0.40	1.5
Cotton	Straw and shell (overground)	4.2	0.40	2.5
Cotton	Straw and shell (root)	1.3	0.56	0.6
Hard Wheat	Straw	1.6	0.15	1.4
Kiwi	Pruning	1.6	0.35	1
Maize	Stalks and cobs	10.5	0.55	4.7
Nectarines	Pruning	2.9	0.40	1.7
Olive Trees	Pruning	1.7	0.50	0.9
Peaches	Pruning	2.9	0.40	1.7
Rapeseed	Straw	4	0.53	1.9
Rice	Straw	3.8	0.25	2.9
Set Aside	Not applied			
Soft Wheat	Straw	2.5	0.15	2.1
Sunflower	Stalks	4	0.40	2.4
Tobacco	Stalks	2.2	0.85	0.3

Production of Thermal and Electrical Energy

In order to calculate the production of thermal and electrical energy for crops, the Lower Heating Values (LHV) were considered [40,41]. In the final stage of calculating the production of thermal and electrical energy using the following formulas respectively:

$$\text{Production of Thermal energy (MJ)}: 0.9 \times \text{Biomass (kg)} \times \text{LHV(MJ/kg)}$$

$$\text{Production of Electrical energy (MJ)}: 0.2 \times \text{Biomass (kg)} \times \text{LHV(MJ/kg)}$$

3. Results and Discussion

The following section includes the calculation of the indicators which are used as criteria in the ELECTRE III model (Table 3). It also includes the ranking of the seven agro-energy regions of the Central Macedonia after the implementation of the ELECTRE III multicriteria model.

Table 3. Calculation of the six criteria for ELECTRE III model.

Alternatives Agro-Energy Regions	Criteria					
	Gross Margin (€)	**Income (€)**	**Variable Cost (€)**	**Biomass Production**	**Production of Thermal Energy (MJ)**	**Production of Electrical Energy (MJ)**
Imathia	82,639,292.18	210,811,094.64	128,171,802.46	153,941.88	2,565,940,026.60	570,208,894.80
Thessaloniki	54,904,658.03	119,336,134.20	64,431,476.17	213,695.21	3,140,541,839.70	697,898,186.60
Kilkis	48,153,421.10	87,650,548.66	39,497,127.56	160,925.00	2,383,266,261.96	529,614,724.88
Pella	174,610,011.65	317,328,408.48	142,718,396.83	161,579.45	2,686,299,186.15	596,955,374.70
Pieria	50,209,550.87	104,365,027.78	54,155,476.91	77,115.67	1,175,256,301.05	261,168,066.90
Serres	80,164,854.89	178,619,541.72	98,454,686.83	318,397.21	4,837,020,975.00	1,074,893,550.00
Chalkidiki	56,526,005.64	135,930,670.10	79,404,664.46	77,969.21	1,275,268,402.80	283,392,978.40

From Table 3 we can conclude that Serres agro-energy region has the highest potential values for biomass production. The second region is Thessaloniki, followed by Pella, Kilkis and Imathia. The agro-energy regions of Chalkidiki and Pieria are the two with the lowest biomass production potentials. The crop plans of Serres and Thessaloniki mainly include arable crops and cereals which have mainly straw as output residues and high biomass values. The crop plans of Pella and Imathia include mainly fruit trees which produce high pruning values but with low output residues. Finally, the regions of Chalkidiki and Pieria have mixed crop plans with olive trees and arable crops. From these results we can conclude that the variety of crops in the existent crop plans is one of the most important factors as regards the biomass production potentials. Thus, agro-energy units with crops with high agricultural output residues have better results as regards the biomass production and in the production of thermal and electrical energy. As regards the comparison between the economic indicators and the biomass production potential we can conclude that biomass production hasn't any relation to the economic results. Agro-energy regions with high values of gross margin such as Pella and Imathia present the lowest biomass production potentials in comparison with the agro-energy regions of Serres and Thessaloniki.

Ranking

The ranking of the agro-energy regions of the Region of Central Macedonia was performed using the ELECTRE III multicriteria model. The criteria (gross margin, income and variable cost, biomass production, production of thermal energy, production of electrical energy) were used to describe the characteristics of each agro-energy region of the Region of Central Macedonia as regards the economic and environmental aspects. Some of these criteria are conflicting, which is important for the implementation of the ELECTRE III model.

For the implementation of the ELECTRE III multicriteria model, it is necessary a set of weights for every criterion in our research. For this reason, a group of experts (including policy makers from the Ministry of Rural Development and Food, the General Directorate of Rural and Veterinary Economy, farmers and researchers) were interviewed. For the definition of the criterias' weights, a questionnaire administered through personal meetings was used. The results of the questions as regards the weights of each criterion are presented in Table 4.

Table 4. Weights of each criterion.

Criteria	Weights (%)
Gross Margin (€)	7.70
Income (€)	7.70
Variable Cost (€)	7.70
Biomass Production	35.10
Production of Thermal Energy (MJ)	22.20
Production of Electrical Energy (MJ)	19.60
Total	100

The ELECTRE III multicriteria model was implemented using the "demo" version of a software developed by the French university "LAMSADE Paris-Dauphine" [38]. Each agro-energy region of the region of Central Macedonia was assigned a unique alphanumeric code for software use. The alphanumeric codes were:

A0001: Agro-energy Region of Imathia
A0002: Agro-energy Region of Thessaloniki
A0003: Agro-energy Region of Kilkis
A0004: Agro-energy Region of Pella
A0005: Agro-energy Region of Pieria
A0006: Agro-energy Region of Serres
A0007: Agro-energy Region of Chalkidiki

The credibility matrix of the ELECTRE III multicriteria models for the agro-energy regions was (Table 5):

Table 5. Credibility Matrix.

Codes	A0001	A0002	A0003	A0004	A0005	A0006	A0007
A0001	1	0.15	0.92	0.85	0.92	0.15	0.92
A0002	0.85	1	0.92	0.85	0.95	0.077	0.98
A0003	0.81	0.15	1	0.67	0.98	0.077	0.9
A0004	0.92	0.22	0.92	1	0.92	0.15	0.92
A0005	0.077	0.21	0.15	0.077	1	0.077	0.92
A0006	0.92	0.92	0.92	0.85	0.92	1	0.92
A0007	0.077	0.15	0.15	0.077	0.92	0.077	1

The concordance matrix of the ELECTRE III multicriteria models for the agro-energy regions was (Table 6):

Table 6. Concordance Matrix.

Codes	A0001	A0002	A0003	A0004	A0005	A0006	A0007
A0001	1	0.15	0.92	0.85	0.92	0.15	0.92
A0002	0.85	1	0.92	0.85	0.95	0.077	0.98
A0003	0.81	0.15	1	0.67	0.98	0.077	0.9
A0004	0.92	0.22	0.92	1	0.92	0.15	0.92
A0005	0.077	0.21	0.15	0.077	1	0.077	0.92
A0006	0.92	0.92	0.92	0.85	0.92	1	0.92
A0007	0.077	0.15	0.15	0.077	0.92	0.077	1

After the implementation of the ELECTRE III multicriteria model, the following ranking emerged for the agro-energy regions of the Region of Central Macedonia where:

$$A0006 > A0002 > A0004 > A0001 > A0003 > A0005 \text{ and } A0007$$

The final ranking of the alternatives (agro-energy regions) presented in the next table (Table 7):

Table 7. Final ranking of the seven agro-energy regions of the RCM.

Ranking	Code	Agro-Energy Region
1	A0006	Serres
2	A0002	Thessaloniki
3	A0004	Pella
4	A0001	Imathia
5	A0003	Kilkis
6	A0005 and A0007	Pieria and Chalkidiki

From the table above, we can observe that as regards the biomass production potentials in the Central Macedonia region, the agro-energy region of Serres has the first position, followed by the agro-energy region of Thessaloniki. The third position is held by the agro-energy region of Pella, followed by the agro-energy region of Imathia. In fifth position we have the agro-energy region of Kilkis. The agro-energy regions of Pieria and Chalkidiki share the final position.

From the results we can conclude that the size of the agro-energy region was an important factor. The crop plan of the agro-energy region of Serres seems to have the best mix of crops that produce biomass. The crop plan includes mainly arable crops and cereals as described in the previous section. The second crop plan, of Thessaloniki, seems to have a similar crop mix as the agro-energy region of Serres. The following crop plans of Pella and Imathia mainly comprise fruit trees.

The next figure (Figure 1) shows the ascending and descending distillations of the optimal agro-energy region which in our case is Serres, for biomass production.

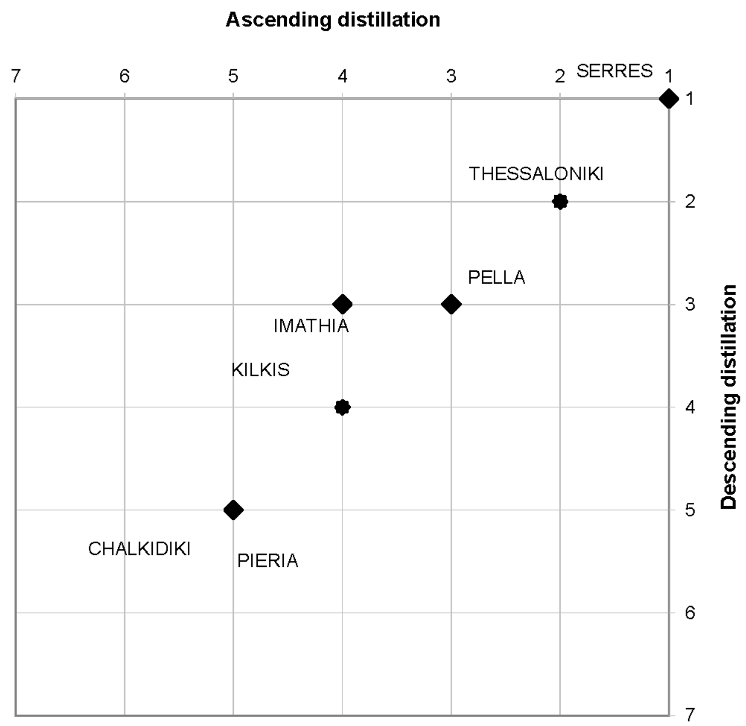

Figure 1. Ascending and descending distillations of the optimal agro-energy region for the biomass production.

4. Conclusions

The main aim of this research was to rank the agro-energy regions in Central Macedonia as regards their potential for biomass production from agricultural residues. For this purpose six main indicators were calculated (gross margin (€), farm income (€), variable costs (€), biomass production (tn), production of thermal energy (mj), production of electrical energy (mj),) for the seven agro-energy regions of the region. These indicators were used as criteria in a multicriteria analysis model. The multicriteria analysis model was developed using the ELECTRE III method. This model was used to rank the crop plans of the seven agro-energy regions under the eight criteria that we have selected. The research also examined the thermal and electrical energy in MWh produced by the biomass from agricultural residues. The results showed that the agro-energy region of Serres had the optimal crop plan for biomass production in the region, followed by the agro-energy region of Thessaloniki. These agro-energy regions had crop plans that included cereals (hard and soft wheat), maize, cotton and rice which are crops that produce high levels of biomass. The next crop plans were the crop plans from the agro-energy regions of Pella and Imathia. These crop plans included fruit trees crops such as peaches and cherries which can produce high levels of residues from their pruning. From the above we can conclude that the biomass production in the region of Central Macedonia can be increased if the farmers were to turn to crop plans that include cultivation options like those of the agro-energy regions of Serres and Thessaloniki. Also, in the multicriteria ELECTRE III model we used criteria such as gross margin and variable costs that are basic criteria in the farmers' decision-making process when they select the crops that they will cultivate. On the other hand, as we know, their decisions do not include the biomass production. The multicriteria analysis managed to include these conflicting selection criteria in the model and the results of the ELECTRE III ranking proposed the optimal crop plans that the farmers can use and the policy makers can suggest.

The main policy message from this study is that the creation of agro-energy districts with the use of the proposed crop plans can lead to an increase in farm income and promote sustainable development for rural areas using agricultural residues for biomass production both for economic and environmental reasons. The proposed crop plans could be an important tool for the local and regional authorities, since they integrate the farmers' desire for profits and the social concerns about environmental issues. The ELECTRE III multicriteria model could be further improved in order to include more economic, environmental and social criteria that affect the biomass production. We postulate that in the future biomass production from agricultural residues will be one of the main criteria for farmers in their crop selection decision-making process. We can suggest that policy makers should encourage public and private investments in the production of energy from biomass and the creation of agro-energy districts in order to achieve better income for farmers and more sustainable development for rural areas.

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