ECONOMICS OF BIOMASS POWER PLANT

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ABSTRACT
This work deals about technology and economics of biomass power plant as renewable source of energy. There is a description of parts of this power plant. In the next part of this work are calculations of annual production costs, unit costs, annual profit and net present value of project. These calculations are solved for three kinds of biomass fuel: vegetable waste, softwood, hardwood and coal as traditional fuel. The amount of investment unit costs for power plants, that use renewable energy sources, will mainly affect the energy density of fuels, resulting specific variable costs.

Keywords: *biomass, biomass power plant, economic efficiency, renewable resources, fuel, wood, vegetable waste, coal*

1. INTRODUCTION

Power plants as sources of electricity have significant influence to the economy of the power system. To avoid serious problems in ensuring consistency between the supply of electric energy and the demand for electric energy is necessary to consider various options for development, as sources. The strategic aspect of most countries independence in electric energy production supports the view, that decisive element meet growing electric energy demand remains mainly the construction of new power plants.

In theory regards the optimization of the development of the sources of the electricity power system. To solve this optimization problem, there are several mathematical models most commonly implemented in computer programs. In the expert and lay discussions about the advantages and efficiency of different construction alternatives of electric power plants are often used false arguments in effort to simplify complex problems inadvertently or even intentionally distort the conditions of profitability.

The results are often distorted by inaccurate input data of calculation or misinterpretation of correct calculation results [1] [10] [11] [20] [21].

2. ECONOMIC EVALUATION OF COSTS OF THE POWER PLANTS

When choosing a particular design variant of power plant we provided that the annual production cost N_{pr} consist of a fixed component N_{fi} and a variable component N_{va}.

$$N_p = N_{fi} + N_{va} \qquad (1)$$

Fixed component N_{fi} can be expressed as

$$N_{fi} = k \, N_i \qquad (2)$$

Investment costs N_i can be calculated as

$$N_i = {}_1N_i \, P_m \qquad (3)$$

Where ${}_1N_i$ is investment costs per *1 kW* and P_m is installed electric power of power plant. Variable component N_{va} can be calculated as

$$N_{va} = n \, A = n \, P_m \, \tau \qquad (4)$$

Where n is specific costs, A is annual production of energy, P_m is installed power of power plant and τ is time of using maximum. The specific costs per unit of the produced energy n of generated electric energy we can calculate as the sum of the specific variable costs n_{va} and the specific costs of externalities n_{ex}.

$$n = n_{va} + n_{ex} \qquad (5)$$

We can rewrite equation $N_p = N_{fi} + N_{va}$ (1) and we obtained the dependence of the annual production costs N_{pr} on the annual production of energy A.

$$N_{pr} = k \, N_i + n \, A \qquad (6)$$

$$N_{pr} = k \, N_i + (n_{va} + n_{ex}) \, A \qquad (7)$$

$$N_{pr} = k_1 + k_2 \, A \qquad (8)$$

If annual production costs N_{pr} are divided by annual production of energy A, we get equation for specific production costs n_{pr} [5] [6] [15] [16] [25].

$$n_{pr} = \frac{k \, N_i}{A} + n \qquad (9)$$

$$n_{pr} = \frac{k \, N_i}{A} + (n_{va} + n_{ex}) \qquad (10)$$

$$n_{pr} = \frac{k_1}{A} + k_2 \qquad (11)$$

If annual production costs N_{pr} are divided by power of plant P_m, we get equation for specific unit production costs $_1N_{pr}$. The equation of all variants we have to divide the same value of power P_m, otherwise the comparison is not possible. Graphical representation of these specific unit costs $_1N_{pr}$ is called the equilibrium diagrams.

$$_1N_{pr} = \frac{k\,N_i}{P_m} + n\,\tau \qquad (12)$$

$$_1N_{pr} = \frac{k\,N_i}{P_m} + \left(n_{va} + n_{ex}\right)\tau \qquad (13)$$

$$_1N_{pr} = k_3 + k_4\,\tau \qquad (14)$$

If annual production costs N_{pr} are divided by time of using maximum τ, we get equation for production costs per hour $_1n_{pr}$.

$$_1n_{pr} = \frac{k\,N_i}{\tau} + n\,P_m \qquad (15)$$

$$_1n_{pr} = \frac{k\,N_i}{\tau} + \left(n_{va} + n_{ex}\right)P_m \qquad (16)$$

$$_1n_{pr} = k_5 + k_6\,P_m \qquad (17)$$

Deciding about the construction of a certain type of power plant brings us many problems connected with the characteristics of individual variants. The proposal is dependent on the annual production of energy A, the installed power of the power plant P_m and the time of using maximum τ.

3. ECONOMIC EVALUATION OF PROFITS OF THE POWER PLANTS

This equation for annual profit c_{ap} considers price of the dispositive electric power c_{fi}, price of the consumed electric energy c_{va}, installed power of power plant P_m, time of using maximum τ, production costs N_{pr}.

$$c_{ap} = c_{fi}\,P_m + c_{va}\,A - N_{pr} \qquad (18)$$

$$c_{ap} = c_{fi}\,P_m + c_{va}\,P_m\,\tau - N_{pr} \qquad (19)$$

The first method calculates values of profit without time factor. Here is a simple equation for the updated profit c_{wotf} over the lifetime of the device t.

$$c_{wotf} = c_{ap}\,t \qquad (20)$$

The total updated profit C_{wotf} will be

$$C_{wotf} = c_{wotf} - N_i \qquad (21)$$

The second method calculates values of profit with time factor. Here is the equation for Net Present Value:

$$NPV = \sum_{i=1}^{t} CF_i\left(1+r\right)^{-t} - N_i \qquad (22)$$

$$q = 1 + r \qquad (23)$$

Where r is interest rate for time and q is factor of time. When all values of annual profits CF_i are practically same, we mark them as average annual profits CF, and we can rewrite the equation like this.

$$NPV = CF\sum_{i=1}^{t} q^{-t} - N_i \qquad (24)$$

When we mark NPV as C_{wtf} and CF as c_{ap}, we can rewrite equation like this.

$$C_{wtf} = c_{ap}\sum_{i=1}^{t} q^{-t} - N_i \qquad (25)$$

Now we can solve and rewrite this equation for total updated profit C_{wtf}.

$$C_{wtf} = c_{ap}\,\frac{q^t - 1}{q^t\,(q-1)} - N_i \qquad (26)$$

Also we can solve this equation for updated profit c_{wtf}.

$$c_{wtf} = c_{ap}\,\frac{q^t - 1}{q^t\,(q-1)} \qquad (27)$$

Here is simple equation for updated profit c_{wtf}, total updated profit C_{wtf} and investment costs N_i [3] [8] [13] [18] [23].

$$C_{wtf} = c_{wtf} - N_i \qquad (28)$$

4. DESCRIPTION OF USED TECHNOLOGY

Most biomass power plants use direct-fired combustion systems. They burn biomass directly to produce high-pressure steam that drives a turbine. The turbine drives a generator. The generator produces electricity. In some biomass industries, the extracted or spent steam from the power plant is also used for manufacturing processes or to heat buildings. These combined heat and power systems greatly increase overall energy efficiency to approximately 80%, from the standard biomass electric energy only systems with efficiencies of approximately 20%. Seasonal heating requirements will impact the combined heat and power system efficiency.

A simple biomass electric generation system is made up of several significant components. For a steam cycle, this includes some combination of the following items: fuel stock, handling equipment, furnace, boiler, pumps, fans, steam turbine, generator, condenser, cooling tower, exhaust / emissions controls, system controls (automated).
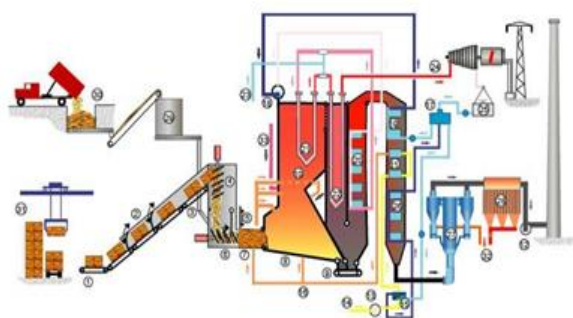
Fig. 1 Figure of power plant

Direct combustion systems feed a biomass feedstock into a combustor or furnace, where the biomass is burned with excess air to heat water in a boiler to create steam. Instead of direct combustion, some developing technologies gasify the biomass to produce a combustible gas, and others produce pyrolysis oils that can be used to replace liquid fuels. Boiler fuel can include wood chips, pellets, sawdust, or bio-oil. Steam from the boiler is then expanded through a steam turbine, which spins to run a generator and produce electric energy. Then is steam condensed in a cooler and goes back to a boiler.

In general, all biomass systems require fuel storage space and some type of fuel handling equipment and controls. A system using wood chips, sawdust, or pellets typically use a bunker or silo for short-term storage and an outside fuel yard for larger storage. An automated control system conveys the fuel from the outside storage area using some combination of cranes, stackers, reclaimers, front-end loaders, belts, augers, and pneumatic transport. Manual equipment, like front loaders, can be used to transfer biomass from the piles to the bunkers, but this method will incur significant cost in labor and equipment operations and maintenance. A less labor-intensive option is to use automated stackers or silo.

Wood thermal power plants typically use one dry kilogram of fuel per one kilowatthour kWh of electric energy production. This approximation is typical of wet wood systems and it is useful for a first approximation of fuel use and storage requirements, but the actual value will vary with system efficiency.

Most wood chips produced from green lumber will have a moisture content of 40% to 55%, wet basis, which means that a ton of green fuel will contain 400 kg to 550 kg of water. This water will reduce the recoverable energy content of the material, and reduce the efficiency of the boiler, as the water must be evaporated in the first stages of combustion [2] [9] [12] [19] [22].

The biggest problems with biomass-fired plants are in handling and pre-processing the fuel. This is the case with both small grate-fired plants and large suspension-fired plants. Drying the biomass before combusting or gasifying it improves the overall process efficiency, but may not be economically viable in many cases.

Exhaust systems are used to vent combustion by-products to the environment. Emission controls might include a cyclone or multi-cyclone, a baghouse, or an electrostatic precipitator. The primary function of all of the equipment listed is particulate matter control, and is listed in order of increasing capital cost and effectiveness. Cyclones and multi-cyclones can be used as pre-collectors

to remove larger particles upstream of a baghouse like fabric filter or electrostatic precipitator.

In a direct combustion system, biomass is burned in a combustor or furnace to generate hot gas, which is fed into a boiler to generate steam, which is expanded through a steam turbine to produce mechanical energy. The mechanical energy is converted to electric energy in generator [4] [7] [14] [17] [24].

5. THE COSTS OF BIOMASS POWER PLANT

For comparison we use power plant with this parameters. Its installed electric power P_m is 8,2 MW. Time of using maximum τ is 8000 h/year. Annual production of electric energy A is 65,6 GWh/year.

Fig. 2 Biomass power plant in town Bardejov

Fig. 3 The stock of biomass and wood

In next table are compared the specific variable cost n_{va} of three types of biomass fuel and coal as traditional fuel.

Table 1 Specific variable cost n_{va}

Vegetable waste	0,054 €/kWh
Softwood	0,061 €/kWh
Hardwood	0,074 €/kWh
Coal	0,079 €/kWh

Table 2 Specific variable cost of externalities n_{ex}

Vegetable waste	0,007 €/kWh
Softwood	0,007 €/kWh
Hardwood	0,007 €/kWh
Coal	0,020 €/kWh

The annual production costs N_{pr} for this power plant can be solved by equation $N_{pr} = k_1 + k_2 \, A$ (8). These calculations are shown on the next figure.
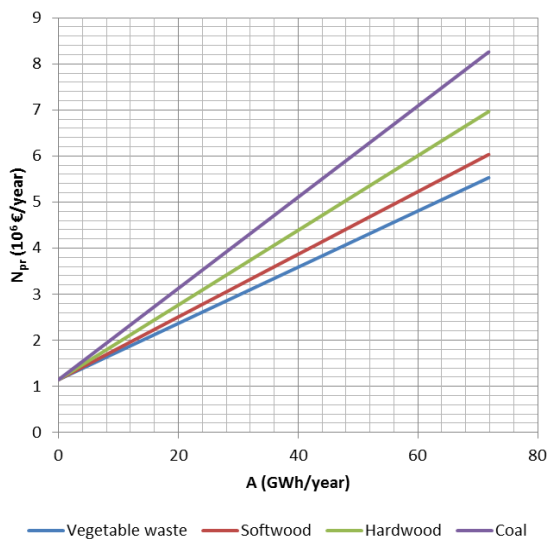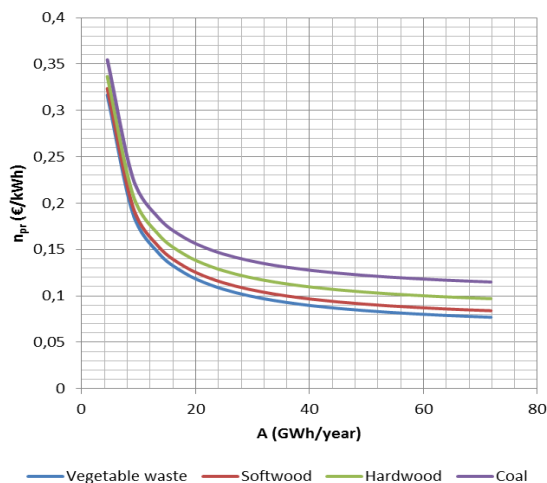

Fig. 4 Annual production costs

The annual production of energy A is 65,6 GWh/year. Now we can see annual production costs N_{pr} are the highest for coal and the least for vegetable waste.

The specific production costs n_{pr} for this power plant can be solved by equation

$$n_{pr} = \frac{k_1}{A} + k_2$$

(11). These calculations are shown on the next figure.

Fig. 5 Unit costs for production of electric energy

The annual production of energy A is 65,6 GWh/year. Now we can see specific production costs n_{pr} are the highest for coal and the least for vegetable waste.

The specific unit production costs $_1N_{pr}$ for this power plant can be solved by equation $_1N_{pr} = k_3 + k_4 \, \tau$ (14). All variants of fuel were divided with same installed electric power P_m. These calculations are shown on the next figure. This figure is called equilibrium diagram.
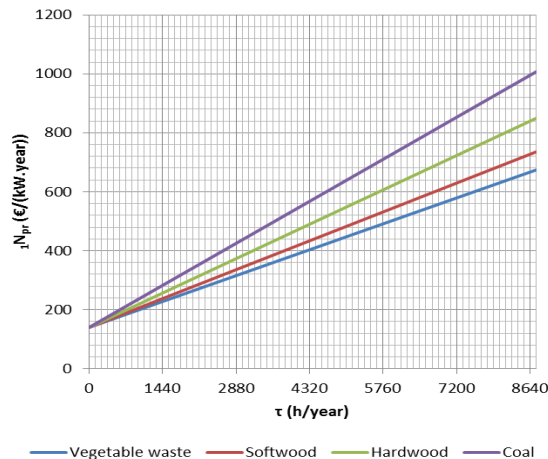

Fig. 6 Equilibrium diagrams

The time of using maximum τ is 8000 h/year. Now we can see specific unit production costs $_1N_{pr}$ are the highest for coal and the least for vegetable waste.

The hourly costs $_1n_{pr}$ for this power plant can be solved by equation $_1n_{pr} = k_5 + k_6 \, P_m$ (17). These calculations are shown on the next figure.
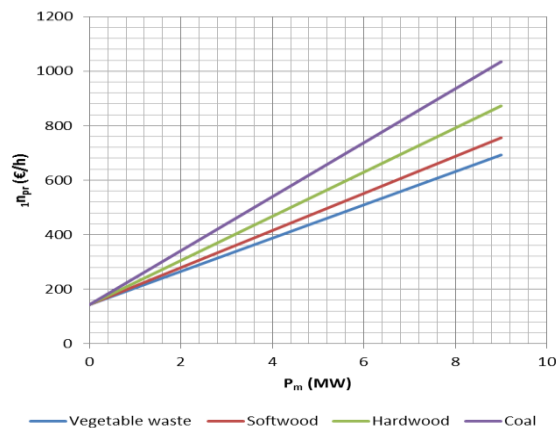

Fig. 7 Hourly costs of production

The installed power of power plant P_m is 8,2 MW. Now we can see hourly costs $_1n_{pr}$ are the highest for coal and the least for vegetable waste.

The annual profit c_{ap} is calculated by the equation $c_{ap} = c_{fi} \, P_m + c_{va} \, P_m \, \tau - N_{pr}$ (19). The annual profit c_{ap} depends on the used fuel. In next table are compared the annual profit c_{ap} of three types of biomass fuel and coal as traditional fuel.

Table 3 Annual profit c_{ap}

Vegetable waste	4462226,8 €/year
Softwood	4003026,8 €/year
Hardwood	3150226,8 €/year
Coal	1969426,8 €/year

Than we can calculate updated profit c_{wotf} by this equation

$$c_{wotf} = c_{ap} \, t \qquad (20)$$

for first method. If we deduct initial costs N_i from updated profit c_{wotf}, we get equation for total updated profit C_{wotf}. The return total updated profit C_{wotf} is calculated by this equation

$$C_{wotf} = c_{wotf} - N_i \qquad (21).$$
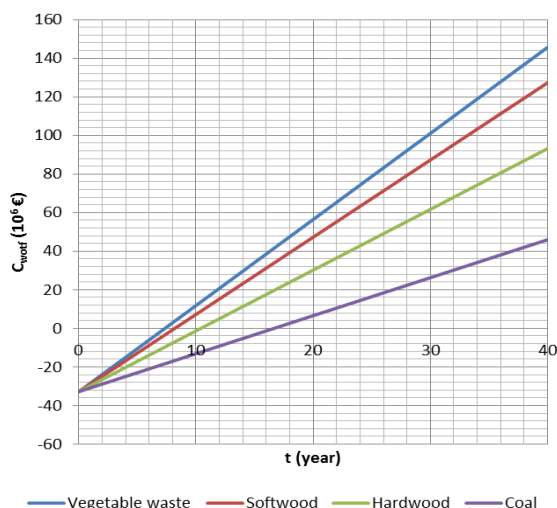
These calculations are shown on the next figure.

Fig. 8 Return profit without time factor

Than we can calculate updated profit c_{wotf} by this equation

$$c_{wtf} = c_{ap} \frac{q^t - 1}{q^t (q - 1)} \qquad (27)$$

for second method If we deduct initial costs N_i from updated profit c_{wtf}, we get equation for total updated profit C_{wtf}. The total updated profit C_{wtf} is calculated by this equation

$$C_{wtf} = c_{wtf} - N_i \qquad (28).$$

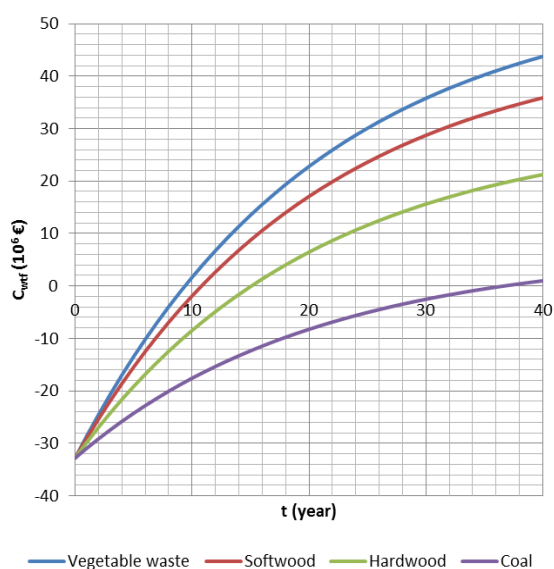These calculations are shown on the next figure.

Fig. 9 Return profit with time factor

These calculations are decided for the choose of fuel.

6. CONCLUSION

These calculations compare some types of biomass fuel for power plant. The variable costs for biomass fuel are less than for coal. If we calculate total updated profit without time factor, time of return of investment costs is between 7 years and 11 years. If we calculate total updated profit with time factor, time of return of investment costs is between 9 years and 15 years. This solution is economically effective, because there is short time of return of investment costs for biomass fuel. This issue we can see in the last two pictures. As vegetable waste we can use some kinds of grass, hay and straw. As soft wood we can use coniferous wood and wood from bushes. As hard wood we can use deciduous woods. There is comparison between biomass fuel and coal. The variable costs for coal are more than for biomass fuel. Expensive coal, as conventional fuel, is not necessary mined in huge volumes for this power plant. The mining of this fuel causes pollution of environment. This solution is economically less effective, because there is longer time of return of investment costs for coal. If we calculate total updated profit without time factor, time of return of investment costs is 17 years. If we calculate total updated profit with time factor, time of return of investment costs is 37 years. The future problems with fossil fuels can be solved. Currently, these calculations simulate results only for biomass power plant. But many types of power plants were invited. For the future calculations can be compared with other types of power plants.

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Alexander Mészáros was born in Rožňava, in 1959. He received the MSc. degree from Faculty of Electrical Engineering, Technical University of Košice in 1983, and the PhD. degree from Faculty of Electrical Engineering, Technical University of Košice in 2002. Since 1996 he has been working at the Department of Electric Power Engineering, Faculty of Electrical Engineering, Technical University of Košice as an assistant professor, since 2009 as an associate professor. His major fields of interests are economic and environmental aspects of electric power systems.

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