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Economic feasibility of CHP facilities fueled by biomass from unused agriculture land: Case of Croatia

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ABSTRACT

In this paper, the energy potential of biomass from growing short rotation coppice on unused agricultural land in the Republic of Croatia is used to investigate the feasibility of Combined Heat and Power (CHP) facilities fueled by such biomass. Large areas of agricultural land that remain unused for food crops, represent significant potential for growing biomass that could be used for energy. This biomass could be used to supply power plants of up to 15 MW_e in accordance with heat demands of the chosen locations. The methodology for regional energy potential assessment was elaborated in previous work and is now used to investigate the conditions in which such energy facilities could be feasible. The overall potential of biomass from short rotation coppice cultivated on unused agricultural land in the scenarios with 30% of the area is up to 10 PJ/year. The added value of fruit trees pruning biomass represents an incentive for the development of fruit production on such agricultural land. Sensitivity analysis was conducted for several parameters: cost of biomass, investment costs in CHP systems and combined change in biomass and technology cost.

1. Introduction

In the European Union's (EU) struggle to achieve the energy package goals in 2020, in particular increasing the share of the EU energy consumption produced from renewable resources to 20%, biomass has a very significant position with 68% share of total gross inland consumption of renewable energy in 2011 and 8.4% of total final energy consumption in Europe in 2011. At the same time biomass is almost exclusive renewable fuel for heat with 95.5% share [1]. In Croatia, besides being widely used for domestic heating in rural areas, biomass is a dominant renewable resource in the most recent National Renewable Energy Action Plan, with a planned contribution of 26 PJ and 85 MW of capacity in 2020 [2]. These ambitious goals rest on biomass due to its socio-economic potential in Croatia, which is higher compared to the other renewable resources because of Croatia's forest and land potential. Croatia has problems with unemployment, similarly to some other countries in the EU, and at the same time large areas of unused agricultural land, both in public and private sectors. Extensive research has been conducted so far on the marginal land use for growing crops for biomass and biofuels [3]. Today, overall agricultural land in Croatia amounts to 2,955,728 ha. Out of that, 1,074,159 ha is considered suitable, 1,074,510 ha is considered to be of limited suitability and 806,328 ha is listed as unsuitable for agricultural production [4]. In order to fulfil its goals regarding renewable energy sources integration, while making a change and progress in other mentioned fields, Croatia might resort to Short Rotation Coppice (SRC), a form of cellulose biomass that has already been developed for energy use in some other countries of the EU. Previous research in this field in EU countries focused on annual yields [5] and most favorable species [6], and impact on soil [7] and biodiversity [8]. These energy crops are eligible for cultivation on a wide range of soils that are of limited suitability or unsuitable for agricultural production. Initial studies have already been carried out in the field of choosing the optimal clones of willow and poplar. These species are common in Croatia and thus most relevant candidates for use on larger scale, as shown for white willow [9], with respect to the issue of marginal land [10] and to the way appropriate clones of willow are chosen [11]. Moreover, initial research has been carried out to frame the overall potential of marginal land on the whole territory of Croatia [12]. Although there are some experimental fields of willow being

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studied, there is no commercial SRC farm currently in Croatia. Recent study discussed the uptake of the SRC by the farmers in Europe [13], which demonstrated that the potential profitability of SRC is not yet recognized, while the study of economics of SRC in continental Europe gives the roadmap toward the increase in feasibility compared to other types of crops [14].

The usage of SRC, as well as other energy crops started in Scandinavian countries right after the oil crisis in the 1970s. Production chains with energy crops are well developed in Sweden, Finland, the UK and Denmark and are making progress in countries of Central and South Europe. Recent data on areas under various energy crops is given in Table 1.

Important part of energy transition toward systems based on renewable energy sources is district heating with combined heat and power (CHP) plants using biomass as the energy source. Because of their importance, a lot of research has been conducted recently to investigate the application of these types of solutions. In [15] results for three variants of combined heat and power (CHP) biomass plants were calculated. Kilkis [16] developed a model for the net-zero exergy district development for a city in Sweden, which among other units includes a CHP plant with district heating and cooling system. Krajačić et al. [17] provided an overview of potential feed-in tariffs for different energy storage technologies. Wang et al. [18] published a paper dealing with multi-objective optimization of a combined cooling, heating and power system driven by solar energy. Raine et al. [19] optimized combined heat and power production for buildings using heat storage. Mikulandrić et al. [20] examined the possibilities of a hybrid District Heating (DH) systems in small towns, with advantages in lower cost when the system is powered by renewable energy. Recently, the study of biomass CHP and DH applications in the urban areas being competitive with natural gas was conducted in Pantaleo et al. [21], with detailed sensitivity analysis conducted in a separate paper [22]. In Rudra et al. [23], the research goes further to propose more complex novel polygeneration systems based on biomass utilization, which increases the efficiency of resource utilization, minimizes the impact on the environment due to distributed generation and, through flexible operation, supports the integration of renewable energy [23]. Research in the use of biomass for CHP systems is well connected to the overall goal to achieve energy systems with 100% energy produced from the renewable sources. In the recent research regarding the possibility of 100% renewable energy system in the whole SEE, biomass is viewed more conservatively than before, with the energy potential of 726 PJ/year for the entire region. The use of SRC could increase this potential further [24].

In this paper, the research builds upon the current state-of-the-art scientific work by showing how unused agriculture land in Croatia could be used to cultivate SRC, which later could be used as fuel in the CHP plants. This is considered firstly for a novel system that combines cooling, heating and power and is supplied by storage. Further elaboration is conducted regarding feasibility of such system and the sensitivity analysis of the most important factors.

2. Metodology

Short rotation coppice species are perennial species which have a lifetime of 15–20 years, depending on the species, and are usually harvested every 2–8 years. In order to have continuous output of biomass for energy plants each hectare of agricultural land deemed to be at the disposal is divided into three fields, with the assumption that in every rotation only one field would be harvested, so that one hectare supplies biomass continuously during the lifetime of the species [25]. Therefore, the technical potential of the respective county or region is calculated in Eq. (1):

Table 1
Cellulosic energy crops in EU in 2011 [1].

	Willow (ha)	Poplar (ha)	Miscanthus (ha)
AT	220–1100	880–1100	800
BE	60		120
DK	5697	2807	64
FR	2300		2000–3000
DE	4000	5000	2000
IE	930		2200
IT	670	5490	50–100
LT	550		
PL	5000–9000	300	
SE	11,000	550	450
UK	1500–2300		10,000–11,000

$$\sum_{i=1}^{n} B_{teh}(i) = \sum_{i=1}^{n} (A(i) * P_y(i) * k + A_f(i) * P_f(i)) \tag{1}$$

where $B_{teh}(i)$ is the technical potential of the county (i) (t), $A(i)$ is the area of unused agricultural land at the disposal (ha), $P_y(i)$ is the yearly production of biomass from the species used on the area A in (t/year) and k is the factor of rotation which determines the pace of harvesting. For every species or clones, factor k can be arbitrated according to the location in question. Furthermore, $A_f(i)$ is the area of the county (i) under fruit trees (ha) and $P_f(i)$ is the yearly production of biomass from pruning of the fruit trees (t/year).

The energy potential of the respective county or region is calculated with the assumption that the obtained biomass is stored after harvesting and finally reaches the gate of energy plant with moisture value of 30% and lower heating value of 3.5 kW h/kg respectively [26]. The energy potential is calculated in Eq. (2):

$$B_{ep(i)} = B_{teh(i,SRC)} * Hd_{SRC} + B_{teh(i,fruit)} * Hd_{fruit} \tag{2}$$

where $B_{ep(i)}$ is the energy potential (GJ/year) of the county (i) and Hd_{SRC} is the lower heating value of the biomass from SRC at the gate of energy plant (GJ/t), while $B_{teh(i,fruit)}$ is the technical potential of biomass from fruit trees pruning (t/year), $B_{teh(i,SRC)}$ is the technical potential of biomass from SRC (t/year) and Hd_{fruit} is the average lower heating value of biomass from fruit trees pruning (GJ/t).

For the calculation of the price of biomass at the gate of power plant, the method from [27] was used in Eq. (3). The price of biomass as a function of the SRC farm distance from the power plant is calculated:

$$C_{B,E} = \sum_{i=1}^{n} \frac{[C_B + (T_p \times U_i)] \times K_{Bi}}{P_B} \tag{3}$$

where $C_{B,E}$ is the price of biomass at the gate of power plant (€/t), C_B is the price of biomass harvested from the SRC farm (€/t), T_p is the specific cost of transport (€/t/km), U_i is the average distance between the farm and power plant (km), K_{Bi} is the amount of biomass from the location (i) (t), P_B is the total yearly amount of biomass used by the power plant (t).

For the purpose of gaining a better insight into regional differences in potential, which is crucial for economic viable choice of location for both SRC farms and biomass power plants, the scenario approach has been adopted. Various percentages of unused agricultural areas have been taken into account and the difference between public and private agricultural land has been considered in order to benefit the future research of different operational and maintenance costs of SRC farms. The farms can be run by hired workforce and mechanisation compared to private landowners that can use their own, slightly modified mechanisation and labor, which might lower the costs significantly.

The cost of the biomass harvested from the SRC farm is calculated according to Eq. (4) [12,25]:

$$C_B = T_S + T_Z + T_{O\&M} \tag{4}$$

where T_S is the cost of seeding material (€/ha), T_Z is the cost of land cultivation and $T_{O\&M}$ is the cost of labor and harvesting in the life cycle of species. Typical costs in Europe are shown in Table 2. The selling price is expressed in Euro per ton of dry matter (DM).

In each scenario, a combination of SRC, predominantly willow and fruit cultures, will be considered for the production of biomass. For the calculation of biomass costs at the respective power plants' gate and the Net Present Value (NPV) for each location, a code programmed in MATLAB has been used. It is an original code from [25], altered in order to take into account unused agricultural land instead of forests and forest residue. The model develops a network of quadrants with each quadrant representing an area of 1 km^2. The model calculates the average price per tonne of biomass ($C_{B,E}$) in each quadrant, and selects the most appropriate site. The code firstly positions in a particular quadrant and then calculates the amount of biomass resources which are sorted according to the distance. Biomass being closer has an advantage over the more distant biomass until it reaches the last source of biomass to be taken. For the most favorable location it lists the correct order of the sources, which it takes the biomass from with the amount of biomass taken from each source. Due to the simple assignment of input data, a piece of code that selects the waste biomass from wood processing industry can be easily modified if there is another potential source of biomass, such as agricultural land planted with SRC. All locations are given in the form of geographical coordinates: latitude and longitude. Distances between specific coordinates of the model are calculated using the Haversine formula, which takes the Earth as a sphere, ignoring the effects of the ellipse.

The Haversine formula has been first used in the beginning of the 19th century. The formula calculates the distances between the two points on a sphere using the spherical triangles. Thus, simplifying the Earth's shape as a sphere instead of an ellipsoid, the Haversine formula can be used. Due to the relatively short distances between different areas in the model, this simplification doesn't influence the result significantly since the mistake never goes beyond 0.5% [28].

3. Case study Croatia

Macro-locations for power plants have been chosen according to local heat demands obtained from the Sustainable Energy Action Plans (SEAP) of the cities considered. In each location that was considered, heat demand was taken from the SEAP and used as a base for calculation of the required CHP installed capacity, which was 15 MW_e and 30 MW_t for each location being investigated.

Since there are no commercial SRC farms in Croatia so far, the price of biomass from such a farm was calculated including the establishment of the farm, yearly expenses for workforce and mechanisation and yearly production of biomass from the hectare of area, taking into consideration various soil quality and suitability. Investment, operation and maintenance costs were estimated to be 6267 €/ha for the whole life cycle of 12 years of willow cultivation, achieving 12 t_{DM}/ha/year or 144 t_{DM}/ha in the life cycle of the SRC farm. Therefore, C_B of biomass from such a farm was estimated to be 43.47 €/t [12]. In the case of willow, a 3-year rotation has been selected for the calculation. Using state owned land (through land concession or other instruments) is beneficial from the point of view of ownership, which is often a great barrier for any area intensive project in Croatia, since private land is often shared by multiple owners. On the other hand, at locations where private land could be utilized without a very costly and time consuming process of dealing with ownership problems, the costs of land and mechanisation could be lower, presenting the investors with the opportunity to reach the scenarios presented in sensitivity analysis, making the SRC production feasible.

Table 2
Typical costs for SRC farms [12,30].

Location	Species	Cultivation costs (€/ha)	Operation costs (€/ha/y)	Selling price (€/t_{DM})
Sweden – Nynas Gard	Willow	1222	330	65
Sweden – Puckgarden	Willow	1110	265	52
Latvia	Willow	1450	n/a	n/a
Latvia – Salixenergi	Willow	1630	480	n/a
France– Bretagne	Willow	2545	355	n/a
Germany – Goettingen	Poplar	2750	250	65
Italy – Rinnova	Poplar	2320	875	55
Croatia	Willow	3916	196	43.47

In order to make comparison, as well as to preserve biodiversity and encourage production in the region, biomass from fruit trees pruning was also taken into account in the scenarios. The amount of biomass from fruit trees was calculated according to [29]. Table 3 reports on how much biomass could be obtained by pruning of plantations of respective fruit cultures. The combustion of other types of biomass with biomass from SRC is considered desirable at this stage in the practice of Central European countries [30].

The separate issue is the statistical coverage of unused agricultural land. It has been followed through yearbooks of the National Bureau of Statistics until the year 2005, when due to the adjustment to the European standards in statistics, unused land was no longer published as a dataset. In the year 2009, a new Agency for Agricultural Land was founded and started to review data on state-owned agricultural land.

Their newest findings were used here to calculate available agricultural land in each county. For private unused agricultural land, data from the Statistical Yearbook 2004 of the National Bureau of Statistics was used. Although the difference of 10 years in datasets could cause some inaccuracies, assumptions in the scenarios were conservative enough to make sure that the calculated technical potential could be actually achieved [31]. In Table 4 the data on unused agricultural land is provided [32].

Private land stands for exclusively private-owned land, while the state-owned land is in the ownership of local self-government or the companies such as the Croatian Forests, owned directly by the country of Croatia. The difference is significant due to the state of the land, concerning the ownership by private citizens, which usually makes the land on the same location more fragmented and causes significant practical difficulties for anyone trying to put the land into use.

For the case study of Croatia, scenarios were devised as follows:

SCENARIO 1 – 30% of unused agricultural land was used to cultivate willow SRC. The scenario was divided according to the ownership to show the difference in local potential when:

(1a) 30% of state-owned land was used
(1b) 30% of private land was used
(1c) 30% of aggregated state-owned and private land was used

SCENARIO 2 – 20% of unused agricultural land was used to cultivate willow SRC. The scenario was divided according to the ownership to show the difference in local potential when:

(2a) 20% of state-owned land was used
(2b) 20% of private land was used
(2c) 20% of aggregated state-owned and private land was used

Table 3
Biomass from fruit trees pruning [29].

	Total biomass (kg/ha)
Fruit trees	
Apple	5571.43
Pear	5833.33
Peach and nectarine	2921.21
Apricot	1619.58
Cherry (sweet and sour)	1783.07
Plum	2053.15
Fig	1281.12
Dry fruit trees	
Walnut	538.04
Hazelnut	1848.48
Almond	1625.17
Grape	
Total	4258.37
Olive	
Total	2522.22

Table 4
Unused agricultural land divided according to ownership [25,32].

County	Public (ha)	Private (ha)
Krapina-Zagorje	115.27	1783
Varazdin	1009.79	1469
Medjimurje	1702.89	2910
Koprivnica-Križevci	2563.36	987
Osijek-Baranja	3826.71	5316
Vukovar-Srijem	4445.69	2662
Virovitica-Podravina	7019.16	5221
Zagreb	7989.94	8890
Bjelovar-Bilogora	9974.94	15,476
Požega-Slavonia	15,391.35	12,875
Brod-Posavina	19,689.77	7326
Karlovac	32,767.84	82,259
Sisak-Moslavina	33,733.16	57,412

SCENARIO 3 – 10% of unused agricultural land was used to cultivate willow SRC. The scenario was divided according to the ownership to show the difference in local potential when:

(3a) 10% of state-owned land was used
(3b) 10% of private land was used
(3c) 10% of aggregated state-owned and private land was used

SCENARIO 4 – 20% of unused agricultural land was used to combine cultivation of willow SRC with the increase in production of the most widespread fruit sorts in Croatia (apple, pear, peach, cherry, plum, walnut and hazelnut) according to the data from [33]. The scenario was divided according to the ownership to show the difference in local potential when:

(4a) 20% of aggregated state-owned and private land was used, divided to achieve a 100% increase in areas under most widespread fruit sorts and to use the rest of the area for SRC cultivation.
(4b) Same as in 4a, but with a goal to achieve a 50% increase in areas under fruit sorts.
(4c) Same as in 4b, but with a goal to achieve a 25% increase in areas under fruit sorts.

District heating systems powered by the acquired biomass ran on novel Combined Heat and Power (CHP) plant, in order to meet as much energy demand as possible. For this case study, data from Table 4 was calculated as the base data of the CHP plant. The District Heating System (DHS) includes heating grid and heat storage to allow the plant to extend its availability during months with lower heat demand and to enable peak shaving.

Recently, following the European Commission's recommendation, a new form of subsidizing the investment in renewable energy sources has been implemented in Croatia. Instead of feed-in tariffs used before, a feed-in premium has been approved to be the main scheme for subsidizing renewables [34]. It is expected that a tender will be called for filling in the quotas set for specific technology in which the offer with the lowest feed-in premium will be chosen. However, as the procedure is only in the starting phase, the range of offers that will be offered is still unclear. Thus, the best approximation can be found in Dominković et al. [35]. The calculated feed-in premium should be around 0.085 €/kW h of electricity supplied to the grid in order that subsidy level remains in the same range as it was the case with feed-in tariffs. For this case study, the level of subsidy is given in Table 5.

In Fig. 1, the simulated behavior of the CHP plant on the market is given. The blue[1] line is the income from the market, according to the Nordpool market prices from 2014, and the red line is the income including the Feed-in Premium.

Since the new Act is not yet in force and no ordinances have been declared to describe how the feed-in premium will be implemented, the sensitivity analysis is conducted under the Act that is still in force and uses a feed-in tariff, calculated on the basis of the average, "blue" tariff from [36].

4. Results

In this section, the results of the methodology applied in the case study of Croatia are presented. Also, the sensitivity analysis is performed at the end of the chapter to discuss the circumstances in which the exploitation of this potential for fuel in CHP could be feasible.

Technical potential and energy potential of biomass from SRC for the scenarios 1a, 1b, 2a, 2b, 3a and 3b for six most promising counties are shown in Fig. 2.

There is a noticeable potential in the Karlovac and Sisak-Moslavina counties due to the large areas of unused agricultural land in those counties. This can be seen in even greater disparity in Fig. 3, which shows the results of technical and energy potential of biomass from SRC for the scenarios 1c, 2c and 3c.

In the scenarios 4a, 4b and 4c shown in Fig. 4, technical and energy potential are lower due to the inclusion of the biomass from fruit trees pruning. However, the advantages of that are larger employment and the reduction of country's fruit import dependence.

Technical and energy potential for all the scenarios for the Continental Croatia (counties from Table 4), is given in Table 6. Counties of the Mediterranean Croatia were not included in this paper because of specific differences in climate and soil, which would influence the choice of SRC culture that should be cultivated. Moreover, the scarcity of agricultural land in those counties might contribute to seeing SRC as a competition with food crops. For the economic feasibility of such power plant and its DHS, the method of the Net Present Value (NPV) was used. Negative results for each of the macro-locations are presented in Fig. 5, which shows nets of 19 × 19 km of each macro-location for the scenario 1c. The values presented in Fig. 5 show that this value chain, connecting SRC and CHP with seasonal storage would not be feasible with the given parameters.

Using the code in Matlab from [35], the techno-economic analysis was conducted for macro-locations in Croatia. Results

[1] For interpretation of color in Fig. 1, the reader is referred to the web version of this article.

Table 5
Base data for the calculation of the CHP plant [37–39].

	Amount	Unit
Power plant availability	0.9	
Biomass price at the SRC field	43.47	€/ton
Lower calorific value (30% moisture)	3,500	kW h/ton
η power plant total	0.87	
η_{el}	0.29	
HTP ratio	2.00	
η storage	0.8	
Storage temperature	90	°C
Power plant specific investment cost	3600	€/kW$_e$
Absorber investment cost	400	€/kW
District system piping cost	5820	€/dwelling
Dwellings connected to DHS	8700	
Storage investment cost	56	€/m^3
Plant's own electricity consumption	6%	
Discount rate	7%	
Feed-in-tariff	0.122	€/kW h$_e$
COP	0.7	
Design temperature for heating	21	°C
Design temperature for cooling	26	°C
Fixed power plant O&M cost	29	€/kW per annum
Variable power plant O&M cost	0.0039	€/kW h
District heating O&M cost	75	€/dwelling per annum
Storage O&M cost	0.39	€/m^3 per annum
Heating energy revenue	0.0198	€/kW h
Project lifetime	14	Years

are supplied in a view of the cost of biomass at CHP plant's location – which was optimized according to this cost.

In order to supply complete information, the cost of biomass for each scenario and location is presented in Table 7. Locations in the vicinity of the Karlovac and Sisak-Moslavina counties have lower prices of biomass from SRC.

Other factors that are challenging for the implementation of SRC biomass based DHS are the size of the heating (cooling) network and the cost of SRC biomass. The cost of the biomass could be influenced in particular by encouraging private landowners to adopt SRC cultivation and use their own mechanization and workforce. In Fig. 6 the result of sensitivity analysis is presented.

The sensitivity analysis was performed for the case of Osijek macro-location because of the least amount of available land for the SRC cultivation in the surrounding counties. Furthermore, this location already has a DHS grid, which is the first criteria that would need to be fulfilled at this point, if the use of SRC is to be feasible.

The factors discussed in the analysis are investment cost, the price of biomass following investment cost changes and the price of biomass without the change of the investment cost.

Therefore, when discussing the lower price of biomass standalone, it refers to only taking into account the lower price of biomass without change of the investment cost or other conditions. When discussing the reduced investment cost, the price of biomass

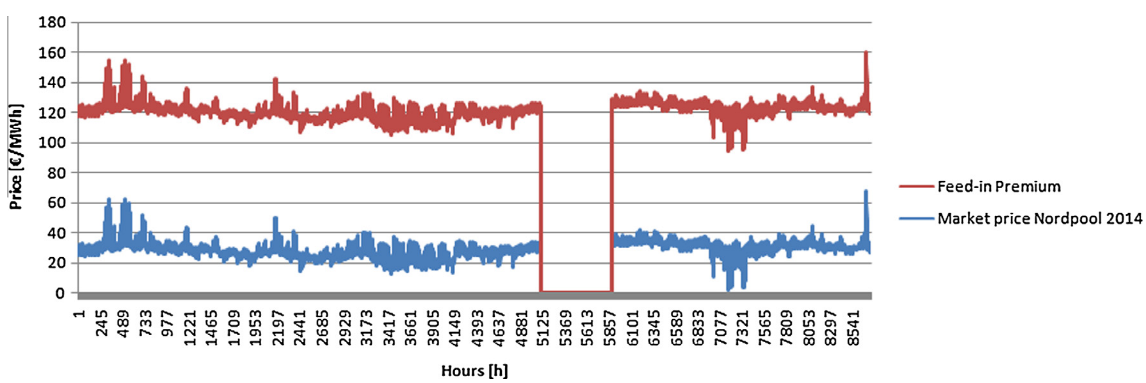

Fig. 1. Model of feed-in premium in market conditions for the CHP plant [35].

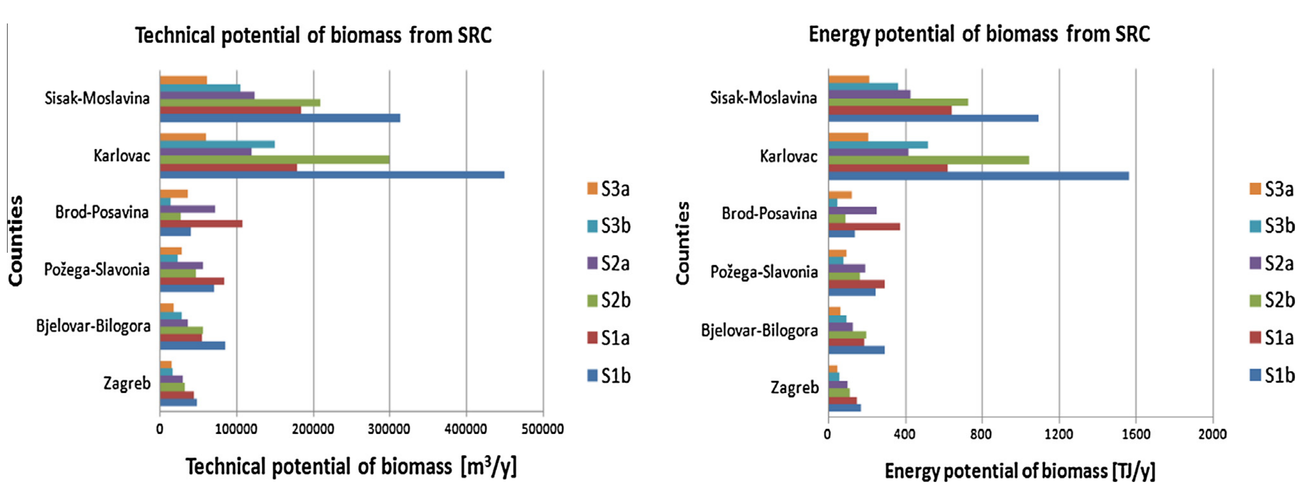

Fig. 2. Technical and energy potential of biomass from SRC in "a" and "b" scenarios.

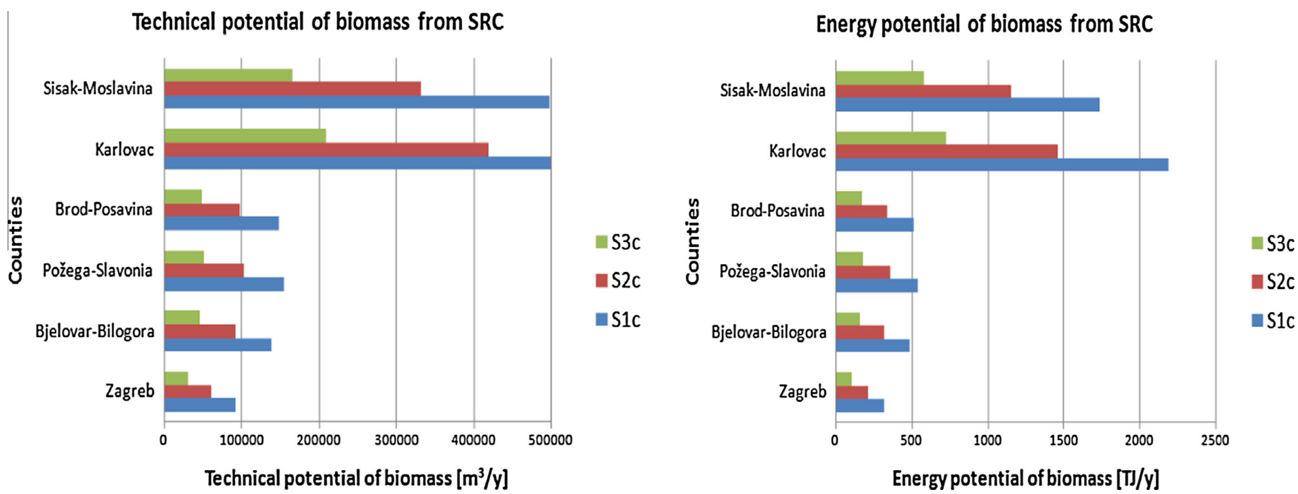

Fig. 3. Technical and energy potential of biomass from SRC in aggregate land scenarios.

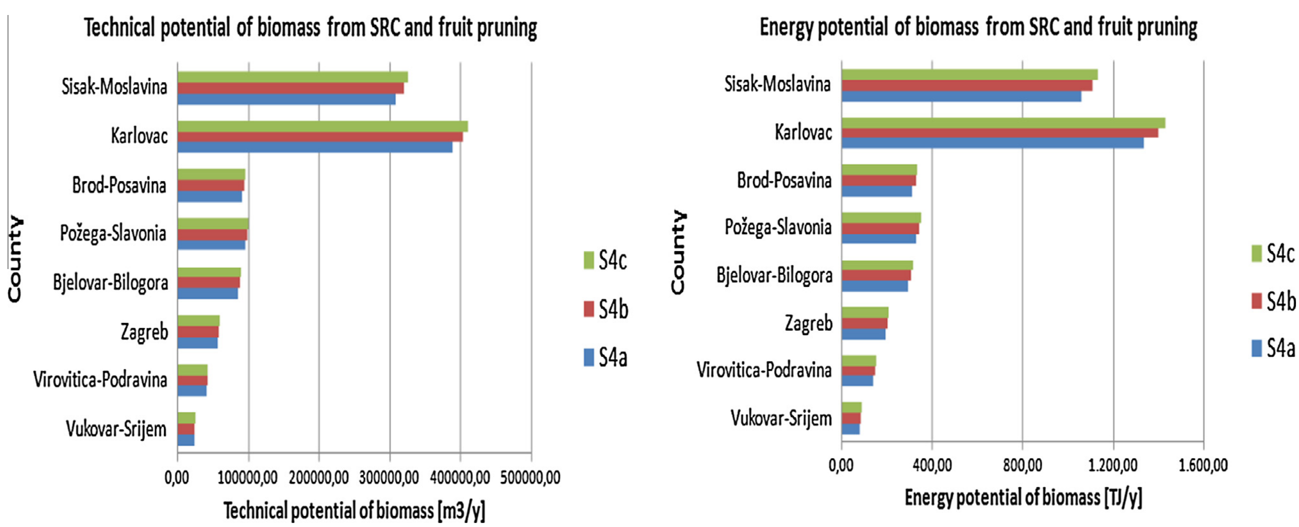

Fig. 4. Technical and energy potential of biomass from SRC and fruit trees pruning.

remains constant, while the combined approach takes into account both effects: investment cost reduction and reduction in the price of biomass at the same time.

It can be seen that only the simultaneous reductions of the investment cost and the price of biomass made the system economically feasible. Large difference toward feasibility is expected and can be reached in reality through incentives or by choosing simpler systems like the already working DH systems with the fuel shift to SRC. Price of the SRC and fruit biomass can be lower if the rate of privately owned land is increased, and the price of fruit pruning biomass decreased. The biomass price can be further lowered by using one's own labor force in a combination with entrepreneurs who own their machinery.

Table 6
Technical and energy potential for aggregated for continental Croatia.

Croatia	Technical potential (m^3/y)	Energy potential (TJ/y)
$S1_a$	1,404,094	4902
$S1_b$	1,426,108	4979
$S1_c$	2,830,202	9881
$S2_a$	936,062	3268
$S2_b$	950,738	3319
$S2_c$	1,886,801	6588
$S3_a$	468,031	1634
$S3_b$	475,369	1659
$S3_c$	943,400	3293
$S4_a$	1,169,257	4176
$S4_b$	1,212,193	4329
$S4_c$	1,233,661	4356

5. Conclusion

Cultivating SRC for biomass has already been commercially established value chain in some of the EU countries, especially in Sweden, Denmark, Germany, the UK, Poland and Italy. In the EU, research continues on the influence of SRC on soil, SRC yield and the best practices to exploit SRC for biomass as a valuable contribution to common energy and environmental goals in 2020 and beyond. In Croatia, SRC can be seen as a new fuel, which fosters the integration of factors such as large areas of unused agricultural land, high unemployment and renewable sources inclusion goals. Analysis of regional potential shows that even conservative assumptions on the area that could be cultivated with SRC could lead to the substantial contribution to meeting local energy demands in a more sustainable way and creating new job opportunities at the same time. At the moment, the most innovative

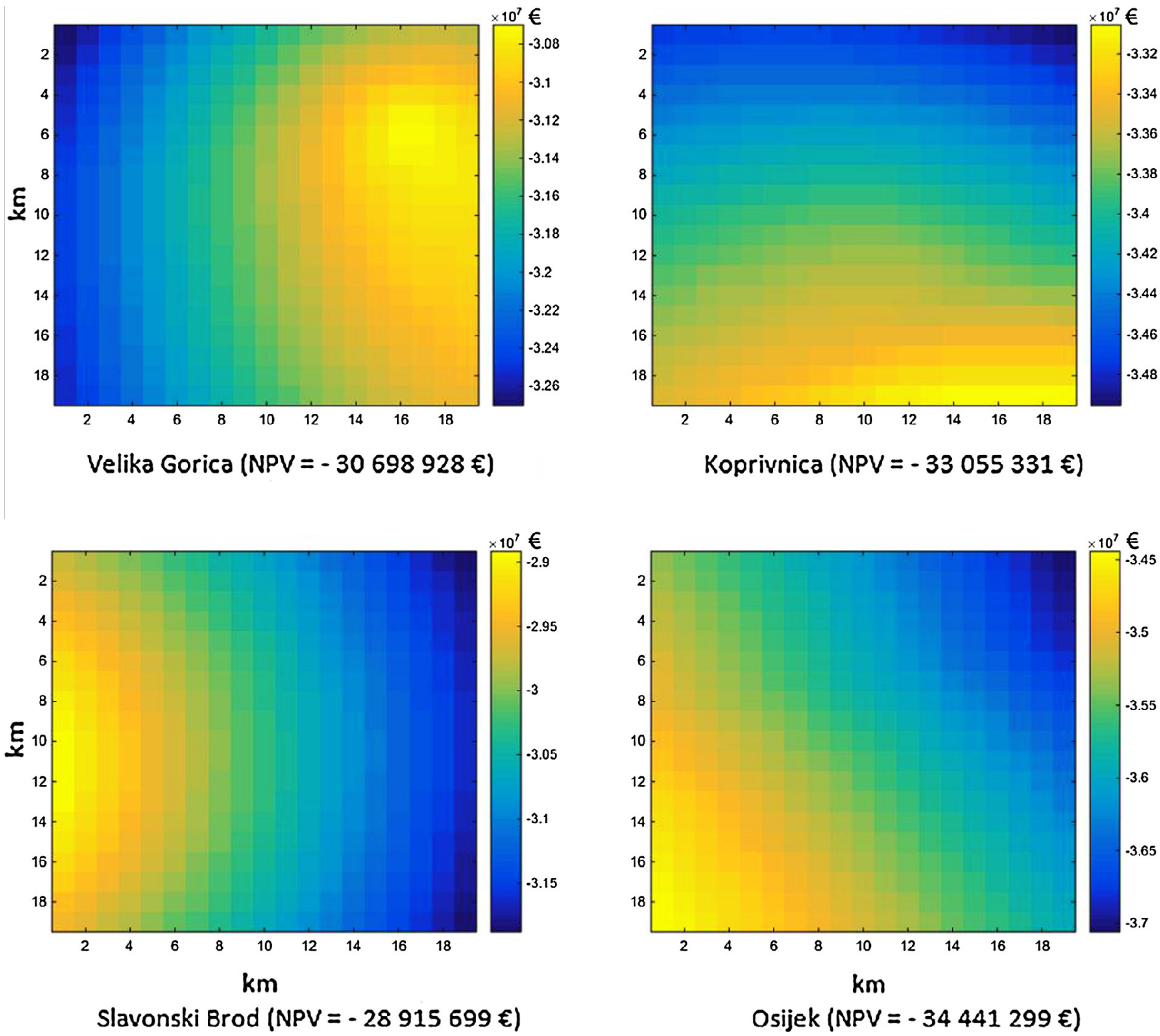

Fig. 5. NPV of optimal locations at each macro-location for the scenario S1c.

Table 7
Cost of biomass at plant location from all scenarios.

Location	Velika Gorica	Koprivnica	Slavonski Brod	Osijek
Scenario	Cost $C_{B,E}$ (€/t)			
S1a	47.7	51.1	45.9	51.9
S1b	47.6	50.2	48.7	52.3
S1c	46.4	48.7	44.7	50.0
S2a	48.2	52.6	47.7	52.9
S2b	48.0	51.8	51.2	55.0
S2c	47.4	49.7	46.2	51.2
S3a	50.7	55.2	53.3	58.9
S3b	49.3	53.8	55.7	61.2
S3c	48.0	52.2	49.2	53.4
S4a	47.5	49.9	46.4	51.5
S4b	47.4	49.8	46.3	51.3
S4c	47.4	49.7	46.3	51.3

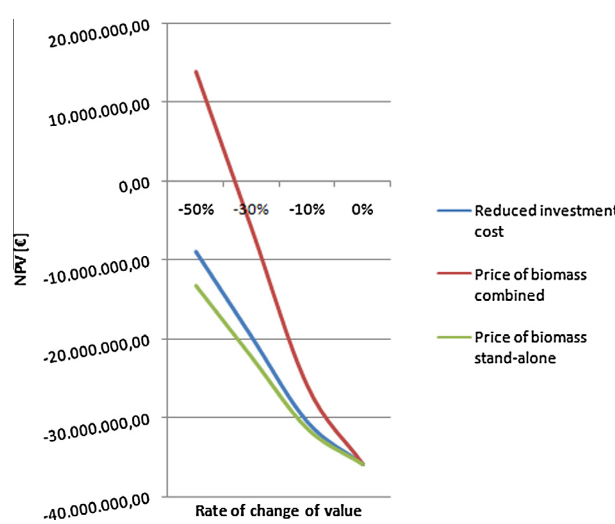

Fig. 6. Sensitivity analysis in relation to investment cost and price of biomass.

approaches with the combined heating and cooling plants with seasonal storage are not the economically feasible way of exploiting biomass from SRC, but some more conventional CHP solutions would be feasible to implement.

Further research should be conducted on more precise determination of the unused agricultural areas which could be used for the SRC cultivation. This could lead to the creation of local value chains which would include SRC and other biomass sources to meet local demand in a sustainable way through DHS. Other important reductions of cost could be achieved by the use of private landowners' own machinery and workforce, which could make the SRC biomass more competitive and interesting for further investigation.

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