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Potential Impact of Biomass Cogeneration Plants on Achieving Climate Neutrality of BIH until 2050

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Abstract

The paper analyzes the potential of Biomass Combined Heat and Power (BCHP) plants in Bosnia and Herzegovina (BiH) in achieving climate neutrality until 2050. Two scenarios for reducing GHG emissions from the power generation sector in BiH until 2050 were developed. Scenarios were developed using LEAP, a software tool for energy policy analysis and climate change mitigation assessment. The complete final energy consumption and existing primary energy mix in BiH were included. Both scenarios imply a significant reduction in electricity generation from coal-fired power plants (CFPP). The first scenario (S1) involves the construction of a substitute CFPP unlike the second scenario in which there is no construction of a new CFPP, but part of the reduction in electricity generation from the CFPPs is compensated by BCHPs. The second scenario (S2) achieves a significantly higher reduction in GHGs emissions and provides an answer to the question of how much wood biomass is needed for the operation of BCHP for enabling the decarbonization of the power generation sector by 2050. S1 also represents a step toward reducing GHG emissions. Emissions from power generation in 2030 are about 60% lower than in 2015, i.e. by closing part of the existing CFPPs fleet, while in 2050 GHG emissions will be reduced by 12.26 million tons of CO_2eq compared to 2015. The main advantage of S2 is the gradual phase-out of CFPPs and construction of BCHPs, which means incomparably lower GHG emissions, negligible in 2050, representing a key argument for the deployment of biomass potential for power generation. The technical potential of unused wood biomass in BiH is 7.44 PJ annually or 620,620 t annually. These quantities would be sufficient for the levels of electricity production in Scenario 2 by 2035. After that, the existing available technical potential is not enough. This means that BiH needs to increase biomass production and its technical potential to enable the implementation of that scenario.

Keywords

GHG Emissions, Cogeneration, Wood Biomass, Climate Neutrality, Energy Planning

1. Introduction

Eco-unfriendly practices such as the current boom in the use of petroleum resources and deforestation as a response to the pressure to meet the growing demands, especially for energy, are the root causes of the increased emissions of anthropogenic sources of global greenhouse gases (GHGs), the primary drivers of climate change. It is expected that GHG emissions will increase by 50% by 2050, mainly due to the expected 70% increase in energy-related CO_2 emissions. If these emissions keep rising at their current rate, it will push the carbon (C) cycle out of its dynamic equilibrium, leading to irreversible changes in the climate system (Wang et al., 2021). Therefore, concrete efforts to reduce carbon emissions and increase carbon sequestration have to be initiated through a variety of socio-economic and technological interventions.

One key approach to addressing climate change is to replace fossil fuels with renewable energy for electricity generation. Carbon emissions from renewable energy power plants are much lower than from fossil fuel power plants. Thus, reliance on fossil fuels to fulfill our energy demand without conservation efforts or increases in renewable energies will eventually lead to catastrophic global impacts. The development of non-fossil fuel energy sources is essential to reducing GHG, avoiding fossil fuel resource depletion, and coping with fluctuating fossil fuel prices. GHG emissions can be substantially reduced if biomass replaces fossil fuels to generate power. Indeed, unlike fossil fuels, burning renewable biomass is considered neutral in GHG emissions (Amin & Talebian-Kiakalaieh, 2018). Clean energy production from biomass could be a viable option to reduce fossil fuel consumption. Wood biomass such as briquette and pellet from unorganized biomass waste and residues could be used as an alternative to wood fuel, as a result, the forest would be saved and a sustainable carbon sink will be developed. Biomass can produce fewer emissions in the range of 14% to 90% compared to emissions from fossils for electricity generation. Therefore, biomass could play a vital role in the generation of clean energy by reducing fossil energy to reduce GHG emissions (Sadrul & Ahiduzzaman, 2012).

The whole economics of introducing biomass cogeneration depends on many factors, primarily on the chosen concept, the installed capacity, the current energy price, and the price of biomass (Obernberger, Thonhofer & Reisenhofer, 2002). One of the aspects that should be also considered is that the amount of biomass that can be produced in any country and indeed at a global scale is inherently limited by the land and material resources available and influenced by land-use competition and economic factors. In recent years there is an increasing awareness of the extent to which sustainability considerations will ultimately constrain the maximum biomass resource available (Thornley, Gilbert, & Hammond, 2015).

An Overview of the Current State of the Power Generation Sector in Bosnia and Herzegovina

The total installed capacity of power plants in Bosnia and Herzegovina (BiH) is 4608.26 MW, of which 2076.6 MW is in large hydropower plants (HPP) and 2065 MW in coal-fired power plants (CFPPs). The installed capacity of wind farms is 134.6 MW, small HPPs 180.18 MW, solar power plants (SPPs) 56.51 MW, biomass power plants 2.11 MW, small wind farms 0.4 MW, while 92.85 MW is installed in industrial power plants. Total gross electricity production in 2021 was 17,055 GWh, while final consumption was approximately 12,170 GWh. Net electricity exports amounted to 4781 GWh (State Electricity Regulatory Commission, 2021).

Electricity consumption increased in the period 2002-2018, from 9150 to 12,170 GWh, which is an increase of about 33%. In 2021, consumption of the transmission system (HV customers) increased by 31.4% and amounted to 1170 GWh. The recovery in consumption is largely due to increased demand in the global metal market, which has the largest electricity consumers in BiH. Consumption of customers connected to the transmission system has increased by 31.4% and amounted to 1170 GWh, while distribution consumption has increased by 4.7% and amounted to 10,468 GWh. In 2021, about 9820 GWh or 57.5% of gross electricity was produced in CFPPs, which use domestic coal and have fairly high specific emissions of CO_2 (about 1.3 tCO_2/MWh) (State Electricity Regulatory Commission, 2021). According to the draft of the National Energy and Climate Plan (NECP), by 2050, it is expected a light increase in electricity demand by up to 10% in 2050, compared to 2020 (MOFTER, 2021).

In the last few years, there has been a trend of increasing capacity using renewable energy sources (RES). Among other things, three biomass plants and three wind farms were put into operation. Small hydro and wind power plants have the largest share among RES, followed by solar and biomass power plants. The share of individual RES in the installed capacity at the end of 2018 in BiH is shown in **Figure 1**.

According to the available information, the Agency for Statistics of Bosnia and Herzegovina has been planning to do again the energy balance, i.e. make its change. This shows that there are still no reliable energy statistics in BiH. The trajectory of BiH now is not entirely clear, as BiH does not have reliable data on the share of RES energy in gross final consumption. Estimates made by the Energy Community Secretariat indicate a percentage of about 42% of the share of RES in gross final energy consumption. This means BiH has already met its 2020 target which was 40% of RES in gross final energy consumption (Numic, 2021).

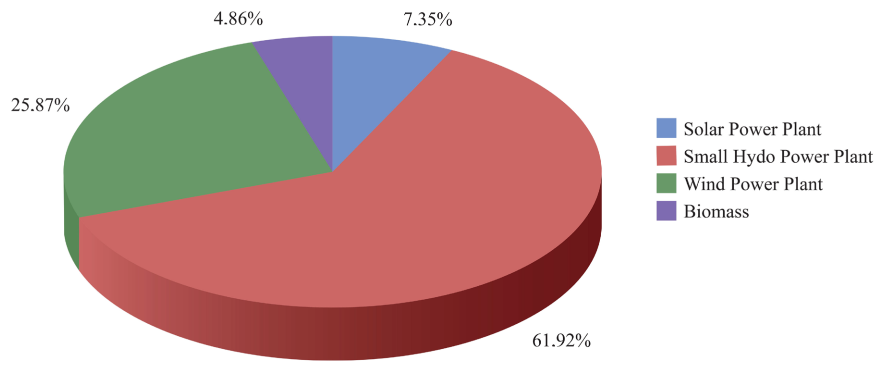

Figure 1. Share of individual RES in the installed capacity for electricity production at the end of 2018 in BiH (ENOVA & CETEOR, 2020).

In 2018, BiH has adopted the Framework Energy Strategy of BiH until 2035. The strategy contains the basic principles of climate policy that are not sufficiently translated into concrete measures. According to the Strategy, the long-term vision of energy in BiH is to create a competitive and long-term sustainable energy system, bearing in mind the aspect of the security of supply. Four scenarios have been developed, where only one leads to a certain reduction in emissions (called mildly-renewable). Other scenarios are based, among other things, on a significant increase in the capacity of CFPPs and their production, so according to three scenarios, domestic coal will continue to be the main source of electricity production. The main disadvantage of these scenarios is that they predict an unrealistic increase in electricity production, by as much as 80% by 2035. There are significant coal reserves and it is a sector that employs a large number of people. The slightly renewable scenario prescient a slight increase in production, but from RES (hydropower, biomass, wind, and solar), while the role of thermal power would be focused on the security of supply (UNDP, 2020).

By signing the Declaration on a Green Agenda for the Western Balkan, on 10th November 2020 in Sofia, the countries of the region pledged to implement measures in the field of climate change, energy transition, and sustainable mobility, through a series of concrete actions, including a carbon taxes and market models to encourage renewable energy sources, as well as gradually abolition of coal subsidies (MOFTER, 2021). The Green Agenda provided by European Green Deal, includes the goal of climate neutrality in EU law till 2050, proposing activities and measures that the EU and Western Balkan countries should jointly adopt, such as harmonization with the EU climate law, development, and implementation of NECP with clear measures about GHG emissions, progressive decarbonization of the energy sector and its implementation through Energy community, prioritizing energy efficiency and its improvement through all sectors (Vlahinic Lenz & Fajdetic, 2021: p 1; Husika, Zecevic, Dzaferovic & Numic, 2022).

In order to achieve the goals contained in the Green Agenda for Western Balkan, Bosnia and Herzegovina (BiH) must further improve its approach to strategic planning, especially in areas related to decarbonization, gradual reduction of the use of fossil fuels with the aim of achieving climate neutrality by 2050. It is clear how great a challenge this is for BiH because the current goals of reducing GHG emissions are not enough to achieve climate neutrality, which is expected in accordance with the commitment expressed by the signing of the Green Agenda (Husika, Zecevic, Dzaferovic & Numic, 2022).

2. GHG Emissions in Bosnia and Herzegovina

As a member of UNFCCC, BiH is required to report on GHG emissions. Through the preparation of the first three national reports on climate change and two biennial emission reports, inventories of emissions from 1990 to 2014 were made using IPCC 1996 methodology. With this in mind, information on GHG emissions is much more reliable compared to the period when the previous Strategy was drafted, and domestic capacities for their monitoring have been improved. In this way, it is possible to more reliably forecast emissions and in this regard define the objectives arising from international agreements (UNDP, 2021). **Figure 2** shows the annual GHG emissions in BiH, where the trend of emissions from 1990 to 2014 can be seen.

As can be seen from **Figure 2**, after the drop in emissions during the period 1990-1995 (due the wartime), in the last 20 years there is a strong trend of increase in GHG emissions.

The highest emissions were in 1990 and amounted to 34.04 million tons of CO_2eq. Emissions were significantly reduced during the period 1992-1995, after which they started to grow. Primarily due to the growth of emissions in the energy sector, total emissions exceeded 20 million tons of CO_2eq in 2008 (UNDP, 2020).

Emissions from other sectors were more than halved between 1990 and 2001, due to a reduction of more than 80% in industrial emissions and 50% in the agricultural sector. In the period 2007-2016, two cyclical trends are noticeable. Specifically, in the period 2007-2011, emissions increased by almost 50%, from 18,788 Gg CO_2eq to 28,108 Gg CO_2eq. The rise in emissions in 2011 primarily occurred due to increased power generation from coal-fired power plants. In 2012, emissions decreased by around 22% compared to 2011 and then increased again in the period up to 2016 by around 36%. In 2012, GHG emissions decreased due to favorable hydrological conditions, which resulted in an increase in production from hydropower plants and a decrease in production from CFPPs (UNDP, 2020). In 2012, emissions decreased by around 22% compared to 2011 and then increased again in the period up to 2016 by around 36%. In 2012, GHG emissions decreased due to favorable hydrological conditions, which resulted in an increase in production from hydropower plants and a decrease in production from CFPPs. Emissions in 2016 amounted to 29.67million tons of CO_2eq, which is about 12.8% less than in 1990 when the highest emissions were measured. Therefore, it can be concluded that there is a growing trend in total GHG emissions and that the change in emissions in a short period is relatively large.

This can be explained by the relatively large share of GHG emissions from the electricity sector in total emissions. The share of individual energy sources in

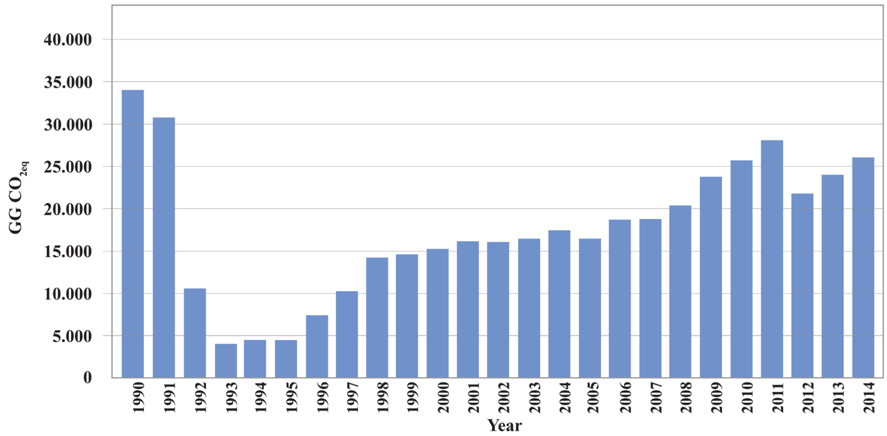

Figure 2. Annual GHG emissions in BiH (UNDP, 2021).

electricity production changes from year to year, which is reflected also in total emissions. In 2016, CFPP Stanari was put into operation, which affected the growth of electricity production from CFPPs by about 19%, compared to 2014. In addition to electricity, a significant impact on increasing total emissions had transport, where emissions increased by approximately 22% in 2016 compared to 2014 (UNDP, 2021).

Figure 3 shows the shares of individual sectors in total emissions from 1990-2014.

Comparing energy production in **Figure 3**, shows the growth of the share of energy production in total GHG emissions from 61% (in 1990) to 64% (in 2014), although emissions (in absolute terms) in that sector were lower in 2014. The share of transport has grown significantly, from 7% to 12%. The share of agriculture recorded a significant decline, while the share of industrial processes remained approximately the same. The share of fugitive emissions from fuel fell from 5% in 1990 to 2% in 2014, which indicates an improvement in the way fuels are handled. It is important to point out that this is about the share in emissions of all GHGs not only carbon dioxide emissions. In the energy production sector, about 90% of emissions come from the power sector, i.e. from coal-fired thermal power plants (MOFTER, 2021).

The target of reducing emissions for 2050 is clear, and that is climate neutrality. To achieve climate neutrality, in addition to GHG emissions, it is important to increase GHG sinks. The sinks of GHGs are forests and land. According to the data from the inventory for the period 1990-2016, they have a declining trend. In 1990, the sinks amounted to about 7.4 million tons of CO_2eq, and in 2016 about 5.8 million tons of CO_2eq. There is a trend of declining sinks. In 2016, the sinks were reduced by about 1.6 million tons of CO_2eq compared to 1990. This amount is approximately equal to the emission of one CFPP in BiH (UNDP, 2021).

3. Potentials of Wood Biomass for Cogeneration in BiH

A significant contribution to GHG emission reduction shortly is expected from

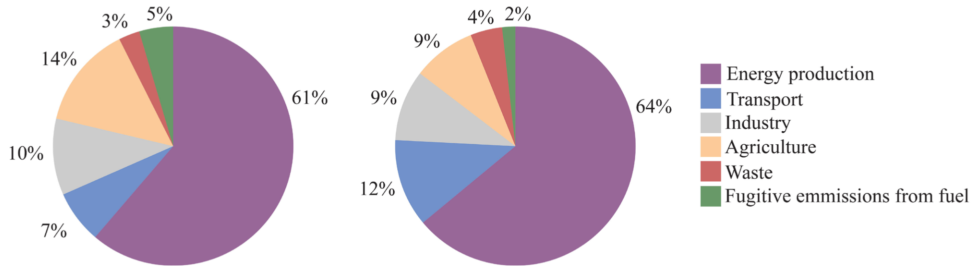

Figure 3. The share of GHG emissions by sectors (1990-2014) (MOFTER, 2021).

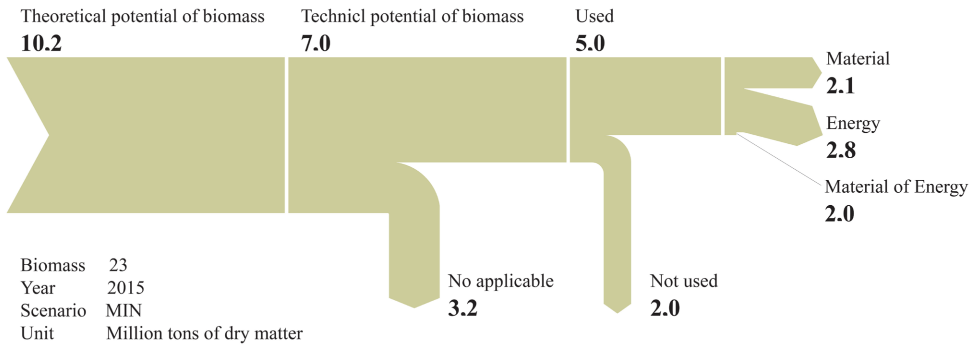

Figure 4. Sankey diagram, biomass resources in BiH from 2015 (minimum scenario) (Pfeiffer, Krause, Horschig, Avdibegovic, Custovic, Ljusa et al., 2020).

biomass, especially wood biomass. BiH is very rich in forests and forest lands, which cover more than 50% of the territory and are one of the most important natural resources.

Despite the significant resource base, so far there is no strategic plan to significantly increase the use of biomass for energy production or the production of biofuels. Forest biomass is the largest biomass raw material stream in Europe.

Figure 4 shows a map of biomass potential in BiH. The biomass potential in BiH in 2015 was between 10.3 (min. value) and 10.4 million tons of dry matter (max. value) and could theoretically, without taking into account the lower thermal power, factors related to conversion and mobilization, cover up to 24% of the country's total primary energy supply (TPES).

Two million tons of dry matter, which is currently "unused", represents a potential share of 716 to 907 ktoe of TPES, with an assumed lower calorific value of 15 to 19 GJ/tDM, 36 which is equal to a share of 12% to 15% of total primary energy supply. Considering the current share of RES in TPES of 9.1%, it is possible to increase the total share of RES in the amount of 21 to 24%. However, these percentages should be carefully considered, as illegal logging is currently not covered by this monitoring system, especially when it comes to potentials from annual forest growth and waste wood (Pfeiffer, A., Krause, T., Horschig, T., Avdibegovic, M., Custovic, H., Ljusa, M. et al., 2020: p. 29).

There is a high energy potential in residues from agriculture, forestry, and the wood industry. Most wood processing companies in BiH use wood residues to heat their premises and/or to dry wood. If wood residues remain, they are sold in companies that produce pellets and briquettes. Instead of using these residues only for heating, or for pellets and briquettes, the residues can be used in cogeneration plants to produce the heat needed for the production process, and also for the production of electricity. It is estimated that 80% of existing residues can be used in cogeneration plants. Based on data from (Numic, 2021), the available technical potential of wood biomass is 7.44 PJ (UNDP, 2014).

The conversion rate for electricity from biomass cogeneration plants varies depending on which technology is used and what capacity is installed, ranging from about 12% to 36%. If it is assumed that the average annual rate of conversion of primary energy into electricity in power plants and cogeneration plants, which can be built in BiH, is 30%, then 13.75 PJ or 3820 GWh of energy potential from available biomass in BiH can annually generate 1070 GWh of electricity. As electricity production in 2014 was 15,029.84 GWh, about 7% of electricity could be obtained from the available technical potential of biomass (State Electricity Regulatory Commission, 2014).

4. Analysis of the Impact of Different Scenarios of Using Biomass for Power Generation on GHG Emissions in BiH

Given that over 50% of GHG emissions come from the power generation sector and that 60% to 70% of electricity (depending on annual rate and distribution of rainfall) is generated in CFPPs with high specific emissions (about 1.3 tCO_2/MWh), it is concluded that the greatest potential for reducing GHG emissions is in the power generation sector. The share of electricity sector emissions in total emissions of BiH in 2016 is almost 50% (UNDP, 2021).

Two scenarios were analyzed, which include the development of the energy mix in the electricity sector in BiH by 2050. These two scenarios represent a simulation of the potential for reducing emissions. The action plan for the implementation of the Green Agenda will also define the operation of coal-fired power plants in this context, but, certainly, their work will gradually decrease until 2050 and completely shut down after 2050.

The scenarios were modeled in the LEAP (Long-range Energy Alternatives Planning) program, which includes the complete final energy consumption and the existing shares of energy sources in BiH. LEAP is a widely-used software tool for energy policy, climate change mitigation, and air pollution abatement planning developed at the Stockholm Environment Institute. As an integrated modeling tool, it can be used to track energy consumption, production, and resource extraction in all sectors of an economy. It can be used to account for both energy sector and non-energy sector GHG emission sources and sinks. In addition to tracking GHGs, LEAP can also be used to analyze emissions of local and regional air pollutants, making it well-suited to studies of the climate co-benefits of local air pollution reduction (Stockholm Environment Institute, n.d.).

To avoid the impact on the economy and the need for electricity imports, the main assumption for both scenarios is that the rate of power generation over time is on the same level as the current ones (net generation around 17 - 18

TWh annually) and there is a slight increase in domestic electricity demand (1% annually). Both scenarios took into account the current production structure, including coal-fired power plants and RES. Schedule of decommissioning of the existing coal-fired plants given in the Draft of the National Energy and Climate Plan until 2030 is applied. The capacities and power generation rate of coal-fired power plants, biomass, and other RES for the period up to 2050 were modeled.

4.1. Scenario 1—Low-Carbon Development Scenario

This scenario aims to reduce GHG emissions from existing, obsolete, and inefficient CFPPs. Figure 5 shows a GHG emission diagram after reducing the production capacity of existing CFPPs by 60% and putting into operation of one new CFPP with 450 MW of power generation capacity.

By 2035, the new CFPP will take over most of the production. Although electricity production is on the same level, emissions are declining slightly due to the higher efficiency of the CFPPs fleet compared to the existing one. Parallel to the construction of new and closing of the existing units in CFPPs, it is necessary to intensify the construction of capacities that use renewable energy sources. CO2 emissions are falling sharply by 2025, primarily due to reduced production from existing CFPPs as a result of environmental constraints and market conditions. After that, emissions stagnate until 2030. The intensive decline in emissions begins in 2030 and continues until 2050 when all existing CFPPs are being closed. No significant increase in domestic electricity needs is expected.

With increasing production from RES, if the market restricts exports, there will inevitably be a decrease in electricity production from CFPPs. This process should be managed to avoid a sharp drop in coal demand and consequent sudden job losses in the mines. A new CFPP has an efficiency level of about 42%, and the existing ones on average just over 30% (Mofter, 2021). In proportion to the increase in the degree of efficiency, the replacement/new CFPP has a lower specific emission of CO_2. The emission reduction in an absolute amount from a new CFPP depends on the rate of production.

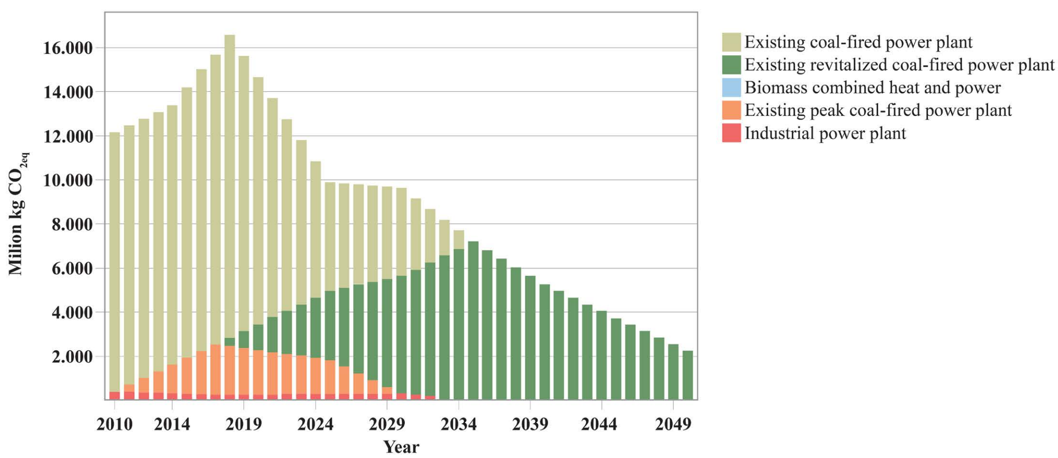

Figure 5. Scenario 1—GHG emissions from the electricity sector in BiH.

This scenario represents a step towards reducing GHG emissions. Emissions in the 2030 year are about 68% lower than in 2015, and the reduction of emissions from existing CFPPs in the 2035 year will be reduced to 0, i.e. CFPPs will be closed. Total GHG emissions for 2050 were reduced by 12,267 million tons of CO_2 compared to 2015.

Figure 6 shows a diagram of electricity production by production sources. The diagram shows that by reducing the capacity for electricity production of existing CFPPs and increasing the production capacity of new CFPPs, the need for electricity is still being met with low-carbon development.

Net production in the 2030 year is increased by about 1.86 TWh, or amounts to 20.74 TWh, compared to 2020, when production was 18.88 TWh.

The share of production from CFPPs should be reduced to about 45%, which still represents a relatively high share of CFPPs. The trend of development of the production mix would develop with similar dynamics as the expected growth of consumption, and the scenario would meet the high security of electricity supply at similar levels as today.

4.2. Scenario 2—Towards Climate Neutral Economy

Scenario 2 is an ambitious scenario on the way to achieving climate neutrality in BiH. By abolishing the production and operation of existing CFPPs in Scenario 1, one part of the plan was achieved, i.e. progress has been made with the aim to completely reduce GHG emissions and achieve climate neutrality. In Scenario 2, there are no new CFPPs (as in Scenario 1). Instead of a new CFPP construction, the operation of BCHPs (Biomass Combined Heat and Power) is predicted, in order to reach zero emission in power generation in BiH until 2050 (supported also by other RES). In this scenario, a high share of renewable energy sources is being planned, and this refers primarily to BCHPs, followed by hydropower, wind, and solar power plants.

Figure 7 shows a diagram of GHG emissions after the production capacity of CFPPs decreased by 30% and the production capacity of BCHPs increased. The figure shows the decline in GHG emissions produced by existing CFPPs after the reduction of their production capacity. This scenario leads to zero-emission of GHG until 2050.

The main advantage of shutting down CFPPs and opening BCHPs is significantly lower GHG emissions, which is a key argument for the use of biomass to reduce the level of GHGs, as well as to achieve climate neutrality, that BiH has been committed to. In addition, available heat from biomass cogeneration plants can be utilized for district heating or other needs. Figure 8 shows a diagram of electricity production by production technologies in Scenario 2.

The diagram shows that by reducing the capacity for electricity production of CFPPs and increasing the production capacity of BCHPs, the need for electricity continues to be satisfied. This scenario is feasible only with the opening and increasing the capacity of wood BCHPs, biogas plants, and storage HPPs, which will enable the integration of larger capacities of wind farms and solar power plants.

Net production of electricity from BCHPs in 2030 will begin to grow, and production of 2.06 TWh is expected to be achieved. The share of production from CFPP should be reduced to about 30%, which allows for further growth of the production capacity of BCHPs. The trend of development of the production capacity plants BCHPs would develop at similar dynamics as the expected growth of consumption, and the scenario would satisfy the high security of electricity supply at similar levels as currently.

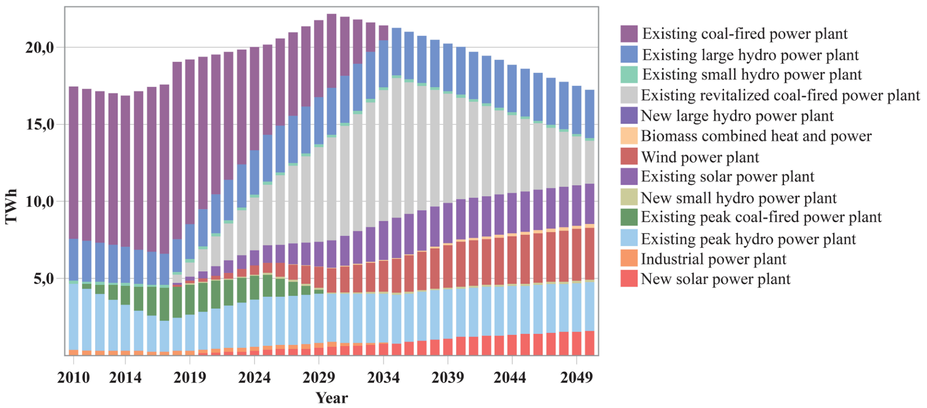

Figure 6. Scenario 1—Mix of electricity production in BiH.

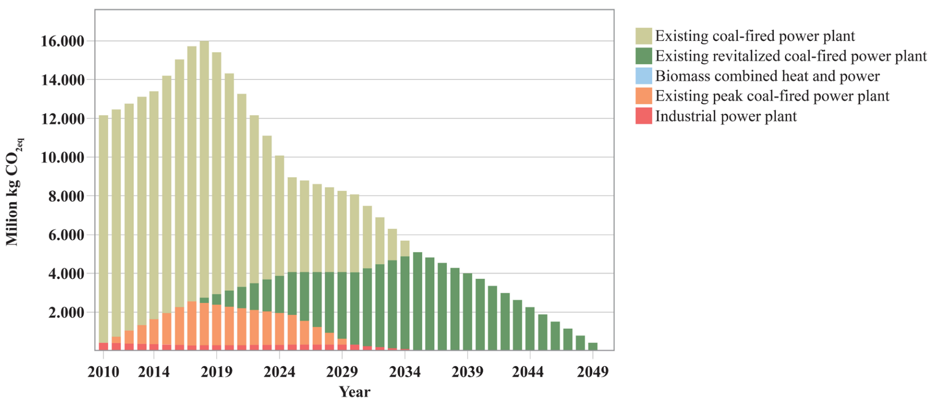

Figure 7. Scenario 2—GHG emissions from the electricity sector in BiH.

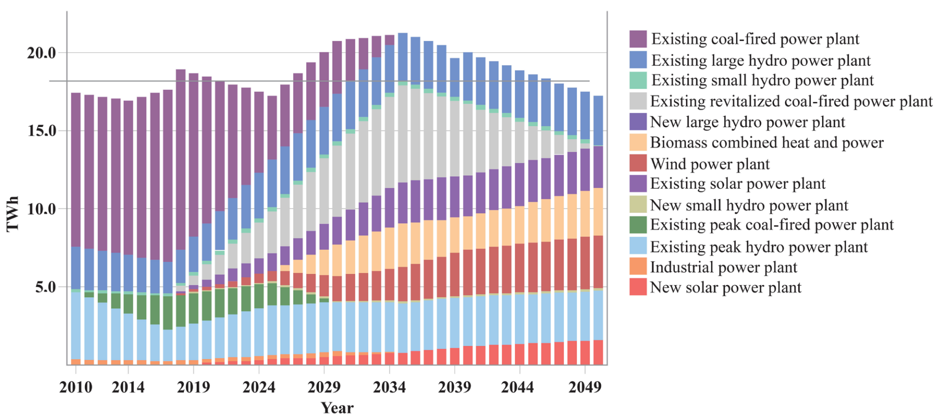

Figure 8. Scenario 2—Mix of electricity production in BiH.

4.3. Analysis of Wood Biomass Potential for Electricity Production in BCHPs

In Chapter 4.2., for Scenario 2, 2.06 TWh of electricity is produced from biomass cogeneration plants in 2030, and in 2050, the total production based on the use of this technology is 3.05 TWh. Based on the obtained amount of power generation, the analysis of the required amount of biomass for the production of electricity for Scenario 2 was performed.

Energy in wood biomass needed for electricity generation is calculated according to the following equation:

$$E = E_b / \eta . \quad (1)$$

E_b—Electricity generated from wood BCHPs (MWh/a).

η—Electrical efficiency of wood BCHPs.

The adopted electrical efficiency of wood BCHPs is 30%.

The required amount of biomass for electricity production is calculated according to the following equation:

$$Q_b = E \cdot H_d . \quad (2)$$

E—Produced electricity in BCHP based on the degree of electrical efficiency (MWh/a).

H_d—The lower heating value of wood biomass (GJ/t).

The adopted lower heating value of wood biomass is:

$$H_d = 12\,\text{GJ/t} = 3.33\,\text{MWh/t} \quad (3)$$

Table 1 shows the results of the calculation of the required annual amount of biomass (calculated based on the above equations) for every 5 years until 2050. The existing technical potential of unused wood biomass in BiH is 7.44 PJ a, or 620,620 t a.

In Scenario 2, as a gradual transition to electricity production in BCHPs, the required amount of wood biomass for electricity production for 2025 is 411,811 t/a. Based on current data on available wood biomass in BiH, it is evident that BiH could meet the current needs of wood biomass in the initial steps towards the transition to electricity production in BHCPs based on the unused technical potential of wood biomass.

However, the required amount of wood biomass in the 2030 year is 2,059,000 t/a, which would lead to higher demand than the existing unused technical potential of wood biomass, amounting to about 620,000 t/a.

Figure 9 shows the gap between the technical potential of biomass and the required amount of biomass for power generation in BCHPs (2025-2050). In spite of the relatively high potential of wood biomass, according to the modeling results, there will be a lack of wood biomass in Scenario 2.

The maximum gap is in 2050 which is around 2.5 million tons of wood biomass. The gap in 2035 is also over 2 million tons because of the high reduction of electricity generation from coal-fired plants and lack of RES capacity (other than BCHPs). In the period 2035-2045, a smaller amount of electricity should

Table 1. The required annual amount of biomass until 2050.

Year	Installed capacity in BCHP P (GW)	Energy in biomass E (GWh/a)	The required amount of biomass to produce electricity Q_b (1000 t/a)
2025	0.06	1371	411
2030	0.29	6856	2059
2035	0.39	9216	2767
2040	0.30	7100	2132
2045	0.37	8633	2592
2050	0.44	10,166	3053

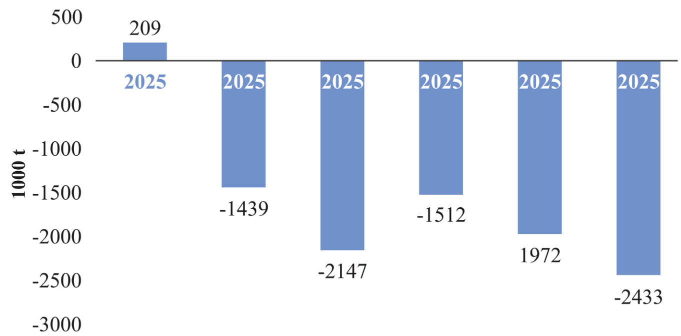

Figure 9. The gap between the technical potential of biomass and the required amount of biomass for power generation in BCHPs (2025-2050).

be compensated from BCHPs because other RES capacities will be increased and will compensate for a bigger part of a reduction in coal-fired plants' electricity production.

It indicates that over the years, according to the analysis of the current situation from the aspect of supply-demand, BiH should work on increasing wood biomass technical potential to achieve a scenario of climate neutrality until 2050. Available wood biomass can be increased by short rotation biomass on degraded land such as an abandoned surface of coal mines.

The development of a regional biomass market would support power generation from BCHPs. Neighboring countries have also high biomass potential. Similar to BiH, the neighboring country, Serbia counts also on the deployment of biomass potential and increase of forest carbon sinks in meeting its GHG emission reduction targets.

5. Conclusion

Based on the data on GHG emissions as well as data on power generation in BiH, solutions which include wood biomass cogeneration plants were investigated for reducing GHG emissions. Significance is given to the development of cogeneration plants as one of the possible solutions based on the fact that it saves primary energy, avoids certain losses in energy transmission, reduces greenhouse gas emissions, provides heat for local needs, and reduces environmental pollution. By combining the production of electricity and heat, cogeneration is an optimal technical and economic solution because it allows the efficient use of biomass for electricity and heat production.

A comparative analysis of the required amount of wood biomass for electricity production and the potential of wood biomass owned by BiH, shows that BiH has a great potential for wood biomass that can be used. Two scenarios are presented, with the aim to reduce GHG emissions in BiH by 2050, using renewable energy sources, i.e. the use of wood biomass in cogeneration plants. In Scenario 2, it has been proven that in the case of the construction of BCHPs instead of a new CFPP, wood biomass consumption in BiH would increase significantly (**Table 1**), so the required amount of wood biomass for 2035 would be 2,767,767 t/a, which would lead to higher demand of the available technical potential of wood biomass, which amounts to around 620,000 t/a. This data is an indication that BiH has sufficient quantities of wood biomass to take initial steps to invest and build BCHPs to achieve the Green Plan, but also that from the aspect of demand, BiH should work on increasing the technical potential of wood biomass to achieve climate neutrality. The trend of development of production capacity of BCHPs would develop at a similar dynamics as the expected growth of consumption, which would allow the scenario to meet high security of electricity supply at similar levels as today and to achieve climate neutrality, which is a basic requirement of the European Union's Green Plan for the Western Balkans, of which BiH is a signatory.

Biomass cogeneration plants would enable a higher rate of integration of renewable energy plants into the power generation system. Therefore, the potential for the use of RES energy in BiH is significant, and overcoming legal, technical, and administrative barriers, and with much greater economic investment for the development and production of electricity from biomass, as well as establishing incentive mechanisms for energy other than electricity, its use can become sustainable and environmentally friendly. A compromise between the technically feasible, economically viable, and environmentally friendly, is the path to the country's development.

The feasibility of BCHPs depends on many factors. In terms of biomass potential, feasibility depends on biomass supply chain logistics and the utilization of available heat from BCHPs. On the other hand, the construction of required BCHPs to compensate for the reduction of electricity generation from coal-fired thermal power plants is a challenge for BiH not only from the RES potential perceptive but more on from social and environmental aspects, taking into account pollutant emissions and loss of jobs in the coal sector. The impact of BCHPs on air quality (emission of air pollutants) requires full-scale analysis which should be the subject of future research. Therefore, integral planning of energy transition is a key factor for the feasibility of analyzed BCHPs.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Amin, N. A. S., & Talebian-Kiakalaieh, A. (2018). Reduction of CO_2 Emission by INCAM Model in Malaysia Biomass Power Plants during the Year 2016. *Waste Management. 73,* 256-264. https://doi.org/10.1016/j.wasman.2017.11.019

ENOVA, & CETEOR (2020). *Strategy for Adjustment and Low Emission Development (Final Draft) of Bosnia and Herzegovina for the Period 2020-2030*.

Husika, A., Zecevic, N., Numic, I., & Dzaferovic, E. (2022). Scenario Analysis of a Coal Reduction Share in the Power Generation in Bosnia and Herzegovina Until 2050. In *10th European Conference on Renewable Energy Systems* (pp. 57-64).

Ministry of Foreign Trade and Economic Relations Bosnia and Herzegovina (MOFTER) (2021). *National Energy and Climate Plan of Bosnia and Herzegovina (BiH) for the Period 2021-2030 (NECP BiH)*.

Numic, I. (2021). *Optimization of Reducing the Use of Coal for Electricity Production by 2050*. Master Thesis, Mechanical Engineering Faculty, University of Sarajevo.

Obernberger, I., Thonhofer, P., & Reisenhofer, E. (2002). Description and Evaluation of the New 1000 kWel Organic Rankine Cycle Process Integrated in the Biomass CHP Plant in Lienz, Austria. *Euroheat & Power, 10,* 18-25.

Pfeiffer, A., Krause, T., Horschig, T., Avdibegović, M., Čustović, H., Ljuša, M. et al. (2020). *Report on the Monitoring of Biomass Potential in Bosnia and Herzegovina*.

Sadrul, A. K. M., & Ahiduzzaman, M. (2012). Biomass Energy for Greenhouse Gas Emission. *AIP Conference Proceedings, 1440,* 23-32.

State Regulatory Commission for Electricity (2014). *Report on the Work of the State Electricity Regulatory Commission (SERC) in 2014*. Bosnia and Herzegovina.

State Regulatory Commission for Electricity (2021). *Report on the Work of the State Electricity Regulatory Commission (SERC) in 2021*. Bosnia and Herzegovina.

Stockholm Environment Institute (n.d.). *The Low Emission Analysis Platform (LEAP).* https://leap.sei.org/help/leap.htm#t=Concepts%2FIntroduction.htm

Thornley, P., Gilbert, P., Shackley, S., & Hammond, J. (2015). Maximizing the Greenhouse Gas Reductions from Biomass: The Role of Life Cycle Assessment. *Biomass and Bioenergy, 81,* 35-43. https://doi.org/10.1016/j.biombioe.2015.05.002

United Nations Development Programme (UNDP) (2014). *Possibilities of Using Biomass from Forestry and Wood Industry in Bosnia and Herzegovina.*

United Nations Development Programme (UNDP) (2020). Nationally Determined Contribution of Bosnia and Herzegovina (NDC) for the Period 2020-2030. 6 p. https://unfccc.int/sites/default/files/NDC/2022-06/NDC%20BiH_November%202020%20FINAL%20DRAFT%2005%20Nov%20ENG%20LR.pdf

United Nations Development Programme (UNDP) (2021). *IV National Communication on Climate Change for Bosnia and Herzegovina*. Draft.

Vlahinic Lenz, N., & Fajdetic, B. (2021). Globalization and GHG Emissions in the EU: Do We Need a New Development Paradigm? *Sustainability, 13,* Article No. 9936. https://doi.org/10.3390/su13179936

Wang, F. et al. (2021). Technologies and Perspectives for Achieving Carbon Neutrality. *The Innovation, 2,* Article ID: 100180. https://doi.org/10.1016/j.xinn.2021.100180