ISSN 1330-3651 (Print), ISSN 1848-6339 (Online)

https://doi.org/10.17559/TV-20210707182728

Subject review

The Effects of Biomass Availability and Preparation on the Sustainability of Power Plants in Croatia

Ante ČIKIĆ*, Slaven ZDILAR, Petar MIŠEVIĆ

Abstract: Energy production from biomass (wood chips) is necessarily limited by its renewability, availability, distance of sustainable supply, preparation and overall exploitation efficiency. A strong encouragement to the construction of plants that produce electricity and heat often represents variable and optimistic assessment of availability and renewability of various types and forms of biomass (especially wood chips), as well as the quality and type of consumers. Possible effects on sustainable cost-effectiveness have been analysed as related to sustainable cost-effectiveness of combined heat and power plants and also heating plants with a special critical consideration of the significance of the production, purpose, conditions, manner and consumption location of electricity and heat. Quantified values present possible limitations and insecurity of using energy transformation in the estimated exploitation period.

Key words: biomass; combined heat and power plant; influential parameters; power plant; sustainable cost-effectiveness; wood chips

1 INTRODUCTION

Biomass is a natural storage of solar energy and represents traditional energy source in the most complex form of renewable energy. It mostly includes forest and agricultural biomass, waste and residues from wood and related industries, non-wood biomass, animal waste and debris and selected urban and municipal waste [1-4]. Croatia has a large potential in the area of forests, agricultural land and wood processing plants, as well as a significant amount of biomass of different origin for the conversion in different form of energy [5, 6]. In general and by optimistic evaluation the advantage of using biomass as an energy source refers to its relatively large availability and usability potential, although each of the different forms of biomass has a different calorific value and requires different procedures for collecting, preparing and conversion, including variable, often high costs of transformation in other form of energy [7].

Determined or estimated data on volumes of forest biomass, wood waste and residue in the timber industry are often used as a base for decisions making for the construction of combined heat and power plants (CHP) or similar plants for the production of electricity and/or heat. The construction of CHP or similar plants in relatively small regions has been encouraged without a critical review of the long-term availability and costs of preparation and supply of biomass, the type and speed of economic development, consumers of heat and economic conditions of production, transport and energy use. Flexibility and social sensitivity need to be taken into account while evaluating the costs of heat from the plant to the remotest consumers [8].

As there is no generally accepted methodology for assessing the influencing parameters (technical, technological, environmental, energy, social, economic, ...) of biomass usage, models have been developed that cover a range of technical, technological, environmental and economic assumptions, which are country specific due to their differences in industrial development, economic activities and capabilities, especially in the wood processing industry in unstable business conditions and market requirements [8].

The most cost-effective use of biomass as fuel is the CHP, for simultaneous production of electricity and heat [9-13]. Frequently, using the same or similar pattern and without a complete and exact analysis, rapid construction of a number of CHP plants and similar biomass-powered (mostly wood chips) plants of different capacity and efficiency is suggested. That contributes to short-term investment performance and less to long-term sustainable development of the local economy. The encouraged production of electricity from renewable energy plants and CHP according to the report of the Croatian Energy Regulatory Agency (HERA) for 2014, amounts to 412 MW (339 MW are wind farms). This presents 5.51% of the total power generation units [14]. The production price of electricity produced in these plants is to about 116 €/MWh, which is about three times of the average energy price on regional stock exchanges in 2014. In the same year eligible producers of electricity were paid a total of approximately € 110 million [14].

2 PARAMETERS OF INFLUENCE AND POSSIBLE APPLICATIONS

On the example of Croatia possible impacts on the sustainability of CHP and heating plants have been analysed, with a critical overview of the availability, preparation and delivery of biomass, the importance of production and purpose, conditions, manner and location of electricity and heat use.

2.1 Amount and Quality of Biomass

Annual quantity and quality of biomass is highly variable. Reported and estimated values many times differed and are not acceptable for decisions for long-term power capacity of biomass conversion equipment (mostly wood chips). Croatian forestry manages 2688687 ha of forest and forest land which accounts for 397963000 m^3 of wood stock, with annual growth rate to 10526000 m^3. Cutting gross volume (annual allowable cut) is estimated to 6564000 m^3 [7]. According to the commercial data of the Croatian Forests from 2015, the possible market delivery amounts to approximately 2200000 m^3 of logs and wood chips, and the demand is estimated to about 5000000 m^3.

The theoretical potential of biomass for electricity production is estimated to around 2.9×10^6 MWh, equivalent to electrical power of about 386 MW (biomass volume about 6860000 m^3/y, with power plant efficiency 0.4 and average wood density 350 kg/m^3 with lower heating value 3 kWh/kg), which accounts for approximately 8.52% power of all power plants in the Republic of Croatia in 2014 (4528 MW). Total electricity use in Croatia for 2014 was about 16.9 TWh. Theoretical electricity production from biomass would cover around 17%, which generally boosts investment optimism in power plants powered by biomass.

The diversity of assortment, quality, moisture and the degree of preparation of biomass significantly influence its energy value, and therefore its use within the conversion into electricity and heat. Real moisture of supplied forest biomass - wood chips is more than 50%, and the moisture of crushed industrial waste amounts to about 45% on average. The mean lower heating value of biomass lies between 2.7 to 3.5 kWh/kg.

2.2 Investments

Driven by environmental, energy and economic effects of biomass use and incentives unit prices of electricity over a defined period [16] in all regions of the Republic of Croatia, investment activities (preparation and construction of a large number of cogeneration and other power plants) have been increasing, promoting a series of positive economic and developmental effects. According to collected information and available data, a series of cogeneration and other power plants of different power capacities have been built. Many new are planned to be build, mostly in central and northern counties, with the total energy capacity amounting to approximately 610-780 MW (electrical power and heat).

The values of energy capacities with the scope of collecting and supplying renewable biomass are shown in Fig. 1. Depending on the lower heating value of chipped biomass at the site of energy conversion, the predictable production from cogeneration plants and similar electrical power plants in a multi-year period amounts to about 140-180 MW$_e$, and heat capacity amounting to about 380-500 MW$_h$. Heat only plants of various capacities designed for technological needs and heating amounts to around 230-280 MW. Expected and cost-effective operation of cogeneration plants is about 7800 h/y, while for the hot-water heating systems it amounts to around 3500 h/y.

With better organization and continued progress in the next few years, the factor of gathering and preparation of forest and agricultural biomass for energy purposes is expected to increase to ≥ 80% of the available resources. Overall predictable performance power capacities (electricity and heat) are grouped in three regions in Croatia with the scope of biomass supply (Fig. 2).

2.3 Cost-effective Biomass Supply Radius

For different biomass quality special means of transportation are required with increased cargo capacity for high moisture biomass. In some countries budgetary limits of viability of truck transport are between 180 km and 250 km, while for train they amount up to 800 km and for boats up to 2000 km.

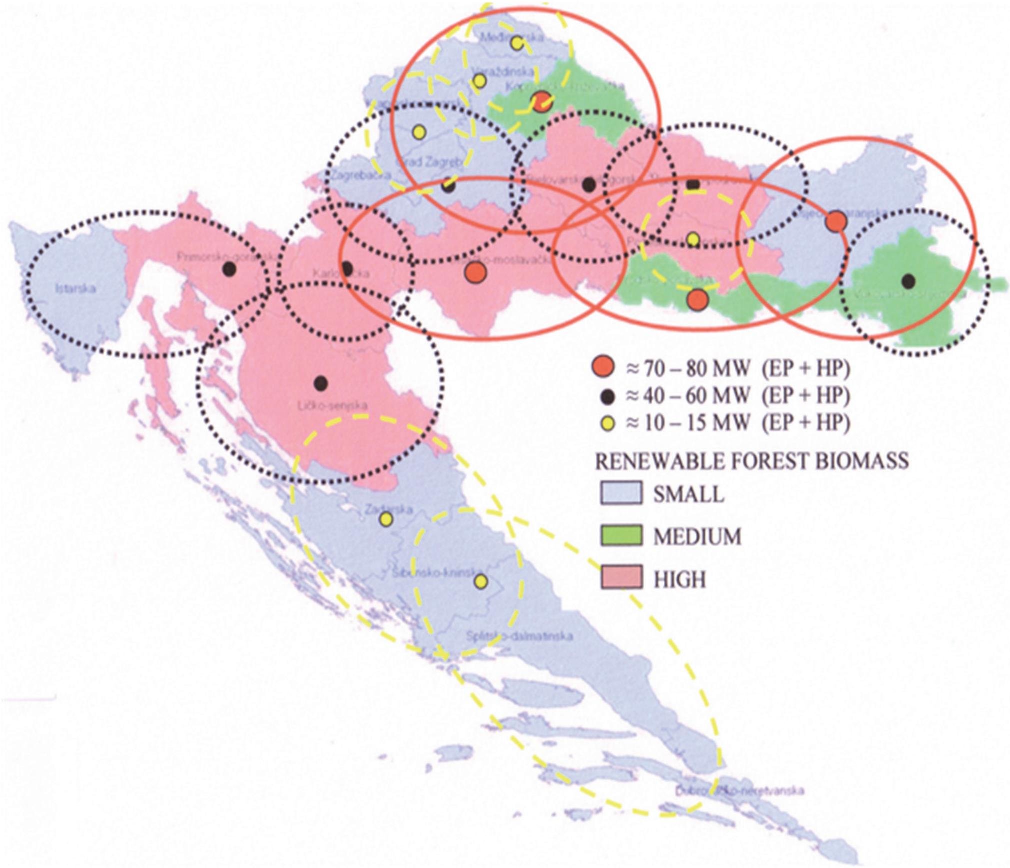

Figure 1 Concentrated energy capacities with the scope of collection and supply of renewable biomass in Croatia

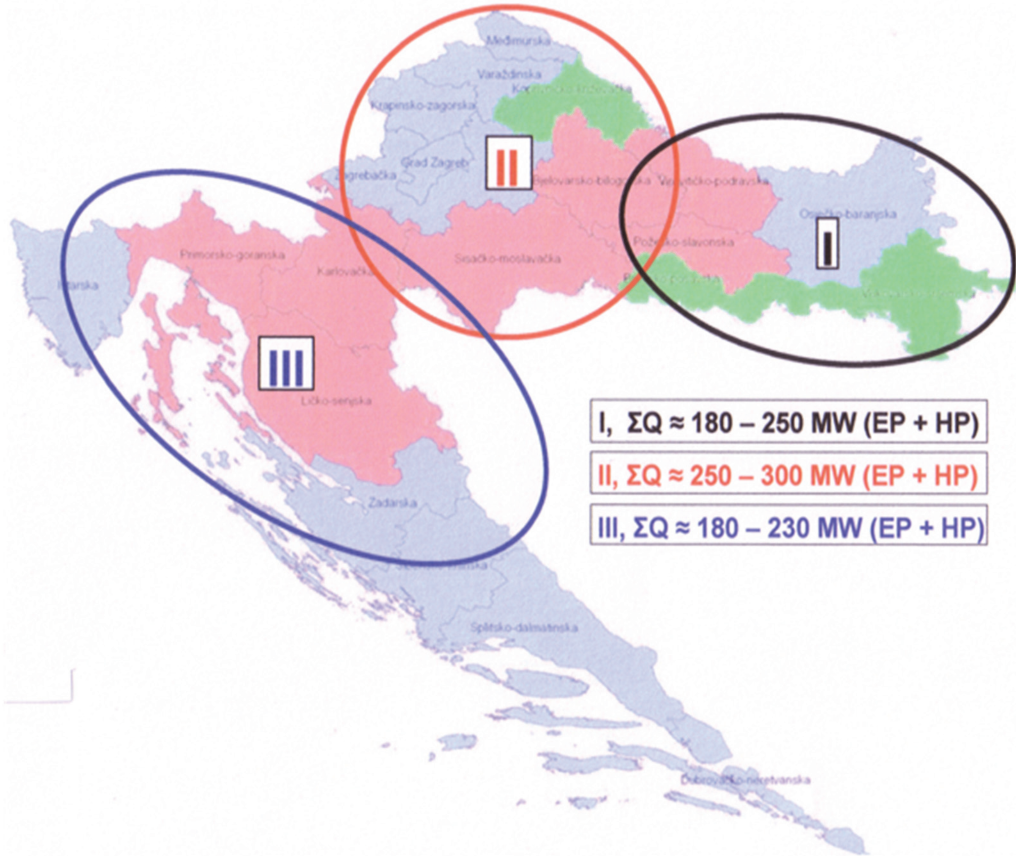

Figure 2 Grouped energy capacities powered by renewable biomass in Croatia - three regions

The cost-effective sustainable supply radius refers to the estimated furthest location within the range of collecting renewable biomass. Systematic and stable solution for the collection, preparation and delivery of the required amount of biomass in a cost-effective radius of operation over a longer period of time for energy plants is important. Long-term unit cost of energy in biomass that is economically equal or more competitive as compared to unit costs of energy ecologically most acceptable conventional fuel (e.g. natural gas) is a prerequisite for success of new bio-plants.

Preferential sale of electricity produced at cogeneration plants makes the supply of consumers with heat and electricity in a particular area technically and economically viable.

The use of electricity and most of the heat in cogeneration and/or a similar plant powered by biomass in a larger economic entity by "succinct - centralized" principle, contributes to production efficiency and cost-effectiveness with a significant reduction of emissions into the environment at the location and per product unit. A smaller portion of the excess electricity and/or thermal energy can be supplied to the power system or small consumers with no apparent effect on the cost of production and distribution. The dispersion of heat to distant consumers as observed from the plant reduces the efficiency and economic viability.

From Croatian experience, the cost-effective radius of collection, preparation and delivery of biomass for the cogeneration plant is estimated to about 120 km. The multiplication of capacities within the scope of the cost-effective renewable energy potential, the cost-effective radius necessarily increases, which significantly increases the costs and jeopardizes the stability of biomass supply to a plant. Overlaying of the cost-effective scope of biomass supply to several cogeneration and hot water plants increases its unit price and different influences develop that significantly affect the quality and the price increase of electrical and thermal energy.

2.4 Energy Projection of Biomass Capacities and Prices

There has been a steady decline in electricity use since 2010 until the end of 2014 (17.9 to 16.9 TWh) partly due to the increasing efficiency and energy saving measures, but mostly because of the economic downturn and the reduction in the purchasing power among the population [14]. The overall decrease in electricity use during this period was about 5.6%.

There are very different shares of the type and quality of firewood and usable remains in regular forest work, which affects the value of biomass fuels and its available energy potential. The deflection from the real data that are not accompanied by precise studies comparable with years of historical data may affect the profitability and long-term instability in the collection, preparation and delivery of sufficient quantities of forest renewable biomass.

The assessment and analysis of waste biomass in wood processing plants are quantified as a necessary remaining part of the production process, and the share of waste sawn timber that frequently results from inadequate thermal processing after drying and/or steaming is not directly indicated, which reduces production efficiency and increases the amount and heating value of biomass [8]. With increasing amounts of waste wood treated by technological processes, biomass price indirectly increases, reducing the productivity of plants and cost-effectiveness of producing energy from this, perhaps the most expensive fuel [8].

Information on the amount, structure, frequency and place of origin and the conditions of waste wood sets the priorities for development or technological renovation in plant for the production of electricity and/or heat. An irrational decision may transform a technically advanced and useful plant for the biomass conversion into economic difficulties for wood processing company. Fig. 3 shows energy capacities for the production of electricity from biomass (mostly wood chips). Including year 2014 total electrical power with subsidized price was 7.69 MW [14, 16]. Final contracts with several eligible producers of electricity from biomass by the end of 2014 achieved total 54.76 MW. Seven plants are of power from 4.66 to 8.6 MW (70%), three units are of 1.52 to 3 MW (11.7%) and twelve plants are from power 0.3 to 1 MW (18, 3%) [14, 16]. With the expected growth reduction in the period from 2015 to 2025, an increase of new power capacities from biomass of 120 MW has been estimated. The production of pellets rose from about 200000 tons in 2012 to about 280000 tons (incomplete data) in 2014. By 2025 estimated production of pellet can reach around 700000 t/y. To produce 1 ton of pellets, around 5.5 m^3 of wood waste of average moisture amounting to 35% is required.

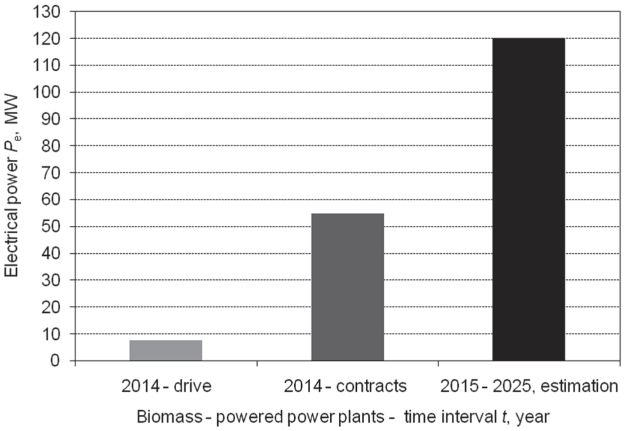

Figure 3 Biomass - powered power plants

The economic costs are usually expressed per unit mass of a ton of biomass at the location of energy facilities. Depending on the accepted method, its determination depends on a number of influential parameters and it is not possible to apply a general model for all regions or countries where biomass represents a significant energy potential. The average cost of biomass of average seasonal moisture at the location of the energy plant can be determined using the following expression [17]:

$$B_{\mathrm{EP}} = \sum_{i=1}^{n} \frac{\left[C_{\mathrm{BM}} + (T_{\mathrm{P}} \cdot L_i) \cdot K_{\mathrm{BM},i} \right]}{Y_{\mathrm{BM}}} \tag{1}$$

where are:

B_{EP} - average biomass price at the location of the plant, €/ton,

C_{BM} - biomass price at the location of collection and preparation, €/ton,

$K_{\mathrm{BM},i}$ - total amount of biomass supplied from area i, ton,

L_i - distance between the location of biomass from area i and the plant, km,

T_{P} - unit cost of biomass transport, €/ton/km,

Y_{BM} - total annual biomass consumption of the plant, ton.

According to user data, in 2015 the average biomass price in Croatia (beech, oak, hornbeam) of seasonal moisture at the location of the plant amounts to around 60 €/t, and biomass of other wood types to around 45-52 €/t.

2.5 Biomass Consumption and Heat Supply

For the heating plant of 1 MW amount between 2800 and 3600 t/y of biomass is required for production of 7800 MWh heat, while for the cogeneration plant of electrical power of 1 MW$_e$ the amount of biomass is ranging from around 10000 to 12000 t/y for 7800 MW$_e$ and 15600 MW$_h$ of heat (average biomass density around 350 kg/m^3, moisture content 22-32% and lower heating value of approximately 2.7 to 3.5 kWh/kg) is necessary when the plant operates around 7800 hours per year. According to experience, with moisture greater than 50%, the annual consumption per 1 MW$_e$ of CHP is required up to 15000 tons/y of supplied biomass (wood chips). An estimated production of thermal power P_t of implemented and contracted cogeneration plants by the end of 2014 and the estimated capacity by 2025 in Croatia is shown in Fig. 4.

As conditioned by the sales of electricity the minimum required thermal power P_{t50} (50%) as heat delivered to consumers should be shown. Examination of several technical solutions, accepted projects and the assessment by year 2025 have been made for quantifying the existing and possible implementation of thermal power P_{tx} of cogeneration and similar plants.

Thermal energy-heat users are mostly of the same type, purpose and power characteristics without their detailed analysis and market valuation at a certain location.

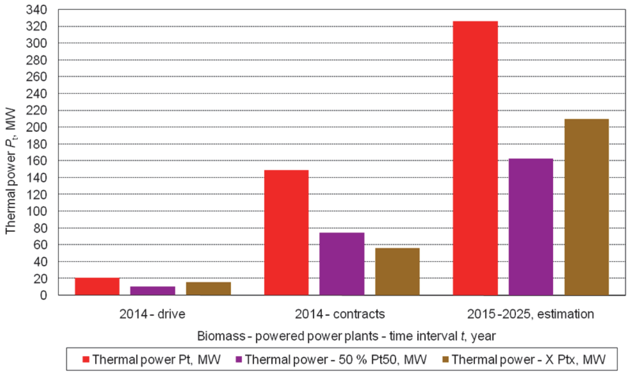

Figure 4 Thermal power of biomass-powered plants

Within construction phase of a cogeneration plant priority is given to the fast construction of the plant for the generation and delivery of subsidized electrical energy. Design of the system for heat distribution and substations for the heat consumer is slowed down. The so-called approved "phase plant construction" contributes to this, which includes:

- Phase I: Production of electrical energy (power plant).
- Phase II: Realization of the consumer with required 50 % heat use of the total available heat, as conditioned by the sales of electrical energy (I).
- Phase III: Total heat use, which is often neglected.

Due to the fact of separate ownership of cogeneration plants and facilities of potential energy users different terms and conditions are often offered so in the long run their economic interests and viability do not match. This reduces the mutual investment interest in intensive development of heat use. Undefined from the aspect of time, and often inadequate implementation of the second and third phase directly affect the operations and efficiency of an energy plant. Relativization of efficiency and by-product quality of rest of the heat (e.g. greenhouses, driers, etc.) at the expense of maximum use of electricity reduces the efficiency, effectiveness, and sometimes justification of a cogeneration plant. Heating plants powered by biomass for industrial use only achieve high efficiency and optimum by conversion of biomass in heat.

3 ENERGY POTENTIAL AND CAPACITY ANALYSIS

Favourable sale of electrical energy produced at a cogeneration plant and supply of heat to individual, residential, public, commercial users in a particular area is technically and economically viable, if there is a systematic and long-term solution for the collection, preparation and delivery of the required amount of biomass in the field of the cost-effective radius. Overlaying of the cost-effective scope of biomass supply of several cogeneration plants results in the increase in its unit price, development of different influences that significantly affect the quality and price increase of electricity and heat. Disproportionate relation between the energy potential of the collected renewable biomass and site selection for the construction and for the purposes of capacities of cogeneration plants expands the scope of supply and may unpredictably increase unit prices and the stability of biomass supply. The location and schedule of cogeneration plant construction depend on the cost-effective radius, minimal overlap of the scope and ability of biomass supply and stability and long-term economic efficiency of, primarily, energy users throughout the whole or most of the year (required use of more than 50% of the total of generated thermal energy).

An estimation of biomass amount for energy production in 2014, a prediction of biomass for energy from existing and planned plants in the period from 2014 to 2017 and the projection of the necessary amount of biomass by 2025 for energy according to an advanced scenario for the construction and operation of facilities of various types and purposes (power plants, heating plant,) are shown in Fig. 5.

According to four different scenarios, it has been determined that annual available biomass for conversion in secondary energy amounts to a minimum of 1312800 m^3 (I), 2954000 m^3 (II), 3299000 m^3 (III) - scenario S1 (Tab. 1), up to a maximum of 4173507 m^3 (IV) - scenario S2 (Tab. 1) [7]. The forecast of available biomass potential for energy conversion by 2025 amounts to 6555660 m^3/y - scenario S3 (Tab. 1). Biomass from energy forests is expected to achieve around 2000000 m^3/y [15]. Theoretical energy potential of biomass is around 11000000 m^3/y - scenario S4.

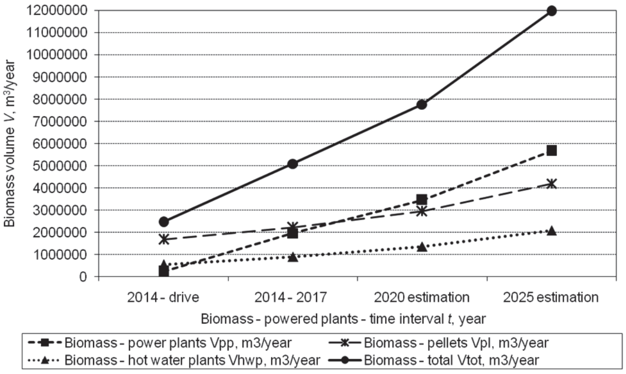

Figure 5 Estimation of biomass for energy

Table 1 Comparison of biomass availability (scenarios S1 – S4 ÷ energy requirements)

Time intervals t, year	Scenario S	Biomass volume according to scenario $V_{S1} - V_{S4}$, m^3/year	Biomass required for energy V_u, m^3/year
2014 - drive	S1	3299000	2470257
2014 - 2017	S2	4173507	5096994
2020	S3	6555660	7768571
2025	S4	11000000	11960000

Comparison of the availability of forest biomass according to scenarios S1 to S4 and the necessary amount of chipped biomass for conversion in different form of energy in the intervals of implemented and contracted plants and assessment of development by 2025 are quantified and presented in Tab. 1. In addition to high factor (≥ 80%) of collecting and preparing biomass, a realistic amount of renewable biomass is from around 4200000 m^3/year up to 5500000 m^3/year, i.e. it is positioned between scenarios S2 and S3. A faster (possibly irrational) investment development of plants for the production of energy in a ten-year period jeopardizes the stability of biomass supply and directly impacts the viability and efficiency of the system. The realization of the agreed facilities for energy production in a shorter period of time (up to 3 years) significantly increases the consumption of biomass. The disproportion between the availability and consumption affects the quality, delivery radius and cost of biomass.

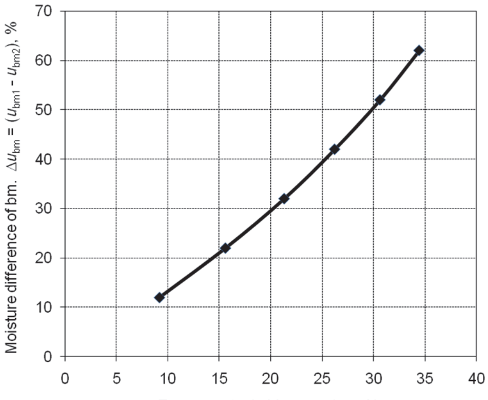

Figure 6 Excess water in biomass 1 at the plant location

High moisture content in supplied biomass $u_{\mathrm{bm1}} > 50\%$ as compared to the averagely acceptable moisture content in biomass before combustion $u_{\mathrm{bm2}} \approx 27\%$, the unit supply amount of biomass per unit of generated energy increases, transport costs go up, the effectiveness is reduced, and planning of the annual amount is uncertain and variable. For the purpose of practical values, difference in biomass $\Delta u_{\mathrm{bm}} = u_{\mathrm{bm1}} - u_{\mathrm{bm2}}$ is shown in Fig. 6, that presents the value of the excess water u_{w} in supplied biomass 1 at the plant location. Practical average bulk density of absolutely dry crushed hardwood amounts to $\rho_{\mathrm{n}} \approx 275$ kg/m^3.

4 ENVIRONMENTAL ASPECT

Conversion of the biomass to electricity and heat is connected also with considerable emissions of particulates and some other pollution gases. This is typical for small production units, which are not able to invest in sophisticated filtration of fine particles with diameter less than 2.5 µm (PM 2.5) and some other gaseous components, for example volatile organic compounds (VOC). The next open question is which amount of the available biomass should be used for conversion in heat through simple burning and which amount should be used for chemical conversion, using the naturally stored carbon in biomass for other purposes (liquid and gaseous furls with addition of solar hydrogen).

5 CONCLUSION

A rational approach is needed regarding the choice of location, size, capacity and speed of construction of power plants in proportion to the availability, cost and sustainability of adequate biomass. With a high factor (≥ 80%) of biomass collection and preparation, the real supply amount of renewable biomass amounts to around 5500000 m^3/year or between presented scenario S2 and S3. Therefore, sustainable and economical construction of energy cogeneration capacities is of up to 90 MW of electrical and approximately 240 MW of thermal power, and hot water plants of thermal power amounting to around 125 MW, and plants for pellet production of around 350000 tons/year. Practically high moisture contents in supplied biomass 1 compared to biomass 2 before combustion ($u_{\mathrm{bm1}} > u_{\mathrm{bm2}}$) affect the actual amount assessment, its lower heating value and cost-effectiveness of energy production. A rational perspective of constructing is related to complete power systems (without construction in phases) that are directly related to consumers of the maximum amount of thermal energy, followed by the ones that consume electrical energy. By multiplying energy resources available within the cost-effective scope of renewable energy potential, the cost-effective radius of supply necessarily broadens as well, which significantly increases the cost and jeopardizes the stability of biomass supply to energy plants over extended periods of time. Given the agreed capacities for the construction of cogeneration plants in 2014, whose electric power amounts to 54.76 MW, a more rational approach to further increase in energy capacities powered by renewable biomass has been proposed.

6 REFERENCES

[1] Gustavsson, L. & Svenningsson, P. (1996). Substituting fossil fuels with biomass. *Energy Conversion and Management, 37,* 1211-1216. https://doi.org/10.1016/0196-8904(95)00322-3

[2] Heinimö, J. & Junginger, M. (2009). Production and trading of biomass for energy - An overview of the global status. *Biomass and Bioenergy, 33*, 1310-1320. https://doi.org/10.1016/j.biombioe.2009.05.017

[3] Parikka, M. (2004). Global biomass fuel resources. *Biomass and Bioenergy, 27*, 613-620. https://doi.org/10.1016/j.biombioe.2003.07.005

[4] Demirbas, M. F., Balat, M., & Balat, H. (2009). Potential contribution of biomass to the sustainable energy development. *Energy Conversion and Management, 50*, 1746-1760. https://doi.org/10.1016/j.enconman.2009.03.013

[5] Evans, A., Strezov, V., & Evans, T. J. (2010). Sustainability considerations for electricity generation from biomass. *Renewable and Sustainable Energy Reviews, 14*, 1419-1427. https://doi.org/10.1016/j.rser.2010.01.010

[6] Mrkobrad, M. (2006). The revision of forest economy in an area must account for new moments (in Croatian). *Croatian forests, 109/110.*

[7] Matić, S. (2007). The requirements of preservation and recovery as a method for obtaining wood for energy and increasing the quality of forests in Croatia. *Proceedings of the scientific symposium, Agriculture and forestry as the producers of the renewable energy sources*, 17-41.

[8] Ćikić, A. & Kondić, Ž. (2010). Research of the waste biomass technical and economic value as one of the technological and energy development criteria of wood processing plants. *Tehnicki Vjesnik, 17*, 53-59.

[9] Bakos, G. C., Tsioliaridou, E., & Potolias, C. (2008). Technoeconomic assessment and strategic analysis of heat and power co-generation (CHP) from biomass in Greece. *Biomass and Bioenergy, 32*, 558-567. https://doi.org/10.1016/j.biombioe.2007.11.014

[10] Boyle, G. (1996). *Renewable energy power for a sustainable future*. Oxford University Press. Oxford, UK.

[11] Papadopoulos, D. P. & Katsigiannis, P. A. (2002). Biomass energy surveying and techno-economic assessment of suitable CHP system installations. Biomass and Bioenergy, 22, 105-124. https://doi.org/10.1016/S0961-9534(01)00064-2

[12] Dornburg, V. & Faaij, A. P. C. (2001). Efficiency and economy of wood-fired biomass energy systems in relation to scale regarding heat and power generation using combustion and gasification technologies. *Biomass and Bioenergy, 21*, 91-108. https://doi.org/10.1016/S0961-9534(01)00030-7

[13] Solantausta, Y., Bridgwater, T., & Beckman, D. Electricity production by advanced biomass power systems. *VTT Research Notes*, 1729.

[14] Annual report on the system of encouraging the production of electrical energy from renewable sources and cogeneration in the Republic of Croatia for 2014, HROTE d.o.o. Croatian energy market operator, Zagreb, March, 2015.

[15] Raguzin, I. (2011). *Model of gains and costs analysis of biomass usage in the production of electrical energy*. Master thesis, Faculty of Mechanical Engineering in Slavonski Brod, Slavonski Brod.

[16] Tariff system for the production of electrical energy from renewable energy sources and cogeneration NNRH 33/07, NN 63/12, NNRH 133/13.

[17] Geographic distribution of economic potential of agricultural and forest biomass residual for energy use: Case study Croatia. *Energy 2011, 36*, 2017-2028.

Contact information:

Ante ČIKIĆ
(Corresponding author)
University North,
Jurja Križanića 31b,
HR-42000 Varaždin, Croatia
E-mail: acikic@unin.hr

Slaven ZDILAR
Ministry of Defence of the Republic of Croatia,
Trg kralja Petra Krešimira IV,
HR-10000 Zagreb, Croatia

Petar MIŠEVIĆ
University North,
Jurja Križanića 31b,
HR-42000 Varaždin, Croatia