COMPREHENSIVE ANALYSIS OF A STRAW-FIRED POWER PLANT IN THE PROVINCE OF VOJVODINA

by

Dragan M. UROŠEVIĆ [a] ***and Branka D. GVOZDENAC-UROŠEVIĆ*** [b]*

[a] VICTORIA GROUP AD, Novi Sad, Serbia
[b] Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia

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In recent years, renewable energy sources have played an increasingly important role in potential energy production. The integration of renewable energy technologies into existing national energy system has therefore become a major challenge for many countries. Due to the importance of this matter, this paper deals with the comprehensive analysis for implementation of a power plant on biomass (straw). The analysis is conducted regarding several key indicators: availability of biomass, regulation, reduction of greenhouse gas emissions, location, land use, electricity price, and social impacts. The analysis also includes favorable price for electricity produced from biomass relevant to national feed in tariffs. In order to demonstrate all above mentioned indicators, the region in Serbia (Province of Vojvodina) with significant potential in biomass, especially in straw, is selected. The results of the analysis are validated trough environmental and social aspects. Special attention is given to identifying risks for this application.

Key words: *power plant, straw, electricity*

Introduction

Today, the generation of electricity has become one of key technological advancements linked to the high quality of life in modern society. With limited fossil fuel reserves and their volatile prices, renewable fuels can provide increased energy security and stable price profiles. Within various renewable energy sources, biomass is the most important renewable source in use today, and electricity production from biomass is currently gaining considerable interest [1, 2]. The USA is the dominant biomass electricity producer at 26% of world production, followed by Germany (15%), Brazil and Japan (both 7%) [3]. There are many biomass types available for the production of electricity. The most common types of biomass used for electricity production are agricultural residues, forest residues and dedicated energy crops.

Energy generation using biomass (including straw) is commonly used in many countries. European countries are pioneers of straw technologies for heat and power generation. In Europe, Denmark is a pioneer in developing power plants using agricultural wastes and the first commercial straw power plant (Haslev) was developed in 1989. Four power plants were developed in Denmark and operated with wheat straw as the only fuel. Large-scale straw power

* Corresponding author; e-mail: gvozdenac@uns.ac.rs

plants were also commissioned in the United Kingdom (38 MW, Ely in 2002) and in Spain (25 MW, Sangüesa in 2002) [4]. The biggest biomass fired power plant today of 150 MW will be finished in 2014 in England (Portbury Dock Renewable Energy Project). It is expected that in the near future more and more energy will be obtained from burning biomass [5].

The contribution of renewable energy sources in the total consumption of energy in Serbia is less than 1%. Technically, usable energy potential of renewable energy sources in the Republic of Serbia is very significant and estimated at over 4.3 Mtoe – of which 2.7 Mtoe is from biomass [6, 7]. More than half of biomass potential or 1.7 Mtoe comes from agricultural biomass. Serbia, as a country with large agricultural land and land under forest, has a great potential for the production of biomass. Forests take up 30% of the total area of the country and agricultural land takes up around 55%. The overall potential of biomass is 63% with reference to other renewable energy sources. Biomass as a clean national resource for energy production is important because of its potential benefits on energy security. In addition to remains from agriculture there are also possibilities of growing biomass crops specifically for energy production without negative effects on food production. The Autonomous Province of Vojvodina in Serbia has significant potential in biomass, especially in straw. In Vojvodina, availability of straw (corn, wheat, soy, barley, and rapeseed) is estimated in total of 5,348 thousands of tons from 1,179 ha [6]. In this region, only minority of straw potential is currently used for energy purposes. Straw as agricultural waste (which is currently mostly burned in the fields) can be used more environmentally friendly. The following analysis will be done for the region of Vojvodina (with the highest availability of straw) and for small scale power plants up to 10 MW.

Based on commercial application so far, direct combustion and thermo-chemical conversion are the most promising technologies for using biomass for heat and/or power generation. Studies have also been made relevant to straw properties and their effect on combustion using various technologies, as well as feasibility studies and barriers analysis for straw utilization and successful projects in Europe and in the United States [4].

Nevertheless, biomass power generation technologies cannot often compete with conventional fossil-fuel based technologies without supporting policies and regulations [8, 9]. With increasing power demand and recent focus on environmental impacts from fossil-based power generation, biomass power projects are promoted through national energy programs. Domestic energy policies have strong impact on the competitive position of each country in the clean energy sector.

There are three primary technology categories used for the combustion based conversion of biomass into electricity: pyrolysis, gasification, direct combustion. Direct combustion is the oldest and simplest, but most inefficient technology. Gasification and pyrolysis have higher efficiencies but require significantly more process control and investment [3, 10, 13].

As solid fuel, biomass is different from coal in combustion characteristics; also there are various fuel properties that differently affect combustion performance of biomass. In the combustion process, energy content, moisture content and chemical composition are the most important biomass characteristics affecting combustion processes. In the biomass combustion process, biomass particle size, energy content, moisture content and volatiles are predominate characteristics affecting the gasification process. Straw-based fuel is known as a problematic fuel due to its high alkali content of ash that may cause deposition [8, 9]. Appropriate boiler technology must be selected to satisfy power plant requirements in terms of capacity, investment efficiency and operating costs; advantages and disadvantages can affect operating performance and operating costs.

The expansion of capacities for electricity generation from biomass has nowadays taken a new concept as the society is more and more concerned about air pollution, biodiversity preservation, global warming and other environmental and social issues [7, 12].

The analysis of straw fired power plant is conducted with reference to several key indicators: availability of biomass, regulations, reduction of greenhouse gas emissions, location, land use, electricity price and social impacts. The whole life cycle of biomass use is considered including collecting, transport, storage, handling and utilization. In order to demonstrate all above mentioned indicators, the region of Vojvodina with significant potential in biomass is selected. The results of the analysis are validated trough environmental and social aspects. Special attention is given to specifying risks for this application.

Methodology

To conduct this assessment, several key sustainability indicators are identified such as relevant legislation, selling price of electricity, and efficiency of energy conversion, total carbon dioxide emissions, availability of straw, different kinds of limitations, water use, and social issues.

Energy law and regulations

The promotion of electricity from renewable energy sources is a high European Union (EU) priority for several reasons including security and diversification of energy supply, environmental protection and social and economic cohesion. Countries such as China, Brazil, the United Kingdom, Germany and Spain with strong national policies aimed at reducing global warming and pollution, provide incentives for the use of renewable energy and have established stronger competitive positions in the clean energy economy. These nations are competing effectively relevant to clean energy jobs and manufacturing.

Authors of the paper [13] pointed out two main types of obstacles contributing to the disappointing diffusion outcome so far: economic obstacles for power generation and resource markets' obstacles. The generation of electricity based on renewable resources, including biomass, is still more expensive than the generation of electricity based on fossil fuels. The energy policy literature identifies a number of policy instruments that governments worldwide apply in order to stimulate the uptake by investors of renewable electricity technologies: feed-in tariffs, tradable green certificates, investment subsidies, tax exemptions/reductions, *etc.*

Energy policy of the Republic of Serbia is defined by the Energy Law and among other things it envisages measures to create conditions for stimulating the use of renewable energy sources. Accordingly, the Energy Law introduces categories of privileged manufacturers of electric and thermal energy who in addition to other fuels use renewable energy sources in the process of energy production. These privileged manufacturers are entitled to subsidies, taxation, customs and other incentives in accordance with the Law and other regulations on taxes, customs duties, subsidies and other incentives. Currently, only specified feed-in tariffs are used according to the type of power plant producing electricity from renewable energy sources and the capacity of the plant installed (P) stated in MW. Table 1 shows biomass power plants feed-in tariffs by installed capacity. Rights and obligations of the buyer and

Table 1. Feed-in tariffs for biomass plants in Serbia

Installed capacity [MW]	Feed-in tariff [€ per MWh]
Up to 0.5 MW	136.00
From 0.5 MW to 5 MW	138.45 – 4.89×P
From 5 MW to 10 MW	114.00

privileged power producer will be defined in a written power purchase contract for the period of 12 years and in accordance with the Energy Law.

Feed-in tariffs have been often assessed in academic literature as 'successful instruments' because they helped in fast diffusion of new technologies in some countries [13]. Another important fact for the lack of biomass power plants in Vojvodina is the absence of reliable resource markets for biomass, which can continuously provide resources of certain quality at prices that make biomass power production profitable under the applicable feed-in tariffs.

Availability assessment and logistics

It is very important to emphasize that in Serbia there is no organized biomass market because of the lack of incentives for agricultural producers. Biomass logistics is one of the most important steps in the realization of projects that are related to biomass. One of the most important steps in the implementation of biomass projects is the logistics of collecting biomass (straw). Understanding of biomass availability at the regional scale is critical when evaluating the economic viability of biomass energy systems [8]. The availability of the straw market and supply is specifically considered. For continuous operation of a power plant, it is crucial to provide necessary amounts of biomass for the nominal operating capacity throughout the year or for the specified number of working hours.

At the territory of the Province of Vojvodina, there is a large potential of straw. The main issue is collecting necessary amounts of straw for electricity production. Comprehensive studies have shown that if a plant is more than 100 km away from the source of straw, it will not create any emission reduction and it will not be profitable. It is recommended to have straw collected in the circle of around the plant in the radius of 50 km. To ensure required quantities of straw for the power plant, it is recommended to enter into long time contracts with nearby suppliers within the radius of 50 km from the power plant. In fig. 1, an example how to consider the availability of biomass during the construction of the plant is given and to mark all the suppliers within 50 km radius from the power plant.

Figure 1. Example how to considered the availability of biomass (straw)

In this way, the supply of biomass will be secured, transportation costs will be kept as low as possible and the emission of greenhouse gases due to the biomass collection will be kept at minimum. If the diameter is larger, the price of straw at the entrance to the plant will be higher and the impact onto the project's profitability will be significant. All these stages influence the energy quality obtained from these resources and affect final production costs of biomass power.

Considering the lack of biomass market at the territory of the Province of Vojvodina, it is of great importance to indicate all specific details that may be critical during the construction of the power plant.

At the territory of the Province of Vojvodina, it cannot be counted on the uniform form of straw bales (such is the case in countries with developed biomass market, for example Denmark, where for energy purposes typical square bales, so called Hesston, are used). Since there are large quantities of round bales in Vojvodina, this type of bales need to be used at the planned power plant. This issue also has great impact on the transport, storage and selection of the power plant equipment (boiler feeding system).

Also, all biomass energy conversion processes will require some form of physical manipulation. Commonly, this includes sorting, storing, sizing, screening and moving the material from one location to the other. Moisture content in bales also affects the quality of biomass as fuel for combustion and gasification processes. Materials with lower moisture content cost less to transport and can reduce the size of handling, processing and energy conversion equipment needed for biomass power production since they require smaller overall volume of feedstock. Because of straws voluminosity and moisture content, a very important issue is straw storage. And, for single units of the power plant (boilers, boiler feeding system), stable function is guaranteed by producers relevant to moisture percentage in straw (most commonly it is maximum 20-22%). Hence, preservation of the quality of straw is of exceptional importance and, that is not easy to achieve when there is no developed biomass market and defined ways of storage. This is what the situation is like in Serbia. Provided quantities can be stored by suppliers and/or at the plant location (it is desirable to have own big stocks because then, the storage conditions can be controlled). Straw stored in the open must be stored according to corresponding regulations and must be protected from rain and snow with nylon covers (the suppliers must be educated about this).

Selection of the location

During the selection of the location for the construction of the biomass power plant, it is necessary to consider a great number of criteria: a) the availability of fuel; largest suppliers of straw need to be nearby (as mentioned in the previous chapter, we are considering the possibility of purchasing necessary quantities of straw within the radius of 50 km from the power plant); b) The selected location should have access roads; c) The selected location should have sufficient quantities of water, d) possibility for the connection to the public power grid, *etc.*

For Vojvodina region, it is of great importance to consider the possibility of the connection to the public power grid having in mind limitations imposed by the National Power Distribution Company. With these criteria, biomass power plants are limited by the connection to middle voltage grid (10, 20 i 35 kV) to max. 3.5 MVA. In case it is planned to install a power plant with larger capacity than mentioned, the only possible way to do that is over 110 kV grid. Also, the location should be near 110 kV power grid (for connecting purposes). In fig. 2, the availability of 110 kV grid at the territory of Vojvodina is shown.

Hence, the most optimal selection of the location will be the result of overlapping figs. 1 and 2 and the location selection according to the available amount of straw within the radius of 50 km and 100 kV grid as close as possible to the power plant.

Technology selection

Various biomass power plants technologies have been developed in recent years depending on the type of biomass used as fuel (straw, wood waste, sunflower shell…). Basic requirements for biomass power plants are reliability, continuous operation on nominal ballast and nominal parameters and efficiency, no matter which type of biomass is used as fuel.

Fuel properties can cause operating problems that affect plant reliability and operating hours; control methods and treatment equipment can result in additional cost. Major problems of biomass combustion are slugging, fouling and corrosion, erosion and NO_x emissions.

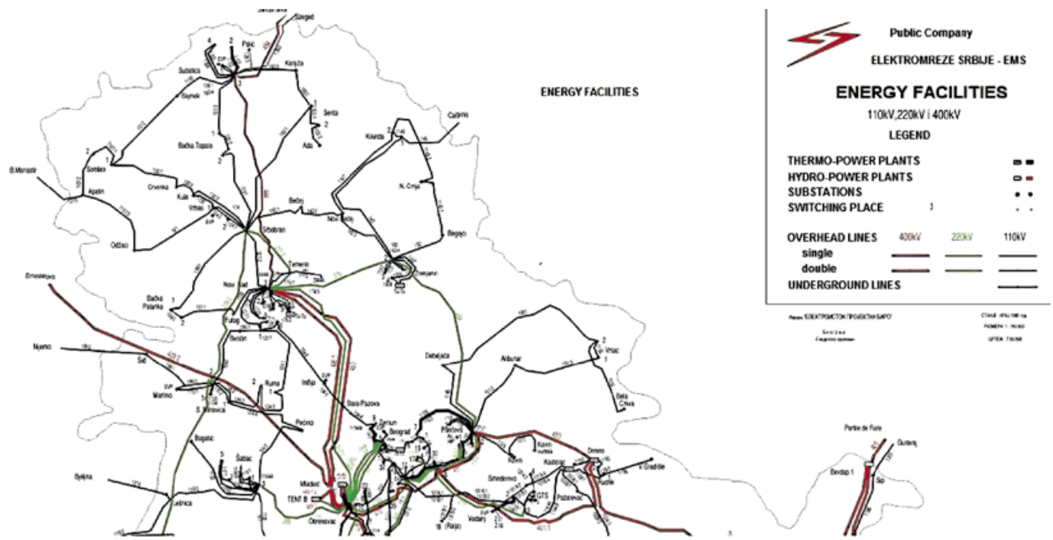

Figure 2. 110 kV grid at the territory of the Province of Vojvodina

Cereal straw and other herbaceous biomass materials have proved to be difficult to burn in most combustion furnaces, especially those designed for power generation. Combustion of straw causes rapid formation of sticky deposits in the convective heat transfer section of the boiler (ash fouling), as well as large molten ash deposits in the furnace (slag). This is highly inconvenient, because power generation from straw can serve a vital public service in reducing atmospheric emissions from open field burning [5].

Moisture content is a major factor affecting straw quality during storage. Moisture of baled straw is 10-18%. When moisture content is over 13%, each 1% increase in moisture reduces power output by 2% for the same straw amount [4].

In addition, development of technologies that can burn more than one type of fuel is very important (different types of biomass, co-firing with coal or wood) so the power plant can run on various resources and guarantee continuous production.

In addition to previously mentioned general criteria for technology selection, it is of great importance to specify criteria that are specific for the territory of Vojvodina by having in mind available types of straw bales and corresponding boiler feeding system needs. In this region, the partaking of roll bales cannot be avoided which significantly increases difficulties relevant to the design of boiler feeding systems. Difficulties arising primarily from debaling and then from achieving constant flow of straw to the boiler are things that have to be considered during the selection of appropriate equipment.

Already mentioned criteria for grid connection, thus, limit the power unit to about 3.5 MVA at the territory of the Province of Vojvodina demands comprehensive analysis if the power plant is going to be constructed with the power bigger than mentioned – if it is to choose more units of less power that is more expensive solution, what is the cost of connecting to 110 kV voltage level *etc.*

Efficiencies of energy conversion from biomass vary widely across different technologies. This is an area under intense development, with many new, highly efficient technologies emerging.

Investment costs, electricity and straw price

Investment costs for biomass conversion to energy exceed other thermal technologies by a factor of 3-4. Due to higher processing volumes and increased handling requirements, capital costs for direct combustion are around $1.9-2.9/kW [3]. In addition to investment costs that can be found in numerous currently available literature, it should be emphasized that the value of investment in the biomass power plant if equipment used is produced in China (in this region, offers with Chinese equipment are considered more often during planning of investment in renewable energy sources) is 2-2.5 times less than equipment of reputable world manufacturers. Therefore, it is very important to pay attention to compliance with standards (often Chinese equipment is not produced according to the EU standards), manufacturing quality, level of documentation, *etc.*

The prices of fuel for the power plant (straw) and of electricity are important to emphasize because they are typical for the considered region and may be significant for the cost-benefit analysis of the project.

With all previously mentioned negative sides, such as the lack of biomass market and other things, it can be said that there is one positive side and that is the price of straw that is cheaper comparing to countries where the biomass market exists. The price of straw is from 30-40 €/t at the location of the power plant.

Based on the valid Decree in Serbia for electricity produced from biomass, the price is € 114 and up per MWh. It is important to emphasize that the commercial price of electrical energy is bellow 6 € cent per kWh which is one of the cheapest in Europe.

This project in Serbia can be also evaluated by using clean development mechanism (CDM). In this way, additional income could be generated and immediately increase the profitability of the project. In China, there were two CDM power plant projects in the Hebei Province in 2006 (two plants of 12 MW capacity) and in Jiangsu in 2007 (25 MW); the plants are operated with rice straw, wheat straw, maize straw and other biomass residues [4].

Results and discussion

Environmental impact assessment

Although open burning of straw is not allowed in Serbia, it is common practice to burn straw after harvest in the open. This results in air emissions that have harmful effects on air quality and human health. Straw as agricultural waste biomass can be the source of alternative energy to substitute fossil energy and reduce greenhouse gas emissions, as well as to avoid local pollution problems from open air burning [4]. Producing electricity from straw is immeasurably better and more environmentally friendly way of using biomass.

Regarding the Kyoto Protocol, the other advantage of this kind of project is CO_2 reduction. Burning biomass is considered to be CO_2 neutral. The amount of produced electricity in the straw fired power plant will reduce the production of electricity at the national level. In Serbia, electricity is mostly produced by burning lignite.

Since we are considering the power plant with the capacity up to 10 MW, such a project will be a small scale CDM project activity. Also, such plants can fall under the following types and categories of CDM projects:

– Type I – renewable energy project activity with maximum output capacity equivalent to up to 15 MW (or appropriate equivalent)
– Category I. D. – Grid connected renewable electricity generation

The project activity will be the installation of a new grid-connected renewable power plant/unit (a Greenfield facility), the baseline scenario will be electricity delivered to the grid by the project activity. This electricity will be otherwise generated by the operation of Serbian grid-connected power plants and by the addition of new generation sources, as describe in the combined margin emission factor. The combined margin emission factor $EF_{grid\,CM}$ is estimated to: 0.832 t_{CO2}/MWh.

Table 2 shows estimations of CO_2 reduction per ton of different straws.

Table 2. Reduction of CO_2 per ton of different straw

Type of biomass	Specific consumption [t/MWh]	CO_2 reduction [tCO_2 per t straw]
Corn straw	1.045	0.796
Wheat straw	1.075	0.774
Barley straw	1.057	0.787
Rapeseed straw	1.082	0.769
Sunflower straw	1.171	0.711
Hemp straw	1.088	0.765

Also, for the straw power plant of 10 MW, the project activity will generate and supply approximately 80,000 Wh per year (estimated number of working hours – 8,000 hours per year) of clean electricity to the Serbian grid. This will lead to GHG emission reductions of approximately 66,560 tCO_2e per year as a result of substitution of grid electricity.

Social impact assessment

There is a wide range of social impacts arising from the production of electricity from biomass. Biomass power is considered as important technology from the standpoint of fuel security. It is also backed-up in political declarations because of its potential to offer jobs in rural areas thus preventing the decline of the agricultural sector and prevent migration of rural population to urban areas [13].

The social aspect of biomass use for energy purposes is reflected in the fact that at the national level, its use leads to the reduction of import dependence and to the employment of local population in newly created jobs. The national labor force is engaged in the construction and installation, designing, servicing, sometimes in the production of the plant and related equipment, *etc.*

Other motives for using biomass for power production are: the prevention of soil erosion by means of energy crops, the reduction of fire disasters due to woody wastes in forests and organic wastes at agricultural fields, and the development of new industrial sector for biomass power technology and services [13].

Risk assessment

For any investor in electricity generation, commercial terms under which the investment is made are of crucial importance: a) the clarity and reliability of the legal framework regarding the purchase contracts, and b) the price per kWh likely to be received during the project's economic lifetime [13].

Table 3. Identified risks of biomass power plant operation

	Risk Name	Probability and Impact Assessment	Overall Risk Rating
1	The risk of insufficient quantities of straw	The possibility of the variation in quantities of straw is small for well chosen locations. In the analyzed location in the region of Vojvodina, the probability of this event is small and does not have major impact.	Medium
2	The risk of price fluctuations of straw	For now, the probability of significant growth of straw prices is small and does not have large impact	Medium
3	The risk of variation of moisture content in straw	There is a real possibility of variations in moisture content due to weather conditions and the inability to complete protection of straw. Therefore, this risk has medium probability and medium intensity.	Medium
4	The risk of physical deterioration of available stocks of straw	Due to long inadequate storage of straw, there is significant risk for compromising its quality. Here, the probability is moderate and the impact is significant.	High
5	The risk of variation of selling price of electricity	The plan is to sell produced electricity at the current feed-in tariff. If such feed in tariff is cancelled, it is going to significantly disrupt business as usual. The probability of this happening is small but the impact is significant. On the other hand, the current selling price of electricity can go up. The probability of this situation in long term scenario is probable and the impact will again be significant.	High
6	The risk of stopping the production process due to equipment malfunction	In case of stopping the production process, urgent response of maintenance service is required. Therefore, this has low to moderate probability of occurrence and moderate impact.	Low
7	Modification of the regulatory conditions considering the wider use of renewable energy sources	Making new laws and regulations regarding the use of RES can significantly improve profitability of this kind of projects. For instance, some tax allowance for RES users.	High

The first quote is highly important in Serbian business environment because the Government's proposed feed–in tariff and obligation to purchase generated electricity are the only things that keep this project profitable since the price of electricity in Serbia is one of the lowest in Europe. Currently, the Serbian Energy Policy has this as the only measure to encourage renewable energy use.

Except general risks associated with project implementation, some more specific project operation risks can be identified in case of straw fired power plant (tab. 3).

In order to assure continuous and stabile electricity production for all listed risks, it is necessary to develop preventive and reactive measures. Good planning of management can reduce some risks which have been assessed. Creating long and medium term procurement plans of straw and making long term contracts with suppliers can reduce the possibility of significant variations in the amount of straw at the entrance to the plant. Building a warehouse with larger capacity, appropriate stock quantity, well-organized handling and internal transport, continuous tracking of straw inventory, demanding allowed percentage of moisture in straw from supplier, *etc.* can significantly reduce some of above mentioned risks.

Conclusions

Wider use of biomass for energy purposes has significant social and environmental benefits. The reduction of emission can also be indirectly achieved through the reduction of electricity production (mainly from lignite) at the national level for the electricity amount produced from biomass. The world has recognized this potential and has been building biomass power plant. However, in Vojvodina, there is no power plant using straw. Currently, straw is used only in few plants for technological purposes.

The general impression is that Vojvodina has solid conditions for the wider use of biomass for energy purposes. With an adequate supply system, biomass can partially replace fossil fuels in order to reduce greenhouse gas emissions and to prevent pollution from open burning of straw. The conceptualization of biomass resources by governmental decision-makers has led them to underestimate the importance of a comprehensive institutional and policy framework for the development of biomass resource markets. The crucial factor in Vojvodina affecting the long-standing profitability of biomass related project problem lies primary in the absence of the biomass market. Since biomass power technologies are more expensive than conventional fossil fuel technologies, the government needs to introduce a series of support instruments to overcome economic obstacles for wider use of renewable energy sources in power production.

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