Analysis of Application of "Power to Gas" Technology in Bosnia and Herzegovina

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***Abstract* – Significant use of renewable energy sources (RES) for production of electrical energy causes issues related to balancing between production and consumption. One of the possibilities for balancing production and consumption of electrical energy is the "Power to Gas" technology (PtG). PtG is a technology for methanation of hydrogen by carbon from carbon-dioxide using surplus of power from a grid. Analysis of PtG application in Bosnia and Herzegovina is described in this paper. The results showed that after deployment of major part of wind and minor part of solar potential, optimal capacity of PtG would be 150 MW.**

***Keywords* – Renewable Energy Sources, Power to Gas, Synthetic Gas**

1. Introduction

Humanity is facing consequences of its long-year adverse impact on the environment which it has been trying to bring under control. From the second half of the 19th century, the use of fossil fuels (coal, petrol and gas) has become prevalent in supplying energy at the global level. The emission of greenhouse gases (GHG), amongst which carbon-dioxide is the most significant one, has an adverse effect on nature and climate changes have been significantly on the rise in the last 30 years. There is a challenge of minimizing negative effects along with the safe and sustainable energy supply. By accepting this challenge, and while adapting to inevitable climate changes, humans resort to use of renewable energy sources (RES). The global policy of subsidizing and investing in RES is focused primarily on electrical energy sector. Therefore, RES have higher share in the production of electricity. In 2013, 22.1% of the total global production of electricity was from RES. Out of that, a small share is from the wind and solar plants, and the highest share (16.4%) is from hydro plants [6]. According to the Energy Report of the World Wild Fund, in 2050, a dominant form of energy to be available to a consumer, regardless of residence, will be electricity. The Report states that at least 60% of electricity will be produced from renewable sources such as wind and solar energy [12].

The issue regarding RES, especially solar and wind energy, is the intermittence, i.e. variable production of electrical energy depending on factors such as wind velocity and intensity of solar radiation. There is a time during the day or year when RES have significant contribution to the production. For example, at night, wind is stronger, and demand is lower, and when the intensity of solar energy is higher, electricity consumption is lower. During the time of low electricity demand, if a network has significant RES capacities, like in wind plants and photovoltaic plants, "surplus" of electricity may appear. It is possible to store the "surplus" of produced electricity and it may be quite significant in achieving high share of RES in the energy system. The storage ensures safe supply during the time of high demand. The existing technologies for storing of energy have a number of disadvantages, including limited storage capacity. On the other hand, in the energy transition towards the so called low-carbon society, natural gas will have a special role due to a relatively low influence on environment compared to coal and petrol, technology flexibility and infrastructure availability. As gas is transported through pipelines along permanent routes and sometimes is subject to geopolitical circumstances, production of synthetic gas is a challenge, which would be a long-term solution for a safe gas supply. Synthetic gas may be used for the same purposes like natural gas [11]. As a solution for these issues, and

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taking into account other facts related to the current status and vision of future, the new "Power to Gas" technology has been developed. The idea is to produce methane by means of the "surplus" of electricity from RES, which can be later stored in the existing gas infrastructure and used in various areas of consumption. Thus, PtG may contribute to the compensation of high oscillations in the production of electricity from wind and solar energy and facilitate long-term utilization of electricity which cannot be integrated directly in the electrical network in the periods of particularly high production of energy from renewable sources. Produced methane can be equally used for heating needs of both industry and transport. It makes PtG a multi-systemic solution which supports the integration of RES in the energy system, and also contributes to the achievement of ambitious targets of GHG emission reduction and sustainability in all areas of consumption [1]. Since natural gas is a fossil fuel which mainly (85-95%) consists of methane (CH_4), the final product of PtG is often referred to as synthetic natural gas (SNG) or synthetic gas.

1.1 Technology of conversion of electrical energy into synthetic gas

Main processes upon which PtG is based are electrolysis of water and hydrogen methanation. Electrolysis and methanation have been in use for a number of years. The innovation is the combination of these two processes and their integration in the energy system.

Chemical methanation is the exothermic catalytic reaction and is usually conducted at the temperature between 200 and 550°C, depending on the catalyst used. The procedure is based on Sabatier reaction presented in the following equation:

$$CO_2(g) + 4H_2(g) \rightleftarrows CH_4(g) + 2H_2O(g) \qquad (2)$$

Carbon-dioxide, necessary for the synthesis with hydrogen, can be obtained from: waste gases from industrial production processes, plants based on fossil fuels, biogas plants or from the atmosphere.

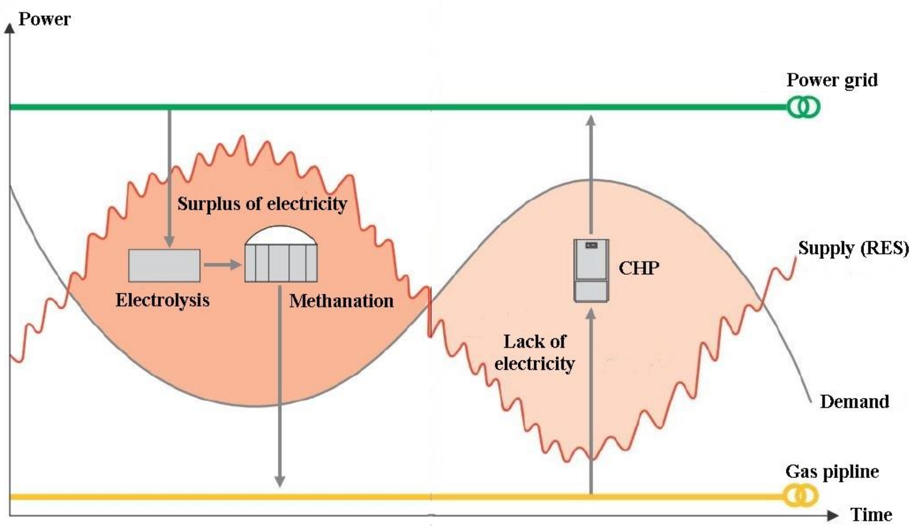

Figure 1. Storing of "surplus" of electricity by means of gas pipelines [7]

Electrolysis of water (H_2O) is the decomposition of water into hydrogen gas (H_2) and oxygen (O_2). The complete reaction is presented by the equation (1):

$$2H_2O\ (l) \rightarrow 2H_2(g) +\ O_2(g) \qquad (1)$$

where: (l) - liquid, (g) - gas.

The disadvantage of technologies using hydrogen is that they cannot be adapted to the needs of the existing infrastructure (gas network, storage facilities). Furthermore, specific safety requirements are needed. Therefore, the use of hydrogen for production of synthetic gas is favoured, which is, after the electrolysis, the next step in the PtG process chain. Hydrogen and carbon-dioxide (CO_2) react to create methane (CH_4), either in chemical or biological reaction and the process is called methanation. A side product of the methanation is water steam.

The extraction of the carbon-dioxide from the atmosphere enables physical separation of a methanation plant site of the point source of carbon-dioxide so that there are multiple possibilities of favorable locations for a PtG plant.

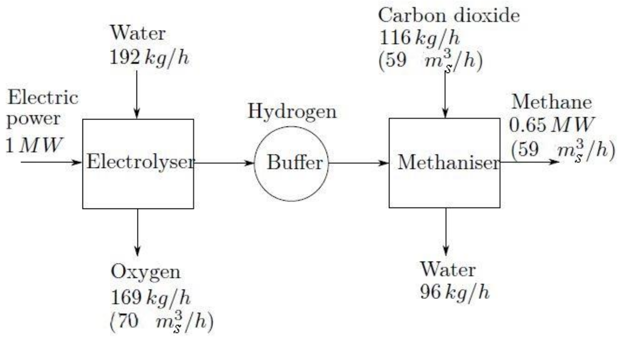

Figure 2. Energy balance of electrolysis and methanation [11]

However, this process has quite low efficiency because the concentration of the carbon-dioxide in the atmosphere is only about 390 ppm (390 molecules of carbon-dioxide per million molecules of air). The extraction of a ton of carbon-dioxide from the atmosphere would require about 8.2 GJ of electricity, and for the extraction from the waste gas flows of the conventional plants 2-4.8 GJ of electricity per ton of carbon-dioxide is needed [3].

Since any technical process implies energy losses, the efficiency of the PtG technology is necessarily reduced in the conversion processes. Figure 3 presents two ways of production of electricity from the synthetic gas. Depending on the phase of the process (compressing and liquefaction) of 100 kWh, as assumed for the input, 10 or 12 kWh of electricity is available to the consumers.

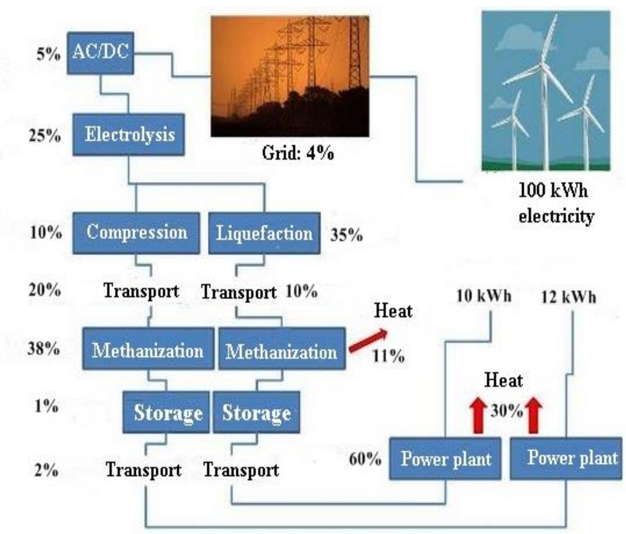

Figure 3. Scheme of efficiency of production of electricity from the synthetic gas [8]

Compared to the other technologies for energy storage, the advantages of the PtG are the following: quick response, availability of great capacity, long-term storage of energy; while the progress is necessary in terms of cost and efficiency [11]. PtG plant operators can offer regulation capacities to the market, both annualy and hourly. [13]. It is assumed that the investment costs for the future PtG plants have decreased from about 3.000 EUR/kW to 750 EUR/kW [14].

2. Application of “Power to Gas“ technology in Bosnia and Herzegovina

2.1 Potentials of renewable energy sources in BiH

Approximately 70% of electricity in BiH is generated from the thermo-power plants based on coal, and 30% from large hydro-power plants. BiH has an enormous RES potential, especially wind potentials, solar energy and biomass. Except for the biomass energy, which is mainly used in a traditional way (combustion in furnaces using wood with low efficiency level), other RES have been used only since recently. It is the result of the introduction of certain subsidy mechanisms for the use of RES (mainly for the production of electricity) and higher prices of energy obtained from the fossil fuels [4]. Solar and wind energy can be used in the territory of BiH, which means that from that aspect there is a possibility of the application of technologies using the conversion of electricity into synthetic gas.

Table 1. Potentials and possibilities of production of electrical energy from renewable sources in BiH [9]

RES	technical potential (MW)	annual production (GWh)
hydro-energy	1,000	4,000
wind-energy	1,200	3,000
solar energy	450	495
biomass	800	3,200
TOTAL	**3,450**	**10,695**

According to UNDP research, a total technical potential of RES (hydro-energy, wind-energy, solar energy and biomass) in BiH is 3,450 MW. Of that, wind potential is greatest, while biomass has significant potential. It can be partly used to balance the network.

2.2 Dimensioning of the “Power to Gas” plant for BiH

By using data on the technical potential of RES provided in Table 1, the analysis of the possibilities of the application of the PtG technology in BiH for 2030 has been done. Figure 4 presents a cumulative

curve of the duration of the load of the network of electrical energy in BiH, and it has been obtained based on the chronological hour-based graph of load for 2012, according to data of the European network of the transmission systems operators for electricity (ENTSO-E). The cumulative curve has been obtained by aligning
the load of the hour-based diagram according to the declining values, regardless of the moment of their emergence.

A larger share of renewable sources in the production of electrical energy in BiH is expected before 2030, due to the need for increased safety of energy supply and mitigation of climate changes. In the realization of the long-term targets, the production from the thermo-power plants and large hydro-power plants will be significantly reduced. According to the Climate Change Adaptation and Low Emission Development Strategy for BiH, the installed power of such plants in 2030 will be 1,500 MW [10].

With expected 6,500 working hours per year, the production from fossil fuels and hydro-energy will result in the amount of 9,750 GWh of electrical energy. On the other hand, the demand for electrical energy is expected in the amount of 500 MW compared to 2012 [2].

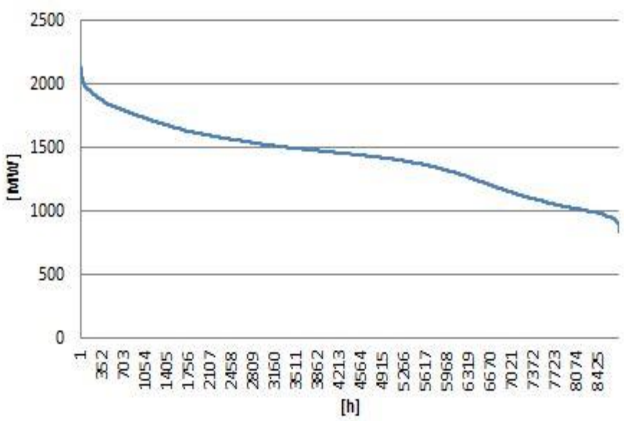

Figure 4. Current load curve of electric-energy network for Bosnia and Herzegovina

The dimensioning of a PtG plant for BiH has been done based on the graph in Figure 5. The criteria upon which the number of working hours mainly depends are: the price of natural gas and price of electricity, and income from the sale of the side products of the electrolysis – oxygen in bottles. Taking into account the price of the natural gas in BiH (around 40 EUR/MWh), and according to the graph in Figure 5, the minimum of working hours of PtG for BiH is obtained: 2,000 hours per year. It is worth noting that the given number of working hours is in case of "free" electrical energy for the PtG.

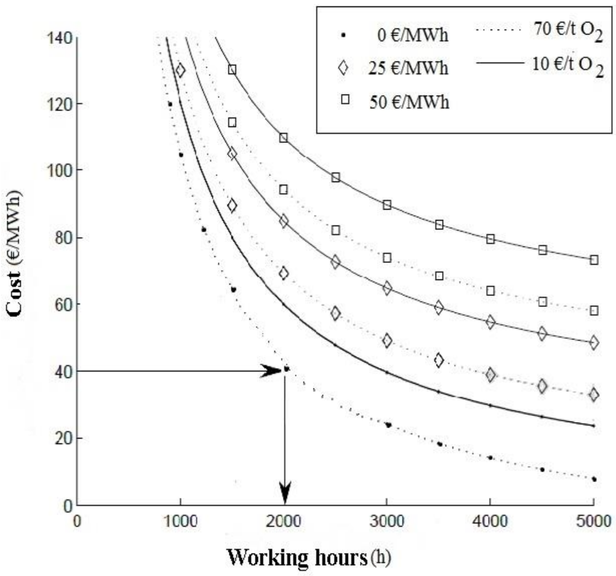

Figure 5. Determination of the minimum number of working hours of the "Power to Gas" plant for achievement of energy sustainability [11]

3. Results and discussion

Taking into account the expected increase in demand for electrical energy and planned new capacities, according to UNDP, and the existing curve of load duration, the curve of load duration for 2030 has been obtained (Figure 6). The area below that curve represents the necessary production of electrical energy. The biggest part of that production will be from RES. Based on technical potential, the total amount of electricity from RES will be 10,695 GWh. The remaining part will be generated from the thermo-power plants using fossil fuels and from large hydro-power plants.

The crossing point of the vertical line of the minimum number of working hours and the curve of the residual load represents the power of the PtG plant which is 150 MW. The amount of the electrical energy that aPtG plant with power of 150 MW would take from the network is calculated as follows:

$$E_{el} = P \cdot \tau \tag{3}$$

where: $P[MW]$ – power of PtG plant

$\tau[h/a]$ - number of working hours per year.

By introducing values in the equation (3), the following is obtained:

$$E_{el} = 150\ MW \cdot 2000 h/a = 300000 MWh/a = 300\ GWh/a$$

PtG plants in BiH could use 300 GWh of "surplus" electrical energy from RES for the needs of balancing the load of electrical network and/or gas supply. There is a possibility of generation of the electrical energy in co-generation and replacement of the natural gas by the synthetic gas. The synthetic gas generated in the PtG can be used for the same purpose as the natural gas.

3.1 Estimate of coal and natural gas consumption reduction by use of energy of synthetic gas from PtG

By using the heat generated in the cogeneration plants that use synthetic gas, the coal and natural gas consumption for heating is reduced.

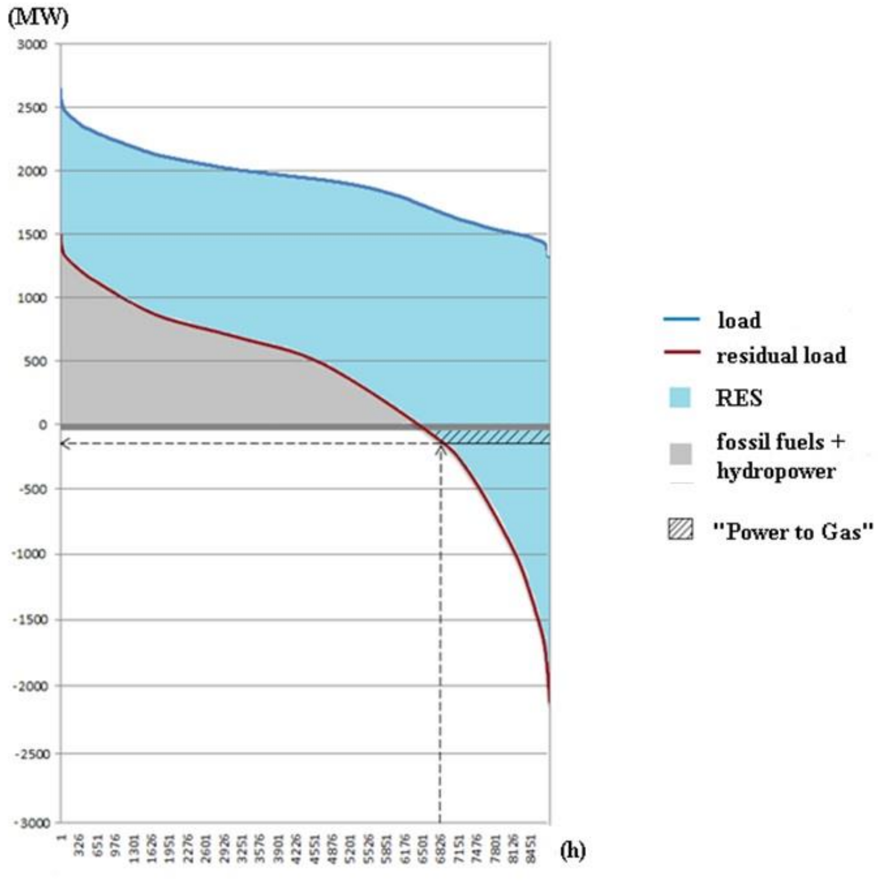

Figure 6. Capacity of the "Power to Gas" plant in Bosnia and Herzegovina

According to Tanner's scheme of the generation of electrical energy from the synthetic gas, the total efficiency is 12% [8]. Based on that, the following is obtained: $300\, GWh \cdot 0.12 = 36\, GWh$ i.e. 36,000 MWh of electrical energy should be supplied to the network at times of peak load. The same source states that 30% of input energy in the PtG can be used as heat. Since the input electrical energy is 300 GWh, it means that 90 GWh of heat could be used for the replacement of heat from fossil fuels.

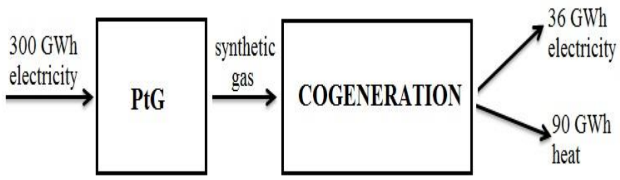

Figure 7. Quantity of electrical energy and heat from the cogeneration using synthetic gas

In order to achieve 90 GWh of heat energy, the expected consumption of energy contained in coal, with the efficiency level of the plant using coal of 75%, is the following:

$$Q_{coal} = \frac{Q_{use}}{\eta} = \frac{90\ GWh}{0.75} = 120\ GWh.$$

The quantity of coal having energy of 120 GWh, is calculated as follows:

$$\Delta B_{coal} = \frac{Q_{coal}}{H_d}$$

where:

$\Delta B_{coal}[t/a]$ – annual coal consumption

$Q_{coal}[MWh/a]$ - annual energy consumption

$H_d[GJ/t]$ – low coal heat power.

A ton of coal in BiH on average has low heat power of 15 GJ, i.e. 4.2 MWh. When calculated according to the formula (2) the following is obtained:

$$\Delta B_{coal} = \frac{120 \cdot 10^3 \frac{MWh}{a}}{4.2 \frac{MWh}{t}} = 28{,}571.43 \ \frac{t}{a}.$$

Therefore, 28,571 tons of coal would be reduced in consumption, due to the use of heat obtained by combustion of the synthetic gas from the PtG. The use of synthetic gas in BiH would be of great significance especially since BiH does not have its own sources of natural gas and is dependent on its import. Natural gas is imported to BiH only from one source and only through a single transport route. All natural gas imported to BiH comes from the Russian Federation, through the transport system of Ukraine, Hungary and Serbia. The capacity of the gas system in BiH is 1 billion m^3/year.

With the level of usability of the plant generating heat energy from of natural gas, the quantity of energy in the natural gas needed to produce 90 GWh is the following:

$$Q_{natural\ gas} = \frac{90\ GWh}{0.9} = 100\ GWh.$$

Since it is possible to obtain approximately 10 kWh of energy from 1m^3 , it follows that for 100 GWh of energy, 10,000,000 m^3 of natural gas would be needed. That amount would be avoided in consumption by using 90 GWh of heat from the synthetic gas produced in PtG plants.

According to the scheme of the energy balance in Figure 2, the total efficiency of the conversion of electrical energy into methane is 65%. On that basis, it follows that in case of a plant consuming 300 GWh of electrical energy, 195 GWh of energy contained in the synthetic gas from PtG is obtained.

In that case, since 1 m^3 of gas corresponds to $\approx$ 10 kWh of energy, the amount of the synthetic gas that will be obtained from PtG is:

$$\frac{195 \cdot 10^6 kWh}{10\ \frac{kWh}{m^3}} = 19{,}500{,}000\ m^3\ .$$

The consumption of the natural gas in BiH is around 8.3 PJ of energy [5], which means that the produced synthetic gas could satisfy 8.5% of total demand, because:

$$195\ GWh = 195\ \cdot 10^6\ kWh = 195 \cdot 10^6 \cdot 3.6\ MJ = 702\ TJ = 0.702\ PJ\ .$$

At the same time, it implies a lower cost for import of natural gas in the amount of 7,800,000 EUR per year.

3.2 Estimate of carbon-dioxide emission reduction

What is further calculated is the reduction of the emission that would be achieved by the integration of a PtG plant in the energy system BiH.

The equation (1) shows that PtG plants in BiH would consume 300 GWh of "surplus" electrical energy from RES. As already demonstrated, the production of the synthetic gas from a PtG would be 36 GWh. The emission factor of the electrical energy in BiH is 720 $kgCO_2$/MWh. In that case, the reduction of the emission of the carbon-dioxide from the electrical grid by application of PtG is:

$$\Delta e_{CO_{2el.grid}} = 36 \cdot 10^3 MWh \cdot 0.72 \frac{tCO_2}{MWh} = 25{,}920\ tCO_2.$$

The reduction of the consumption of coal by using heat energy, obtained by combustion of the synthetic gas, also contributes to the reduction of the emission of the carbon-dioxide that is calculated as follows:

$$\Delta e_{CO_2 coal} = Q_{coal} \cdot k_{coal}$$

where:

$\Delta e_{CO_2 coal}[tCO_2] -$ reduction of emission due to the reduction of coal consumption

$Q_{coal}[MWh] -$ avoided consumption of coal energy

$k_{coal}[tCO_2/TJ] -$ the emission coefficient of carbon-dioxide for coal.

The emission coefficient for dark coal is 94.15 tCO_2/TJ, and the avoided consumption of coal energy is $Q_{coal} =$ 120 GWh = 432 TJ. By adding values in the equation, the total reduction of the emission of the carbon-dioxide, due to reduction of coal consumption, is obtained.

$$\Delta e_{CO_2 coal} = 432\ TJ\ \cdot 94.15\ \frac{tCO_2}{TJ} = 40{,}672.8\ tCO_2\ .$$

The reduction of the emission of the carbon-dioxide, due to reduction of consumption of the natural gas, is calculated as follows:

$$\Delta e_{CO_2 nat.gas} = Q_{nat.gas} \cdot k_{nat.gas}$$

where :

$Q_{nat.gas}[MWh] -$ avoided consumption of energy from natural gas

$k_{nat.gas}[tCO_2/TJ] -$ the emission coefficient of carbon-dioxide for natural gas.

The emission coefficient of the carbon-dioxide for natural gas is 55.82 tCO_2/TJ, and the avoided consumption of energy from natural gas is 100 GWh, i.e. 360 TJ. It follows:

$$\Delta e_{CO_2 nat.gas} = 360\ TJ \cdot 55.82\ \frac{tCO_2}{TJ} = 20{,}095.2\ tCO_2.$$

For BiH that now produces electrical energy mainly in thermo-power plants, the integration of PtG using energy from renewable energy sources, in which BiH is abundant, would have great significance. Thermo-power plants are known to be big polluters. In accordance with the targets of mitigation of climate changes caused mainly by application of fossil fuels, BiH will have to make changes in energy supplying.

The technology of PtG contributes to the reduction of the emission of carbon-dioxide that is the most prominent greenhouse gas, thus being an environmentally acceptable solution. The total reduction of emission that would be achieved in BiH by application of PtG is 66,592.8 tCO2 in case of replacement of heat from coal by heat from synthetic gas, or 46,015.2 tCO2 in case of replacement of heat from natural gas.

4. Conclusion

Due to an increasingly high share of renewable, intermittent sources of energy, the electrical-energy system faces a challenge of adaptation to the fluctuations of the network load. Propped by storage of energy, only renewable energy sources can respond to the requirements of mitigation of climate changes, safety of energy supply, social and economic development and job creation. The technology enabling the storage of energy in the long-run is the “Power to Gas”. This technology connects electrical and gas network and thus contributes to safer supply of electrical energy and gas. Bosnia and Herzegovina, a country of unconsumed potentials of renewable energy sources, has prerequisites for the application of PtG technology. It is in particular true if we take into consideration the expected rise in demand for electrical energy, future shutdown of a number of units of the existing plants using coal, tendency of development and integration in EU programmes and because of the fact that BiH is dependent on import of natural gas. The total technical potential of the renewable sources in BiH is assessed to be 3,450 MW. The expected production of electrical energy on the basis of that potential is 10,695 GWh. Of that, the “surplus” of electrical energy that could be used for PtG plants, of power 150 MW, is about 300 GWh.

It is calculated in the paper that of 300 GWh of energy “surplus”, PtG in BiH could produce 19,000,000 m^3 of synthetic gas that could be used in various sectors of demand including: heating, production of electrical energy and transport. By using heat obtained by combustion of the synthetic gas from PtG, annual coal consumption, currently being the main energy source in BiH, would be reduced by 28,571 ton.

The idea behind the “Power to Gas” is anyway the reduction of the adverse environmental impact, i.e. the reduction of the emission of greenhouse gas into atmosphere. By application of PtG in BiH, the total reduction of emission to be achieved in case of replacement of heat from coal to heat from synthetic gas is 66,592.8 tCO_2, i.e. 46,015.2 tCO_2 in case of replacement of heat from natural gas.

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