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Integration of bioethanol fuel cell cogeneration systems into Latvian energy supply system

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Abstract. Dependence on imported energy sources and growth of electricity prices in Latvia are the main reasons for use of new renewable energy technologies such as fuel cell cogeneration plants, which could play an important role not only in increase of use of domestically produced bio-ethanol, but also as the energy import minimizing solution. The techno-economic model of bio-ethanol fuel cell cogeneration plant built with "RETScreen 4.0" simulation program (http://www.retscreen.net/) is presented in the work. The results obtained show the dependence of electricity production costs on bio-ethanol price, bio-ethanol reforming efficiency and investment costs. The electricity production costs of fuel cell cogeneration plant are compared with the electricity purchase tariff from cogeneration plants using renewable fuels set by the existing legislation. The results show the technical and economic feasibility of bio-ethanol powered fuel cell cogeneration plants in Latvian energy supply system under several scenarios of development of critical impact factors.

Keywords: reform, bioethanol, cogeneration, feasible studies, fuel cells

1. INTRODUCTION

Latvian energy sector has a diverse energy mix, which is mainly based on imported natural gas and hydro resources (Fig.1). Latvia has comparatively well developed power, natural gas supply and district heating systems, and as a consequence the electricity is basically produced by hydro power plants and by cogeneration plants, which are operated according to district heating demand, and part of electricity is imported (Fig.2).

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However, such factors as rapid economic growth, increase of natural gas prices, planned shutdown of Lithuanian Ignalina Nuclear Power Plant and dependency on imported natural gas and electricity require development of domestic power production capacities and increase of use of renewable energy sources.

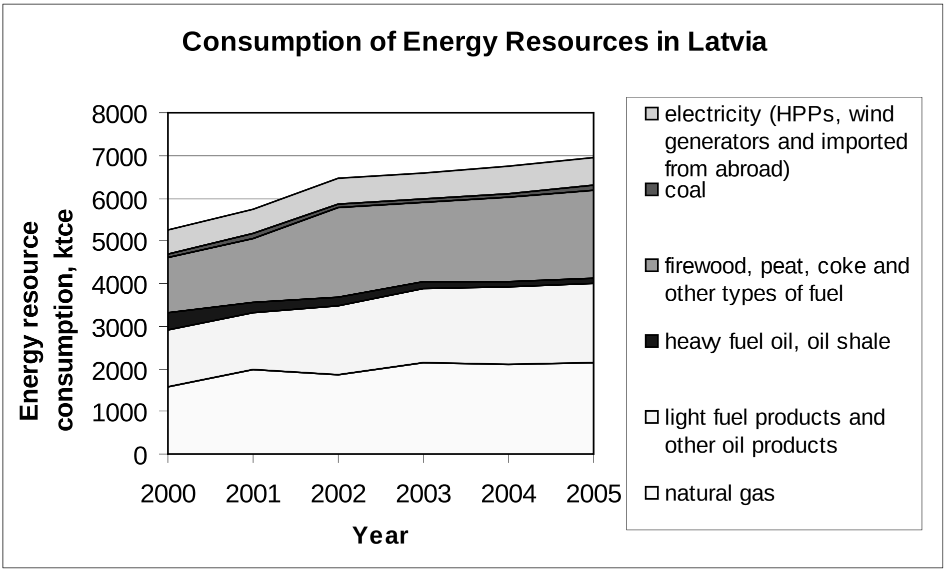

Fig. 1. Consumption of energy resources in Latvia, in ktce (1 ktce = 0,02931 PJ) (source: state JSC Latvenergo, Ministry of Economics, Central Statistical Bureau)

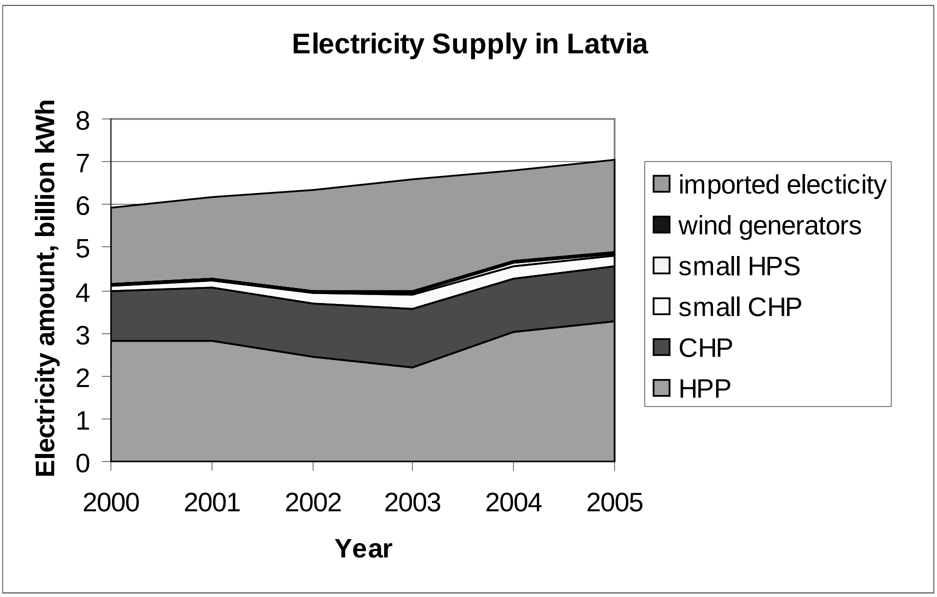

Fig. 2. Electricity supply in Latvia (source: state JSC Latvenergo, Ministry of Economics, Central Statistical Bureau)

The main objectives of the Latvian energy policy now are to ensure sustainable accessibility to necessary energy resources and security of supply in order to foster economic growth and improve quality of life; to ensure environmental quality retention and meet the objectives set in the Kyoto protocol of UN FCCC and Latvian Climate Change Program on GHG emissions reduction for years 2005 – 2010. The Ministry of Economics has developed the policy-planning document "Guidelines for Development of Energy Sector for 2007-2016", where the main priorities are security of supply, increase self sufficiency and facilitate diversity of supplies as well as reduction of dependency on external suppliers of primary energy resources, increase of effective use of renewable sources of energy and energy production in cogeneration (CHP) processes. The main objective of the Latvian Governmental Policy is to reach a balance between electricity demand and supply from domestic power plants by years 2011–2012. Activities of efficient use of energy and supplies from power plants which use domestic fuel and renewable energy resources at highly effective CHP's will be used to achieve the above-mentioned objective to its utmost. The remaining necessary proportion of capacities will be diversified to other types of fossil fuels in order to decrease over-abundant dominance of natural gas (Latvian Ministry of Economy, 2008). In addition to above mentioned, there is an additional regulation, which promotes renewable CHP development, and fuel cell CHP plants are included among the supported technologies. As the fuel cells nowadays are rapidly developing technology, there is a particular interest to see how such non-conventional technologies can be used to meet Latvian energy supply security target, and to evaluate economical competitiveness of these technologies.

2. MODELLING OF BIOETHANOL FUEL CELL COGENERATION SYSTEM

2.1. Description of the model

Electricity purchase price from CHP's using renewable energy source, calculated according to Latvian legislation depends on installed electric capacity and natural gas price, and currently is 152.8 EUR/kWh for the considered fuel cell CHP system. This electricity price is chosen for evaluation of competitiveness of modelled fuel cell CHP system. The modelling of the system was made with the help of "RETScreen 4.0" simulation program, which allows to make energy model with cost, emission and financial analysis. Proton exchange membrane fuel cell (PEMFC) is chosen for analysed system since it is suitable for use in cogeneration plants due to its high capacity density, low operation temperatures and fast start-up. Since the PEMFC can be operated with reformate gas as a fuel, domestically produced bioethanol is chosen as a fuel. The electricity price for the project was calculated with conditions that IRR is 12 %.

In the fuel cell CHP scenario the PEMFC CHP in combination with natural gas boiler should provide the total heat amount for the area indicated in the Table 1. Installed heat capacity of PEMFC CHP is chosen as 0.5 of maximum heating load (Table 2) and provides the base heating load but the natural gas boiler provides peak load. Economic lifetime is assumed to be 8 years since technical lifetime of such system most likely would not exceed 40 000 h (Table 2) (*Gielen and Simbolotti, 2005*). PEMFC CHP operates by following heat load.

2.2. Technical input data

The model is based on nowadays possible PEMFC power capacity, which is 1 MWe maximum, and than according to α – value (0.87) the heating capacity of the system was estimated. Thereafter such heat consumer (30 000 m^2 area) was chosen whose heating load is twice as big as PEMFC heating capacity. The model consists of two scenarios or cases which are compared in result of calculations. For the base case all heating is supplied by natural gas fired boiler, and for evaluation of potential GHG reductions by combined heat and power production in fuel cell system, it is assumed that the electricity in the base case is produced by coal condensing power plant. The technical data for the base case are shown in Table 1.

Table 1. Technical description of the system in the base case

Characteristic	**Values, type**
Heated area	30 000 m^2
Technology	Boiler
Fuel	Natural gas
Seasonal efficiency	85 %
Maximum heating load of the building	80 W/m^2
Domestic hot water demand	10 % of total
Total heat amount produced annually	6 223 MWh
Peak heating load	2.4 MWh
Annual fuel consumption	775 729 m^3

Monthly average heating loads are shown in Fig. 3, and it can be seen from the graph that PEMFC CHP cannot operate during summer months due to limitation of minimum operating capacity. Electricity load is 0, because in CHP-scenario it is assumed in the model that all electricity produced by PEMFC CHP is delivered to the grid.

2.2.1. GHG emission reduction analysis

Since bio-ethanol is assumed to be CO_2 neutral, use of PEMFC CHP scenario allows to achieve CO_2 emission reduction (Fig. 4). Amount of electricity produced by coal fired condensing plant in the bases case is equal to the electricity amount produced at PEMFC CHP, and thermal efficiency of the condensing plant is 40 %. It was assumed that electricity losses in transmission and distribution networks for the base case are 12 %.

Table 2. Technical description of CHP scenario

Characteristic	Values, type
CHP system – heating base load system	
Technology	PEM FC
Availability	7 600 h/year
Fuel	Hydrogen
Annual fuel consumption	287 625 kg
Installed power capacity	1 MWe
Minimum operation capacity	25 % of installed
Electricity exported to grid annually	3 910 MWh
Installed heat capacity	1.2 MWh
Total heat amount produced annually	4 692 MWh
Heat rate	9 000 kJ/kW
CHP system – heating peak load system	
Technology	Heating boiler
Heating capacity	2.4 MW
Total heat amount produced annually	1 531 MWh
Fuel	Natural gas
Annual fuel consumption	190 827 m^3
Seasonal efficiency	85 %

The total annual CO_2 emission reduction in comparison to the base case scenario is 5003 tCO_2/year.

2.3. Economical input data

2.3.1. Investment costs, and operational and maintenance costs

Information provided for PEMFC in the range of 3 – 50 kWe was used for calculation of investment costs (Table 3) (*New Technologies for CHP Applications. 2006*).

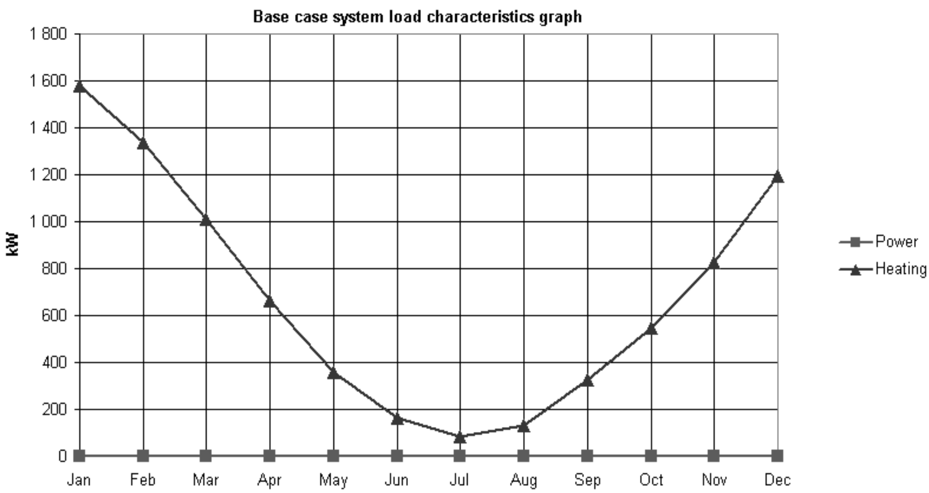

Fig. 3. GHG emission reduction analysis

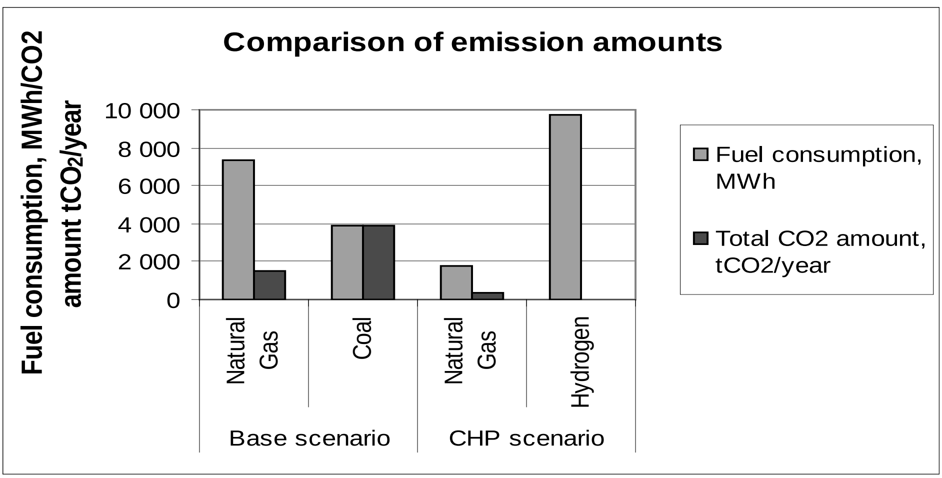

Fig. 4. Comparison of CO_2 emissions

As can be seen, the main part of total investment costs should be used for fuel cell investment and installation (87 %), after that follow investment costs in heating boiler (8 %).

2.3.2. Fuel costs

For the model simulation two types of fuels are used – hydrogen produced from bio-ethanol and natural gas. The price of natural gas (set for users with annual natural gas consumption not bigger than 1 260.10^3 n.m^3) is 0.302 EUR/m^3 without VAT. Natural gas price changes according to the change of price of heavy fuel oil, and taking into account that Latvian natural gas prices are nearly the same as in the other EU countries, it was estimated that during the economic lifetime of PEMFC CHP systems, natural gas prices will rise by 3 %/year. Hydrogen costs, when hydrogen rich gas is produced via autothermal reforming process, depends on efficiency of the autothermal reforming process, and the hydrogen production efficiency range for the model is assumed to be from 142.6 g to 262.5 g (theoretical maximum) of the hydrogen from 1 kg of bioethanol. For the average hydrogen production of 202.6 gH_2/kg ethanol, 6.2 l of bioethanol should be reformed to get 1 kg of hydrogen. Bioethanol prices in Latvia are in the range of 0.71 – 0.85 EUR/l, and in the calculations it was assumed that the bioethanol price is 0.78 EUR/l which leads to the hydrogen price 4.85 EUR/kg (*Kalniņš, 2006*). Fuel cost comparison is shown in the Table 4 for both scenarios, and it is seen from the table that total fuel costs in CHP scenario are 1 453 166 EUR, where 96 % are hydrogen expenses and only 4 % - expenses for natural gas.

Table 3. Costs in CHP scenario

Type of costs	Amount
Total investment costs, EUR	
Feasibility study	2 846
Development	2 846
Engineering	4 269
Power system (fuel cell)	2 253 643
Heating system (peak-load heating boiler)	204 894
Tests and putting into operation	7 114
Contingencies	126 622
Total investment costs	2 602 234
Annual costs, EUR	
Operation and maintenance costs	67 701 EUR
Periodic costs, EUR	
Fuel cell renovation (after 5 years of operation)	450 729 EUR

2.3.3. Other financial parameters

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

- Annual fuel price incremental rate – 3 %;
- Annual inflation incremental rate (average) – 4 %;
- Discount rate – 12 %.

Annual income is divided into two groups – income from electricity sales and income from sales of GHG emission credits. The price of emission credits is assumed to be 25 EUR/tCO_2 and for the achieved GHG emission reduction (Fig.4) the total income from sales of GHG emission credits is 125 075 EUR/year. The fuel costs for heat production in the base case are considered as the income in PEMFC CHP case.

The main factors that affect financial viability of PEM FC CHP system are:

- Electricity sales price to the grid;
- Hydrogen price;
- Investment costs.

Table 4. Fuel costs for both scenarios

Scenario	**Type of fuel**	**Required costs, EUR/year**
"CHP" scenario	Hydrogen	1 395 562
	Natural gas	57 604
Base case scenario	Natural gas	234 165

3. RESULTS

After identification of all critical parameters of PEMFC CHP system, different operation scenarios are calculated in order to compare electricity production costs by the CHP system with electricity purchase price which is calculated according to Latvian legislation and would be applicable for the considered CHP (152,82 EUR/MWh). Dependence of the electricity production cost on hydrogen and bioethanol prices is shown in the Fig. 5. The electricity production cost is calculated with target to reach IRR of 12% for 8 year period at the given level of constant investment, operation and maintenance costs. It is also assumed that CO_2 emission credit is 25 EUR/ t CO_2 t equiv. The price of hydrogen (Fig.5) is calculated by using various bioethanol prices at the bioethanol reforming efficiency – 202.6 g of hydrogen from 1 kg of bioethanol.

The main factor apart from the investment costs which affect PEMFC CHP electricity production costs most is expenses for hydrogen fuel. But, the hydrogen expenses are directly influenced by bioethanol price and bioethanol reforming efficiency. Therefore, the dependence of electricity production cost on bioethanol reforming efficiency and price of the bioethanol is shown in the Fig. 6. Three different bioethanol reforming efficiencies (see Table 5) are considered in the calculations in order to show the relation between the reforming efficiency and electricity production cost.

The minimum price of bioethanol is taken from the source Cardona Alzate and Toro (*2006*) and is equal to 0.09 EUR/l, but the maximum bioethanol price used in calculations is estimated according to average bioethanol prices in Latvia (0,71 – 0,85 EUR/l) (*Kalniņš 2006*).

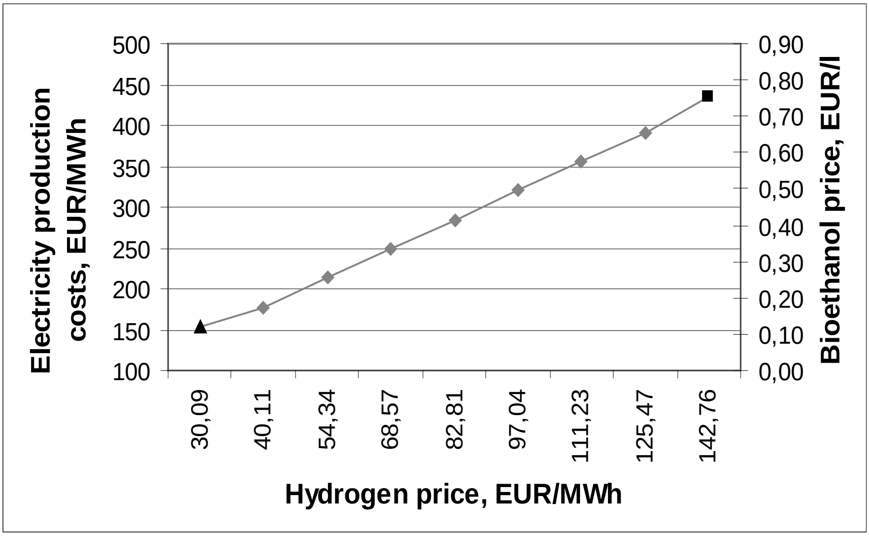

Fig. 5. Dependence of electricity production cost on hydrogen price

Table 5. Bioethanol reforming efficiencies used in calculations

Name	H2 - min	H2 - average	H2 - max
Amount of hydrogen, g/kg bioethanol	142.6	202.6	262.5

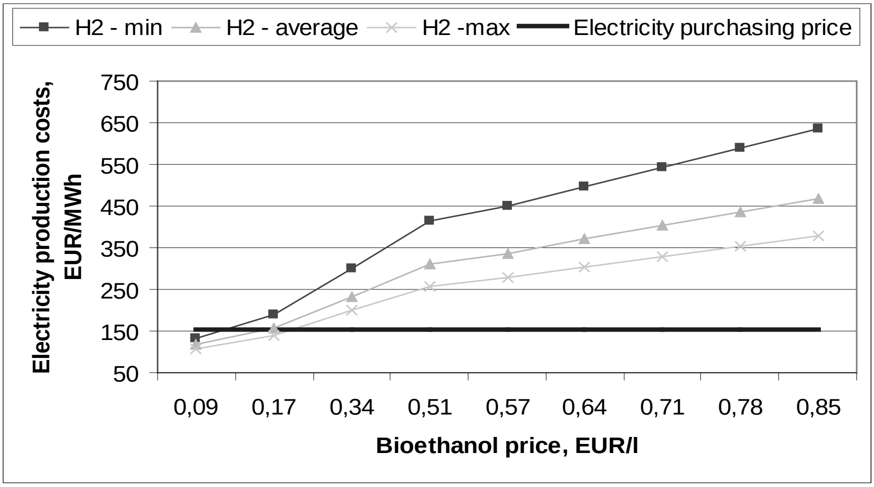

Fig. 6. Dependence of electricity production cost on bioethanol reforming efficiency and bioethanol price. Investment cost used in calculations is 2 600 EUR/MWe

The influence of financial support and hydrogen price on electricity production cost and comparison of that cost with the electricity purchase price set by Latvian legislation is shown in Fig. 7. Three levels of financial support were chosen:

- I minimum – 1 301 117 EUR (half of the required investment costs);
- II average - 2 602 234 EUR (equal to the total investment costs);
- III maximum – 5 204 468 EUR (twice as big as the investment costs).

The bioethanol autothermal reforming efficiency values which are used in the calculations presented in Fig. 7 are the same which are shown in the Table 5. Prices of bioethanol used in calculations (Fig. 7) are within range varying from 0.51 to 0.85 EUR/l (0.51; 0.57; 0.64; 0.71; 0.78; 0.85). Electricity production cost is estimated for each value of the bioethanol price, amount of financial support and reforming efficiency.

As can be seen, when the amount of financial support is half from investment costs (level I) than for all three bioethanol reforming efficiencies the electricity production cost is higher than the electricity purchase price set according Latvian legislation. Better results can be achieved in II financing scenario when the maximum bioethanol reforming efficiency and minimum bioethanol price is chosen. The scenario III shows that at this level of financial support even at the minimum bioethanol reforming efficiency and minimum bioethanol price the electricity price is relatively close to the electricity purchase price set according to Latvian legislation. Table 6 shows the required level of financial support in order to get PEMFC CHP electricity production cost equal to the electricity price set according to Latvian legislation (152.82 EUR/MWh) for the range of values of hydrogen price.

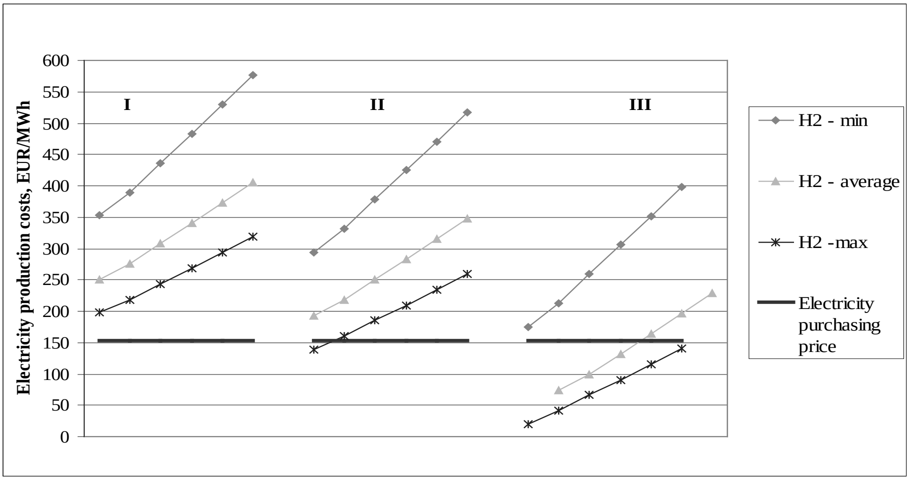

Fig. 7. Dependence of electricity production costs on amount of financial support and bioethanol reforming efficiency

Table 6. Amounts of financial support needed to achieve the electricity production cost equal to the electricity purchase price 152.82 EUR/MWh (CHP scenario)

Hydrogen price, EUR/MWh	94,19	104,67	117,64	130,62	142,76	156,99
Additional financing, thous.EUR	3 503	4 074	4 784	5 493	6 156	6 911

Sensitivity of the electricity production cost on investment cost, fuel costs and income from CO_2 credit sales is shown by results of the sensitivity analysis The above mentioned factors were changed in a range $\pm$10 % from the reference PEMFC CHP scenario's values, where the values of those factors are:

- Total investment costs 2 599 392 EUR;
- Fuel costs – 1 453 165 EUR/year;
- Price of CO_2 credits – 25 EUR/tCO_2.

Electricity production cost in the reference PEMFC CHP scenario is 434,5 EUR/MWh

In Fig. 8 it can be seen that the fuel costs affect the electricity production costs at the greatest extent. Positive influence of incomes from sales of CO_2 credits is relatively small at the assumed price level of CO_2 credits. Therefore, in order to achieve the competitive electricity production cost, firstly the fuel price should be minimized, and than, the decrease of system's investment costs should be considered.

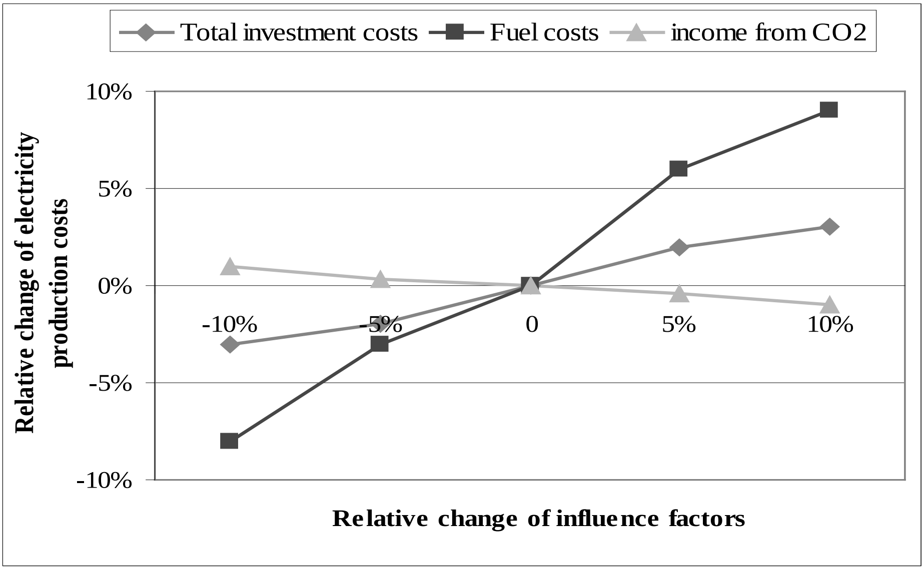

Fig. 8. Sensitivity analysis of electricity production costs

4. CONCLUSIONS

The PEMFC CHP simulation was done to calculate techno-economic viability of such systems and determine the possibility of integration of such systems into Latvian energy system, if the hydrogen is produced from bioethanol. The results show that such projects are competitive with other renewable CHP projects if bioethanol price is <0.12 EUR/l by minimum bioethanol reforming efficiency (142.6g/1kg bioEtOH), when the reforming efficiency is maximum (262.5g/1kg bioEtOH) than the project could be competitive by bioethanol prices <0.19 EUR/l. When the financial support is added, which is equal to total investment costs by maximum bioethanol reforming efficiency, the project could be competitive by bioethanol price <0.51 EUR/l, when the average bioethanol reforming efficiency is achieved, the project is competitive by bioethanol price <0.71 EUR/l, but with financial support which is twice as big as total investment costs.

The main factor affecting competiveness of analysed PEMFC CHP project is the fuel price, which is influenced by bioethanol price and reforming efficiency of the bioethanol. Therefore, it is critical for research and development activities to achieve greater reforming efficiencies of bioethanol, lower bioethanol production costs and also specific investment costs in fuel cell technologies.

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