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RESEARCH ARTICLE

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Multi criteria analysis of the energy potential of agricultural residues: The case study of Međimurje County in Croatia

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Abstract

Aim of study: The utilization of agricultural residues may become one of the major sources for production of energy from biomass. The objective of this paper was to analyse the type and quantity of agricultural residues and to determine their energy potential.

Area of study: The Međimurje County (north Croatia).

Material and methods: The paper analyses three models of sustainable agricultural residues management applying the multi-criteria analysis. The assessment included potentially available quantities of residues in crops, fruit, viniculture and livestock production. For determining the most appropriate model of residues utilisation the multi-criteria analysis was applied.

Main results: The results show that total quantities of agricultural biomass amount to 323,912 t with energy potential of 1,092 TJ annually. The largest sustainably available potential of agricultural biomass consists of biomass from arable crops production, with total quantity of 33,670 t followed by 281,233 t of manure from livestock production. The lowest share of potential biomass are pruning residues in fruit and grapevine production with total available residual quantity of 8,109 t. Also, it results from the multi-criteria analysis that a central large scale plant for biogas production is the most feasible facility for such production.

Research highlights: The results of this paper provide ground for further development of the models for assessing the sustainability of using agricultural residues, and they can also serve as a basis for assessments of bioenergy projects in specific regions of the European Union.

Additional keywords: renewables; biomass; sustainability; energy utilization; county level; European Union.

Authors' contributions: SG: design of the research, analysis of data. NV: coordinating the research project and supervising the work. SP: critical revision of the manuscript.

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Introduction

By-products of the agricultural production can become valuable feedstock for bioenergy and bio-industry, and manure can be transformed into biogas and fertilizers. This stimulates the energy transition and a more substantial recycling of nutrients. It also contributes to replacing the sources and materials that are harmful for the environment and non-renewable sources and materials, as well as to reduction of food losses and food waste. There is a clear need to encourage investments in restructuring of agricultural production capacities, modernisation, innovation and application of new technologies and possibilities based on digital technologies, such as precision agriculture and clean energy, in order to enhance sustainability of individual farms and their competitiveness and resilience, including resilience to negative influences of climate changes. There is a growing awareness that the current approach to energy is unsustainable and ecologically unacceptable (Bilandžija *et al.*, 2018). Climate changes are evident and our influence on the changes ongoing in the nature and in the environment is beyond dispute. The availability of sufficient quantity of energy is a prerequisite for economic development of any country, but also of the possibility to meet the needs of all other consumers. The renewable energy sources carry a great potential for satisfying ever growing energy needs and for reducing dependence on fossil fuels (Fernandes & Costa, 2010; Dell'Antonia, 2014).

All sorts of biodegradable residues are desirable feedstock for production of all types of useful energy. The limitations in removal of biodegradable residues and the limitations of raw materials for biofuels production have placed emphasis on those materials which had been defined as biodegradable waste. One of the biggest problems that may occur and which must be prevented is the food *vs*. energy competition. A possible solution is the utilisation of residues from agricultural production as a source of biomass, *i.e.* biofuels. This would mean that the stalks of wheat or maize, after being used for food, are used as biomass feedstock for energy production. Regardless of the way the biomass is used, it is necessary to meet the main criterion of renewability, namely, the quantity of biomass used should be equal to the quantity of biomass renewed in the environment (Kaltschmitt, 2011; Sarkar *et al.*, 2012).

One of the main features of biomass is that it represents a very versatile energy source, which potentially provides not only electrical energy but also heat energy and biofuels which can be used in the transport sector. It is also one of those rare renewable sources which can be preserved and can generate energy on demand (Rentizelas *et al.*, 2009).

The life cycle of biomass as a renewable raw material has a neutral CO_2 emission effect. Due to this, biomass is considered as a safe and clean material, with unlimited availability and potential for wide range utilisation in energy and fuel production (Lam *et al.*, 2008; Fernandes & Costa, 2010).

One of the most important obstacles to more significant use of biomass for energy supply is the cost of biomass supply chain and the technology for its conversion into useful energy forms. The characteristic of most sorts of agricultural biomass is that their availability is seasonal (Sambra *et al.*, 2008; Rentizelas *et al.*, 2009). The period when particular types of biomass are available is very limited and depends on the crop, harvesting period, weather conditions and requirements for new sowing on the particular agricultural surface. Since today most of energy from biomass is limited to one-time use, it is necessary to store large quantities of biomass for a rather long period of time, in order to make it available for the plant operation during the whole-year period. The limited timeframe for collecting large quantities of biomass results in significant season-based requirements for resources, in form of equipment and workforce.

The best way of using resources from agricultural biomass is to use them on a local scale. Such resources usually involve high collection and transportation costs, but are still economically attractive. Often, better availability, due to a well-developed supply system and better market access, will lower the price of the raw material (Faaij *et al.*, 2002; Hillring, 2002; Vesterinen & Alakangas, 2002; Faaij, 2006). Not all residues are usable as energy source and in developed countries it was determined that only 35% of residues can be removed without harmful effects on future yields (Asakereh *et al.*, 2014). The availability and utilisation of biomass is intertwined with various sectors of the economy: agriculture, forestry, food production, paper industry, construction material production, and most extensively, with the energy sector (Faaij, 2006). The available biomass can, with use of various technologies, be converted into electricity and/or internal energy (heat) or it can be transformed into commercially more suitable energy forms (pellets, briquettes, chippings) (Pantaleo & Shah, 2013). Final product of any utilisation process, *i.e.*, processing of organic biomass, can be classified in three principal groups: energy production (heat energy and electricity), transport fuels, and chemical products (McKendry, 2002; Cantrell *et al.*, 2008; Kaltschmitt, 2011).

Several studies have dealt with assessing the potential of various agricultural and forestry residues available for energetic purposes in different regions in the world. Pending on particular conditions, different sorts of biomass include agricultural residues, from residues from harvesting or processing, municipal and industrial waste and waste from production and industrial processes. The work of Searle & Malins (2016) gives the assessment of sustainably available cellulose waste and residues in for biofuel production in 28 European Union (EU) member states, in the context of the European directives regarding use of biofuels in transport by using sustainable sources such as residues and waste. The analysis includes three types of residues: agricultural residues, forestry residues and waste. The availability was estimated of the agricultural residues of 12 crops with highest production in the EU: barley, maize, oat, olives, rapeseed, rice, rye, soybean, sunflower, triticale, wheat, and sugar beet. The analysis used the statistical data on production and surfaces in the period from 2009 to 2013. The results show that total production of all 12 crops in 28 EU member countries amounts 315.9 million t/year. Out of this quantity, 196.1 million tonnes is recommended to be used for improvement of soil productivity, 9.8 million tonnes for energy, heat and biogas production, 26.4 million tonnes for other needs, and 84.6 million tonnes for biofuels production.

Fernandes & Costa (2010) investigated in their work the potential of biomass residue, *i.e.*, agricultural and forestry residues, for energy production in the region of Marvão in Portugal. The Marvão region was identified as optimal for installing small scale biomass plants for heating given a relatively high potential of biomass residues that was identified. The results show that total potential of agricultural residues is 7,973.34 t with energy potential of 78,138.73 GJ/t. The calculation of this potential encompasses 75.88 ha of orchards, 2,575.02 ha of surfaces under wheat, 2,619.46 ha of grassland, 1990.66 ha of olive groves and 7.77 ha of vineyards. Dell' Antonia (2014) in his work brings the results regarding energy potential from anaerobic digestion of animal waste and agricultural residues in the region of Friuli Venezia Giulia (northwest Italy). The biogas potential of the region was calculated at 55.8 Nm^3/t from animal waste, and 54% of this potential comes from cattle production (there are 89,162 heads of cattle in the region), 23% from pig farming (216,430 pigs) and 23% from poultry farming (6,951,512 birds). The potential of biogas energy in this region amounts to 1,128 TJ. The work states that the potential of biogas produced from agricultural residues is sufficient to replace 2.8% of final energy consumption in the region (3,339 ktoe) and up to 3.3% of final consumption of electricity (864 ktoe) given the electric energy conversion efficiency of 30%. Navickas *et al.* (2009) investigated the potential and possibilities of biogas production from agricultural raw materials in 10 districts in Lithuania. The results show that in the investigated districts there would be available 72.1 million m^3 of biogas from livestock production (106 thousand heads of cattle, 565 thousand pigs and 7.9 million tonnes of poultry manure) which is potential feedstock for 432.5 GWh of energy. In the work by Monforti *et al.* (2013) publicized is the computational approach based on geographical estimation of potential bioenergy production from residues of eight arable crops (wheat, barley, rye, maize, rice, rapeseed and sunflower) in the EU. The results show that the estimated crop residues in the EU-27 could provide fuel for about 850 plants which would expectedly produce about 1500 PJ of bioenergy per year.

Other studies (Celma *et al.*, 2007; Daioglou *et al.*, 2016; Singh, 2016) have also shown that there is energy potential in agricultural biomass and that biomass can be used for production of energy and that agricultural residues production is related to the volume of agricultural production, crop production and yield. Further development of the production and utilisation of biomass should follow certain basic principles, such as high conversion efficiency, competitiveness and sustainability. The challenge of utilising biomass is not in biomass availability but in its sustainable management, conversion and its supply to the market in a form of a modern and affordable energy service. In a practical sense, the effectively available biomass for energy is determined by certain technical, environmental and other limitations (Kaur, 2015). The sustainable use of residues and waste for renewable energy, which represents a limited environmental risk, should be stimulated and globally promoted (Cigolotti, 2012).

The assessment of overall social assets and liabilities of any activity is the basic principle of the so called sustainable development which includes economic and social elements and environmental protection elements. The sustainable development means not only the economic progress but also the preservation of natural resources and the quality of the environment. This means that it is not justified to use particular resources if overall costs exceed total benefits of their use. Total benefits and liabilities are related to possible direct and indirect impacts on: ecosystem, human health, economic activities, and society. As such, the analysis of these factors should encompass all relevant factors (both measurable and non-measurable ones), as well as the importance of their influence and probability of occurrence (Rumenjak, 2002).

The food supply compromises the "anthropogenic" ecological changes while the biggest individual source of such changes is the agricultural production system as such. Namely, the agricultural production systems themselves endanger future food production. Certain environmental changes represent threat to food production. In addition, the agricultural production, with its present features, significantly jeopardizes the components of the environment. It is deemed that agriculture, including the changes aimed at obtaining new land surfaces, is a source of emissions of CO_2, CH_4 and NO_X, causing the "greenhouse effect". This means that the method of agricultural production must be changed in order to reduce the emissions of harmful gases. Given the fact that the agriculture is based on use of natural resources, it is directly affected by the environment degradation. The reduced ozone layer leads to diminishing photosynthesis which, generally speaking, decreases the effects of plant production. On the other side, global warming will bring about major changes in the agricultural activities schedules. The interdependence of agricultural production and environment is in the agriculture–environment interaction, since the agriculture itself adds to the degradation of its own resources (*e.g.*, use of chemicals). Pesticides and herbicides contribute to pollution of soils and waters. The sustainable agriculture is based on application of the technologies which enhance productivity and at the same time mitigate negative influences on natural (soil, water and biodiversity) and human resources (rural population and consumers). The priority of the EU is to achieve a sustainable agricultural and rural development, which presumes "management and conservation of natural resources and directing of technological and institutional changes in a way to ensure achieving and continuous meeting of the needs of present and future generations". This is in accordance the EU strategy for sustainable development and jobs creation (EC, 2010).

Because of all this, there is a growing need for changing the current conditions of the farmers and purposeful use of agricultural residues, in order to prevent serious environmental problems, at the same time, enabling increased local and regional economic activities and efficiency, thus generating additional revenues from agriculture. Given the fact that today most of agricultural residues in Croatia are not used for energy, the objective of this work is to analyse the types and quantities of the agricultural residues and determine their energy potential. By use of multi-criteria analysis for the area of the Međimurje, the assessment of three models for use of available agricultural residues has been carried out with the aim to ensure efficient management of biodegradable residues following the principle of avoiding the insecurity conflicts and threats to the environmental components and to the County's economy.

Material and methods

The area of investigation is the Međimurje County. The county is situated at the north part of Croatia. It has a surface of over 729.25 km^2 and is the smallest Croatian county covering only 1.29% of total territory of Croatia. Climate conditions in this region make it suitable for production of almost all agricultural crops grown in the moderate continental climate belt, especially for production of maize, commercial potato, vegetables and industrial plants. The largest part of the arable surfaces in the County is under cereal grains, with dominant maize which covers 12,000 ha. Wheat is sown on 3,700 ha, and barley on 2,000 ha. Rye, oat and other cereals are produced at a lesser extent, on 800 ha total (Office of State Administration in the Međimurje County, 2017).

This investigation uses the statistical and cadastral data on agricultural land and the data on crop yields. The analysis was carried out of the zoning data on the use and purpose of land surfaces in the County which were provided by the County Zoning Office; the data regarding use of agricultural land from the ARKOD Farmer Register held by the Paying Agency for Agriculture, Fishery and Rural Development; the data on status and changes of land cover and purpose of using land which were provided by the CORINE Land Cover Croatia database of the Croatian Agency for Environment and Nature.

In this investigation the crops were selected on the basis on the mentioned databases and the sources which describe the method of using land in the County. The calculation of the quantity of biomass from crop residues includes the crops which take the largest part of land surfaces, namely wheat, barley, maize and rapeseed. The calculation of the quantity of biomass from fruit production includes apple plantations and vineyards for calculation of pruning residues from viticulture. The overview of the agricultural land surfaces in the areas of towns and municipalities of the Međimurje County which were subject of this investigation is given in Table 1.

Table 1. Surfaces under agricultural crops in the areas of towns and municipalities of the Međimurje County (ha).

Town/Municipality	Wheat	Barley	Maize	Rapeseed	Vineyards	Orchards
Čakovec	443.70	295.80	1,012.03	147.30	79.66	93.06
Mursko Središće	234.19	156.13	510.67	84.78	29.61	44.98
Prelog	317.99	211.99	1,162.05	245.83	59.53	129.22
Belica	173.99	116.89	433.42	15.85	33.25	32.22
Dekanovec	21.77	14.51	158.00	16.09	4.55	4.45
Domašinec	154.03	102.69	760.04	48.49	27.78	29.81
Donja Dubrava	133.72	89.14	270.95	96.65	10.29	11.40
Donji Kraljevec	205.74	137.16	723.04	61.76	30.18	61.40
Donji Vidovec	74.28	49.52	213.21	106.54	13.92	16.01
Goričan	143.73	95.82	413.41	70.81	15.51	23.26
Gornji Mihaljevec	95.85	63.90	525.15	35.24	99.62	33.51
Kotoriba	122.33	81.55	279.29	135.90	14.33	18.60
Mala Subotica	259.90	173.26	948.87	104.94	47.73	49.48

Table 1. Continued.

Town/Municipality	Wheat	Barley	Maize	Rapeseed	Vineyards	Orchards
Nedelišće	233.96	155.97	1,090.00	131.59	51.08	78.66
Orehovica	101.07	67.38	515.36	41.31	27.78	26.46
Podturen	131.48	87.65	555.67	47.70	22.28	23.30
Pribislavec	88.07	58.71	71.20	11.54	9.33	12.12
Selnica	143.26	95.51	467.41	11.22	21.07	17.02
Strahoninec	95.61	63.74	104.21	9.51	8.68	9.69
Sveta Marija	150.87	100.58	309.82	139.39	16.25	41.28
Sveti Juraj na Bregu	116.27	77.51	427.83	23.72	40.53	27.53
Sveti Martin na Muri	95.67	63.78	355.49	20.64	23.81	23.88
Šenkovec	30.16	20.10	170.22	12.62	5.93	8.60
Štrigova	49.92	33.28	395.89	4.94	241.52	51.53
Vratišinec	130.43	86.95	217.24	30.80	17.96	24.54
Total	3,747.99	2,343.39	12,090.47	1,655.16	952.18	892.01

The data on the numbers of specific type of livestock were taken from the database "Common Register of domestic animals on number of caws, sheep, pigs and hoofed animals" (https://hpa.mps.hr/jrdz-izvjestaji/broj-domacih-zivotinja/). For the calculation of the livestock units (LU) certain coefficients from the I. Action Program for protection of waters against pollution caused by nitrates from agricultural sources (Official Gazette, 15/13) were applied. According to the data from the Croatian Agricultural Agency, in the area of the Međimurje County the most common livestock productions are cattle, pig and poultry farming. Table 2 presents the numbers of livestock and relevant livestock units used in this investigation.

The data on average grain mass to biomass ratio in arable crops used in this investigation are given in Table 3. The grain mass to biomass ratio in wheat, whose straw is most often used for biomass, or, grain to straw ratios are calculated for the plant top end, and are between 1 and 1.2 in relation to grain. The same ratio is found in barley; in rapeseed it is 2 in relation to grain. Based on the measurements of the yield of specific parts of maize plant in relation to grain, it was found that the yield of usable maize stalks (foliage and stalk excluding the 20 cm at the bottom) is 60–90% in relation to the grain yield (Brkić & Janić, 2011; Bilandzija *et al.*, 2012; Kricka *et al.*, 2012; Voca *et al.*, 2016). Given the fact that there are no data at the county level about the yields of specific crops, the average yield used in this investigation was calculated on the basis of the 5-year medium values (2010–2014) (The Croatian Bureau of Statistics, 2015).

There are a number of different calculations for lower heating value for specific sorts of biomass both in professional and scientific literature. Table 3 presents the lower heating values that were used in this investigation. The heating value is the most important parameter for calculating biomass energy, as it represents the amount of energy that is released in the complete combustion process (Krička *et al.*, 2012; Asakereh *et al.*, 2014). With the view to compare different goals and valorisations of potential social benefits and costs of installing a system of supply and use of agricultural residues in the area of the county, the multi-criteria analysis has been performed. Multi-criteria analysis can be used for determining one most suitable option, for classifying the options or simply for differentiating acceptable and non-acceptable options so that a limited number of options can be short listed for an in-depth assessment. For multi-criteria analysis the goals should be quantifiable, but not necessarily expressed in monetary units. This enables that, in addition to financial and economic costs and benefits, the analysis may include different environmental and social indicators as well.

Three alternative models were numerically assessed by multi-criteria analysis: Model A1, central large biogas production plant; Model A2, biogas plant on individual farms; and Model A3, bioenergy plant in accordance with four criteria.

The additional sub-criteria were added to each of the four criteria, *i.e.*, giving 19 sub-criteria overall. Table 4 shows the selected criteria with sub-criteria according to which the three proposed models were assessed.

The first methodological step in implementing the multi-criteria analysis was to outline the analysis criteria and sub-criteria. The categories of the criteria and sub-criteria were defined in relation to possible influences on the environmental components

Table 2. Number of cattle, pigs, and reared chickens and conversion to livestock units in the County.

Town/Municipality	Cattle	Livestock unit	Pigs	Livestock unit	Reared chicken	Livestock unit
Čakovec	1,346	1,346	10,791	1,619	540,000	1,350
Mursko Središće	112	112	286	43		
Prelog	1,062	1,062	2,435	365	90,000	225
Belica	373	373	8,157	1,224		
Dekanovec	8	8	327	49		
Domašinec	513	513	1,573	236		
Donja Dubrava	1,064	1,064	252	38	90,000	225
Donji Kraljevec	365	365	6,399	960		
Donji Vidovec	32	32	633	95		
Goričan	11	11	405	61		
Gornji Mihaljevec	1,110	1,110	10,116	1,517	460,000	1,150
Kotoriba	2	2	267	40	660,000	1,650
Mala Subotica	422	422	4,345	652	180,000	450
Nedelišće	500	500	10,162	1,524	630,000	1,575
Orehovica	444	444	1,574	236	590,000	1,475
Podturen	526	526	1,946	292		
Pribislavec	117	117	513	77		
Selnica	319	319	379	57		
Strahoninec	192	192	845	127		
Sveta Marija	152	152	851	128	150,000	375
Sveti Juraj na Bregu	503	503	1,129	169	120.000	300
Sveti Martin na Muri	176	176	440	66		
Šenkovec	45	45	983	147	300,000	750
Štrigova	1,000	1,000	2,727	409	360,000	900
Vratišinec	206	206	291	44		
Total	10,600	10,600	67,826	10,175	4,170,000	10,425

in a broader sense (influence on quality of the environmental components, traffic, settlements and population, burden on the environment) in connection to the procedures of agricultural residues management, from generation to final processing of residues. After identification, the assessment was carried out in the way that each criterion was ranked from 1 to 4, where 1 is allocated to the most important criterion. After that the importance of each criterion was defined, by assigning 100 points among four criteria. The weight of a criterion increases with its importance. After that, each sub-criterion is given its

Table 3. Biomass calculation agricultural crops in Međimurje county.

Field crops	Grain mass *vs* biomass ratio	Yield (t/ha)	Biomass	Lower heating value (MJ/kg)
Maize	1:1	4.7	Maize stalk	16.47
Wheat	1:1	3.8	Wheat straw	16.44
Barley	1:1	6.3	Barley straw	17.90
Rapeseed	1:2	2.7	Rapeseed straw	14.62
	Pruned biomass (t/ha)		**Biomass**	**Lower heating value (MJ/kg)**
Apple plantations	1.05		Pruning residues	17.06
Grapevine plantations	0.95		Pruning residues	17.05

Table 4. Categories of criteria and sub-criteria.

Criteria	Sub-criteria
USE OF AGRICULTURAL RESIDUES	Energy independence Rural development Jobs Preservation of fossil fuel reserves Low emission of harmful gases Elimination of environmental issues
ENVIRONMENTAL IMPACT	Impact on air quality Impact on soil Impact on waters Impact on population and human health Impact on land purpose
SELECTION OF PLANT LOCATION	Size of land and access Possible problems with neighbourhood Property rights relative to selected location Vicinity of other plants Accessibility and congestion level of existing thoroughfares
FUNDING	Private funds National funding sources International and EU funding sources

own importance. The importance may refer to any value between zero and maximum importance given to the said criterion. After ranging and assigning the importance to the criteria and sub-criteria, each criterion with sub-criteria was estimated in three models. The estimate was made by a numerical scale (5=excellent, 4=very good, 3=good, 2=poor and 1=very poor). Finally, the result was calculated for each sub-criterion for each model in accordance with its importance and the results were summed up in order to obtain the total. In this work the simple Excel table from the State University of North Caroline was used for ranking (https://projects.ncsu.edu/nrli/decision-making/MCDA.php).

Results and discussion

The main agricultural residues in the area of the Međimurje County are residues from wheat, straw, stalks, leaves, *i.e.*, material which remains in the fields or orchards and vineyards after harvesting or pruning, as well as manure from the livestock production (caws, pigs, and reared chickens). The quantity and energy potential of sustainably available agricultural residues are determined by residues from the crop production, fruit production, vineyards and livestock production.

The available agricultural residues in the Međimurje County from the crop production are wheat straw, barely straw and stalks of maize and rapeseed. Table 5

Table 5. Potential quantity and energy potential of 30% biomass of wheat, maize, barley, and rapeseed in the areas of towns and municipalities of the Međimurje County.

Town/ municipality	Wheat		Maize		Barley		Rapeseed	
	Biomass (t)	Energy (TJ)	Biomass (t)	Energy (TJ)	Biomass (t)	Energy (TJ)	Biomass (t)	Energy (TJ)
Čakovec	626.04	10.29	1,912.68	31.50	337.44	6.04	238.14	3.48
Mursko Središće	329.94	5.42	965.79	15.91	177.84	3.18	137.70	2.01
Prelog	448.38	7.37	2,196.18	36.17	241.68	4.33	398.52	5.83
Belica	245.34	4.03	818.37	13.48	133.38	2.39	25.92	0.38
Dekanovec	31.02	0.51	298.62	4.92	17.10	0.31	25.92	0.38
Domašinec	217.14	3.57	1,436.4	23.66	117.42	2.10	77.76	1.14
Donja Dubrava	188.94	3.11	512.19	8.44	101.46	1.82	157.14	2.29
Donji Kraljevec	290.46	4.77	1,366.47	22.51	156.18	2.79	100.44	1.47
Donji Vidovec	104.34	1.72	402.57	6.63	57.00	1.02	173.34	2.53
Goričan	203.04	3.34	780.57	12.86	109.44	1.96	115.02	1.68

Table 5. Continued.

Town/ municipality	Wheat		Maize		Barley		Rapeseed	
	Biomass (t)	Energy (TJ)	Biomass (t)	Energy (TJ)	Biomass (t)	Energy (TJ)	Biomass (t)	Energy (TJ)
Gornji Mihaljevec	135.36	2.23	992.25	16.34	72.96	1.31	56.70	0.82
Kotoriba	172.02	2.83	527.31	8.68	93.48	1.67	220.32	3.22
Mala Subotica	366.60	6.03	1,793.61	29.54	197.22	3.53	170.10	2.49
Nedelišće	329.94	5.42	2,060.10	33.93	177.84	3.18	213.84	3.13
Orehovica	142.41	2.34	973.35	16.03	76.38	1.37	66.42	0.97
Podturen	184.71	3.04	1,050.84	17.31	100.32	1.79	77.76	1.14
Pribislavec	124.08	2.04	134.19	2.21	67.26	1.20	19.44	0.28
Selnica	201.63	3.31	882.63	14.54	109.44	1.95	17.82	0.26
Strahoninec	135.36	2.22	196.56	3.28	72.96	1.31	16.20	0.24
Sveta Marija	212.91	3.50	585.90	9.65	115.14	2.06	225.18	3.29
Sveti Juraj na Bregu	163.56	2.69	808.92	13.32	88.92	1.59	38.88	0.57
Sveti Martin na Muri	135.36	2.23	670.95	11.05	72.96	1.31	34.02	0.49
Šenkovec	42.30	0.69	321.30	5.29	22.80	0.41	21.06	0.31
Štrigova	70.50	1.16	748.44	12.33	37.62	0.67	8.10	0.12
Vratišinec	183.30	3.01	410.13	6.75	99.18	1.78	50.22	0.73
Total	5,284.68	86.88	22,846.32	376.28	2,853.42	51.08	2,685.96	39.27

shows that the total available residues of wheat grown in the Međimurje County amount to 5,284 t and the energy potential to 86.88 TJ. Total quantity of available after-harvest maize residues, which can be used for energy production in the County area, amount to 22,846 t, and have total energy potential of 376.28 TJ. Total available barley residues amount to 2,853 t, with energy potential of 51.08 TJ. Total available residue for energy production after harvest of rapeseed is 2,686 t, with energy potential of 39.27 TJ.

Pruning is one of the most important measures in the cultivation of orchards and vineyards. Pruning residues are problematic because they must be removed from the production areas and, therefore, they are treated as waste. Most often the pruned biomass is collected and burnt on the spot, *i.e.*, in the orchards and vineyards, or grinded and ploughed in. In this way the pruned residues are wasted as a valuable and quantitatively significant source of heat energy.

In the county area it is possible to collect 4,950.6 t of biomass from orchards, with energy potential of 84.45 TJ. Overall potential for energy production from pruned biomass from the county's vineyards is 4,058.75 t (Table 6).

It is known that livestock production provides manure, used mainly for soil fertilisation, but it can also be used for production of biogas. In the area of the Međimurje County there are breeding capacities for cattle, pigs and chickens. The results show that the largest quantities of manure by livestock unit come from cattle breeding, in amount of 100,594 t/year, which makes 36% of overall annual manure quantity which amounts to 281,233 t/year. Manure from reared chicken production amounts to 98,933 t/year (35% of total manure quantities); pigs manure amounts to 81,705 t/year (29% of total manure quantity). The results show that it is possible to produce 100 TJ of energy from cattle manure, 104 TJ from pigs manure and 180 TJ from chicken manure. In total, manure makes 385 TJ of energy in the area of the Međimurje County (Table 7).

In the Međimurje County a total of 323,912 t of agricultural biomass is available (Fig. 1a): 42,680 t from arable crops production, orchards and vineyards, and 281,233 t from livestock production. The distribution of the overall sustainable availability of residues from production of arable crops, fruits, vineyards and livestock production in the County averages 12,956 t, *i.e.*, it ranges between 886 and 42,556 t.

Total energy value of agricultural biomass in the County area (Fig. 1b) amounts to 1,092 TJ, out of which 707 TJ comes from arable crops, fruit crops and grapes production and 385 TJ from livestock production. In the area of the county, total energy value averages 44 TJ, *i.e.*, it ranges between 7 TJ and 119 TJ.

The largest sustainably available potential of agricultural biomass and, thus, of energy in the area of the Međimurje County consists of biomass from arable crops production, with total quantity of 33,670 t and energy potential of 553 TJ (51%). It is followed by potential biomass from livestock production with total quantities of manure amounting to 281,233 t and energy potential of 385 TJ (35%). The lowest share of potential

Table 6. Potential quantity and energy potential of 100% biomass from vineyards and orchards in the areas of towns and municipalities of the Međimurje County.

Town/Municipality	Vineyards		Orchards	
	Biomass (t)	Energy (TJ)	Biomass (t)	Energy (TJ)
Čakovec	340.00	5.79	516.15	8.80
Mursko Središće	127.50	2.17	249.75	4.26
Prelog	255.00	4.35	715.95	12.21
Belica	140.25	2.39	177.60	3.02
Dekanovec	21.25	0.36	22.20	0.37
Domašinec	119.00	2.03	166.50	2.84
Donja Dubrava	42.50	0.72	61.05	1.04
Donji Kraljevec	127.50	2.17	338.55	5.77
Donji Vidovec	59.50	1.01	88.80	1.51
Goričan	68.00	1.16	127.65	2.17
Gornji Mihaljevec	425.00	7.25	188.70	3.21
Kotoriba	59.50	1.01	105.45	1.79
Mala Subotica	204.00	3.48	271.95	4.63
Nedelišće	216.75	3.69	438.45	7.47
Orehovica	119.00	2.03	144.30	2.46
Podturen	93.50	1.59	127.65	2.17
Pribislavec	38.25	0.65	66.60	1.13
Selnica	89.25	1.52	94.35	1.60
Strahoninec	38.25	0.65	55.50	0.94
Sveta Marija	68.00	1.16	227.55	3.88
Sveti Juraj na Bregu	174.25	2.97	155.40	2.65
Sveti Martin na Muri	102.00	1.73	133.20	2.27
Šenkovec	25.50	0.43	49.95	0.85
Štrigova	1,028.50	17.54	288.60	4.92
Vratišinec	76.50	1.30	138.75	2.36
Total	4,058.75	69.20	4,950.60	84.45

Table 7. Produced quantity of cattle, pigs and chicken manure in the areas of towns and municipalities of the Međimurje County.

Town/Municipality	Cattle		Pigs		Chickens	
	Manure mass (t/year)	Energy (TJ)	Manure mass (t/year)	Energy (TJ)	Manure mass (t/year)	Energy (TJ)
Čakovec	12,773.54	12.73	13,000.57	16.59	12,811.5	23.41
Mursko Središće	1,062.88	1.05	345.29	0.44		
Prelog	10,078.38	10.04	2,930.95	3.74	2,135.25	3.90
Belica	3,539.77	3.52	9,828.72	12.54		
Dekanovec	75.92	0.07	393.47	0.5		
Domašinec	4,868.37	4.85	1,895.08	2.41		
Donja Dubrava	10,097.36	10.06	305.14	0.38	2,135.25	3.9
Donji Kraljevec	3,463.85	3.45	7,708.80	9.83		
Donji Vidovec	303.68	0.30	762.85	0.97		
Goričan	104.39	0.10	489.83	0.62		
Gornji Mihaljevec	10,533.9	10.5	12,181.51	15.54	10,913.50	19.94
Kotoriba	18.98	0.01	321.20	0.40	15,658.50	28.61

Table 7. Continued.

Town/Municipality	Cattle		Pigs		Chickens	
	Manure mass (t/year)	Energy (TJ)	Manure mass (t/year)	Energy (TJ)	Manure mass (t/year)	Energy (TJ)
Mala Subotica	4,004.78	3.99	5,235.56	6.68	4,270.50	7.80
Nedelišće	4,745.00	4.73	12,237.72	15.61	14,946.75	27.31
Orehovica	4,213.56	4.20	1,895.08	2.41	13,997.75	25.58
Podturen	4,991.74	4.97	2,344.76	2.99		
Pribislavec	1,110.33	1.10	618.31	0.78		
Selnica	3,027.31	3.01	457.71	0.58		
Strahoninec	1,822.08	1.81	1,019.81	1.3		
Sveta Marija	1,442.48	1.43	1,027.84	1.31	3,558.75	6.50
Sveti Juraj na Bregu	4,773.47	4.75	1,357.07	1.73	2,847.00	5.20
Sveti Martin na Muri	1,670.24	1.66	529.98	0.67		
Šenkovec	427.05	0.42	1,180.41	1.50	7,117.50	13.00
Štrigova	9,490.00	9.46	3,284.27	4.19	8,541.00	15.61
Vratišinec	1,954.94	1.94	353.32	0.45		
Total	100,594.0	100.15	81,705.25	104.16	98,933.25	180.76

biomass are pruning residues in fruit and grapevine production with total available residual quantity of 8,109 t and energy potential of 154 TJ (14%). The Međimurje County has 72,926 ha of land, out of which the arable agricultural surfaces occupy 34,989 ha, or 48% of the total county's land. It can be asserted that the Međimurje County has a large potential for food production. In addition to food production, it has a great potential for production of energy from agricultural residues.

Only the existing biomass, that is obtained from fruit and grapevine pruning, residues from arable crops and residues from livestock production, amounts to 323,912 t. From this 30% of total quantities it is possible to generate energy value of 1.092 TJ. The existing values alone could provide the feedstock for energy production, while it should be kept in mind that the potential of the county's agriculture is much larger. It is expected that it will be used for economic and environmental development of the county.

Total sustainably available biomass from crops can be efficiently used for production of energy, heat, biogas or biofuels, giving due consideration to the sustainability of utilisation of unused residues. On the basis the presented results regarding the availability of agricultural residues in the county the estimate was made of three models proposed for utilisation of residues from agricultural production in the area of the county. Table 8 shows the results of the estimation for the three proposed models.

The results show that best ranked is Model A1 (central large plant for biogas production) with 1,475 points, followed by Model A3 (bioenergy settlement) with 1,254 points, and Model A2 (biogas plant on individual farms) with 1,161 points (Fig 2.).

Model A1 performs best, *i.e.*, best satisfies the given interest, in the criterion *Selection of plant location* with 590 points, then in the criteria *Impact on the environment* (336 points), *Funding* (308 points). Its lowest performance is in the criterion *Utilisation of agricultural residues* (185 points).

Model A2 has the same performance in the same criteria as Model A1, but with different points: *Selection of plant location* with 600 points, *Impact on the environment* (241 points), *Funding* (176 points) and *Utilisation of agricultural residues* (144 points).

Model A3 also performs best in the criterion *Selection of plant location* with 520 points; in the criterion *Funding* this model has 308 points; then 241 points in the criterion *Impact on the environment* and 185 points in *Utilisation of agricultural residues* (Fig 3.).

As demonstrated above, the criterion *Selection of plant location* is best ranked with all three models, but its score is highest in Model A2. Within this criterion, in all three models, the sub-criterion *Possible problems with neighbourhood* has the highest rank, followed by the sub-criterion *Vicinity of other plants* in Model A1 and Model A2, while in Model A3 the sub-criterion *Land size and access* ranks highest. In this criterion category the lowest ranking is realised in Model A1 and the sub-criterion *Accessibility and congestion level of the existing thoroughfares;* in the model A2 the lowest is the sub-criterion *Land size and access* and the sub-criterion *Vicinity of other plants* in Model A3.

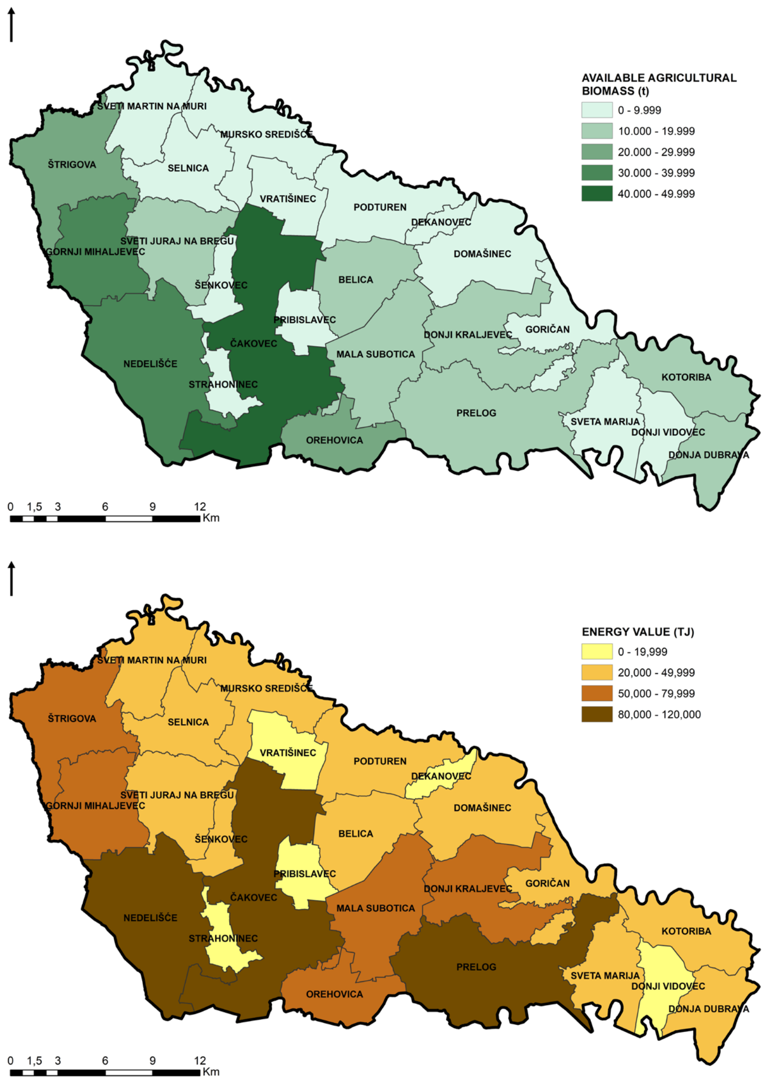

Figure 1. Distribution of total sustainably available quantities (a) and energy potential (b) of agricultural residues in areas of towns and municipalities of the Međimurje County.

Table 8. Results of the estimate of the most suitable model for utilisation of agricultural residues in the Međimurje County.

Categories of criteria and sub-criteria	Model		
	A1	A2	A3
UTILISATION OF AGRICULTURAL RESIDUES	241	144	185
Energy independence	25	15	20
Rural development	32	16	24
Jobs creation	72	54	54
Preservation of fossil fuels reserves	60	30	45
Low emissions of harmful gases	40	20	30
Elimination of environmental issues	12	9	12
IMPACT ON THE ENVIRONMENT	336	241	241
Impact on air quality	100	75	75
Impact on soil	60	30	30
Impact on waters	80	40	40
Impact on population and human health	66	66	66
Impact on purpose of land	30	30	30

Table 8. Continued.

Categories of criteria and sub-criteria	Model		
	A1	**A2**	**A3**
SELECTION OF PLANT LOCATION	590	600	520
Land size and access	120	60	120
Possible problems with neighbourhood	140	175	140
Property rights of the selected location	105	140	105
Vicinity of other plants	125	125	75
Accessibility and congestion level of existing thoroughfares	100	100	80
FUNDING SOURCES	308	176	308
Private funds	88	88	88
National funding	110	44	110
International and EU funding	110	44	110
TOTAL	1,475	1,161	1,254

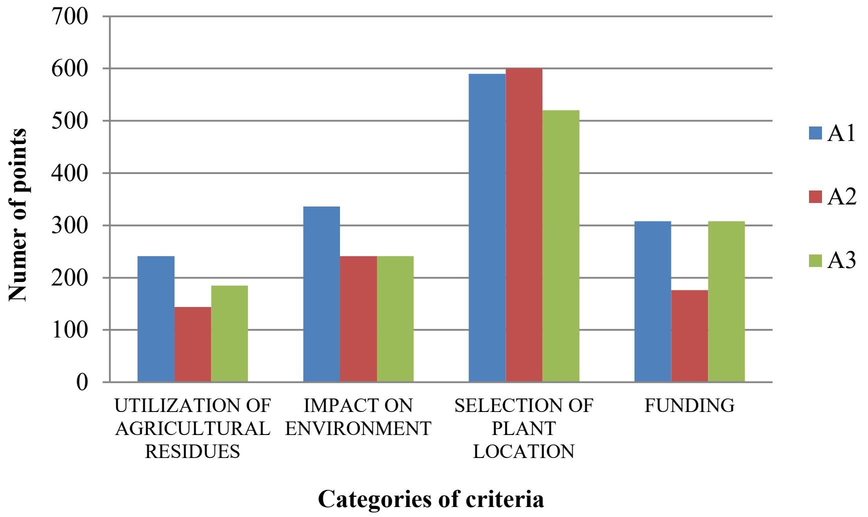

Figure 2. Overview of distribution of criteria on the three estimated models.

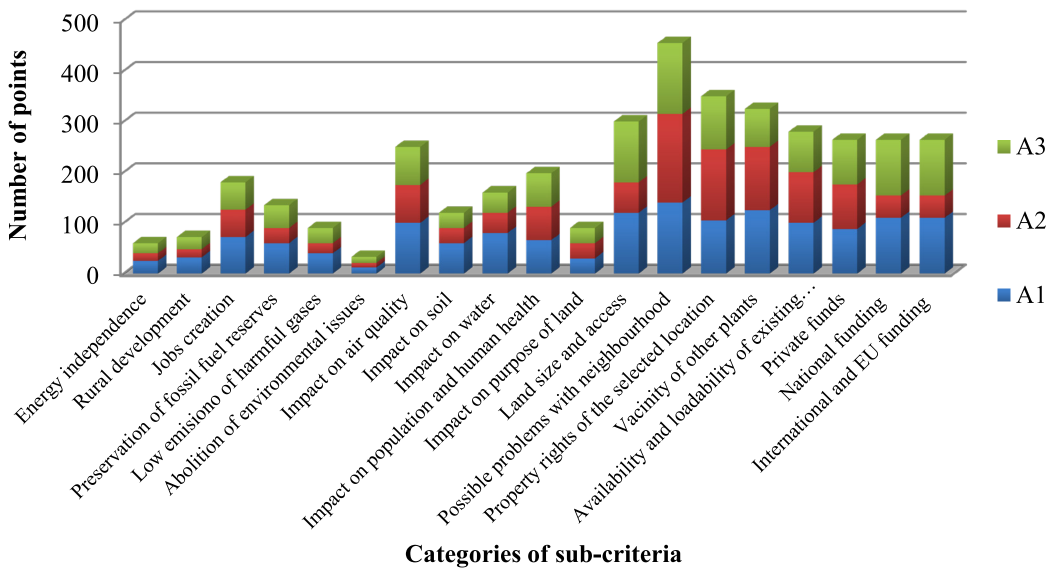

Figure 3. Overview of distribution of sub-criteria on the three estimated models.

In the criterion *Impact on the environment*, the sub-criterion *Impact on air quality* has the highest ranking in all three models. The least number of points in all three models has the sub-criterion *Impact on purpose of land*. In the criterion *Utilisation of agricultural residues* the sub-criterion *Jobs creation* has the highest ranking in all three models, while the sub-criterion *Elimination of environmental problems* ranks lowest in all three models. In the criterion *Funding* the sub-criterion *Private funds* has the lowest points in Model A1 and Model A3, while in Model A2 two sub-criteria, *National funding* and *International and EU funding*, have the lowest number of points, *i.e.*, they have same number of points. Figure 3 shows the distribution of all sub-criteria in the estimation of the three models.

In the three proposed models, the best ranked Model A1 represents a central plant for biogas production, as it best satisfies the interest regarding the possible problems with the neighbourhood, vicinity of other plants, size of and access to land, funding issues, property right of the location, impact on air quality and accessibility and congestion of the existing thoroughfares, while it has the lowest capacity to satisfy the interests in relation to elimination of environmental problems, energy independence, impact on purpose of land, rural development and low harmful gases emission. In other two proposed models of using agricultural residues in the Međimurje County the results show the highest fulfilment of the interest in relation to the sub-criteria within the criterion *Selection of plant location* and *Funding*, and the lowest fulfilment of the interests related to *Utilisation of agricultural residues* and *Impact on the environment*.

The results show that the agricultural residues have potential to play a vital role in energy supply and the potential of residues from agricultural production has been inadequately and ineffectively utilised in the local energy supply and the economic development of the Međimurje County. In the county's area, overall quantities of agricultural biomass amount to 323,912 t/year, out of which 42,680 t/year is biomass from arable crops, fruit and grapevine production, and 281,233 t/year biomass from livestock production. The results demonstrate that total energy potential of agricultural biomass amounts to 1,092 TJ annually, out of which 707 TJ coming from arable crops, fruit and grapevine residues, and 385 TJ from biomass from livestock production.

After estimating the three models of agricultural residues utilisation it results that a central large biogas production plant appears would be the most suitable solution.

Energy from agricultural residues offers the possibility to enhance the rural development and environmental protection, which means that a large part of electricity and heat energy demand can be met by locally produced biomass and other renewable energy sources. In this way the added value stays in the local community and provides support for local and regional economic development.

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