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Evaluation of Croatian agricultural solid biomass energy potential

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ABSTRACT

Agricultural solid biomass has been widely recognized as an important source of renewable energy with huge production potential. The utilisation of agricultural solid biomass as feedstock for energy production is continuously growing all over Europe. As shown in the current country's balance of energy production and consumption, Croatia is highly dependent on imported fossil fuels. The aim of this paper is to determine the available agricultural solid biomass and its energy potential in Croatia. The quantity and energy potential of solid biomass refer to post-harvest residues, pruning residues, agro-industrial solid waste and biomass from *Miscanthus* energy crop. In relation to potentially available agricultural biomass, three scenarios have been developed (progressive – S1, optimistic - S2, and conservative – S3) of introducing solid biomass in the renewable energy production sector. On the basis of these scenarios, it can be concluded that in Croatia the following quantities of agricultural biomass are available: 3050.3 t (S1); 1441.8 t (S2); and 733.68 t (S3). These quantities give energy potential of 51.14 PJ (S1), 24.06 PJ (S2), and 12.18 PJ (S3) respectively.

1. Introduction

Sustained population growth will remain a key driver of increasing energy demand, along with economic and social development. Although conventional fossil fuels (e.g., coal, oil and natural gas) are the prime sources of energy worldwide, they do not offer sustainability for longer period, especially for countries which do not have abundant fossil fuel reserves [1]. According to the objectives of the 2030 Framework for Climate and Energy and the 21st UN conference on climate change and Paris Climate Agreement, renewable energy sources are described as one of the most important segments not only for realisation of energy self-sufficiency but also for mitigating climate changes by lowering greenhouse gas emissions [2]. The use of biomass as renewable energy source in the energy sector is constantly growing due to a number of factors such as need for alternative energy sources, increased government initiatives for renewable energy technologies, substantial untapped biomass potential and low emissions [3].

Energy generated from the biomass production is currently the fourth most common energy source in the European Union, after nuclear energy, other types of renewable energy and solid fossil fuel energy. Compared to the primary production of renewables in the European Union, biomass energy has the largest share, of 63.11% (123,592 ktoe), and is followed by hydro energy with a share of 16.46% (32,242 ktoe) and wind energy with a share of 11.11% (21,768 ktoe) [4].

The biomass resources can be considered as a promising solution to the problems related with thermal power resources such as coal that are major source of environmental pollution [3].

In a longer perspective, more biomass must be expected to be converted to energy services in the EU countries to meet the long term targets. The demand for biomass for energy in the European Union will increase from the current 5.7 EJ yr^{-1} to 10.0 EJ yr^{-1} by 2020. Demand for biomass will probably increase also beyond 2020, and not only in Europe [5].

Biomass as a renewable energy source is almost CO_2 neutral, and average heating value of bioenergy crops is comparable to that of brown coal. In general, by substituting coal with biomass it is possible to achieve a 93% decrease of net CO_2 emission per unit of heating value and an 84% decrease of this emission by using CHP process where natural gas would be replaced with biomass [6].

The main processes for obtaining energy from biomass include direct combustion, pyrolysis, gasification, hydro gasification, liquefaction, anaerobic digestion, alcoholic fermentation and trans-esterification. Each technology has its own advantages, depending on the biomass source and the form of energy needed [7]. Combustion is the most important technology used for producing heat and energy from

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Table 1
Biomass production from arable crops and energy potential in Croatia (average annual values 2010–2015).

Biomass source	Area (ha)[11]	Grain yield (t ha^{-1}) [11]	Mass ratio (t t^{-1})	Biomass yield (t ha^{-1})	Available biomass for energy $Ab_{50\%}$ (t ha^{-1})	LHV (MJ kg^{-1}) [18,19]	Energy potential $Ab_{50\%}$ (MJ ha^{-1})
Maize	284,327	6.35	1:1	6.35	3.18	16.47	52,292
Wheat	167,814	4.83	1:1	4.83	2.42	16.44	39,730
Barley	50,234	3.88	1:1	3.88	1.94	17.90	34,756
Sunflower	33,359	2.77	1:2	5.54	2.77	17.78	49,191
Soy	58,765	2.40	1:2	4.80	2.40	15.75	37,800
Rapeseed	17,811	2.65	1:2	5.30	2.65	14.62	38,743

biomass. It is a process with a number of economic and environmental benefits [8]. It is generally recommended that the biomass electrical plant and the raw material generation point be located within a distance of 80 km [9].

According to the Annual energy report of Croatia [10], in the period 2010–2015 average energy consumption was 414.7 PJ with primary energy production of 236.5 PJ; in the same period average import of energy amounted to 277.3 PJ, while 101.6 PJ was average export of energy. Out of total energy consumed, about 67% was imported, while 57% of primary energy was produced in Croatia (a part of primary energy production is included in exported energy). These data make it evident that Croatia is an energy dependent country and that it demands to increase energy production in order to achieve energy stability and enhance its energy self-sufficiency. In 2013 Croatia became a member of the European Union, and since then the production of renewables started to grow significantly, with the aim to meet climate and energy goals of the European institution. Out of total primary energy production, the largest portion comes from natural gas (72.22 PJ), followed by hydro power (69.61 PJ) and fuel wood and biomass (59.81 PJ).

Croatia is a small country in southeast Europe whose area is approximately 56,594 km^2, but 52% of total territory is agricultural land. In the continental part of the country, the largest part of the agricultural land is used for arable crops production, while in the coastal area prevail viticulture, olive groves and orchards. Of total arable surfaces in Croatia, about 80% of the land is under maize, wheat, soybean, sunflower, and rapeseed, while of perennial crops the most common ones are grapevine, olive, apple and plum [11].

Given the fact that the use of biomass for energy mainly involves woody biomass, there is a demand for biomass of agricultural origin. Agricultural solid feedstock includes: arable crops residues, pruned biomass, agro-industrial waste and biomass obtained by cultivation of energy crops.

Based on the available data, it is considered that almost one third of the agricultural land is not in use, which opens the possibility of introducing energy crops in agricultural production without creating competition between food and energy. In cultivation of lignocellulosic energy crops the focus should be put on utilisation of the abandoned agricultural land. According to the digital CLC database [12], total abandoned agricultural land in Croatia amounts to 541,930 ha, which represents a great potential for introducing energy crops without affecting the existing agricultural production. There are many ecological advantages of perennial crops production, such as reduced soil erosion, soil carbon storage, and high nutrient-use efficiency [13]. Perennial grass *Miscanthus x giganteus* is one the most often investigated energy crops both in Europe and in Croatia.

The aim of this investigation was to determine energy potential of the available agricultural biomass from post-harvest residues, orchard pruning residues, agro-industrial solid waste and energy crop *Miscanthus* in Croatia. Three scenarios (progressive, optimistic and conservative) were developed to analyse the effects of introducing biomass in the renewable energy sector. Given the fact that in Croatia forest biomass is currently the only raw material used for producing energy from solid biomass, based on each scenario the specific aim of this study is to determine (I) potential increase of total energy produced as well as of energy from forest biomass using agricultural biomass as fuel (II) introduction of the grass *Miscanthus* as energy crop on the abandoned land in Croatia.

2. Assessment of agriculture biomass and energy potential in Croatia

2.1. Arable crops residues

Soil is a non-renewable natural resource, and therefore it should be managed in a sustainable way. Organic matter, such as arable crop residues, is the most important factor which defines soil fertility. It is important to note that arable residues, except for the purpose of maintaining soil organic matter, must meet the demands of animal farming and contribute to reducing erosion and evapotranspiration. Although there is no agreement on the percentage of herbaceous residues available for energy production, some authors [14–17] state that 25–50% of biomass can be used for this purpose. The residues are dried naturally in order to reduce the water contents from 30–50% to 20% and this process can be carried out in the open fields [3]. The available quantity of biomass is estimated on the basis of harvest ratio which, for most of cereal crops and oilseed crops is 1:1 / 1:2. These ratios represent the approximate values, which are related to agro-ecological specificities of the cultivation area and agro-technical measures applied during the arable crops cultivation. Lower heating value differs from one crop to another and depends on composition, content of combustible and non-combustible elements, total amount of ash and moisture. In arable crops LHV is from 14.6 to 17.9 MJ kg^{-1} [18,19]. Table 1 shows surfaces, average yields, mass ratio, potentially available biomass yields, lower heating values and energy potential of the most represented arable crops in Croatia.

In Croatia, approximately 80% of total agricultural land is under arable crops, which gives a total of 3372.205 t of biomass annually. The presented values of available arable crop biomass for energy production as well as energy potential are based on 50% total available biomass (Table 1). The presented data show that maize, as the most commonly grown crop in Croatia, could give the largest amount of energy per hectare (52,292 MJ ha^{-1}). Furthermore, the highest energy yield per hectare can be achieved by using biomass from sunflower (49,191 MJ ha^{-1}) and wheat (39,730 MJ ha^{-1}). However, sunflower is grown on significantly smaller agricultural surfaces than wheat, so, wheat, together with maize, represents the most important crop in utilisation of biomass for energy.

2.2. Pruned biomass

Orchards and vineyards must be pruned on annual basis. This operation results in large amounts of biomass that are potentially available as a source of bioenergy. The residues generated from orchards and