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Technological Alternatives for Use of Wood Fuel in Combined Heat and Power Production

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Abstract **– Latvia aims for 40% share of renewable energy in the total final energy use. Latvia has large resources of biomass and developed district heating systems. Therefore, use of biomass for heat and power production is an economically attractive path for increase of the share of renewable energy. The optimum technological solution for use of biomass and required fuel resources have to be identified for energy planning and policy purposes. The aim of this study was to compare several wood fuel based energy conversion technologies from the technical and economical point of view. Three biomass conversion technologies for combined heat and electricity production (CHP) were analyzed:**

- **CHP with steam turbine technology;**
- **gasification CHP using gas engine;**
- **bio-methane combined cycle CHP.**

Electricity prices for each alternative are presented. The results show the level of support needed for the analyzed renewable energy technologies and time period needed to reach price parity with the natural gas – fired combined cycle gas turbine (CCGT) CHPss. The results also show that bio-methane technology is most competitive when compared with CCGT among the considered technologies regarding fuel consumption and electricity production, but it is necessary to reduce investment costs to reach the electricity price parity with the natural gas CCGT.

Keywords **– Biomass, bio-methane, combined heat and power, renewable energy, techno-economic analysis.**

I. Introduction

Use of fossil fuels is entrenched in the national energy sector of many countries. Through extensive use of fossil fuels, the following problems evolve – climate change, environmental pollution and energy dependence on import that stimulates increase of prices of energy resources, electricity and heat. Development of sustainable energy systems by replacement of fossil fuels with renewable energy sources (RES) to the maximum extent can reduce a share of fossil energy sources in the energy sector. In the Latvian energy sector, the main renewable energy sources are provided by water at large hydro power stations and by biomass used in the individual heating installations of the household sector as well as the boiler plants of the district heating sector. Increase of the use of biomass in the Latvian energy sector can help to decrease the total dependence on fossil fuels, especially on natural gas. The main target of Directive 2003/30/EC [1] on the promotion of the use of biofuels or other renewable fuels for transport was to stimulate the use of renewable energy, including use of biofuel in the transport sector. The Directive defines that the total consumption of biofuel in the transport sector in the EU member states had to reach 2% in 2005 and 5.75% in 2010 [1]. Unfortunately, Latvia did not achieve this goal and the total share of biofuel was only 2,6% in 2010 [2] The collective target set for the member states of the European Union for renewable energy usage is defined in Directive 2009/28/EC on the promotion of the use of energy from renewable sources [3]. The Latvian goal is to reach a level of 37 % of the primary renewable energy use in the national energy balance by the year 2016 [4]. The "Guidelines for Use of Renewable Energy 2006–2013", however, had established that in 2010 the amount of electricity produced from renewable sources had to reach 49.3% of the total electricity consumption, but in reality 48.5% of the electricity was produced from RES [5]. According to the draft of the development strategy of Latvian energy sector for the time period up to 2030 developed by the Ministry of Economy, one of the main goals is to reduce import of natural gas from the existing supplier by 50% [6]. The research on potential energy mix in Latvia around year 2050 which would be 100% based on renewable energy sources [7] revealed that such a scenario may be technically possible; however no economic valuation of the costs was done in the study.

The aim of this study was to compare several wood fuel based energy conversion technologies from the technical and economical point of view. The main task of the analysis was to determine electricity production costs per 1 MWh depending on fuel costs and investment for the technology of choice. The obtained electricity production costs reflect the minimum electricity price, which would recover investments in given technologies over a 20 year period if the discount rate is equal to 12%.

II. Materials and Methods

Three biomass conversion technologies for combined heat and electricity production (CHP) were analyzed:

- biomass CHP with steam turbine technology (further in text: type of technology - 1);
- biomass gasification CHP using gas engine (type of technology - 2);
- bio-methane combined cycle CHP (type of technology - 3).

Biomass CHP steam turbine technology was chosen as the "base scenario" because biomass steam turbine technology is widely used and has achieved technological maturity compared with gasification technologies. Biomass gasification technologies are still in active research stage and have a big potential in improvement of technical parameters and cost reduction in the use of wood fuel. Bio-methane production via biomass gasification and subsequent conversion processes of synthesized gas offers further advance in combined heat and power production sector. Because bio-methane has larger energy density in comparison to synthesized gas from biomass gasification, it is possible to use bio-methane with higher efficiency in gas engines. Bio-methane production technologies are still in the beginning of the development stage. The first and only plant of this type is in Guessing (Güssing, Austria), which has been working since 2009. It is planned to build this kind of bio-methane plant in Sweden and Switzerland [8].

The production of bio-methane includes several steps. Within the thermo-chemical conversion path, a gas containing primary CO_2, CO, H_2O, H_2 and CH_4 is generated by gasifying solid biofuels. Subsequent gas cleaning for the elimination of tars-, sulphur-, nitrogen- and chlorine-compounds avoids catalyst-poisoning in the subsequent methanation processes. Depending on the gas composition and the applied methanation process, the H_2/CO ratio has to be adjusted before methanation. Finally, the gas is dried, compressed and injected into the natural gas grid [9, 10, 11, 12] or can be used in on-site energy conversion technologies.

To define and compare economic benefits of different CHP stations, estimates of revenues and expenditures were made using data from Table 1. Revenues consist of income from heat and electricity sales, but expenses - from capital costs, fuel costs, and operation, and maintenance (O&M) costs. All calculations were made for a 20 year period.

The amount of produced heat and electricity, and fuel consumption for each CHP station was calculated based on the technical data of the chosen technologies (see Table 1). The following data were defined as the main input parameters for analyzed CHP technologies:

- installed electrical capacity of all CHP stations is equal to 1 MWe.
- utilization time of installed capacities (capacity factor) of CHPs is 4511 hours per year.

Capital investment of biomass gasification CHP using gas engine (Table 1) includes also biomass gasification equipment. Capital investment of gas and steam turbine combined cycle CHP using bio-methane (Table 1) includes investment in bio-methane production equipment. Low heat generation and electrical efficiency of biomass gasification CHP using gas engine (Table 1) is due to the fact that synthesized gas has a rather low heating value, i.e. typical lower heating value of biomass synthesized gas is between 4-14 MJ/nm^3 [16, 17]. Low heat generation efficiency of the gas and steam turbine combined cycle CHP using bio-methane is due to heat consumption of gasification and methanation processes.

Financial parameters that are used as an input in the model are the following:

- annual natural gas price incremental rate – 2.5%;
- annual inflation rate – 2.5 %;
- calculation period (economic lifetime) – 20 years.

One of the most important criteria for potential building of biomass CHPs is the availability of biomass resources. In Latvia's case, the technically available biomass potential is between 20 – 25 TWh [18]. It is assumed in this study that wood chips are used as a fuel in biomass CHPs, and the following price and quality parameters of wood chips were used:

- initial average price of wood chips – 6 Ls/m^3 loose volume (without VAT) [19];
- lower heating value of wood chips is equal to 0,8 MWh/m^3 loose volume [20];
- annual increase of wood chips price is equal to 2,5%.

The main task of the analysis was to determine electricity production costs per 1 MWh depending on fuel costs and investment. It was assumed that due to the learning effect, the capital investment of gas and steam turbine combined cycle CHP using bio-methane could decrease by approximately 20% in the time period until 2020. For this reason, the electricity production costs per 1 MWh for bio-methane fired gas and steam turbine combined cycle CHP was calculated using specific investment costs of 5000 and also 4000 Ls/kW$_e$, assuming that such capital investment level can be achieved by 2020. To calculate electricity production costs, it is necessary to define heat price, and initial heat price used in calculations for biomass technologies 22 Ls/MWh and 40 Ls/MWh for natural gas combined cycle CHP.

TABLE I

TECHNICAL AND ECONOMICAL CHARACTERIZATION OF TECHNOLOGIES [8, 13, 14, 15]

Technology	power-to-heat ratio	Heat generation efficiency	Electrical efficiency	Capital investments, thous. Ls/MWe	O&M costs, Ls/MWhe
Biomass CHP with steam turbine technology	0,30	0,60	0,27	4700	4,9
Biomass gasification CHP using gas engine	0,63	0,43	0,27	5000	5,5
Bio-methane combined cycle CHP	1,00	0,20	0,34	6000	5,5

* 1 LVL = 1,42 EUR

III. Results

The Figure 1 shows the produced amount of electricity and consumed amount of fuel per 1 MWh of heat produced in the three considered biomass utilization technologies and natural gas combined cycle CHP (electric capacity is 1 MWe in all cases). Since the power-to-heat ratio for bio-methane combined cycle CHP is higher than for biomass steam turbine and gas engine technology, it is possible to produce more electricity based on the same quantity of heat energy. At the same time, the total fuel consumption efficiency of biomass steam turbine CHP is higher than the total fuel efficiency of biomass gasification CHP using gas engine and steam turbine combined cycle CHP using bio-methane.

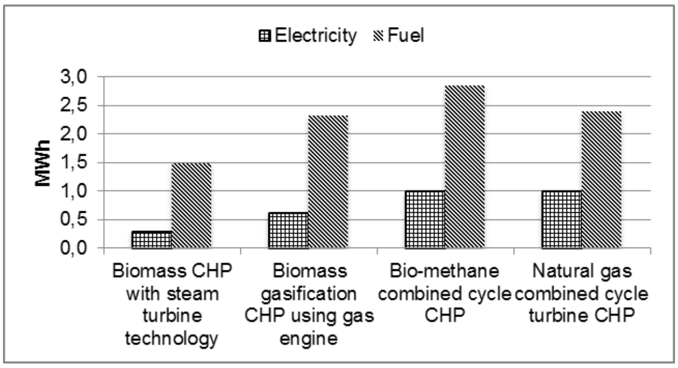

Fig. 1. Amounts of produced electricity and consumed fuel per 1 MWh of heat production

The prices of fossil energy resources are expected to increase considerably in the future due to growing demand, increased costs of extracting the more difficult accessible resources and the fall of supply capacity which may not meet the demand. Figure 2 shows forecasts of natural gas and wood chips prices for the time period of 2012-2035. The price of natural gas is expected to increase considerably (approximately 4 times), but in the same time the level of wood chips price might growth for 40%.

Fig. 2. Prices of natural gas and wood chips during 2012-2035

Figure 3 shows the electricity production costs per 1 MWh for the analyzed CHP technologies with initial heat prices for biomass technologies equal to 22 Ls/MWh and 40 Ls/MWh for natural gas combined cycle CHP. The influence of the amount of total investment of bio-methane CHP on electricity production costs is also estimated and shown in Figure 3.

The highest costs of electricity production (Fig. 3) during the considered period is for the bio-methane combined cycle technology with a total investment 6000,000 Ls, i.e. the costs of electricity production could reach circa 260 Ls/MWh in 2035. At the same time, the biomass CHP with steam turbine technology could produce electricity at approximately the same production cost level as natural gas CCGT, with electricity production costs increasing from 89 up to circa 140 Ls/MWh during a 20 year period. The electricity production costs in case of biomass gasification CHP using gas engine are considerably higher than for the natural gas CHP and biomass steam turbine CHP, because of high capital and O&M costs. The incremental rate of O&M costs was assumed to be equal with the annual inflation rate in calculation of electricity production costs.

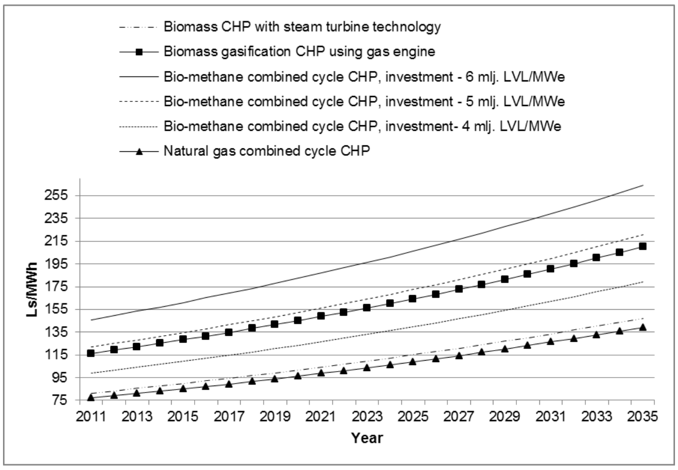

Fig. 3. Costs of electricity production for time period 2012-2035 at the initial heat price 22 Ls/MWh for biomass technologies and 33 Ls/MWh for natural gas combined cycle CHP

Figure 3 clearly shows tha,t by lowering investment in case of bio-methane CHP (see. Figure 3 – bio-methane CHP, investment - 4 milj. LVL/MWe), it is possible to reduce electricity production costs, but they are still approximately 28% higher as in case of natural gas CHP, i.e. the difference between electricity prices by bio-methane combined cycle CHP and natural gas combined cycle is about 40 Ls/MWh in year 2035. The difference between electricity prices of bio-methane combined cycle CHP and biomass gasification CHP using gas engine, in case investment in the bio-methane combined cycle CHP 5000,000 Ls, is circa 85 Ls/MWh. If investments in bio-methane combined cycle CHP technologies could decrease for about 1000,000 Ls/MWe, then this technology could be competitive with biomass gasification CHP using gas engine technology and natural gas combined cycle turbine CHP (see Fig. 3).

Calculations showed that most critical parameters, which have significant influence on electricity production costs is amount of total investment and fuel price, and that O&M costs is not so important (the change of O&M costs by 20% changes electricity production costs by less than 1%). For this reason the influence of total investment and fuel (biomass) price on the electricity production costs for all three considered biomass based energy technologies was chosen for further sensitivity analysis.

Initial total investment costs were equal to capital investment in Table 1, and initial fuel price was 6 Ls/m^3 loose volume (without VAT) or 7.5 Ls/MWh.

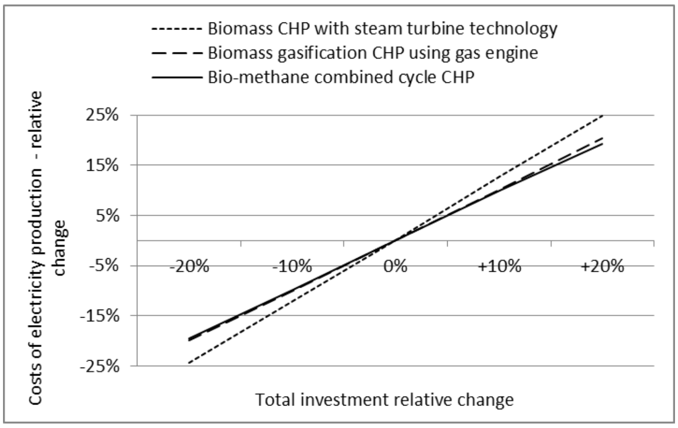

Fig. 4. Influence of total investment on electricity production costs for biomass technologies at constant fuel price and O&M costs

Figure 4 clearly shows that, in case of biomass CHP with steam turbine technology, by lowering investment by 20% it is possible to produce electricity for 25% lower production costs. The influence of total investment on electricity production costs of biomass gasification CHP using gas engine and bio-methane combined cycle CHP has approximately the same nature: costs vary by approximately 17% if the total investment is changed by 20%. The sensitivity analysis shows that, if the total investment is changed from +20% to -20%, the absolute values of electricity production costs change as follows:

- for biomass CHP with steam turbine technology by about ± 33.5 Ls/MWh;
- for biomass gasification CHP using gas engine by about ± 35.5 Ls/MWh;
- for bio-methane combined cycle CHP by about ± 42.5 Ls/MWh.

The influence of fuel (biomass) price on electricity production costs can be seen in Figure 5.

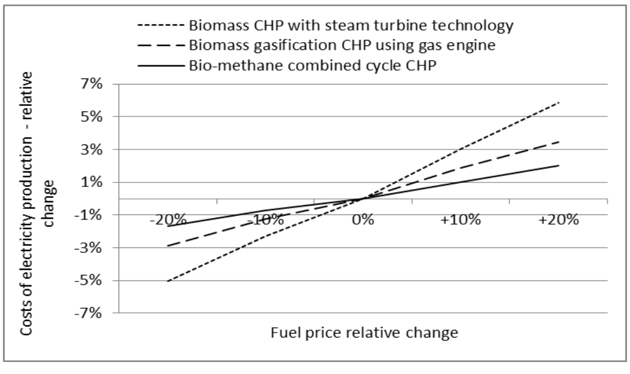

Fig. 5. Influence of fuel price relative on electricity production costs for biomass technologies at constant total investment and O&M costs

The same biomass type and prices was used for all three biomass based energy technologies. Results (see Figure 5) indicate that electricity production costs at constant investment amount and constant O&M costs depend on fuel price in the range of ±5%. Figure 5 shows that biomass CHP with steam turbine technology is the most sensitive to fuel price changes, because this technology has a lower power to heat ratio compared to the other technologies and consumes more fuel to produce the same amount of electricity. In this case, a 20% increase in the fuel price leads to an approximately 7% increase of production costs. Because bio-methane combined cycle CHP has the highest electrical efficiency among the considered technologies and therefore fuel price has less influence on electricity production costs, i.e. the electricity production costs change by approximately 1% if the fuel price is varied by 20% (see Figure 5). The results of the sensitivity analysis show that, if the fuel price is varied from +20% to -20%, electricity production costs change in absolute value as follows:

- for biomass CHP with steam turbine technology by about ± 7.5 Ls/MWh;
- for biomass gasification CHP using gas engine by about ± 6.5 Ls/MWh;
- for bio-methane combined cycle CHP by about ± 3.5 Ls/MWh.

IV. CONCLUSIONS

Results show that the bio-methane combined cycle CHP technology is the most competitive with natural gas-fired CCGT when compared with biomass CHP with steam turbine technology and biomass gasification CHP using gas engine from respect of fuel consumption and produced amount of electricity per 1 MWh of heat. However in case of bio-methane combined cycle CHP technology, it is necessary to reduce level of investment costs to reach the electricity cost level of the natural gas-fired CCGT by approximately 50%.

The costs of electricity production per 1 MWhe of considered biomass-based energy technologies is in the range from circa 140 to 250 Ls/MWh depending on the investment in the biomass cogeneration plant and type of the technology. The analysis shows that the level of support needed for the analyzed renewable energy technologies is:

- for biomass CHP with steam turbine technology – 7.90 Ls/MWh;
- for biomass gasification CHP using gas engine -70.8 Ls/MWh.
- and for bio-methane combined cycle CHP is from 39.6 Ls/MWh up to 85.0 Ls/MWh (depending on total investment amount).

The sensitivity analysis indicates, that the most important factor, which has significant influence on electricity production costs is total investment. At the same time sensitivity analysis also shows that, for technologies with high electrical efficiency, i.e. bio-methane combined cycle CHP, the fuel price does not have such impact on electricity production costs as for the technologies with lower electrical efficiency, i.e. biomass CHP with steam turbine technology.

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