Feasibility of Biomass Co-firing in Large Boilers—The Case of EPBiH Thermal Power Plants

Admir Bašić, Enisa Džananović, Anes Kazagić and Izet Smajević

Abstract This paper investigates the possibilities and the sustainability of "biomass for power" solutions on a real power system. The case example is JP Elektroprivreda BiH d.d.—Sarajevo (EPBiH), a typical conventional coal-based power utility operating in the region of South East Europe. Biomass use is one of the solutions considered in EPBiH as a means of increasing shares of renewable energy sources (RES) in final energy production and reducing CO_2 emissions. This ultimately is a requirement for all conventional coal-based power utilities on track to meet their greenhouse gas (GHG) cut targets by 2050. The paper offers possible options of biomass co-firing in existing coal-based power plants as a function of sustainability principles, considering environmental, economic and social aspects of biomass use. In the case of EPBiH, the most beneficial would be waste woody biomass and energy crop co-firing on existing coal-based power plants, as suggested by biomass market analyses and associated technological studies including lab-scale tests. Four different options were considered, based on different ratios of biomass for co-firing: 0 %w-reference case, 5, 7 and 10 %w of biomass. The CO_2 parameter proved to be a key sustainability indicator, effecting the most decision making with regard to preference of options from the point of economy and sustainability. Following up on the results of the analyses, the long-term projection of biomass use in EPBiH has shown an increase in biomass utilization of up to 450,000 t/y in 2030 and beyond, with associated CO_2 cuts of up to 395,000 t/y. This resulted in a 4 % CO_2 cut achieved with biomass co-firing, compared to the 1990 CO_2 emission level. It should be noted that the proposed assessment model for biomass use may be applied to any conventional coal-based power utility as an

A. Bašić (✉) · E. Džananović · A. Kazagić · I. Smajević
Vilsonovo šetalište 9, 71000 Sarajevo, Bosnia and Herzegovina
e-mail: ad.basic@elektroprivreda.ba

E. Džananović
e-mail: en.dzananovic@elektroprivreda.ba

A. Kazagić
e-mail: a.kazagic@elektroprivreda.ba

I. Smajević
e-mail: i.smajevic@elektroprivreda.ba

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option in contributing to meeting specific CO_2 cut targets, provided that the set of input data are available and reliable.

1 Introduction

Co-firing biomass and bio-waste in coal-fired power plants is one of the most straightforward biomass applications in the short-to-medium term, as set out in the European Commission's White Paper on Energy for the Future: Renewable sources of energy [1]. The main reason for the use of biomass as a co-fuel is its dual role in greenhouse gas (GHG) mitigation, by being a substitute for fossil fuels (bio-energy) and a carbon sink [2]. Fuels derived from biomass contain less sulphur, ash and trace elements as well. Current research on co-firing is focused on controlling combustion behaviour, emissions, corrosion, agglomeration, and fouling-related problems. Biomass used for combustion in industrial-scale furnaces must meet a number of criteria, including: availability throughout the year to ensure security of supply, high density to minimize transportation costs, a sufficiently high heating value and an acceptable price [2]. As reported by Baxter et al. [3] and Koppejan [4], wood residues meet these requirements.

In the last decade, significant progress was made in the utilization of biomass in coal-fired power plants. Over 250 units worldwide have either tested or demonstrated co-firing of biomass or are currently co-firing on a commercial basis [5]. Coal is often replaced with up to 30 % of biomass by weight in pulverised coal based power plants, as in Belgium, Canada, Denmark, Finland, the Netherlands, Sweden, United Kingdom, Germany, Poland and the United States. Most of these projects refer to co-firing biomass with high-rank coal (both bituminous and anthracite), while availability of projects on biomass co-firing with low-rank sub-bituminous coal and lignite is more scarce, like the project involving Greek lignite reported in the work by Kakaras [6]. Estimates made by Poyry for the International Energy Agency (IEA) World Energy Outlook suggest that there is a certain potential for biomass sufficient to replace a 10 %th of coal in all coal-based power plants in the world [7]. Furthermore, progress is made in application of different types of municipal solid waste as a fuel in coal-based power plants (solid recovered fuel—SRF or refuse derived fuel—RDF, including their gasification). However, along with research, development and demonstration projects and technologies, economic and social issues of biomass to power solutions have to be investigated as well, to achieve sustainable biomass-based power systems.

2 State-of-the-Art

The co-combustion of biomass or waste with a base fuel in a boiler is a simple and economically suitable way to replace fossil fuels and utilise waste [8]. In addition to that, co-combusting in a high-efficient power station means utilising biomass and waste in a process with a higher thermal efficiency than what other ways had been possible, as reported by Leckner [9]. However, due to transportation limitations, the additional fuel will only supply a minor part (less than a few hundred MW fuel) of the energy in a plant. As according to the same author there are several options of “biomass for power” in large combustion plants, as for example:

- co-combustion with coal in pulverised or fluidised bed boilers,
- combustion on added grates inserted in pulverised coal boilers,
- combustors for added fuel coupled in parallel to the steam circuit of a power plant,
- external gas producers delivering its gas to replace an oil,
- gas or pulverised fuel burners.

Biomass can further be used for reburning in order to reduce NO_x emissions [10], or for after-burning to reduce N_2O emissions in fluidised bed boilers. A combination of fuels can give rise to positive or negative synergy effects, of which the interactions between S, Cl, K, Al and Si are the best known, which may give rise to or prevent deposits on tubes [11], or may have an influence on the formation of dioxins [9].

Co-combustion has a number of potential advantages. A brief list, as reported by Leckner [9], is given below:

- reduction of CO_2 emissions from fossil fuels,
- increased use of local fuels,
- conversion of biomass and waste fuels with a high efficiency and under controlled environmental conditions,
- there are no formal size limitations, although there are certain economic restrictions on how far voluminous and disperse materials such as biomass and waste can be transported, which can limit the size of a plant using such fuels,
- seasonal variations inherent in some biofuels can be adequately handled, because the ratio of the added to the base fuel can easily be scaled down from its maximum value,
- less complicated than other alternative conversion methods for biofuels and, hence, potentially economically advantageous,
- the amount of added fuel employed can be adjusted to the availability of biofuels and wastes within a reasonable transportation distance from the conversion plant, and
- possible positive synergy effects with different fuels can be utilised.

Disadvantages can also be expected in form of:

- the costs of some additional equipment or treatment processes need to be considered,
- the threat of harmful influence on the power plant, caused by the added fuel,
- possible negative synergy effects if the added fuel has some extreme properties (like some wastes) or if the combination of fuels is unfavourable, and
- lack of experience, as reflected from two of the above points.

Better knowledge of these effects may help the positive ones to be used and the negative ones to be avoided [9].

Over the last decade many research studies were conducted in order to investigate the biomass co-firing phenomenon. As an example, Wang et al. [12] evaluated the combustion behaviour and ash properties of a number of renewable fuels, like rice husk, straw, coffee husk and RDF derived from municipal waste. The work used a drop tube furnace to evaluate the combustion behaviour and ash properties of biomass, waste derived fuels, pine and coal. Kupka et al. [13] investigated the ash deposit formation during the process of co-firing coal with sewage sludge, saw-dust and refuse derived fuels in a drop tube furnace, to optimize biomass co-firing blends. Williams et al. [14] investigated the emission of pollutants from solid biomass fuel combustion. Emissions and ash-related problems were investigated in the Bosnian case as well, by co-firing Bosnian coal with waste woody biomass [15, 16], where some specific benefits and synergy effects were observed. Co-firing Bosnian coal with woody biomass in existing coal-fired power plants is hence considered a perspective combustion technology in the Bosnian case. Examples of biomass co-firing can be found in other industries as well, like in the example of biomass co-firing in the cement industry, as reported by Mikulcic et al. [17].

When it comes to GHG emissions and policy related issues, which present important supporting tools when considering more extensive biomass use, further considerable research can be found as well. GHG and pollutant emissions coming from the energy sector are very high today, which forces countries all over the world to take cost-effective steps for their mitigation, by creating adequate policies [18, 19]. CO_2 storage in underground reservoirs can result in very low—perhaps even near-zero—net GHG emissions, depending on the share of biomass used as input and its CO_2 signature, as reported by Aitken et al. [20]. Royo et al. [21] developed a methodology applied to the Spanish case, by which a significant biomass co-firing potential and a subsequent GHG emission reduction could be achieved over large territories.

Overall, the given examples illustrate that research in biomass co-firing has so far mainly been performed in order to optimize the fuel mix through minimizing ash-related problems and emissions. Biomass co-firing in large power plants is mainly considered in reducing CO_2 emissions, improving security of supply and reducing operational costs by fuel cost optimization. However, less attention was given to economy and sustainability issues of biomass co-firing solutions, where authors found only some related work. As an example, Umar et al. [22] investigated the market response to six sustainability-related topics, thereby identifying several key factors for consideration by the government. The research involved an electronic and conventional postal dissemination of questionnaires to palm oil producers in Malaysia. Samsatli et al. [23] gave a novel MILP formulation of the Biomass Value Chain Model (BVCM), which accounts for the economic and environmental impacts associated to the end-to-end elements of a pathway: crop production, conversion technologies, transport, storage, local purchase, import (from abroad), sale and disposal of resources, as well as CO_2 sequestration by carbon capture and storage (CCS) technologies and forestry. It supports decision-making around optimal use of land, biomass resources and technologies with respect to different objectives, scenarios and constraints. Objectives include minimizing the cost, maximizing the profit, minimizing GHG emissions, maximizing energy/exergy production or a combination of these. The main contribution of this work is reflected in demonstrating the additional merit of biomass co-firing in this specific case and its contribution to economy and sustainability.

3 System Under Consideration—EPBIH Utility

3.1 General Description of the System Under Consideration—EPBiH Power Utility

The analyses performed in this work are demonstrated on an example of a real power system. The case example is JP Elektroprivreda BiH d.d.—Sarajevo (EPBiH), a typical conventional coal-based power utility operating in the region of South East Europe. EPBiH is part of the Energy Community of South-East Europe (SEE) and is situated in Bosnia and Herzegovina (BiH). The total power output of EPBiH amounts to approximately 8000 GWh/y and is generated at two coal-based thermal power plants (TPP), i.e. TPP Tuzla and TPP Kakanj, three large hydro power plants (HPP) on the river of Neretva, and a small number of small HPPs (sHPP) with a share of approximately 1 %.

Table 1 provides an overview of some basic information for existing TPPs addressed in the case study. The data is later on used as input parameters for the calculation and assessment of sustainability indicators. Both TPPs use indigenous low-rank coal, consuming about 6,500,000 t/y and generating around 6,500,000 tCO_2/y. Annual output of heat generated at the cogeneration units of TPP Tuzla and TPP Kakanj accounts for approximately 400 GWh/y [24].

Table 1 Basic data on existing TPP units of EPBiH

Generation facilities	Installed capacity [MW]	Efficiency [%]	Domestic fuel cost [€/10^6kcals]	Variable O&M costs [€/kW per month]	Fixed O&M costs [€/kW per month]	Planned retirement year
TPP Tuzla unit 3	100	24.78	2.99	1.00	2.7	2018
TPP Tuzla unit 4	200	30.13	3.09	1.37	2.4	2021
TPP Tuzla unit 5	200	29.88	2.82	0.72	2.6	2030
TPP Tuzla unit 6	223	32.73	2.86	0.41	1.4	2030
TPP Kakanj unit 5	118	31.55	2.78	0.65	3.5	2023
TPP Kakanj unit 6	118	32.14	2.72	0.39	2.0	2030
TPP Kakanj unit 7	230	30.93	2.68	0.67	7.3	2030

3.2 *Development Targets for Thermal Power Plants of EPBiH*

Over the past ten years, the total net efficiency of EPBiH's power plants has increased from 24 to 31 %. This was accomplished by applying specific measures such as decommissioning old thermal power units (4 × 32 MW in TPP Kakanj and 2 × 32 MW in TPP Tuzla) and modernising all of the other existing coal-based power units. At the same time, CO_2 emissions were reduced from 9500,000 t/y (1990) to the current level of 6,500,000 t/y [24].

EPBiH, however, is still facing challenges despite the improvements made. Requirements for further energy efficiency and CO_2 emission reduction measures are mandatory for the company to keep and improve its position on the market. It should also help the company comply with the energy efficiency and environmental regulation, as well as give support to the low-carbon future. Based on the planned generation portfolio development and an annual power demand projection until 2030, a new generation portfolio was optimized and projected in order to reach specific energy and decarbonisation targets. The portfolio expansion took into account plans of EPBiH to construct new generation facilities, while at the same time taking into consideration the requirements for replacement capacities. Replacement capacities are considered with respect to TPPs planned to be decommissioned by 2030. The dynamics for their decommissioning are defined as part of the Long-term development plan of EPBiH. The choice of the commissioning dynamics of all other TPP associated facilities is subject to analysis, performed with regard to sustainability and decarbonisation criteria, partially conducted as part of this work as well. Additional inputs involve the current investment plans for desulphurization (DeSOx) and denitrification (DeNOx) facilities, planned in order to address obligations arising from the Large Combustion Plants Directive (LCPD) and Industrial Emission Directive (IED) (Directive 2009/28/EC, Directive 2012/27/EU).

The development plan will overall result in new TPP, HPP, wind power plant (WPP), photovoltaic power plant (PVPP) and biomass power plant (BPP) projects. To effect further CO_2 emissions reduction, co-firing coal with biomass is planned in all EPBiH TPPs [24].

3.3 Biomass for EPBiH Power Plants—Resourcing

The residues of the wood processing industry, agricultural and forest residues, as well as dedicated energy crops, are among the most abundant sources of energy in Europe. Making use of forest and agricultural residues in the power industry does not only help replace a certain amount of fossil fuels, but it also helps reduce their disposal in the environment, cutting down emissions of the greenhouse gas CH_4 (by avoiding biomass decomposition). Additional benefits include new job creation in establishing the required biomass supply chain (collection, transportation) and an overall better perspective for the development of energy, forestry and agriculture in the country.

Biomass has a significant potential as a source of energy in BiH. It is estimated that the total annual technical biomass energy potential in BiH is over 33PJ, which is equivalent to more than 3 million of BiH lignite [25]. The most significant source of biomass for energy production in BiH is waste woody biomass originating from forestry (forest residues), as well as from the wood industry (wood chips, sawdust). Agricultural residues have a significant energy potential in BiH as well and are mainly located in the northern, central and southern parts of the country. Several assessments of the BiH biomass potential were performed so far and the results of one of these studies (EU/FP6/INCO/ADEG), reported by Schneider et al. [25], are presented in Table 2.

Table 2 Data on annual potential of biomass in BiH (FP6 Project ADEG), [25]

	Available amounts (per year)	Energy potential [PJ]	Origin
Biogas from farms	200,000 m^3	0.51	Agriculture
Fruit growing waste	211,257 t	0.74	Agriculture
Grains residues	634,000 t	8.88	Agriculture
Leguminous plants and oil seeds remains	3858 t	0.04	Agriculture
Woody waste from industry	1,142,698 m^3	7.53	Forestry
Firewood	1,466,973 m^3	13.2	Forestry
Woody residues from forestry	599,728 m^3	2.62	Forestry
Total technical potential		33.52	

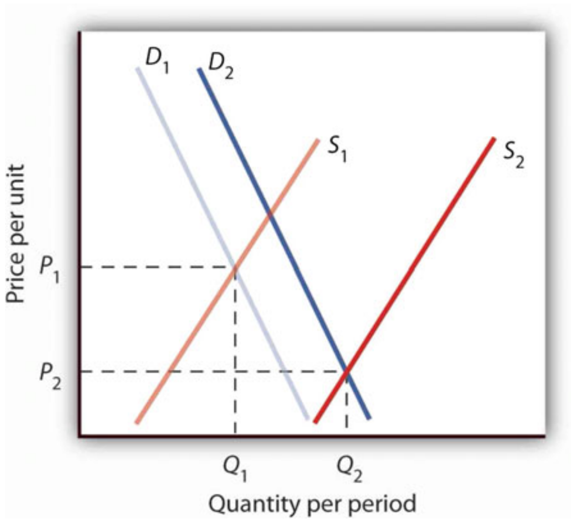
BiH has also certain conditions suitable for the cultivation of fast-growing energy crops. This option is currently subject to research and power plants are one of the potential beneficiaries of such a CO_2 neutral fuel.

3.4 Biomass Market

Biomass market in BiH is not developed enough at the moment to supply PE EP BiH with required amount of biomass. Introducing pellets and briquettes for heating private apartments started a small market of biomass but that is not enough to secure needed amounts of biomass for PE EP BIH, and prices are still unstable. It can be expected that both the supply and prices will be constant if the demand is constant. Biomass market in BiH is a typical representative of the new market. For example, in the project in EP BiH it was assumed that the price would be approximately 16.00 €/t, but when the project started, the price of wooden biomass was five to six times higher than expected. The reason for this is that there is no established market, and when the demand increased, the supply did not change. But if the demand was constant, the supply would increase and the new price would be formed, as presented in Fig. 1. Based on the market research, the assumed price of biomass would be 6.00 KM/GJ.

One of possible solutions for PE EB BiH is to form a long term contract with suppliers, such as forest companies in BiH, just like, for example, HEP (electrical energy company in Croatia) did and secured approximately 400,000 t/a of biomass. The seller has product placement, and the buyer has constant prices, a sufficient amount of biomass and a safe supplier. However, the biggest potential for biomass

Fig. 1 Biomass price



is inside PE EP BiH, for coal mines to grow energy crops. It is best to grow Miskantus; one hectare can replace up to 9000 l of fuel.

3.5 Projections and Biomass Co-firing Options in the Case of EPBiH

It is anticipated that the future of coal-fired power plants will only be certain if their CO_2 emissions are below 550 kg/MWh. In order to fulfill such conditions in a long-term view and in the absence or delay of CCS implementation and development, the new coal-fired power units of EPBiH are required to reach a net efficiency of 43 %, using at the same time 25 % of biomass.

The first steps of introducing biomass in the power generation portfolio of EPBiH were already made. After years of laboratory research, the implementation of a pilot project trial run on the TPP Kakanj Unit 5 in April 2011 has proven a technological viability of using at least 7 %w of waste woody biomass (sawdust) mixed with specific brown coal, as reported by Smajevic et al. [26]. The method involved first mixing biomass and coal on the coal depot, transporting the mixture by the belt conveyor to the bunker and the mills, and injecting it into the boiler through existing coal burners. This method of direct co-combustion allows a use of 7-10 % of biomass in the fuel mix without causing any operational problems, in the case of TPP Kakanj. Other forms of co-combustion, allowing higher shares of biomass in the mixture (10–30 %), are also considered. These involve indirect mixing and co-combustion of the fuel blend in the boiler via biomass gasification or special biomass burners.

Overall, a projected use of 7 %w of biomass at all power units of EPBiH, used at an average rate of 3000 h/y, would reduce the total CO_2 emissions of EPBiH by 4 %, as reported by Smajevic et al. [26]. EPBiH has therefore announced plans to introduce biomass into its generation portfolio, in order to reach long-term CO_2 cuts. These are concurrent with plans of energy efficiency improvements and the construction of new more efficient thermal power plants [24]. According to the plan, by the end of the planning period covered by the Long-term development plan of EPBiH, it is technologically feasible and therefore can be planned to exploit biomass in existing and new thermal power units of EPBiH. The projected share of biomass in the fuel mix is indicated in Table 3.

Therefore, the primary objective of biomass use in existing and new power units of EPBiH in the coming years is to reduce CO_2 emissions, as well as to optimize fuel and operation and maintenance (O&M) costs. The 2030 projections show that there is a technological potential for the TPPs of EPBiH to have an annual power generation of up to243 GWh at existing and 885 GWh at new units coming from biomass. Taking only a 50 % of the estimated fuel consumption at the new units alone, an annual volume of at least 225,000 t/y in long-term biomass use would be achieved.

Table 3 Projection of the biomass share in the fuel mix of EPBiH thermal

	Power from biomass [MWe][a]	Annual generation [MWh][a]	Annual biomass consumption [t][b]	Annual CO_2 cut [t]
Kakanj TPP unit 5 (118 MWe)	7.5	24,000	16,000	18,500
Kakanj TPP unit 6 (118 MWe)	7.5	24,000	16,000	18,500
Kakanj TPP unit 7 (230 MWe)	17	54,000	35,000	40,000
New Kakanj TPP unit 8 (450 MWe)	75	225,000	130,000	115,000
Tuzla TPP unit 4 (200 MWe)	16	45,000	30,000	36,000
Tuzla TPP unit 5 (200 MWe)	16	45,000	30,000	36,000
Tuzla TPP unit 6 (223 MWe)	17	45,000	35,000	40,000
New Tuzla TPP unit 7 (450 MWe)	110	330,000	160,000	140,000
New Tuzla TPP unit 8 (450 MWe)	110	330,000	160,000	140,000
Existing units	81	243,000	162,000	188,000
New units[c]	295	885,000	450,000	395,000

[a]The projection of power and power generation based on energy from biomass, is projected based on a share of 7 %w of biomass in the mixture with coal for existing units and a 25 % share of biomass in the mixture for new units, along with an operating rate of 3000 h/y under the regime of co-combustion at each unit (for the remaining time of the year the units are operated on coal only)
[b]Annual consumption of biomass for the projected power generation and net efficiency of a given unit, and for an average net calorific value of biomass of 14,000 kJ/kg
[c]If a CCS technology is not implemented

4 Financial Assessment od Biomass Co-firing Options in Case of a EP BiH Power Plant Kakanj

4.1 Methodology

In this research we used the following scientific methods: statistical methods, comparative methods, the method of analysis, synthesis methods, and we also used scientific methods to collect data necessary to carry out the necessary conclusions. The detection method was used in determining the truth of individual facts. The comparative method was used for comparing prices of fuel and biomass, and fees for pollution in Croatia and EU. The methodology applied in financial analysis is common for projects in PE EP BiH and is compliant with the methodology of international financial institutions and economic theory.

4.2 Inputs for Analysis—Case of TPP Kakanj

Thermal power plants vary according to technological characteristics and according to the type of applied technology implementation of co-firing, which will have different impact on business results. A project like this one will have an initial investment, an impact on costs of, for example, the material for production, maintenance, emission of pollutants, and, less likely, an impact on NUS products, administration and other costs. For the analysis, the results and conclusions from project in PE EP BiH will be used. The project of co-firing of biomass and coal is performed in TPP Kakanj, Unit 5, but because of the characteristics of Unit 5 and Unit 6, the conclusions can be applied to Unit 6. The main objective of the pilot project was to test the possibility of introducing the practice of co-firing biomass and coal in order to reduce CO_2 emissions. The conclusions important for economic analysis are that the amount of biomass burned cannot exceed 7 % of the total amount of coal, calculated by weight, at 3000 h. Co-firing in this volume does not require any additional investments and realizes the positive environmental aspects. Biomass could be mixed with coal at existing depots in the framework of the existing principles of homogenization of coal at the depot, and, most importantly, the production of energy does not depend on the quantities of biomass.

For better performance and longer life expectancy for analyses, Unit 6 is used for the analysis, and this Unit is observed isolated from TPP. There are two options for Unit 6: to implement co-firing biomass and coal or not.

For this analysis, net book value of assets is used as an initial investment. Due to conclusions that an additional investment for co-firing is not needed, the initial investment is the same for both options. The difference is in the variable costs. The biggest change will be in the material for production. This cost is about 40 % of all costs in EP BiH, and coal is about 60 % of all costs of the thermal power plant. Savings of 1 % in these costs mean savings of over 1.5 million in TPP Kakanj. The introduction of biomass will directly affect the reduction of emissions, and therefore a reduction in costs related to air pollution.

According to experimental testing with 7 % w biomass and 3000 operating hours per year, the results are:

- Reducing CO_2 emissions by about 8.5 %,
- Reduction of SO_2 emissions by about 3.6 % and
- Reduction of NO_x by about 2.3 %.

Based on the above information and based on expected emissions, we can calculate savings for the financial analysis. Moreover, in this analysis the expectation of additional increase of fees and new fees for CO2 should be considered. Biomass is CO_2 neutral fuel and is recognized as renewable energy, so it is important to note that co-firing of 7 %w biomass in coal will reduce emission of CO_2 for about 8.5 %. For example, in Croatia, the fee for CO_2 emission is 18 kn/t and 100 kn/t if pollution is more than allowed. Similar regulation will be developed in BiH in the near future, and this cost can be partially avoided with co-firing of biomass and coal.

The fixed expenses should be the same for both options. Maintenance facilities and operational readiness are of utmost importance, but it is proven there will be no negative effects on production processes. In TPP Kakanj, co-firing will not change the depreciation and salaries, and it is expected that there will be no changes of other costs.

TPP generate income from electrical energy, thermal energy, NUS products, renting equipment and other unexpected revenues. Co-firing will have an impact on income from electrical energy, so it can be assumed that other revenues will be the same with or without co-firing. Income from electrical energy will be changed trough incentive price for renewable energy which is regulated by law. For complete financial analysis, private and social costs and the benefits of the project have to be calculated. It is most difficult to valorise social costs, but the society and the State recognized it and that is why there is the incentive price.

4.3 Results of Economic Parameters

The final decision about realization of co-firing depends on the results of financial analysis. For this purpose we made a cash flow and a projection for two options for Unit 6 TPP Kakanj: Option 1—traditional, Option 2—co-firing. Both options can be used only for this project because it is calculated isolated from other units and TPP. For the analysis the static and dynamic indicators have to be calculated, but the most realistic and the only ones presented are IRR and NPV (Fig. 2).

The first analysis was conducted in 2013 and based on market information at that time. The investment is not needed, coal would be substituted with biomass and biomass is more expensive than coal. Tax for pollution is lower for Option 2 but not significantly since biomass is more expensive than coal. It follows that electrical

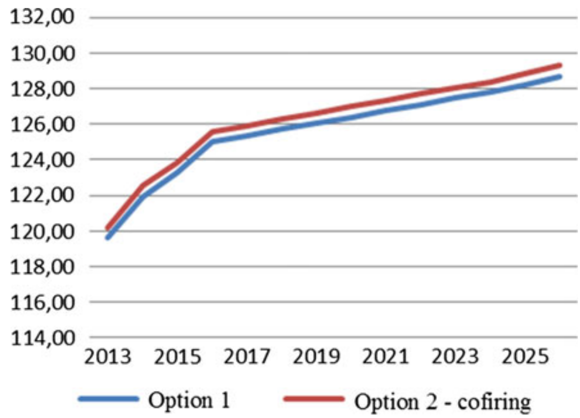


Fig. 2 Production cost

energy from co-firing biomass and coal is more expensive (Fig. 1. Production cost) for about 1 % for market conditions in 2013 (biomass price and pollution fee).

In spite of the higher production cost, the decision about the implementation of the project can be made based on the financial analysis with included calculations of all revenues, including the revenues for electrical energy with the incentive price for renewable energy. PE Elektroprivreda will choose the project with better results (Table 4; Figs. 3 and 4).

Implementing the project of co-firing, PE EPBiH would have a higher annual profit as long as biomass price is lower than 9.80 KM/GJ, as shown in Fig. 4. It needs to be noted that the information about the net profit and the loss can be interpreted only with a remark that this projection for Unit 6 is isolated from TPP and the net book value is calculated as an investment.

Table 4 Economic indicators

	Option 1	Option 2
Pay-back period	–	13
Rate of return	1.90	3.56
Reproduction rate	9.31	10.96
NPV	-18440797	5813825
IRR (%)	−2.30	0.69

Fig. 3 Net profit/loss

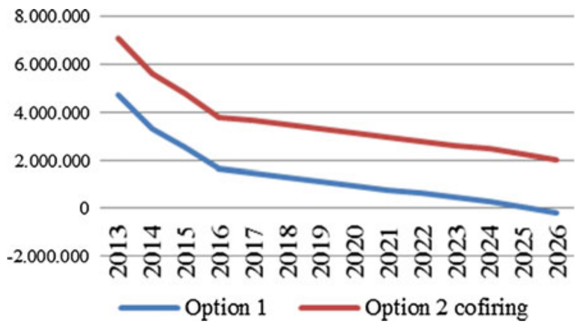
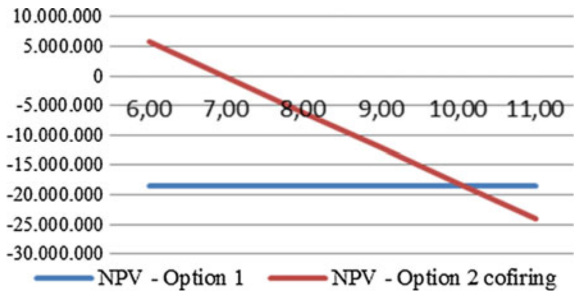


Fig. 4 Biomass price and NPV



Now, when results in 2016 are analyzed, it can be seen that coal and biomass price, depreciation and other costs are unchanged, but there have been many changes in the electrical energy market since 2013.

Electrical energy price suffered unexpected decline and in March the price was 50 KM/MWh. Laws in BiH are changed and there is more competition. Many companies/consumers are leaving EP BiH and buying electrical energy from other suppliers. The price for households is not changed, but this price is calculated based on electric energy from hydro and thermal power plants. Nowadays, it is more profitable to buy electric energy for 50 KM/MWh and not produce it in TPP. Reduced production causes the same fixed cost, and the higher price per unit, which was approximately 130.00 KM/MWh in TPP Kakanj for the period January–April. If the price of electric energy of 60.00 KM/MWh is assumed in the financial analyses, the result for Unit 6 will be negative and the net loss will be higher than 30 mil KM/a.

PE Elektroprivreda BiH recognized this problem and the solution for this is offered in the two projects: District heating systems of cities Visoko, Breza, Vogošća and Sarajevo from TPP Kakanj cogeneration units and Project of co-firing biomass and coal.

Both projects are in a phase of feasibility study. Heating will secure more production, lower pollution and lower costs per unit, and feasibility study will show whether it is worth investing in that project. The second project is related to co-firing of biomass and coal. For this project, the incentive price for renewable energy is the most important.

In BiH in 2016, the incentive, guaranteed price for energy from biomass by law is 31,292 KM/MWh. For Unit 6 in TPP Kakanj, it means that 9 % of annual energy would be generated from biomass, and for this energy TPP Kakanj would get the stimulating price of 31,292 KM/MWh.

Market changes just confirmed that co-firing of biomass and coal would diversify the risk and reduce the negative effects of lower price electric energy or other expected negative effects, such as an increase of coal price, pollution taxes and similar. Figures 5 and 6 can show what has happened in the last three years,

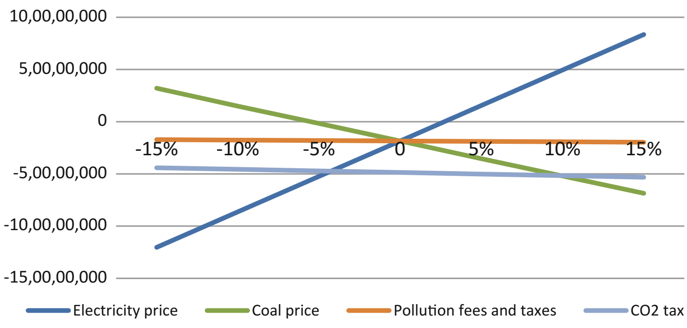


Fig. 5 Sensitivity analysis—option 1

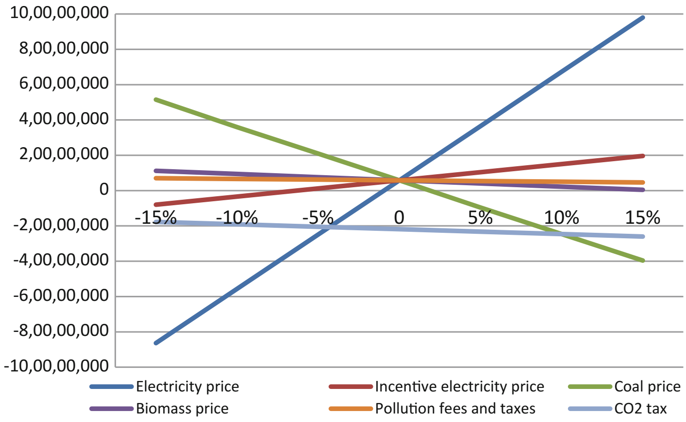


Fig. 6 Sensitivity analysis—option 2 cofiring

and what else may happen in next period. When observing economic indicators and the risk for TPP in terms of the unstable market, now, even more than before, the conclusion is obvious: PE Elektroprivreda should implement the project of co-firing.

5 Conlusions

In the last decade, significant progress was made in the utilization of biomass in coal-fired power plants. While many research studies were conducted to investigate the biomass co-firing phenomenon, like ash-related problems or emissions, far less attention was given to the investigation of sustainability of "biomass for power" solutions, and to the economy as well. In this work, the assessment is performed for EPBiH, a typical conventional coal-based power utility operating in the region of South East Europe.

On the basis of the performed analyses, it was concluded that the CO_2 parameter proves to be a key sustainability indicator in the considered case, effecting the most decision making with regard to the preference of biomass co-firing options from the point of economy as well as sustainability. Market changes just confirmed that co-firing of biomass and coal would diversify the risk and reduce the negative effects of lower price of electric energy or other expected negative effects, such as an increase of coal price, pollution taxes, etc.

The results demonstrate the additional merit of biomass co-firing for this specific case and its contribution to sustainability. The model presented in the paper can be applied to any power utility provided that the set of input data is available and reliable.

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