CONCEPT OF CO-FIRING COAL WITH BIOMASS AND NATURAL GAS – ON TRACK OF SUSTAINABLE SOLUTION FOR FUTURE THERMAL POWER PLANTS

by

Nihad HODŽIĆ[a]***, Izet SMAJEVIĆ***[a,b]***, and Anes KAZAGIĆ***[b*]

[a] Faculty of Mechanical Engineering, University of Sarajevo, Sarajevo, Bosnia and Herzegovina
[b] EP Electric Utility of B&H, Sarajevo, Bosnia and Herzegovina

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This paper presents R&D project of multi fuel concept for future coal-based power plants, demonstrated on example of co-firing Middle-Bosnia brown coal with waste woody biomass and natural gas. Pulverised combustion lab-scale furnace has been used for the co-firing tests, varying up to 20%w portion of biomass and up to 10%th portion of natural gas in the fuel mix. Tests were purposed to optimize the combustion temperature, air distribution, including over fire air system, fuel combination and fuel distribution, including reburning concept, as function of emissions and combustion efficiency estimated through the ash deposits behaviours and unburnt. Considering application of proposed multi fuel concept in case of TPP Kakanj unit 6 (118 MW_e) set here as a referent power plant, temperature levels and fuel distributions for lowest emissions of CO_2 and NO_x were found during lab tests, provided that combustion efficiency is at an acceptable level. Derived research results yield input data for calculation sustainability indicators of multi fuel concept for the referent power plant, considering 6 fuel options – different combinations of coal, biomass and natural gas. Single criteria analysis and multicriteria sustainability assessment have been done, giving an advantage to the options of co-firing coal with woody biomass and natural gas in the case demonstrated.

Key words: *multi fuel concept, co-firing, biomass, natural gas, reburning*

Introduction

Emissions of CO_2 from world power industry driven by fossils has continuously grown up in past years, estimated at over 60% in total world CO_2 emissions. In the same time coal-based power generation has also grown, overcoming in recent years 40% of total world electricity generation [1]. Coal is still an important energy source in many countries as it is cheap and available. Even with the ambitious plans on the global level to move to a less carbon-intensive economy, coal will continue to dominate the world's energy mix at least in next 5-10 years. Improving coal's environmental performance through clean coal technologies (CCT) and carbon capture sequestration and storage (CCS) is a key to its future role in the energy mix. If more cleanly, coal power plants will keep advantage to deliver a reliable supply of low-cost energy. Most of the countries have produced their own CCT and CCS roadmaps, which set out the key research, development and demonstration (RD&D) objectives and milestones, and clarify the technological challenges that need to be overcome. Many

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[*] Corresponding author; e-mail: a.kazagic@elektroprivreda.ba

of them regard international collaboration and knowledge transfer as important elements in developing and deploying CCT and CCS [2]. Beside current different biomass co-firing solutions, wider introducing different kind of biomass (waste biomass, energy crops) and gaseous fuels (natural gas, biogas) into coal-base power plants, depending on the availability and affordability, is an option for so called multi fuel concept (MFC) of coal power generation. Such a solution for an innovative thermal power plant – multi fuel power plant, based on co-firing coal with biomass and natural gas (or biogas), along with fuel cost optimization, should enable even an improved security of supply of coal-based power plants to be achieved. Considering state-of-the-art of MFC for coal-based power plants, augmentation of RD&D activities accompanied by international collaboration and knowledge transfer focused on emissions issue, ash deposits problems, energy efficiency and operation flexibility, is needed in further developing and deploying MFC, as well as in analysis of sustainability of such a concept in any particular case.

The main emphasis in the present paper is the analysis of sustainability of a multi-fuel system, based on real measured inputs, derived from the experimental research. Optimization of fuel composition for a multi-fuel system in function of sustainability of referent power plant under consideration can be regarded as the main novelty in the present work. Additional contribution of the work to the increase of the scientific knowledge is in particular results yielded for a multi-fuel system based on coal, woody biomass and natural gas, under specific conditions prevailing in the demonstrated case.

Multi fuel concept of future coal-based power plants

Global coal-based power generation is not compatible with international climate targets; problems which power sector based on coal faces today are conducted with high CO_2 emissions comparing to lower CO_2-intensive energy resources, particularly various renewable energy sources (RES). Environmental sensitivity issue and consequent stronger requirements posed to fossil-fueled power plants in relation to reduction of SO_2, NO_x and dust emissions, according to industrial emissions directive (IED), along with CO_2 taxes, significantly contribute to a poor cost effectiveness of conventional fossil-fueled power plants. Development of CCT goes in line of further increasing net efficiency and improving cost-effectiveness of coal-based power generation. Thus, some important RD&D projects to achieve more efficient coal-based power plants are in progress in this light (for example RD&D projects of advanced ultra-supercritical steam power plants – A-USC) [3]. Nevertheless, biomass is used more and more in coal-based power plants all around world, with over 200 single co-firing applications in Europe already, primarily aiming to reduce CO_2 [4, 5]. Estimations made by Poyry for international energy agency (IEA) suggest that there is potential of biomass in the world sufficient to replace 10%th of coal in all coal-based power plants in the world [6]. Finally, according to IEA, carbon capture sequestration and storage is expected to enter into commercial use by 2030, as a final step towards near zero CO_2 emissions of coal-based power generation, with around 15% of electricity coming from CCS-equipped plants by 2050 [7].

Although significant efforts have been undergone and are still ongoing to provide perspectives for CCT based power generation, power system of EU indisputably goes toward an energy transition (Ger: Energiewende). In its Fifth Assessment Report, the intergovernmental panel on climate change (IPCC) also sees coal-based power generation as having no long-term prospects [8]. From the other side, the growing number and amount of renewables in the supply mix create transmission imbalances that need to be managed [9]. Thus, in the future low-carbon power system, it is reasonable to place future efficient, environment friendly and flexible coal-based power plants serving as one of alternatives for the baseload and secure reserve. Otherwise, despite of such a scenario for 2050 and beyond, the present trends of all current estimations suggest that coal will keep its dominant role in the next 5-10 years. It is particularly expressed globally due to China's industrial expansion and progress of coal projects, although China has shown growing interest in market-based CO_2 pricing and is expected to establish a nationwide emission trading system by 2016 [10].

Various ways of reducing coal-based power generation are currently under discussion. However, a holistic sustainable concept is required for future power system. The concept based on sustainable multi-fueled thermal power plants of near-zero GHG emissions to cover reserve and take a part in the peak loads of future sustainable power system in 2050 and beyond is proposed here, providing necessary diversity of a power mix and enabling, through the cluster of such thermal power plants on global level, to contribute in managing GHG emissions of the future power system.

Methodology

This paper presents R&D project of multi fuel concept and its benefits demonstrated on example of co-firing Middle-Bosnia brown coal with waste woody biomass and natural gas. PC Lab scale furnace designed and installed at Mechanical Engineering Faculty of University in Sarajevo (MEFUS) has been used for various test runs of the co-firing, varying fuel portions; up to 20%w portion of biomass and 10%th portion of natural gas in the fuel mix. Purpose of testing was to optimize the combustion temperature, air distribution, including OFAS, and fuel portions and fuel distributions, including reburning concept, as function of emissions of CO_2, SO_2, NO_x and combustion efficiency estimated through ash deposits behaviour and unburnt.

Wide range of process temperature have been applied: 950-1,560 °C, while excess air ratio in the first zone of combustion varied between 0.9-1.2. Moreover, primary/secondary air ratio varied to investigate optimum set for different combination of fuels and particular process conditions. In addition to the air staging, effects of the fuel staging on NO_x have been investigated by use of natural gas and woody biomass (*reburning*). The aim of the research was to determine the characteristics of combustion in terms of the effects of the application of multi-fuel concept to the NO_x, SO_2 and CO_2 emissions, ash-related problems and combustion efficiency.

Results from lab-scale furnace tests are then used as input data for sustainability assessment of multifuel concept of a referent power plant which uses basic coal − in this case TPP Kakanj unit 6 (118 MW_e).

Lab-scale tests

Lab-scale furnace

Lab-scale furnace *electrically heated entrained PF flow reactor,* designed at MEFUS, was used for the experiments, fig. 1. In essence, the experimental reactor comprises a 3 m length alumina-silicate ceramic tube, with a diameter of 230/200 mm, where combustion takes place, surrounded by SiC stick-type electric heaters and three-layer insulation, fig. 2. The temperature of the reaction zone is controlled by a programmable logic controller (PLC) with thyristor units for each of the heating zones, allowing the process temperature to be varied at will across the range from ambient to 1,560 °C. The maximum power of the electrical heaters used to maintain temperature in the reaction tube is 70 kW, while nominal or thermal power of the reactor is 20 kW. Pulverized fuel is introduced into the reactor by means of a volumetric feeder, mounted above the reactor. The feeder is equipped with a speed controller, allowing mass flow in the range of 0.25-5 kg/h. Air for combustion, coming from the air blower, is divided into carrier air (primary air), secondary air, tertiary air, and over fire air (OFA) line. The first three air portions are introduced into the reactor over the swirl burner settled on the top of the reactor, so the air-fuel particle mixture flows downward [11-14].

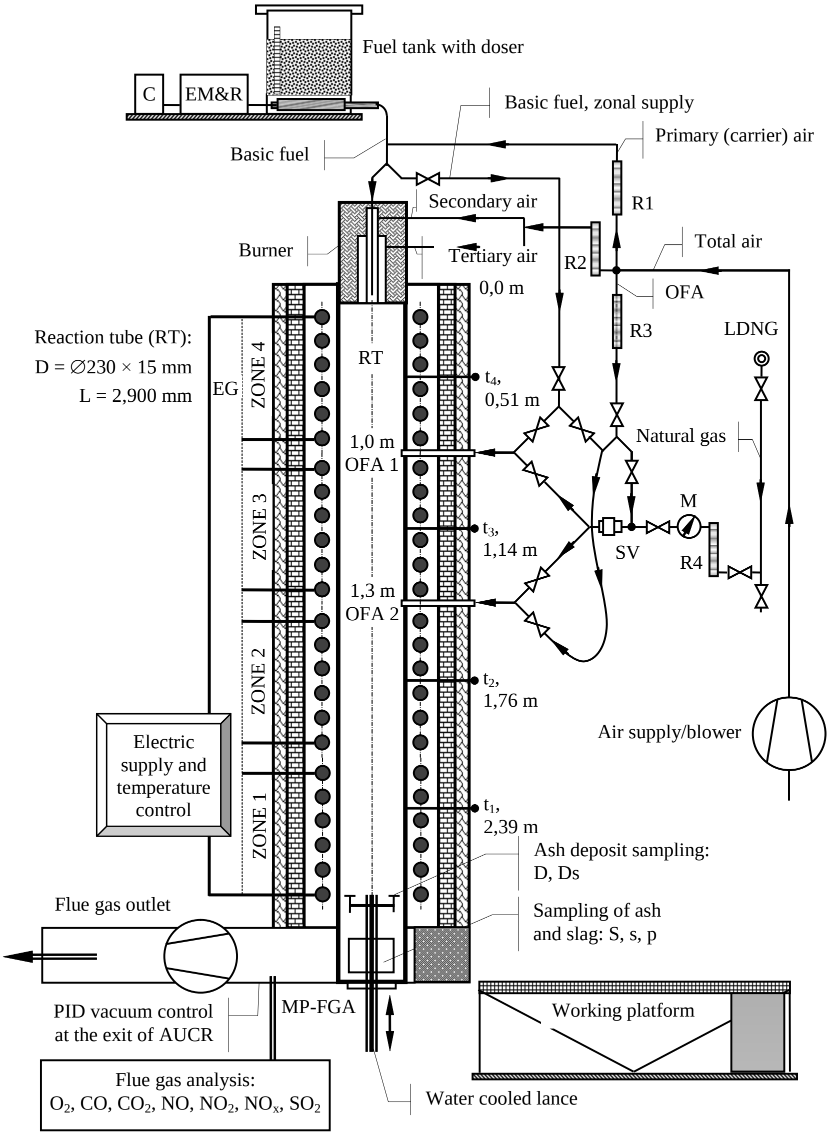

Figure 1. Principal scheme of the experimental furnace
C – speed controller of fuel supply, EM&R – electric motor and gearbox, RT – reaction tube, R_i – flow meters for measuring the flow of air and natural gas, EG-SiC – electric heaters arranged in four zones/levels, LDNG – laboratory distribution of natural gas, SV – safety valve with integrated flame arrester, M – manometer, MM-ADP – measuring point/flue gas analysis

Fuel test matrix

Various blends of those coals (basic blend was K70B20Z10 – with shares of components in the coal mixture: Kakanj 70%w, Breza 20%w and Zenica 10%w), have been used in combination with woody biomass and natural gas. At this, share of woody biomass in the blend varied between 5-20%w while share of natural gas varied between 5-10%w. Proximate and ultimate analyses of some fuel tested are given in tab. 1.

Woody biomass (B) is a mix of different types of waste woody biomass in form of sawdust. Used coal/biomass blends additionally moistured because postponement during winter days on the open depot, affecting reducing the LHV, tab. 1. Subjected coals are low-graded coals, with a low reactivity, high content of ash, high content of sulphur and strong propensity to the slagging and fouling due to inconvenient ash composition (high content of alkali components in ash, see tab. 2) and consequently low melting temperatures [15].

Table 1. Proximate and ultimate analysis of the fuels tested

Fuel	K100	K80Br15Z5	K70Br20Z10	K60Br25Z15	U100	B100	U95B5	U93B7
No.	1	2	3	4	5	6	7	8
Proximate analysis [%] as-received								
Moisture	10.05	10.50	10.71	10.92	13.90	21.63	19.06	18.09
Ash	47.20	43.07	40.84	38.61	37.88	0.52	34.33	33.05
Volatiles	24.95	26.73	27.71	28.69	28.97	64.14	29.32	31.16
Fixed C	17.79	19.69	20.73	21.78	19.25	13.72	17.28	18.59
Combustible	42.74	46.42	48.44	50.47	48.22	77.86	46.60	48.86
Ultimate analysis [%] as-received								
Carbon	29.39	32.64	34.48	36.32	32.62	38.92	33.12	33.36
Hydrogen	2.25	2.29	2.33	2.36	2.60	4.95	2.20	2.52
Sulphur	2.44	2.38	2.41	2.44	2.06	0.14	1.57	1.59
Nitrogen	0.71	0.73	0.75	0.76	0.72	0.17	0.81	0.75
Oxygen	7.94	8.36	8.48	8.59	10.22	33.67	9.91	10.63
Heating value [kJkg^{-1}] as-received								
Gross	12,132	13,240	13,898	14,555	13,351	15,564	12,651	13,446
Net	11,436	12,535	13,171	13,817	12,496	14,081	11,759	12,510

Table 2. Chemical ash composition of tested fuels

Fuel	K100	K80Br15Z5	K70Br20Z10	K60Br25Z15	U100	B100	U95B5	U93B7
No.	1	2	3	4	5	6	7	8
SiO_2	53.82	49.49	46.30	43.81	41.77	25.72	37.54	40.42
Fe_2O_3	9.98	9.68	9.86	9.90	9.18	18.00	9.98	9.18
Al_2O_3	16.26	15.83	15.48	15.22	16.58	20.03	18.81	17.21
CaO	5.40	9.73	11.98	13.98	14.40	17.28	16.64	14.76
MgO	5.40	5.66	5.76	5.86	2.56	6.40	2.88	1.60
SO_3	5.22	5.84	7.04	7.79	9.66	4.02	7.18	7.08
TiO_2	0.40	0.40	0.40	0.39	0.45	<0.01	0.45	0.40
Na_2O	0.388	0.37	0.38	0.38	2.948	3.002	4.012	5.533
K_2O	1.262	1.15	1.07	1.01	1.345	4.016	1.127	2.246

Experimental results

Emissions of NO_x, SO_2 and CO_2

NO_x emissions. Selected research results of NO_x emissions are derived from results reported in [16] focussing on factors affecting the emission of NO_x, in relation to co-firing coal with woody biomass and gas, changing one or more parameters (temperature, air flow) and applying one or more primary measures in the combustion chamber, namely changing composition of the fuel, air staging, staged combustion of primary fuels and the use of natural gas as an additional fuel (reburning). In the tests, natural gas is used as an additional fuel (reburning), with two values of the gas energy (heat, *th*) input to the process: 5%th and 10%th. Natural gas is supplied into the furnace by gas installations equipped with measuring and regulating valves, with the introduction of gas into the reaction zone carrying out via the side inlet pipes (also used in some modes for supply of OFA air), one or both simultaneously, see fig. 2. Under such conditions, the basic fuels U100, UP (coal-gas reburning), U95B5 and K70Br20Z10, have been tested at different process temperatures: 1,350 °C, 1,400 °C and 1,450 °C, fig. 2.

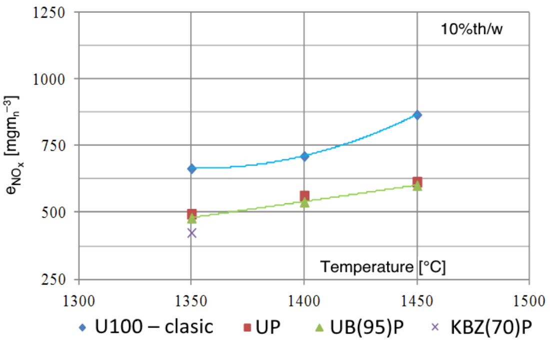

Figure 2. Emissions of NO_x during co-firing coal and biomass using natural gas as an additional fuel, as function of the composition of basic fuel and the process temperature

So, the diagram shows the NO_x emissions in co-firing coal and biomass with natural gas (in reburning mode) compared with the measured emissions from the combustion of coal U100. Significant reduction of NO_x emissions was recorded; for more than 250 mg/m_n^3 at 10%th gas content. Thus, by a mix of coal and biomass U95B5 at 10%th gas reburning, presented in diagrams as UB(95)P, NO_x emissions was reduced at temperature 1,350 °C from 710 to 450 mg/m_n^3 compared to the emissions of coal U100, or approximately by 37%. Furthermore, when co-firing coal with biomass and natural gas at a temperature of 1,450 °C, the NO_x emissions of 602 mg/m_n^3 was measured, which is lower by 30% compared to the emissions of coal U100 (866 mg/m_n^3) at this temperature.

SO_2 emissions. Regarding SO_2 emissions, slight decrease of SO_2 emissions was recorded that was proportionally to adding the biomass into fuel, fig. 3. Generally, over the test temperature range, 1,350-1,450 °C, there is no considerable change of SO_2 emissions during co-firing coal with biomass with changing process temperature, position and amount of OFA or supply of gas for reburning, fig. 4. The thermal input of gas in the fuel mix during reburning test runs was 10% (10%th/w).

CO_2 emissions. CO_2 emissions were measured during the tests, with reductions recorded in co-firing coal with biomass and natural gas compared with the cases without use of gas. For example, for the case coal only, at temperature 1,350 °C, CO_2 emission was 0.258 kg/m_n^3. For comparison, co-firing coal with 5%w of woody biomass and 5%th of natural gas, at the same temperature, has generated CO_2 emissions at 0.232 kg/m_n^3. It was expected result considering lower potential of natural gas to the CO_2 emissions compared to coal. In calculation of CO_2 indicator, woody biomass has been considered as CO_2 neutral fuel.

(a) (b) (c) (d)

Figure 3. Ash deposits samples collected during co-firing tests running different fuel combinations; (a) U90P10/1, 350 °C, (b) U100/1, 400 °C, (c) U95B5/1, 400 °C, (d) U90B10/1, 400 °C

Ash deposition behavior

Ash deposits during co-firing trial runs were collected on the ceramic probes inside the reactor, see fig. 2, to analyse shape, structure, adhesion, cohesion and chemical composition of the ash deposits for different combination of the fuels and different process conditions. Photos of the deposits for some co-firing cases are given in fig. 3.

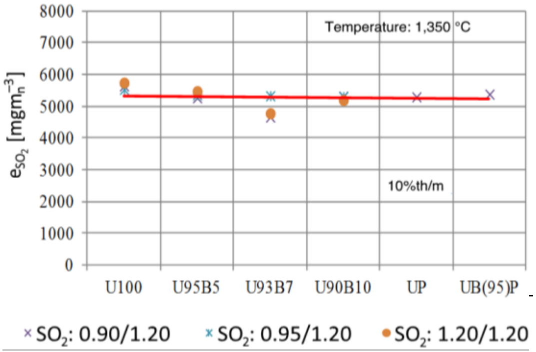

Figure 4. Emissions of SO_2 during co-firing coal with woody biomass and natural gas, as function of fuel combination and air distribution

Generally, there was not observed any significant change in shape and structure of deposits for different fuels tested, considering that slag spheres at higher temperature flowing over the surface is normal situation in slag-tap furnaces, which is case in fig. 3d. Furthermore, there is no deterioration of form of deposits in the co-combustion campaigns in relation to the campaign reference coal (U100). On the contrary, deposits of co-combustion campaigns are somewhat more crispy and easy-to-remove. So, they are normal and acceptable deposits that are crisp and as such easily removable from the boiler area, see fig. 5, and do not represent a threat to the stability of the operation and efficiency of the boiler, particularly in campaigns of reburning with natural gas, see fig. 3a.

Combustion efficiency

Combustion efficiency was estimated from one side through the content of unburnt in the fly ash collected on the ceramic probes in lower part of the reaction tube, see fig. 1, as well as in the slag collected on the bottom of the reactor, and from the other side through CO emissions measured during the test runs.

Unburnt in samples of slag and fly as his satisfactory for all test modes, indicating that the combustion process in the test furnace is well developed in all test modes, which also contributes to the reliability of test results. Maximum proportion of unburnt in slag and ash was observed in test mode U90B10/1,400 °C, see fig. 5, and is most likely caused by a stronger influence of larger granulation (particle size distribution) of tested woody biomass in relation to coal. Namely the coal-biomass blend has not been mechanically treated and prepared – the fuel mixture is prepared in the laboratory by mixing fuel U100 and B100. In reburning campaigns of co-combustion coal and biomass with gas, unburnt in slag and ash deposits is generally lower than in tests with other combinations of fuels, fig. 5.

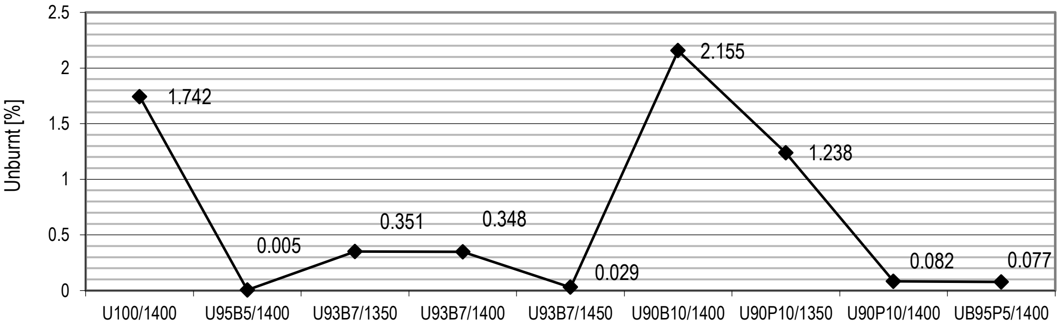

Figure 5. Unburnt for tests with different fuel combinations

What is additionally important for the co-firing test regimes with natural gas as a supplementary fuel, in general very low CO emissions were measured, especially at higher process temperatures, *e. g.* averaging only about 3 mg/m_n^3 at 1,450 °C, fig. 6.

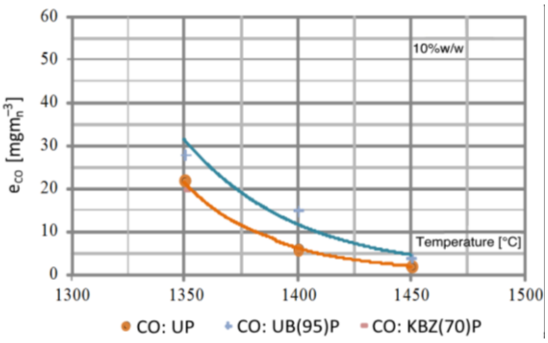

Figure 6. CO emissions during co-firing coal with woody biomass and natural gas

Sustainability assessment of multi fuel concept considered

Sustainability assessment model applied

The main objective of sustainability analysis applied in this paper is to investigate from the aspect of sustainability optimal fuel composition for a referent power plant using the basic coal – in this case CHP Kakanj TPP unit 6 (118 MW_e). Six selected fuel combinations, here named options, have been considered, namely:

- Option 1: Coal only (U100),
- Option 2: Co-firing coal with biomass with 5%w of woody biomass (U95B5),
- Option 3: Co-firing coal with biomass with 7%w of woody biomass (U93B7),
- Option 4: Co-firing coal with biomass with 10%w of woody biomass (U90B10),
- Option 5: Co-firing coal with natural gas (reburning) with 10%th of natural gas (U-P10),
- Option 6: Co-firing coal with biomass (with 5%w of woody biomass) and natural gas (reburning) with 10%th of natural gas (UB-P10).

In the work, sustainability assessment is applied, considering environmental, economic, resources and social criteria, to investigate effects to the sustainability of different fuel options for a referent power plant. The methodology procedure has been presented on the flow chart given in fig. 7, adopted from work [17].

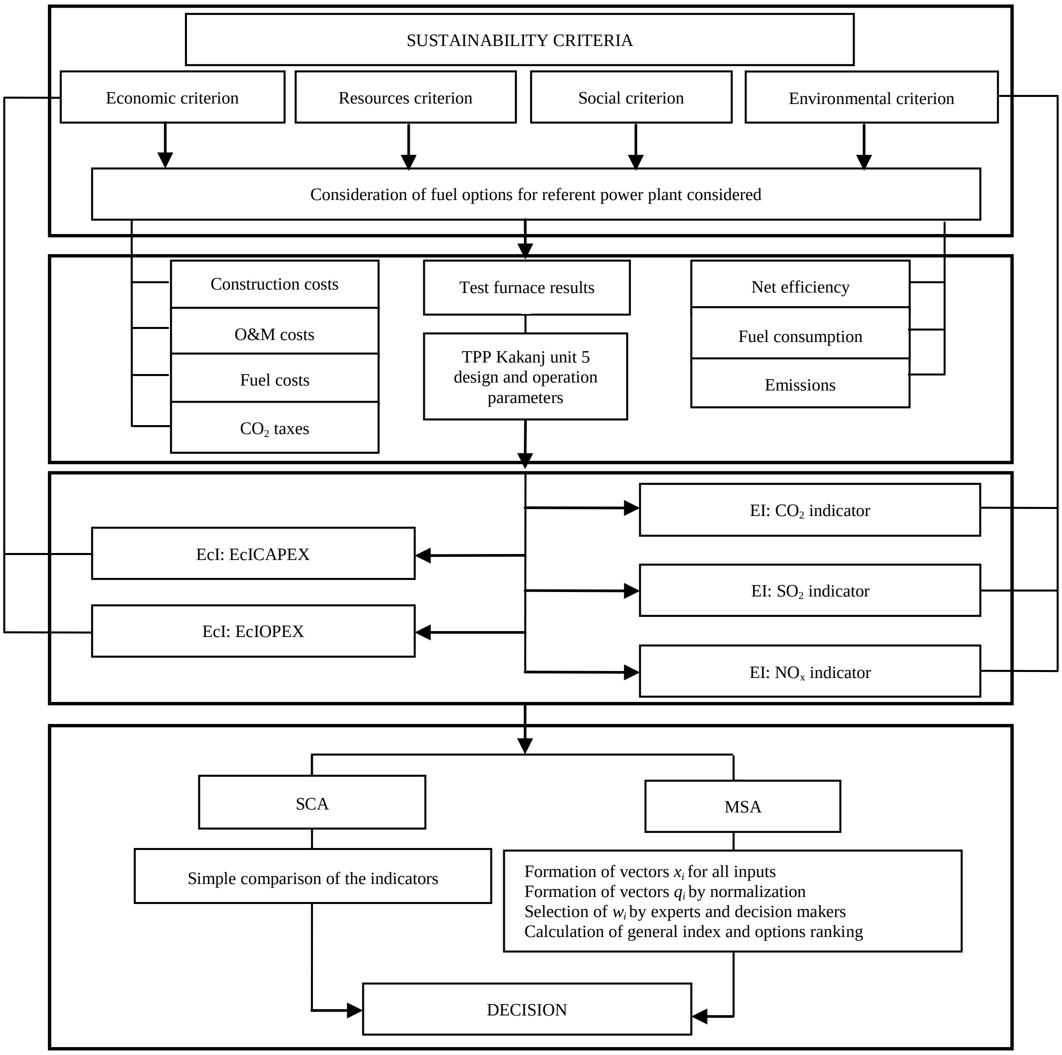

Figure 7. Flow chart of the model used within analysis, adopted from work [17]

Further, specific environmental and economic sustainability indicators, shown in tab. 3, which are typically used when considering a power system, due to their high-effecting influence on sustainability of such a system, see [17-19], are set out and estimated on the basis of real *measurable* input data such as net efficiency, fuel consumption, emissions, construction costs, operation and maintenance (O&M) costs, fuel costs and CO_2 taxes, as indicated in fig. 7, and which are derived from presented test furnace trial runs and calculated on the base of operational and design characteristics of TPP Kakanj unit 5. Obtained results, which are based on real measurements, have been finally discussed by single criteria analysis (SCA) and MSA.

EI calculated and presented for different scenarios in this analysis are: *CO_2 – indicator, SO_2 – indicator* and *NO_x – indicator*. As the most important EcI for this analysis *Invest-*

ment indicator (EcICAPEX) and *Indicator of energy costs* (EcIOPEX) are considered, taking into account fixed and variable O&M costs, including fuel costs, costs of desulphurization ($DeSO_x$) and denitrification ($DeNO_x$) and CO_2 taxes.

The social aspect is analysed by non-valuable indicators, *i. e. Diversity indicator* and *Industry development*. Social impacts of the diversity of fuels and development of the industry sector are evaluated for different options to support sustainability analysis based on environmental and economic indicators, [17].

Table 3. Sustainability indicators considered

Type of indicator	Single indicators	Unit
Environmental indicator (EI)	CO_2 indicator − $EICO_2$	kgkWh^{-1}
	SO_2 indicator − $EISO_2$	kgkWh^{-1}
	NO_x indicator − $EINO_x$	kgkWh^{-1}
Economic indicator (EcI)	Investment indicator − EcICAPEX	EUR per kWh
	Energy costs indicator − EcIOPEX	EUR per kWh
Social indicator (SI)	Diversity indicator	–
	Development of industry	−

Single criteria analysis

Sustainability indicators, discussed above and shown in tab. 3, have been calculated for all six options of multi fuel concept considered. In calculation the indicators, planned annual power generation of referent TPP Kakanj unit 6 until decommissioning the unit in 2030, as well as dynamic plan of complying the unit with large combustion plants directive (LCPD) and industrial emissions directive (IED) (desulphurisation plant to be installed in 2018 and denitrification plant in 2022) have been taken into account, according to the plans for the unit given in the long-term development plan of EPB&H power utility with strategic plan [20]. Average net electrical efficiency of 30.68 of the power station was adopted for all options of the multi fuel concept under consideration, tab. 4, taking also into account the laboratory test findings on the factors effecting combustion efficiency. Fuel consumptions have been calculated based on lower heating value of the fuels used, the net efficiency and assuming total generation in period 2016-2030 of 7,106 GWh, tab. 4.

In calculation environmental indicators, emissions records from the test runs have been considered. In estimation the economic indicators, CAPEX and OPEX of desulphurisation and denitrification were also taken into account. For instance, different multi fuel concept options under consideration require consequently different percentage of SO_2 removal needed, affecting the CAPEX.

Table 4. Net efficiency, fuel consumptions, CO_2 emissions and CO_2 tax costs for period 2016-2030

Fuel options		Option 1 U100	Option 2 U95B5	Option 3 U93B7	Option 4 U90B10	Option 5 U-P10	Option 6 UB-P10
Indicator	Units						
Total generation	GWh	7,106	7,106	7,106	7,106	7106	7,106
Average net eff.	%	30.63	30.63	30.63	30.63	30.63	30.63
Coal consump.	000 t	6,240	5,883	5,761	5,614	5,685	5,396
Biomass consump.	000 t	0	310	434	624	0	284
Gas consump.	000 t	0	0	0	0	174	174
CO_2 emissions	000 t	7,433	7,136	7,032	6,853	7,264	6,993
CO_2 tax costs	000 EUR	212,414	203,924	200,956	195,848	207,569	199,836

Another key issue influencing significantly to the OPEX, is CO_2 tax costs, see tab. 4, that has been estimated for the considered options assuming CO_2 price projections in EU as given in [21, 22].

Results of the indicators are shown in tab. 5, considering operation period of the power station of next 15 year (2016-2030). SCA was obtained by simple mutual comparison the indicators of all multi fuel options under consideration. Thus, if SCA is applied, it can be noted that, considering CO_2 emissions, option with highest percentage of woody biomass is preferable. From the environmental aspect − considering indicators of SO_2 and NO_x emissions only, option of co-firing coal with biomass and natural gas has an advantage over all other options. However, from the economic aspects of investments (EcICAPEX) and energy costs (EcIOPEX), this option is not favourable, because of very high price of natural gas in the case of Bosnia and Herzegovina, which is at least three times greater per LHV than price of coal and waste biomass over entire considered period. The presented example shows that, within SCA, the selection of the optimal option for the power system depends exclusively on selected criteria.

Table 5. Results of EI and EcI

Fuel options		Option 1 U100	Option 2 U95B5	Option 3 U93B7	Option 4 U90B10	Option 5 U-P10	Option 6 UB-P10
Indicator	Units						
EICO2	kgMWh^{-1}	1,046	1,004	990	964	1022	984
EISO2	kgMWh^{-1}	5.3037	5.1720	5.1286	5.1182	4.7645	4.8891
EINOx	kgMWh^{-1}	2.0929	2.0577	2.0968	2.0534	1.5576	1.5562
EcICAPEX	EUR per MWh	4.64	4.70	4.83	5.06	5.12	5.31
EcIOPEX	EUR per MWh	73.71	72.25	71.84	71.31	79.19	77.47

Multicriteria sustainability assessment

To improve results of SCA, the MSA is applied, which takes into account all set criteria at the same time. Different criteria are adopted by respective weighting factors, giving a realistic and reliable sustainability rating of the options under consideration. The MSA incorporates previously defined sustainability indicators, and specific criteria, adopted by weighting factors, which are being agglomerated into general sustainability index, according to the MSA procedure, [17-19]. Which combination of weighting factors will be applied or be decisive for decision makers in specific case, depends on the nature of the energy system under consideration, environment and economic issue of the area, fuels availability and affordability, as well as specific situation of the investor. All these aspects should be taken into account when defining weighting factors. So, based on argumentation and facts under the foregoing aspects, experts/scientists and decision makers together define values of specific weighting factors, aiming to provide a realistic and reliable sustainability rating of the options under consideration, [17]. As final result of the MSA procedure, a list of priority of considered options is obtained. Within the MSA performed in this paper, on the base of specific situation respecting the quality of air in area of the domain of EPB&H, as well as GDP in B&H and specific financial projections of the company, equal importance assigned to the environmental and economic criteria, *i. e.* equal weighting factors have been assigned to the group of environmental and economic indicators, as a basic case. Following the procedure of MSA, values of weighting factors and vectors of specific criteria, which actually present normalized SI values, together with general index and ranking the options for this basic case, are given in tab. 5. Moreover, a wide range of values of weighting factors in relation to the basic weighting factors distribution have been investigated within sensitivity analysis of MSA. Generally, obtained results of MSA improve SCA results. In principle, assigning equal importance to EI and EcI, option of co-firing coal with waste woody biomass and natural gas has proved to be the preferable option, tab. 6.

In that case option of highest share of waste biomass (option 4) is preferred over option of coal-natural gas (option 5). Giving an advantage to environmental criteria over economic criteria, option 6 positioned as preferable, see tab. 7.

Table 6. Weighting factors, specific criteria vectors, general index and ranking of the options, case $\sum w_i$EI:$\sum w_i$EcI = 0.5:0.5

RES Scenario		Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
Indicator	w_i	U100 (q_i)	U95B5 (q_i)	U93B7 (q_i)	U90B10 (q_i)	U-P10 (q_i)	UB-P10 (q_i)
EICO2	0.167	1	0.960	0.946	0.922	0.977	0.941
EISO2	0.167	1	0.975	0.967	0.965	0.902	0.906
EINOx	0.167	0.998	0.981	1	0.979	0.743	0.742
EcICAPEX	0.250	0.880	0.891	0.897	0.905	0.970	1
EcIOPEX	0.250	0.931	0.912	0.907	0.901	1	0.978
Q		0.9534	0.9378	0.9376	0.9300	0.9304	0.9268
Ranking		6	5	4	2	3	1

Table 7. Weighting factors, specific criteria vectors, general index and ranking of the options, case $\sum w_i$EI:$\sum w_i$EcI = 0.6:0.4

RES Scenario		Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
Indicator	w_i	U100 (q_i)	U95B5 (q_i)	U93B7 (q_i)	U90B10 (q_i)	U-P10 (q_i)	UB-P10 (q_i)
EICO2	0.200	1	0.960	0.946	0.922	0.977	0.941
EISO2	0.200	1	0.975	0.967	0.965	0.902	0.906
EINOx	0.200	0.998	0.981	1	0.979	0.743	0.742
EcICAPEX	0.200	0.880	0.891	0.897	0.905	0.970	1
EcIOPEX	0.200	0.931	0.912	0.907	0.901	1	0.978
Q		0.9618	0.9439	0.9435	0.9343	0.9185	0.9134
Ranking		6	5	4	3	2	1

However, when economic criteria is preferred, already at 10% of advantage over environmental criteria, and more further, then options with biomass becoming more preferable against options with natural gas, see tab. 8 – the case of 20% greater influence of economic criteria over environmental criteria.

Table 8. Weighting factors, specific criteria vectors, general index and ranking of the options, case $\sum w_i$EI:$\sum w_i$EcI = 0.4:0.6

RES Scenario		Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
Indicator	w_i	U100 (q_i)	U95B5 (q_i)	U93B7 (q_i)	U90B10 (q_i)	U-P10 (q_i)	UB-P10 (q_i)
EICO2	0.133	1	0.960	0.946	0.922	0.977	0.941
EISO2	0.133	1	0.975	0.967	0.965	0.902	0.906
EINOx	0.133	0.998	0.981	1	0.979	0.743	0.742
EcICAPEX	0.300	0.880	0.891	0.897	0.905	0.970	1
EcIOPEX	0.300	0.931	0.912	0.907	0.901	1	0.978
Q		0.9430	0.9298	0.9298	0.9237	0.9407	0.9386
Ranking		6	3	2	1	5	4

In addition, the effects to the diversity of fuels and the number of employees in industry and the power sector for six different fuel options have been considered, evaluating those social indicators as non-valuable characteristics. Option of co-firing with waste biomass and natural gas have been shown to be favourable option from social aspect particularly against options with no waste woody biomass.

Conclusions

Multi fuel concept for future thermal power plants is promising solution to provide cost-effective power production of future RES-based power system, either MFC is used for the base-load or as backup. Holistic approach is to be applied in development MFC to provide sustainable solutions. In this paper, R&D project of MFC and its benefits, demonstrated on example of co-firing Middle-Bosnia brown coal with waste wooden biomass and natural gas, has been presented. Derived research results yield input data for calculation sustainability indicators of a MFC based power plant, giving through single criteria analysis and multicriteria sustainability assessment, an advantage to the options of MFC in the case demonstrated.

Thus, assigning equal importance to the environmental and economic criteria, along with further giving advantage to the environmental criteria, option of co-firing coal with waste woody biomass and natural gas has proved to be the preferable option. Otherwise, it should be stated that results of the analysis presented here are function of specific local conditions and specific circumstances relating for example to the costs of all three fuels considered; coal, waste woody biomass and natural gas, as well as their availability and affordability, then depend also on the net efficiency of the power unit considered as well as its specific design and operational characteristics and parameters. In other words, what is assessed as most sustainable option for one specific case of multi fuel concept under consideration, does not mean that it would be optimal option for some other specific cases.

For that reason, it is recommended to apply MSA for any new case of multi fuel concept according to the methodology demonstrated here, and taking into account specific local conditions for the case as aforementioned.

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