Article

Possible Scenarios for Reduction of Carbon Dioxide Emissions in Serbia by Generating Electricity from Natural Gas

Dardan Klimenta [1,*] **, Marija Mihajlović** [2] **, Ivan Ristić** [3] **and Darius Andriukaitis** [4]

[1] Faculty of Technical Sciences, University of Priština in Kosovska Mitrovica, Kneza Miloša 7, 38220 Kosovska Mitrovica, Serbia
[2] Faculty of Geography, University of Belgrade, Studentski Trg 3, 11000 Belgrade, Serbia; marrija.mihajlovic@gmail.com
[3] Freelance Consultant in the Field of Electric Power Engineering, Generala Štefanika 18, 11041 Belgrade, Serbia; r.ivan75@mts.rs
[4] Department of Electronics Engineering, Kaunas University of Technology, Studentu 50-438, 51368 Kaunas, Lithuania; darius.andriukaitis@ktu.lt
* Correspondence: dardan.klimenta@pr.ac.rs

Abstract: The main purpose of this paper is to develop possible scenarios for reducing carbon dioxide (CO_2) emissions in Serbia by switching from coal-fired to natural gas-fired electricity generation by the end of 2050. Accordingly, the challenges are to establish scenarios and identify measures that are best suited to all Western Balkan countries. In particular, this paper proposes a number of energy mix scenarios that offer some options for reducing CO_2 emissions while maintaining an economic way of consumption. Projections of these reduction scenarios are obtained by combining the Kaya identity with the emission factor method. A simplified methodology based on sensitivity analysis is used as a source of data to estimate the nonstatistical uncertainty limits for the projections of the reduction scenarios. The sensitivity analysis is carried out using historical data from Serbia for the period from 1990 to 2019. In addition, a direct verification of the proposed methodology is performed based on historical data for 2020. The developed scenarios 1 and 2 show that CO_2 emissions could be reduced by 10.94% and up to 74.44% from baseline in 1990, respectively. The obtained results are also contrasted with the data available for some other countries with similar experiences. Finally, it is found that the developed scenarios are achievable only at significantly decreased levels of coal-fired electricity generation.

Keywords: carbon dioxide (CO_2) emissions; coal; electricity generation; natural gas (NG); reduction scenario

1. Introduction

In the period from 1990 to 2018—except in 2009, when there was an outbreak of the influenza A (H1N1) pandemic—global energy-related CO_2 emissions increased year to year [1,2]. According to [1,3], the global energy-related CO_2 emissions in 2018 amounted to 33.5 Gt CO_2 and were shared by economic sectors in the following manner: electricity and heat generation: 43.75%; transportation: 25.93%; industry: 19.33%; buildings: 9.04%; and other sectors: 1.95%. Coal-fired electricity generation and corresponding CO_2 emissions decreased by 3% and 2%, respectively, in 2019, for the first time in history [4]. In addition, global energy-related CO_2 emissions in 2019 were 0.1 Gt CO_2 lower than in 2018 [1]. As primary energy demand dropped by nearly 4% in 2020 due to the COVID-19 pandemic, global energy-related CO_2 emissions decreased by an additional 5.8% and amounted to 31.5 Gt CO_2 [1]. The declines were caused by a sharp decline in CO_2 emissions from the electricity and heat generation sector (the so-called energy sector), thanks to the expanding role of renewables (mainly wind and solar energy), fuel switching from coal (or lignite) to natural gas (NG), very mild winters during the period 2018–2021, and higher nuclear power output [4,5].

Although Serbia is not one of the most developed economies in the world and has no nuclear power plants, an increase in CO_2 emissions from the energy sector in the period following 2018 was recorded in this country [6]. This is contrary to the global trend. According to [7], Serbian energy-related CO_2 emissions in 2018 amounted to 44 Mt CO_2 and were shared by economic sectors as follows: electricity and heat generation: 68.18%; transportation: 13.64%; industry: 9.09%; buildings: 2.27%; and other sectors: 6.82%. Regardless of an increased usage of renewables (such as hydro, wind, biomass, biogas, and solar energy), switching from solid and liquid fossil fuels to NG in the majority of district heating systems, and very mild winters during the given period, the mentioned increase in CO_2 emissions was caused by an increased usage of coal in coal-fired power plants (CPPs). In addition, natural gas-fired power plants (NGPPs) contributed to a further increase in global energy-related CO_2 and other greenhouse gas (GHG) emissions but to a significantly lower extent compared with CPPs. In the particular case of Serbia, since the second string of the TurkStream natural gas pipeline (the so-called Balkan Stream pipeline) became operational in the course of 2020 [8], special attention should be paid to the generation of electricity and heat from NG.

The release of methane (CH_4), which is the second most abundant GHG after CO_2, is of particular importance for the application of natural gas-fired combined heat and power (CHP) technology. Although CH_4 is released into the atmosphere in smaller quantities than CO_2, its ability to trap heat in the atmosphere is about 25 times greater [9]. Consequently, CH_4 leaks are reported to nullify or reverse any climate change benefit experienced from the switch from solid and liquid fossil fuels to NG [10–12]. This does not apply in the case of Serbia because coals from the Kostolac and Kolubara basins have relatively small lower heating values and release enormous quantities of poisonous gases during combustion. This can be generalized to the other Western Balkan countries, namely: Bosnia and Herzegovina, Montenegro, North Macedonia, and Croatia, where some types of coals have a lower heating value higher than the ones used in Serbia. From this perspective, it is also important to note that energy-related GHG emissions are only a portion of the total anthropogenic GHG emissions and that global CO_2 emissions rose as the worldwide economic activity recovered at the end of 2020.

Serbia itself is not at the cutting edge when it comes to global GHG emission reductions; however, according to [13], this country is among the 10% of countries in the world whose CPPs pollute the environment to the highest extent. In addition, environmental campaigners have taken legal action against the state-owned Public Enterprise Electric Power Industry of Serbia (PE EPS) for exposing Serbian and EU citizens to poisonous gases six times above the allowed limit, in breach of both national and international law [14]. Moreover, the EU is preparing a new tax for countries such as Serbia, where energy-related CO_2 emissions are higher than allowed [15]. Accordingly, in the case of Serbia, as in most regions worldwide, there is already a significant international interest in the switch from coal-fired to natural gas-fired electricity generation, including renewables.

The top 10% of countries in the world with the most polluting CPPs are China, India, the United States, South Africa, South Korea, Germany, Ukraine, Poland, the United Kingdom, Kazakhstan, Russia, Japan, Serbia, Australia, Mexico, Israel, Romania, and Taiwan [13]. According to this list, Serbia takes 13th place, but with its CPPs of 4448 MW, it should actually be in 12th place. In Serbia and the majority of these countries, electricity generation by CPPs is also inefficient. For instance, the authors of [16] identify sources of polluting and inefficient electricity generation by CPPs in China. Large-scale measures taken to overcome one or both of these two issues in China are as follows: (i) switching from CPPs to natural gas-fired CHP plants [17,18]; (ii) replacing CPPs with photovoltaic (PV) power plants [19,20]; (iii) the use of wind power plants instead of CPPs [21,22]; (iv) implementing projects of flue gas-fired combined cooling, heating, and power (CCHP) plants [23,24]; and (v) the use of geothermal energy for district heating instead of coal-fired heating [25,26], etc.

In the case of Serbia, switching to NG currently represents the most suitable measure in the light of the reduction of local and regional GHG emissions. In addition, there are a number of publications on related topics, providing the readership with useful details about GHG emissions in Serbia in general [27,28], CO_2 emissions from various types of coals used in Serbian CPPs [29,30], climate change policies and plans relating to the Southeast European countries [31,32], renewable energy development trends in Serbia and the other Western Balkan countries [33,34], and so on. Moreover, some papers deal with CPPs and/or NGPPs in other countries and regions of the world, namely: India [35], Germany [36], Turkey [37], Algeria [38], Asia-Pacific [12], Southeast Asia [39,40], South Korea [41], Egypt [42], etc. Accordingly, there is no paper reviewing the potential effects of the Balkan Stream pipeline on CO_2 emissions in Serbia, reviewing planned NGPPs in Serbia, or dealing with possible scenarios and necessary measures for reducing CO_2 emissions in Serbia by the end of 2050 (by means of natural gas-fired electricity generation).

In this paper, reliable projections are made of CO_2 emissions reduction scenarios for the Serbian energy sector up to 2050, and a number of associated measures are then identified, answering the questions of how the transition from CPPs to NGPPs can reduce CO_2 emissions, to what extent, and with which consequences. The projections are made based on the relevant data, actual state, and current plans, and the assumption that possible development trends of renewables in Serbia will follow the current predictions about the rising proportion of electricity generation from renewable energy sources (RESs) in the EU's gross electricity demand up to 2050. In particular, the projections are made using the Kaya identity [43–48] and emission factor method [49,50], and by varying the levels of electricity generation from coal, NG, and RES and priorities related to the measure implementation, taking into account the political environment, status of legislation, actual state of the economy, energy sector responsiveness to new development trends, etc.

Specifically, the Kaya identity [43–48] is usually used for quantifying global CO_2 emissions from anthropogenic sources (in Mt of CO_2 per year) and is expressed as the product of the global population (in billions of persons), global gross domestic product (GDP) per capita (in current USD per year), energy intensity of global GDP (in TWh or TJ per billions of current USD), and CO_2 intensity of the energy supply (in Mt of CO_2 per TWh or TJ). The emission factor method [49,50] estimates direct GHG emissions from stationary combustion processes in line with the principles of the GHG protocol. In addition to the mentioned methods, there are many other methods that can be used to estimate global GHG emissions, such as the so-called IPAT model [47], Logarithmic Mean Divisia Index (LMDI) decomposition method [51], LMDI decomposition method based on energy allocation analysis [51], method of marginal emission factors [52], etc. Furthermore, a number of other methods that can be used for the same purpose are already outlined in [53]. In order to estimate the uncertainty limits for the projections, sensitivity analysis is performed using historical data from the Serbian energy sector for the period 1990–2019. The emission projections for 2020 are directly compared with the corresponding actual data. The results include all electricity generation capacities in Serbia, except the ones located in Kosovo.

2. Necessary Data and Methodology

Along with a number of data, the Kaya identity [43–48], necessary assumptions, and emission factor method [49,50] are used for the development of different projections of the annual CO_2 emissions from the Serbian electricity generation sector. In addition, the Kaya identity factors are used as a basis for the introduction of all assumptions necessary for the purpose of applying the emission factor method. Afterwards, based on those projections, measures for the reduction of CO_2 emissions up to the end of 2050 are defined.

2.1. The Kaya Identity and Historical Data

In the context of the effects of the electric power system and socioeconomic parameters on CO_2 emissions, the original Kaya identity is adapted and expressed as follows [43–48]:

$$E_{a,t} = P \cdot \frac{G}{P} \cdot \frac{C_{el}}{G} \cdot \frac{E_{a,t}}{C_{el}} \tag{1}$$

where $E_{a,t}$ represents the annual CO_2 emissions from the Serbian electricity generation sector in Mt CO_2/y, P is the total population of Serbia in millions, G is the Serbian GDP in billions of current USD, and C_{el} is the annual gross electricity consumption of Serbia in TWh/y. These four parameters directly define the Kaya identity factors. Figures 1 and 2 show the historical changes in the electric power system and socioeconomic parameters. It should be noted here that the values for $E_{a,t}$ are taken from the annual reports of PE EPS or estimated based on the values of the specific energy consumption from the annual reports and other documentation of PE EPS. In addition, G/P is the Serbian GDP per capita in thousands of current USD per year, C_{el}/G is the electricity intensity of Serbian GDP in TWh per billion of current USD, and $E_{a,t}/C_{el}$ is the CO_2 intensity of the electricity supply in Mt CO_2/TWh. These three ratios together with the population P represent the Kaya identity factors. Figure 3 shows the historical changes in the Kaya identity factors.
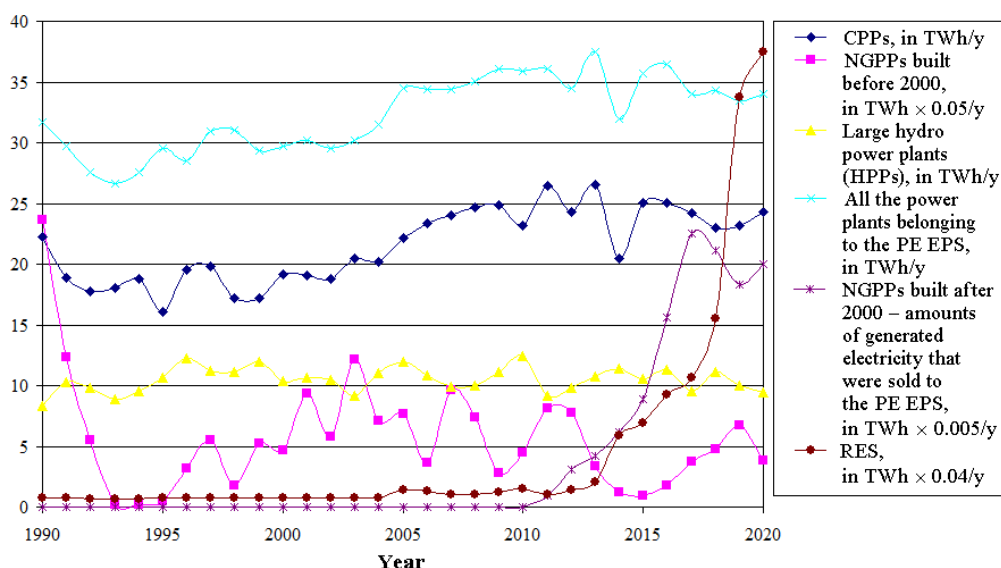

Figure 1. Annual electricity generation in Serbia from various power plants [54–57].

As usual, in papers of this kind, projections of CO_2 emission reduction scenarios are considered as emission inventories for a future period of time in which historical data are replaced by a number of logical expectations and assumptions [49,50]. According to the historical data from Figures 1–3, all the parameters and factors have been affected by the national, regional, and global crises, such as the disintegration of the former Socialist Federal Republic of Yugoslavia (in 1991); the civil wars in Croatia (1991–1995) and Bosnia and Herzegovina (1992–1995) and the associated large waves of refugees; the economic sanctions imposed on the Federal Republic of Yugoslavia by the UN Security Council (between May 1992 and November 1995 and between October 1996 and October 2000); the NATO bombing campaign against the Federal Republic of Yugoslavia (March-June 1999); the Great Recession of 2008, referring to the economic downturn between 2008 and 2013, which coincided with the outbreak of the influenza A (H1N1) pandemic in 2009; and the global recession caused by the COVID-19 pandemic in 2019, 2020, and 2021. On the other hand, compared to EU countries that had already started activities to improve the operation of their power plants based on the relevant EU directives in the early 1990s, Serbia started the same activities after 2000. Thus, for example, due to the consequences

caused by the COVID-19 pandemic, the completion and commissioning of NGPP Pančevo were postponed for more than one year compared to the original plans. This finally resulted in a substantial prolongation of the implementation period of the NGPP Pančevo project by approximately two years. In particular, it took four instead of the planned two years.
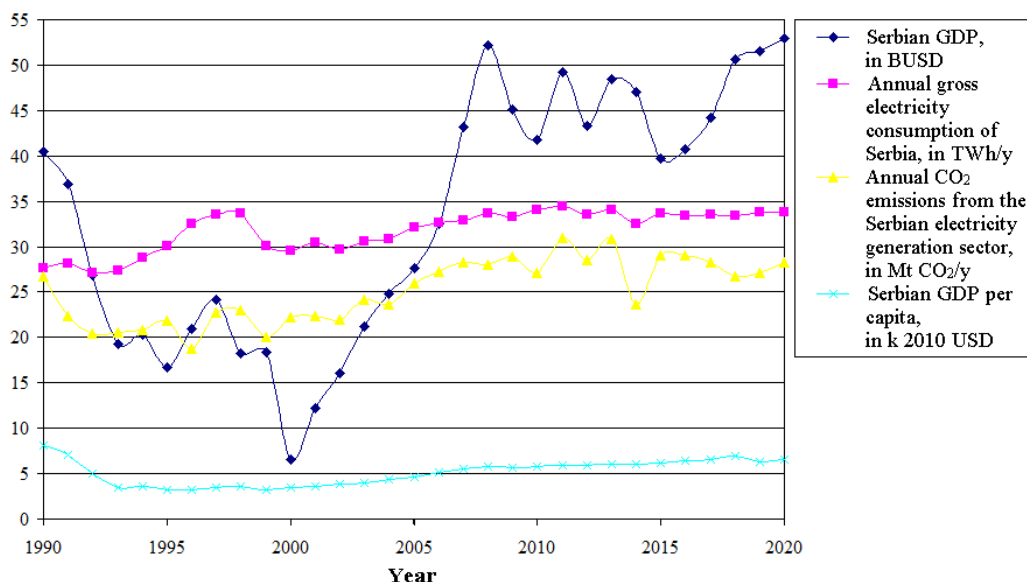

Figure 2. Changes in the parameters relevant for determining the Kaya identity factors [6,55,57–64].
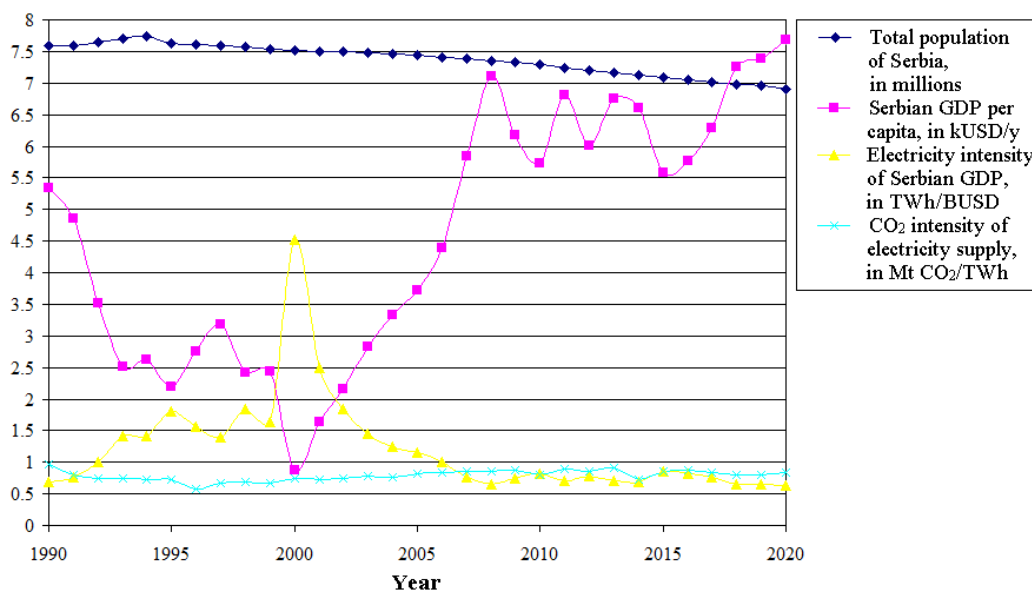
Figure 3. Changes in the Kaya identity factors.

In addition, the total population of Serbia increased between 1990 and 1994 due to a high level of immigration while it decreased continuously since 1994 [65,66]. The GDP per capita in constant 2010 USD grew in Serbia from 1999 to 2020 but with some minor deviations: it significantly declined in 2019, and has not yet reached the level of 1990. Moreover, the Serbian gross electricity consumption grew from 1990 to 1998, had a decline of about 10% in 1999, also grew from 2000 to 2006, and has been approximately constant (at an average level of 33.481 TWh/y) since 2006. For the Serbian GDP in current USD (from Figure 2), Serbian GDP per capita (from Figure 3), and electricity intensity of Serbian GDP (from Figure 3), 2000 can be regarded as a ground-breaking year. This ground-breaking year

coincides with the fact that the European integration process of Serbia started practically after the suspension of economic sanctions in 2000; that is, with the beginning of political and economic reforms in Serbia. During the whole period under consideration, there were several phases during which the annual CO_2 emissions were increasing, and several phases during which they were decreasing. CO_2 emissions were, between 1991 and 2005, below those of 1990, and since 2006, excluding 2014, they were above that level. Moreover, CO_2 emissions showed a declining trend from 2011 to 2019 (Figure 2). This trend has coincided with a clear rising trend in the electricity generation from RESs (Figure 1), which is in accordance with the national strategy [67]. However, this reduction was 12.65%, and CO_2 emissions did not reach the 1990 level, which certainly requires much more serious action in the direction of raising the share of RESs in the total generation of electricity. Table 1 shows how the amounts of renewable energy used for the generation of electricity and heat in Serbia relate to the national RES potential.

Table 1. Structure of the exploitable RES potential in Serbia [68,69].

Renewable Energy Source	Exploitable RES Potential [68,69]		Amounts Used for Electricity Generation in 2020		Amounts Usually Used for Electricity and Heat Generation	
	GWh/y	%	GWh/y	%	GWh/y	%
Biomass (including biogas)	38,379	53	189.905	0.26	11,630	16.06
Hydro	19,526.77	26.96	9701.386	13.4	10,571.67	14.6
Solar	6978	9.64	13.262	0.02	13.262	0.02
Wind	2326	3.21	966.579	1.33	966.579	1.33
Geothermal	2326	3.21	0	0	0	0
Biodegradable waste	2884.24	3.98	0	0	0	0
Total	72,420.01	100	10,871.132	15.01	23,181.51	32.01

Furthermore, the changes in the electric power system and socioeconomic parameters, and the effects of the crises were directly reflected in the changes in the Kaya identity factors from Figure 3. The most important details that can be seen from this figure are that there are some trends in the changes in these factors since 2007, and that these trends can be further used to specify key assumptions and develop possible scenarios for reducing CO_2 emissions in Serbia by 2050. In addition to this, multiplying the four factors from Figure 3 by each other produces the resultant curve (1) that is identical to curve representing the annual CO_2 emissions from the Serbian electricity generation sector in Figure 2.

According to the historical changes in the Kaya identity factors in Figure 3, the following conclusions can be drawn: (i) Compared to 6.964 million in 2019, the total population of Serbia will decrease by an average of 0.54% annually during the period up to the end of 2050 and it will probably be about 5.8 million at this time. (ii) Compared to 6338.4 USD in 2019, the Serbian GDP per capita (in constant 2010 USD) will grow by an average of 1.93% annually by the end of 2030; in 2030, it will reach that of 1990 and it will continue to grow by 2% annually up to the end of 2050. (iii) By the end of 2050, the electricity intensity of Serbian GDP and CO_2 intensity of the electricity supply will decrease or remain at the levels of the associated averages for the period 2007–2019.

2.2. Data on Existing and Planned CPPs and NGPPs

In order to develop possible scenarios for reducing CO_2 emissions from the Serbian electricity generation sector by generating electricity from NG, it is necessary to have insight into the current and future state of CPPs and NGPPs. In particular, it is necessary to determine the average and potential values of performance indicators, annual CO_2 emissions, and annual CO_2 emission intensities for all the existing and planned CPPs and NGPPs, using the calculation method proposed in Appendix A [6,49,57,70–72].

For each CPP built before 2000, the average values of annual electricity generation (Q_{el}) and hourly lignite consumption (m_L) are determined based on five records (actual values) of Q_{el} and m_L for the years (t) from 2015 to 2019, respectively. In addition to this,

the average values of hourly mazut consumption (m_M), hourly naphtha consumption (m_N), and annual number of operation hours (t_{op}) are determined based on the five estimates of m_M, m_N, and t_{op} for the years (t) from 2015 to 2019, respectively. Then, the average values of Q_{el}, m_L, m_M, m_N, and t_{op} are used for the determination of the average values of the electrical efficiency (η_{el}), annual CO_2 emissions ($E_{a,t}$), and annual CO_2 emission intensity (IE_a). The same approach is also applied to each NGPP built before 2000, of course, bearing in mind that there is no NGPP that uses secondary fuels together with NG. For any NGPP built after 2000, a value of 7500 h/y is assumed for t_{op} while all other average performance indicators are taken directly from the manufacturers and from [73].

Table A1 lists the actual performance indicators, estimated annual CO_2 emissions, and estimated annual CO_2 emission intensities for Serbian CPPs and NGPPs built before 2000, for the period from 2015 to 2020. The average values of the performance indicators, annual CO_2 emissions, and annual CO_2 emission intensities for the existing Serbian CPPs and NGPPs are outlined in Tables A2 and A3, respectively. Table A2 is entirely based on Table A1 while Table A3 is partly formed on the basis of Table A1. Tables A1–A3 can be found in Appendix B [6,30,73–75].

The development of possible scenarios also requires overviews of CPPs and NGPPs, which should be constructed in Serbia during the next few decades. There are many different scenarios dealing with the estimation of the total demand for new CPPs, CPPs that need to be modernized, and CPPs that will be shut down during the period 2018–2024. All the scenarios are based on the EU directives 2001/80/EC [76] and 2010/75/EU [77], and the Energy Sector Development Strategy of the Republic of Serbia for the Period by 2025 with Projections by 2030 [67], which relies predominantly on the electricity generation in CPPs. Accordingly, this paper will not focus on these scenarios, but it will be based on the mentioned EU directives and strategy. In the case of planned CPPs and NGPPs, the calculation method from Appendix A is used again to determine the potential values of their performance indicators, annual CO_2 emissions, and annual CO_2 emission intensity. Specifically, the potential value of Q_{el} for each planned CPP is determined using the actual lower heating values for lignite (LHV_L) and mazut (LHV_M), together with the assumed values for m_L, m_M, t_{op}, and η_{el}; that is, Equations (A6) and (A10). Similarly, in the case of each planned NGPP, the potential value for Q_{el} is determined using the actual lower heating value for NG (LHV_{NG}), and the assumed values for hourly NG consumption (m_{NG}), t_{op}, and η_{el}. The potential values of the performance indicators, annual CO_2 emissions, and annual CO_2 emission intensities for planned CPPs and NGPPs are outlined in Tables 2 and 3, respectively.

2.3. Necessary Assumptions

The three conclusions derived from the historical changes in the Kaya identity factors and data presented in Tables 2, 3, A2 and A3, are further used as a basis for assumptions necessary for the development of possible scenarios for reducing CO_2 emissions. The mentioned assumptions are:

- Serbia will continue to base its electricity supply independence on electricity generation from lignite (in CPPs)—Scenario 1; or Serbia will redefine its electricity supply independence policy and base it on electricity generation in HPPs and RESs (i.e., Serbia will continue with the implementation of the so-called EU's "20-20-20" targets)—Scenario 2.

Table 2. An overview of the potential values of the performance indicators, annual CO_2 emissions, and annual CO_2 emission intensity for the planned CPPs in Serbia [78].

No.	CPP *	Planned Electricity Generation Units and Their Powers	Potential Electrical Efficiency **	Potential Fuel Consumption			Potential Annual Number of Operation Hours ****	Potential Annual CO_2 Emissions	Potential Annual CO_2 Emission Intensity
				Basic		Secondary			
				Lignite		Mazut ***			
				LHV_L	m_L	m_M			
		MW	%	GJ/t	t/h	t/h	h/y	Mt CO_2/y	g CO_2/kWh
1	Kolubara B	1 × 354.2 or 2 × 375	40	6.28	399 or 844	0.399 or 0.844	7340	1.867 or 3.949	907.6 or 907.6
2	Kostolac B3	1 ×350	40	7.8	317	0.317	7340	1.84	907.9
3	Nikola Tesla B3	1 × 750	40	6.7	791	0.791	7340	3.947	907.7
4	Novi Kovin	2 × 350	40	7.8	634	0.634	7340	3.681	907.9
5	Štavalj	1 × 300	40	18.148	117	0 or 0.117	7340	1.5	864.5
	Sum	2454.2 or 2850	-	-	2258 or 2703	2.258 or 2.703	-	12.835 or 14.917	-

* According to [78], the planned construction period for each planned CPP is between four and six years. In addition to this, the CPP Kolubara B and CPP Nikola Tesla B3 should use lignite from the Kolubara basin, the CPP Kostolac B3 and CPP Novi Kovin should use lignite from the Kostolac basin, and the CPP Štavalj should use coal from the Štavalj coal mine. All CPPs listed in this table should belong to the PE EPS. ** For each planned CPP, it is assumed that the electrical efficiency should be equal to 40%. *** It is assumed that the mazut consumption per hour is 0.1% of the lignite or coal consumption per hour. **** For each planned CPP, it is assumed that the annual number of operation hours for any future year should be equal to the one estimated in [71].

Table 3. An overview of the potential values of the performance indicators, annual CO_2 emissions, and annual CO_2 emission intensity for the planned NGPPs in Serbia [78,79].

No.	NGPP * and Planned Year of Commencement of Operation	Planned Electricity Generation Capacity	Potential Electrical Efficiency	Potential Amount of Thermal Energy	Potential Fuel Consumption	Potential Annual Number of Operation Hours	Potential Annual CO_2 Emissions	Potential Annual CO_2 Emission Intensity
					NG			
					m_{NG}			
		MW	%	MW$_{th}$	Sm^3/h	h/y	Mt CO_2/y	g CO_2/kWh
1	Pančevo, 2021	3 × 64 = 192	43.11 **	141	43,000	7500	0.619	468.5
2	Jug (in the City of Novi Sad), 2020	4	44	4	~1020	7500	0.015	459
3	Voždovac (heating plant in the City of Belgrade), 2021	3 × 3.328 = 9.984	44	10.035	2541.3	7500	0.037	459
4, 5, 6 and 7	Kragujevac, Novi Sad, Belgrade, Niš, etc., 2031	1000	43.11 **	>700	~224,000	7500	3.223	468.5
	Sum	1205.984	-	>855.035	~270,561.3	-	3.894	-

* NGPP 1 belongs to the petroleum industry of Serbia (NIS), NGPP 2 belongs to the Public Utility Company Novosadska Toplana Novi Sad (PUC Novosadska Toplana Novi Sad), NGPP 3 belongs to the PUC Beogradske Elektrane, and NGPPs 4–7 should belong to NIS. ** For combined hot water and steam generation [79].

- Electricity supply independence under Scenario 1 implies that a significant portion of the average annual gross electricity consumption of Serbia by the end of 2050 should be covered by CPPs.
- Newly built CPPs will be used only as a replacement for the old ones, and electricity generation from lignite, by the end of 2050, will not exceed the level of the average generation for the period 2015–2019.
- Serbia will continue with construction activities and investments in the area of RESs, and various development sub-scenarios in this area will also be possible.
- The construction of larger NGPPs will slow down or stop the construction of small NGPPs, and the generation of electricity in NGPPs built after 2000 will be constant up to the end of 2050.

- NGPPs Pančevo, Jug, and Voždovac have been completed in the period 2020–2021 and have started generating electricity at the beginning of 2022 while the construction of each of the four remaining NGPPs from Table 3 will take three years. They will be built in phases according to the one-by-one principle and will start generating electricity in 2025, 2028, 2031, and 2034.
- NGPP Novi Sad, built before 2000, will stop generating electricity at the end of 2026, i.e., when the new NGPP Novi Sad is built.
- Differences that may occur between the generated and consumed electricity amounts under Scenarios 1 and 2 will be exported.

2.4. Emission Factor Method

For the purpose of the application of the emission factor method, the annual CO_2 emissions from the Serbian electricity generation sector are expressed as a function of time in the following manner [49,50]:

$$E_{a,t} = \sum_{s=1}^{5} E_{a,s}(t) = \sum_{s=1}^{5} q_{S,s}(t) \cdot Q_{el,s}(t) \cdot F'_{E,s}(t) \tag{2}$$

where $q_{S,s}(t)$ is the specific energy consumption (in GJ/GWh) for the sub-sector s in the year t, $Q_{el,s}(t)$ is the electricity generation (in GWh/y) for sub-sector s in the year t, and $F'_{E,s}(t)$ is the aggregated CO_2 emission factor (in t CO_2/GJ) for the sub-sector s in the year t.

The values of the specific energy consumption used for the existing CPPs (sub-sector $s = 1$), NGPPs built before 2000 (sub-sector $s = 2$), NGPPs built after 2000 (sub-sector $s = 3$), planned CPPs (sub-sector $s = 4$), and planned NGPPs (sub-sector $s = 5$) are 10,729.6, 14,004.1, 8541.4, 10,729.6, and 8348.5 GJ/GWh, respectively. Hence, it is assumed that the Serbian electricity generation sector consists of three sub-sectors in terms of historical CO_2 emissions or five sub-sectors in terms of future CO_2 emissions. The values used for $Q_{el,s}(t)$ are presented in Figure 1.

Since details on the fuels and processes are available for the three/five sub-sectors, the aggregated CO_2 emission factor for the sub-sector s in the year t is estimated from the weighted CO_2 emission factors for the associated fuel types as [50]:

$$F'_{E,s}(t) = \sum_{k} p_{s,k}(t) \cdot F_{E,s,k}(t) \tag{3}$$

where $p_{s,k}(t)$ is the share of a given fuel type within a given sub-sector (1, 2, 3, 4, or 5), $F_{E,s,k}(t)$ is the default CO_2 emission factor for a given fuel type (in t CO_2/GJ), and k is the type of fuel ($k = L$ stands for lignite or coal, $k = M$ for mazut, $k = N$ for naphtha, and $k = NG$ for natural gas). According to Tables A1 and A2, for existing CPPs during the 2015–2019 period, the average shares of lignite, mazut, and naphtha were $p_{1,L}(t) = 0.9933$, $p_{1,M}(t) = 0.006$, and $p_{1,N}(t) = 0.0007$, respectively. The same is applied to sub-sector $s = 4$ (that is, to planned CPPs from Table 2). For sub-sector 2, it is assumed that older NGPPs, in accordance with Tables A1 and A3, have used only NG as fuel. This assumption is justified by the fact that in the last decade, older NGPPs have used only NG to generate electricity [6,55,57]. Previously, these NGPPs mainly used liquid fuels such as mazut, naphtha, or gasoline. For instance, until 2003, CHP Novi Beograd generated heat and electricity only from gasoline while today, it generates only heat from NG and mazut. This power plant had three units, where each of them consisted of a 32 MW turbine and a 40 MVA turbo generator. The amounts of electricity generated by CHP Novi Beograd during the 1990–2003 period are included in the corresponding annual electricity generations represented by pink curve with square markers and turquoise curve with x markers in Figure 1. In addition, newer NGPPs belonging to sub-sector 3 actually use only NG (Table A3). Accordingly, the shares relating to the fuel type used in existing NGPPs are $p_{2,NG}(t) = 1$ for $s = 2$ and $p_{3,NG}(t) = 1$ for $s = 3$. The same is applied to sub-sector $s = 5$ (that is, to planned NGPPs from Table 3). All the default CO_2 emission factors are based on the 2006 IPCC Guidelines [49]. Therefore, the

associated aggregated CO_2 emission factors are $F'_{E,1}(t) = 0.100839$ t CO_2/GJ, $F'_{E,2}(t) = 0.0561$ t CO_2/GJ, $F'_{E,3}(t) = 0.0561$ t CO_2/GJ, $F'_{E,4}(t) = 0.100839$ t CO_2/GJ, and $F'_{E,5}(t) = 0.0561$ t CO_2/GJ.

2.5. Historical CO_2 Emissions in Serbia

Insight into the applicability of the emission factor method can best be gained by using it for the determination of historical CO_2 emissions that are known or can be estimated from other available and relevant data. Figure 4 shows a comparison between the available (official) and estimated values of historical CO_2 emissions for the Serbian electricity generation sector in the period 1990–2020. For the period 2008–2020, according to this comparison, differences between, on one side, the official values and, on the other, the values estimated based on the country-specific and default CO_2 emission factors are from −3.25 up to +1.56% and from +3.35 up to +7.94%, respectively. In addition, differences between the two curves representing the estimated values in Figure 4 amount to 6.06–6.85% for the entire period. The main reason for such differences in the period 1990–2020 is the use of country-specific CO_2 emission factors to estimate CO_2 emissions that are missing. Moreover, reports on the state of the environment in the PE EPS have been published regularly since 2002, and only official CO_2 emissions for 2008 and the period 2010–2020 were available when writing this paper. Therefore, it is evident that the official data are underestimated by less than 10%, which represents a good starting point for estimating CO_2 emissions by 2050, of course, if reliable assumptions can be made. Furthermore, it is interesting to note here that the share of power plants firing liquid fossil fuels and NG in the total CO_2 emissions was the highest in 1990 and amounted to 3.72%.
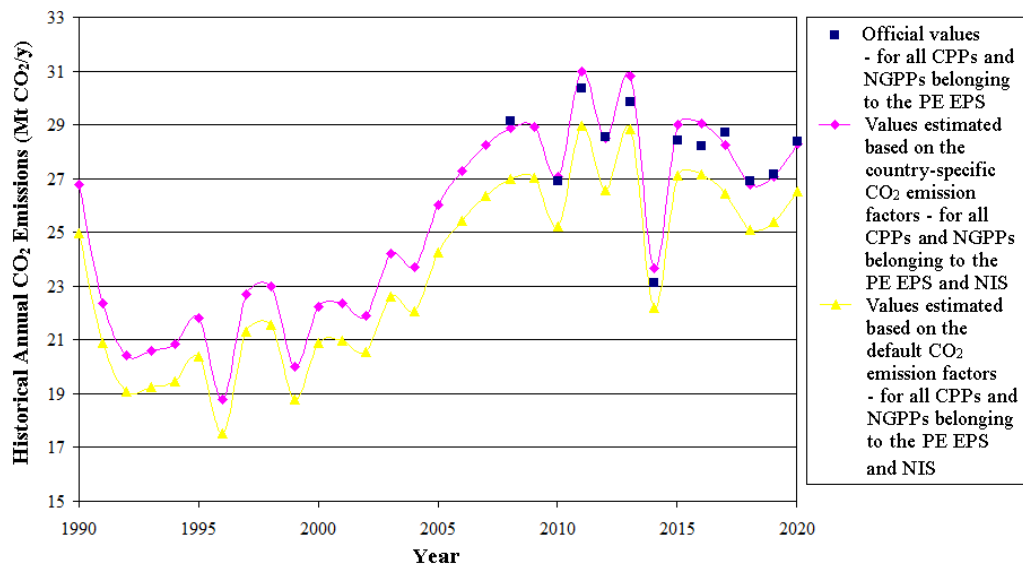
Figure 4. Historical annual CO_2 emissions from Serbian CPPs and NGPPs [6,55,57].

2.6. Sensitivity Analysis

Sensitivity analysis and determination of the uncertainty limits within which CO_2 emissions can be expected by the end of 2050 are performed on the basis of known data on historical annual CO_2 emissions $E_{a,t}(t)$ and electricity generation $Q_{el,s}(t)$ in CPPs and NGPPs for the period 1990–2019. In particular, values are determined of the coefficients linking CO_2 emissions to electricity generation in CPPs and NGPPs for each year within the period 1990–2019. Each of these coefficients is calculated as a product of the corresponding values for the specific energy consumption $q_{S,s}(t)$ and the aggregated CO_2 emission factor $F'_{E,s}(t)$ from Equation (2). In addition, these coefficients differ according to the power plant types.

Historical annual CO_2 emissions $E_{a,t}(t)$ and the expected values of $q_{S,s}(t)$ and $F\prime_{E,s}(t)$ for the existing CPPs ($s = 1$), NGPPs built before 2000 ($s = 2$), and NGPPs built after 2000 ($s = 3$) are used for the calculation of CO_2 emissions from the sub-sectors $s = 1, 2,$ and 3 for each year t within the period 1990–2019, using the following three expressions:

$$E_{a,s}(t) \ = \ E_{a,t}(t) \cdot \frac{q_{S,s} \cdot Q_{el,s}(t) \cdot F\prime_{E,s}}{\sum\limits_{s=1}^{3} q_{S,s} \cdot Q_{el,s}(t) \cdot F\prime_{E,s}}, \ s \ = \ 1, 2 \text{ and } 3, \tag{4}$$

where $q_{S,1}$ = 10,729.6 GJ/GWh, $q_{S,2}$ = 14,004.1 GJ/GWh, and $q_{S,3}$ = 8541.4 GJ/GWh are the specific energy consumptions for the sub-sectors $s = 1, 2,$ and 3, respectively; and $F\prime_{E,1}$ = 0.100839 t CO_2/GJ, $F\prime_{E,2}$ = 0.0561 t CO_2/GJ, and $F\prime_{E,3}$ = 0.0561 t CO_2/GJ are the aggregated CO_2 emission factors for the sub-sectors $s = 1, 2,$ and 3, respectively.

Accordingly, coefficients showing the sensitivity of CO_2 emissions to electricity generation, for each of the three sub-sectors ($s = 1, 2,$ and 3) and for each year t within the period 1990–2019, are obtained as:

$$p_s(t) \ = \ \frac{E_{a,s}(t)}{Q_{el,s}(t)}, \ s \ = \ 1, 2 \text{ and } 3, \tag{5}$$

Then, the mean values:

$$p_{s,av}(t) \ = \ \frac{\sum\limits_{i=1}^{j} p_{s,i}}{j}, \ s \ = \ 1, 2 \text{ and } 3, \tag{6}$$

and the standard deviations:

$$\sigma_{p,s}(t) \ = \ \sqrt{\frac{\sum\limits_{i=1}^{j} [p_{s,i} - p_{s,av}(t)]^2}{j}}, \ s \ = \ 1, 2 \text{ and } 3, \tag{7}$$

for the sensitivity coefficients $p_s(t)$ are determined. In the previous equations for $p_{s,av}(t)$ and $\sigma_{p,s}(t)$, the coefficient j represents the number of historical data used.

Specifically, it is assumed that the number of historical data used equals the number of years for which a forecast is made. Thus, for instance, for 2025, the coefficient j amounts to 2025–2019 = 6, which means that data from the recent past are used first as the most relevant for forecasting in the near future. Annual CO_2 emissions for any sub-sector ($s = 1, 2$ or 3) can be determined as:

$$E_{a,s}(t) \ = \ p_{s,av}(t) \cdot Q_{el,s}(t), \ s \ = \ 1, 2 \text{ and } 3, \tag{8}$$

which is further used to develop the equation for the standard deviation of annual CO_2 emissions:

$$\sigma(E_{a,s}) \ = \ \sigma(p_{s,av} \cdot Q_{el,s}) \ = \ Q_{el,s} \cdot \sigma(p_{s,av}), \tag{9}$$

that is,

$$\sigma_{E,s}(t) \ = \ Q_{el,s}(t) \cdot \sigma_{p,s}(t) \tag{10}$$

which is valid for the year t of forecasting.

The previous equation can also be written in the following form:

$$\sigma_{E,s\%}(t) \ = \ \frac{Q_{el,s}(t) \cdot \sigma_{p,s}(t)}{Q_{el,s}(t) \cdot p_{s,av}(t)} \cdot 100 \ = \ \sigma_{p,s\%}(t) \tag{11}$$

where $\sigma_{E,s\%}(t)$ and $\sigma_{p,s\%}(t)$ are the corresponding percentage standard deviations.

Since annual CO_2 emissions in the future, according to the emission factor method and the associated Equation (2), will come partly from the existing CPPs ($s = 1$), partly from NGPPs built before 2000 ($s = 2$), partly from NGPPs built after 2000 ($s = 3$), partly from planned CPPs ($s = 4$), and partly from planned NGPPs ($s = 5$), then an equivalent standard deviation that takes into account all types of electricity-generating plants must be determined. The equivalent standard deviation is determined based on the calculated values of the percentage standard deviations for the existing CPPs ($s = 1$), NGPPs built before 2000 ($s = 2$) and NGPPs built after 2000 ($s = 3$), and the amounts of electricity generated from the corresponding power plants in the considered scenarios $Q_{el,s}$, where $s = 1, 2$, and 3, i.e.,

$$\sigma_{E,s\%}(t) = \frac{\sum\limits_{s=1}^{3} Q_{el,s} \cdot p_{s,av}(t) \cdot \sigma_{p,s\%}(t)}{\sum\limits_{s=1}^{3} Q_{el,s} \cdot p_{s,av}(t)} \tag{12}$$

In the previous expression, CPPs and NGPPs that were planned to be built after 2019 are included in the first and third terms of the numerator, respectively. Based on this, $E_{a,\max}(t) = E_{a,av}(t) \cdot [1 + 2 \cdot \sigma_{E,s\%}(t)]$ and $E_{a,\min}(t) = E_{a,av}(t) \cdot [1 - 2 \cdot \sigma_{E,s\%}(t)]$ are identified as the upper and lower uncertainty limits for the projection of CO_2 emissions in the year t, respectively; while $\pm 2 \cdot \sigma_{E,s\%}(t)$ is identified as a confidence interval with respect to the corresponding mean value $E_{a,av}(t)$. In connection with this, the mean (expected) value of CO_2 emissions for the year t of forecasting $E_{a,av}(t)$ represents the value of CO_2 emissions on the basis of which the corresponding projections are drawn in Section 4. The confidence interval of $\pm 2 \cdot \sigma_{E,s\%}(t)$ is adopted because this is the interval most commonly used in engineering to ensure that some projections belong to a particular interval with a probability of 95.45%.

3. Effects of the Balkan Stream and Natural Gas Sustainability

3.1. Potential Effects of the Balkan Stream on CO_2 Emissions

In 2019, according to Table A3, the total annual consumption of NG for the needs of electricity generation in 20 Serbian NGPPs was approximately 133.4 million Sm^3/y, whereas 35.8 million Sm^3/y (or 26.82%) of this amount was obtained from Serbian NG fields while the remaining amount (73.18%) was imported from other countries. NGPPs from Table A3 labeled with the numbers 6–19 use NG from domestic sources, and are located in their vicinity and belong to NIS while the remaining six NGPPs use imported NG. According to Table 3, the amount of about 2.0292 billion Sm^3 of NG per year will be required for the planned NGPPs. This amount is almost equal to the capacity of the Balkan Stream pipeline that is projected for Serbia, and which amounts to between 1.8 and 2 billion Sm^3 of NG per year [8,80–82]. Accordingly, it can be concluded that after the construction (i.e., commissioning) of all the NGPPs from Table 3, the entire projected capacity of 1.8–2 billion Sm^3/y will be used for the generation of electricity. However, the maximum amount of NG that could be delivered to Serbia by the Balkan Stream pipeline equals to 4.5 billion Sm^3/y, which means that the difference between this maximum amount and the associated capacity projected for Serbia would be available to other consumers.

Based on Tables A2 and A3, the average annual CO_2 emission intensity for CPPs equals 1080.7 g CO_2/kWh and is about twice as high as in the case of NGPPs. Accordingly, assuming the same annual number of operation hours for both old and new units, the replacement of each old CPP unit by a new NGPP unit of the same capacity would result in a reduction in the annual amount of CO_2 emissions by more than 50%; namely, by 56.05% in the case of units A1 and A2 of the CPP Nikola Tesla A, 63.06% in the case of the CPP Kolubara A, 60.35% in the case of the CPP Morava, and 66.24% in the case of the CPP Kostolac A. In particular, the replacement of all old CPP units (having a total installed capacity of 1126 MW) will decrease the annual amount of CO_2 emissions from $E_{a,t} = 5.946$ Mt CO_2/y to $E_{a,t} = 2.305$ Mt CO_2/y.

The planned NGPPs from Table 3 will be built in the vicinity of Serbian cities with the highest degree of industrialization, high traffic intensity, outdated district heating systems, and the like, and thus with the highest level of air pollution in the period from 2001 to 2019. These were, according to [83–86], the cities of Belgrade, Novi Sad, Niš, Subotica, Kragujevac, Pančevo, Obrenovac, Lazarevac, Valjevo, Kostolac, etc. Moreover, some of these cities are located very close to the existing and planned CPPs (from Tables 2 and A2, respectively) while Belgrade was the most polluted city in the world for a few times during 2019 [87,88]. For instance, the cities of Obrenovac, Lazarevac, Valjevo, and Belgrade are located near the Kolubara basin, that is, the largest existing Serbian CPPs, and so on. Figure 5 shows the layout of existing and planned CPPs and NGPPs with respect to the part of the Balkan Stream pipeline running across Serbia and with respect to two local NG pipeline systems.
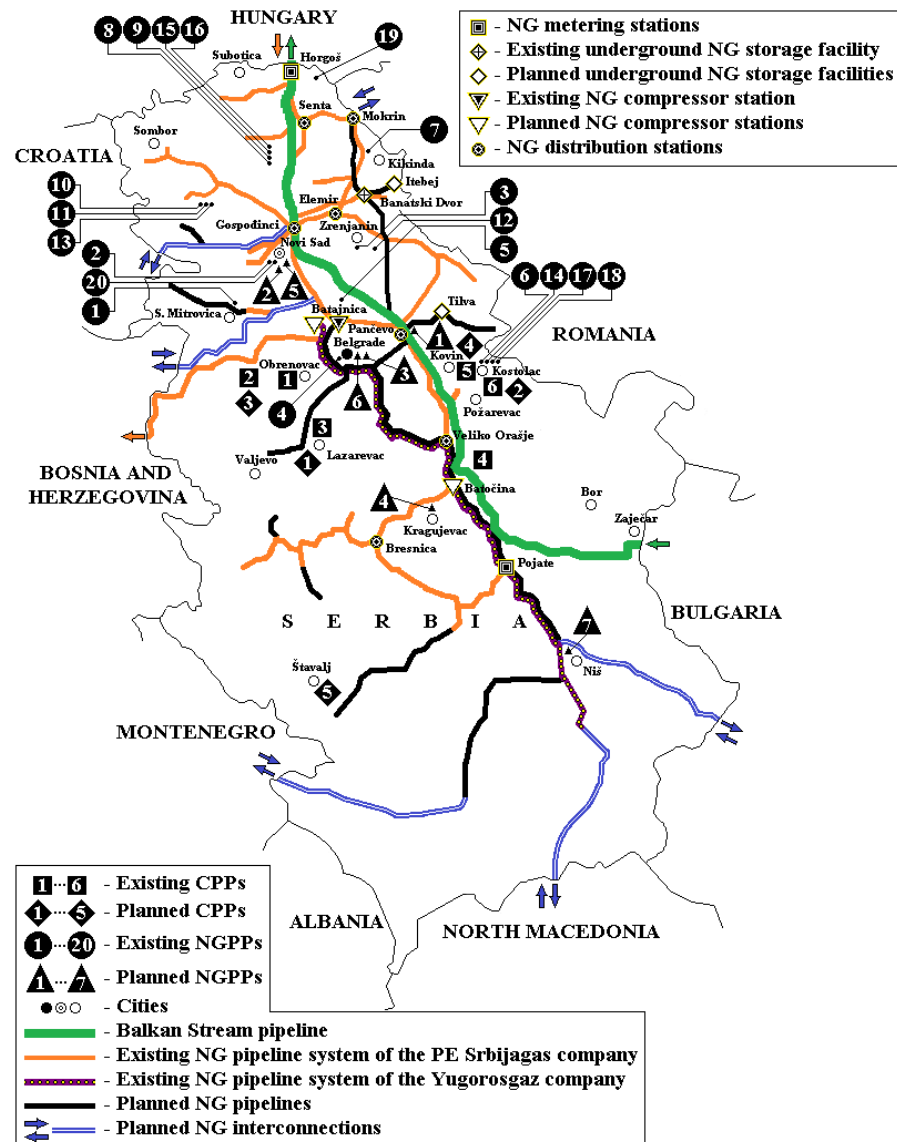

Figure 5. The layout of the existing and planned CPPs and NGPPs with respect to the part of the Balkan Stream pipeline running across Serbia and with respect to local NG pipeline systems.

Therefore, it is obvious that the Balkan Stream pipeline, together with NGPPs that will be supplied by it, will significantly reduce the annual amounts of CO_2 emissions from the Serbian electricity generation sector, and the levels of air pollution in the largest Serbian cities.

According to Figure 5, for all old CPPs, and for most of the planned ones, it can be said that they are or will be built in the Kolubara and Kostolac basins, that is, near the city of Belgrade. As for the existing 20 NGPPs, 15 of them are located north of Belgrade, i.e., in Vojvodina, where domestic NG fields are located and where the NG infrastructure is almost completely developed; while four of them are located in the Kostolac basin (east of Belgrade), and one in Belgrade. Accordingly, it is clear that the Balkan Stream pipeline has intensified planning in order to build new NGPPs in the Belgrade area and in the southern parts of the country; namely: two in Belgrade, where there is a well-developed NG infrastructure, and one each in Kragujevac and Niš, whose local NG distribution networks are not yet developed.

3.2. Natural Gas Sustainability

Serbia is a developing country that produces, stores, and imports NG. The total annual production of NG, which was delivered to the Serbian transmission and distribution system, was 293 million Sm^3 in 2019, which is 12.5% less than the production in 2018 [54]. In 2019, a total of 2.609 billion Sm^3 was available for domestic consumption from: domestic production, underground storage (in Banatski Dvor), and imports, and 2.325 billion Sm^3 of NG was consumed [54]. Most of NG is imported from Russia under a long-term agreement [89]. Imports of NG from Russia under long-term and other agreements amounted to 2.197 billion Sm^3 in 2019, and all required quantities were imported over the Hungarian transmission system [54]. In 2019, 8% less NG was consumed than in 2018. Consumption of NG in residential buildings increased by about 5% while in heating power plants, it decreased by slightly less than 9%, and in industry, it decreased by more than 9% [54]. In particular, the scope of NG in Serbia, in terms of CO_2 emission reduction, mainly lies in the energy (heat generation) and industry sectors. Accordingly, the concept of sustainability with regard to NG is very important for Serbia.

In order to establish whether NG can be used as transition fuel in the achievement of the sustainable energy solutions, together with reducing CO_2 emissions, an STEEP analysis is carried out in accordance with the procedure proposed in [90]. The sustainability parameters/dimensions considered in the STEEP analysis are the following [90]: social (S), technological (T), economic (E), environmental (E), and political (P). These five parameters form the so-called STEEP framework. The STEEP framework has one parameter less than the most commonly used PESTEL framework [90], and that is the legal parameter (L). The STEEP framework is applied to the case of Serbia with the aim of identifying the key drivers and potential barriers for each existing issue. All key drivers and potential barriers identified are outlined in Table 4. The STEEP analysis carried out in [90] covered the following countries: India, Norway, Iran, and the UK, which gives readers the opportunity to contrast the case of Serbia with these countries.

Table 4. STEEP parameters in the case of Serbia.

Sustainability Parameter	Key Drivers	Potential Barriers
Social (S)	• Growing pressure for reducing GHGs from the EU and its own citizens • Largest growth in NG usage comes from energy and industry sectors • Limited availability of hydropower • Population decline since 1994	• Availability of significant lignite and coal resources • Underdeveloped culture for optimized energy management and consumption • Increasing demand for safe and fully clean energy production and distribution
Technological (T)	• Availability of well-known and proven technologies, such as CHP, CCHP, underground NG storage, etc. • Switching from CPPs to NGPPs • Construction of interconnecting NG pipelines between Serbia and its neighboring countries	• Physical distance from exporting countries • Currently underdeveloped infrastructure to distribute NG in many Serbian regions • A continuous decline in domestic NG production since 2013 • Lack of strategic NG interconnections
Economic (E)	• Improvement of energy intensity and energy efficiency indicators • Growth in NG revenues • Creation of good opportunities for local and foreign investors • Domestic NG production important for job creation and economic growth	• Level of investment required for infrastructure development • Lack of regional competitiveness in the NG market • Low electricity prices • Expected introduction of a new EU tax on energy-related CO_2 emissions in Serbia
Environmental (E)	• Reduction of GHG emissions in line with the EU's "20-20-20" targets • Overall reduction of pollution • Switching from coal to NG • The use of NG for heating will decrease in the future due to expected mild winters	• Overreliance on lignite and coal resources leads to environmental issues • Fugitive methane emissions from NG industry operations • Methane emissions from coal mines • Increased use of NG in buildings will increase national GHG emissions
Political (P)	• Compliance with the Paris Agreement and commitment to reduce CO_2 emissions by 9.8% by 2030 compared to those in 1990 • Intergovernmental agreements between Serbia and exporting countries • National strategy for the development of energy sector	• Periodic problems in the construction of the Balkan Stream pipeline • Unstable global geopolitical situation • Sanctions on the Russian energy industry imposed by the USA, the EU, and their allies • Acting in accordance with the EU's geopolitical interests

4. Results and Discussion

Scenario 1 or Scenario 2 can further be divided into a number of possible sub-scenarios. Figure 6 shows the region of possible sub-scenarios within Scenario 1.
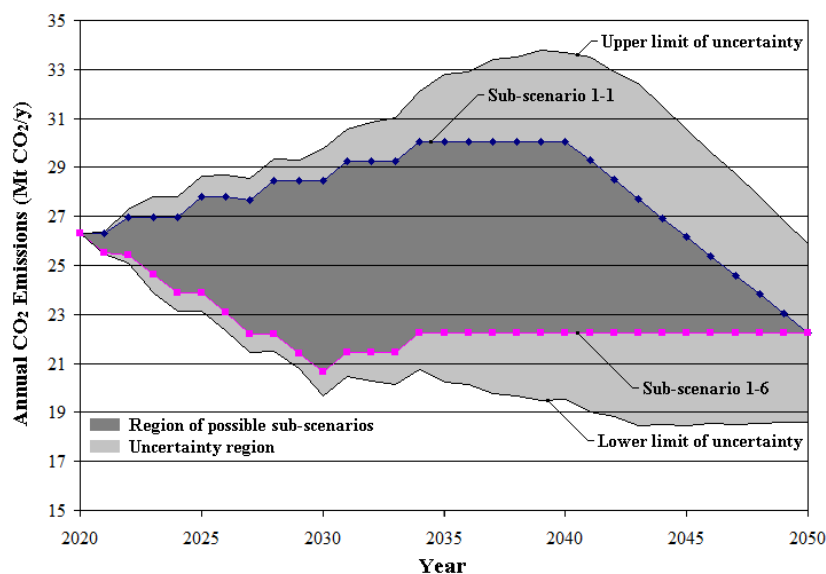
Figure 6. Region of possible sub-scenarios for annual CO_2 emissions from the Serbian electricity generation sector together with the corresponding upper and lower limits of uncertainty for the period 2020–2050, taking into account national targets relating to the independence of the electricity supply, that is, Scenario 1.

Appendix C gives an overview of six of the many possible sub-scenarios within Scenario 1. These sub-scenarios are shown together with their upper and lower limits of uncertainty in Figure A1. According to Figure A1, Sub-scenario 1-1 surrounds the region of possible sub-scenarios from the upper side while the Sub-scenario 1-6 surrounds the region from the lower side. Sub-scenario 1-1 assumes that, by the end of 2040, the generation of electricity from lignite should be at the level of the average generation of electricity from lignite for the period 2015–2019, and then it should start to decrease by 3% annually until it reaches 70% of the given average. According to Sub-scenario 1-6, by the end of 2030, the generation of electricity from lignite should be reduced by 3% annually until it reaches 70% of the average electricity generation from lignite for the period 2015–2019, and then it should remain unchanged until the end of 2050.

Regarding Scenario 1 and Figure 6, the following should be observed: (i) Each of the possible sub-scenarios predicts that CO_2 emissions from the Serbian electricity generation sector should finally be equal to 22.248 Mt CO_2/y, which means that under each of these sub-scenarios, CO_2 emissions could be reduced by 10.94% compared to the corresponding estimated value of 1990. (ii) Sub-scenarios similar to Sub-scenario 1-1 would at first have rising trends and then declining trends while sub-scenarios similar to Sub-scenario 1-6 would have non-rising trends during the entire period under consideration. (iii) The wavy parts of these sub-scenarios illustrate the potential effects of the phased construction and commissioning of the planned NGPPs on CO_2 emissions from the Serbian electricity generation sector by 2034. (iv) According to these sub-scenarios, there is a possibility that annual CO_2 emissions from the Serbian electricity generation sector should significantly exceed that of 1990, specifically reaching 30.063 Mt CO_2/y. (v) If Serbia, for some reason, gives up or alters its position on the accession to the EU, then it can be said with some confidence that the actual scenario of reducing CO_2 emissions from the Serbian electricity generation sector by 2050 could be between Sub-scenarios 1-1 and 1-6.

In addition, six of all possible sub-scenarios within Scenario 2 are overviewed in Appendix C and shown in Figure A2. At the same time, Figure A2 shows the corresponding upper and lower uncertainty limits. According to Figure A2, Sub-scenarios 2-1 and 2-5 surround the region of possible sub-scenarios from the upper and lower sides, respectively. Sub-scenario 2-1 assumes that, in 2020, the generation of electricity from lignite should be at the level of the average generation of electricity from lignite for the period 2015–2019,

and then it should be decreased annually by the amount of electricity generated in planned NGPPs. In accordance with Sub-scenario 2-5, the annual gross electricity consumption should be reduced by 20% by 2050, the generation of electricity from lignite should be reduced annually by the amounts of electricity generated in planned NGPPs and RESs, and by the amount of the decline in the annual gross electricity consumption, and everything else should be the same as in Sub-scenarios 2-3 and 2-4 (which are defined in Appendix C). The region of possible sub-scenarios within Scenario 2 is presented in Figure 7.

Regarding Scenario 2 and Figure 7, the following should be noted: (i) Each of the possible sub-scenarios shows that annual CO_2 emissions from the Serbian electricity generation sector can finally be significantly lower than that of 1990. (ii) Each of these sub-scenarios is in line with the EU's "20-20-20" targets. (iii) It seems that zero CO_2 emissions from the Serbian electricity generation sector cannot be reached at the end of 2050. (iv) Sub-scenario 2-5 appears to be the best possible scenario for the Serbian electricity generation sector. (v) If Serbia decides to achieve the EU's "20-20-20" targets and accelerate the EU accession process, then it is evident that the actual scenario of reducing CO_2 emissions from the Serbian electricity generation sector by 2050 could be one of the sub-scenarios from Figure 7.

In connection with these projections, the application of the proposed methodology also resulted in an underestimation of CO_2 emissions for 2020. This can best be seen from the comparison between, on one side, the yellow curve with triangle markers or official CO_2 emissions from Figure 4 and, on the other, the results presented in Figure 6 or Figure 7. CO_2 emissions in 2020 amounted to 26.525 Mt CO_2/y in accordance with yellow curve with triangle markers from Figure 4, and 28.381 Mt CO_2/y in accordance with the official data. Based on Figures 6 and 7, CO_2 emissions in 2020, according to Sub-scenario 1-1 or Sub-scenario 2-1, amounted to 26.311 Mt CO_2/y. This value is lower by 0.81% and 7.29% if compared to the CO_2 emissions of 26.525 and 28.381 Mt CO_2/y, respectively. From the point of view of engineering, these differences are reasonable for the proposed estimation procedure. Therefore, it is obvious that CO_2 emissions from the Serbian electricity generation sector in 2020 correspond to Scenario 1; that is, Sub-scenario 1-1.
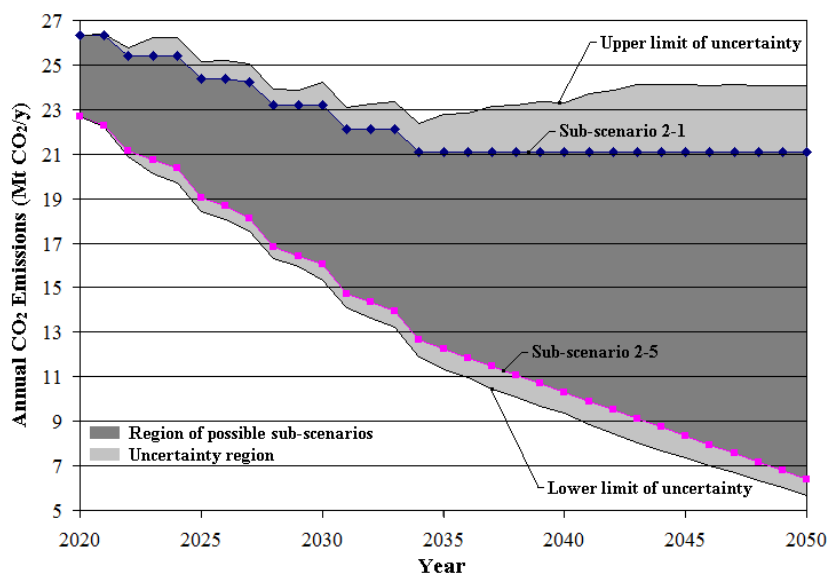

Figure 7. Region of possible sub-scenarios for annual CO_2 emissions from the Serbian electricity generation sector together with the corresponding upper and lower limits of uncertainty for the period 2020–2050, taking into account the EU's "20-20-20" targets, that is, Scenario 2.

It is interesting to see what the shares of certain technologies were in the total electricity generation in Serbia in 2020 and what they might be after the construction of all the NGPPs from Table 3. The actual shares of electricity generation for 2020 and projected shares of electricity generation according to Sub-scenario 2-4 (defined in Appendix C) for 2034 are represented by bars (a) and (b) in Figure 8, respectively. The projected shares (b) in Figure 8 are obtained assuming that the annual electricity generation and the amount of electricity generated in HPPs in 2034 should be the same as the ones for 2019, that the annual gross electricity consumption in 2034 should be the same as the average one for the period 2006–2019, and that electricity generation in CPPs in 2034 should be reduced by the amounts of electricity generated in all NGPPs built after 2000 and RESs, and, at the same time, increased by the amount of electricity generated in NGPPs built before 2000.

Figure 8 clearly shows that there is a possibility that Serbia can remain independent in terms of the electricity supply even if electricity generation from lignite falls slightly below 30%. However, in the case of Serbia, the RESs construction campaign must be continued, and the construction of planned HPPs with higher capacities must begin as soon as possible. Moreover, it is evident that new players will appear in the Serbian electricity generation sector. The companies that are building NGPPs in Serbia and which are most interested in the success of the Balkan Stream project could certainly be these new players, namely: NIS and Gazprom Energoholding Serbia. As for electricity generation, NIS has been generating electricity since 2012 and has been selling a portion of that electricity amount to the PE EPS. Figure 9 shows the annual amounts of electricity generated and sold by NIS during the period 2012–2020, and the appropriate projections for 2022. The projections are obtained assuming that the amount of electricity consumed (internally) by NIS in 2022 could be the same as in 2020 (i.e., 405.74 GWh/y). According to Figures 8 and 9, assuming that the total amount of electricity generated in Serbia in 2022 could be the same as the one in 2020, the share of electricity generation of NIS in the total electricity generation for 2022 could be 3.6%. Under the same assumptions, after the commissioning of NGPPs 4-7 with a total installed capacity of 1000 MW, the share of electricity generated by NIS could reach the order of 24% (bar (b) in Figure 8).
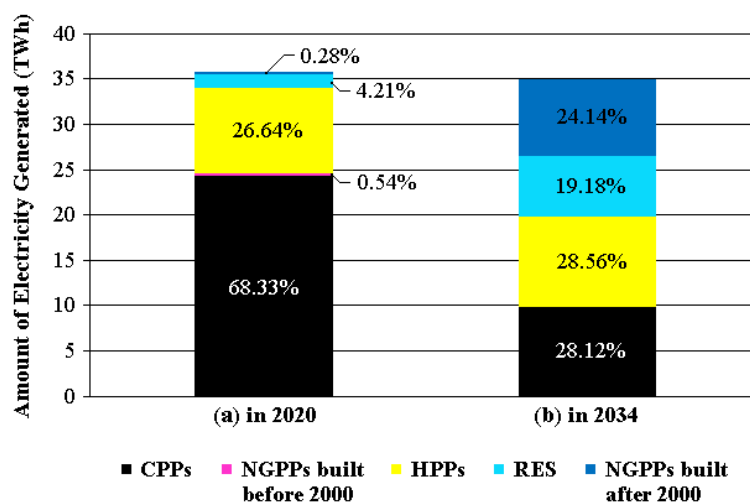
Figure 8. Electricity generation in Serbia: (**a**) in 2020—actual data [55]; and (**b**) in 2034—a projection according to Sub-scenario 2-4.
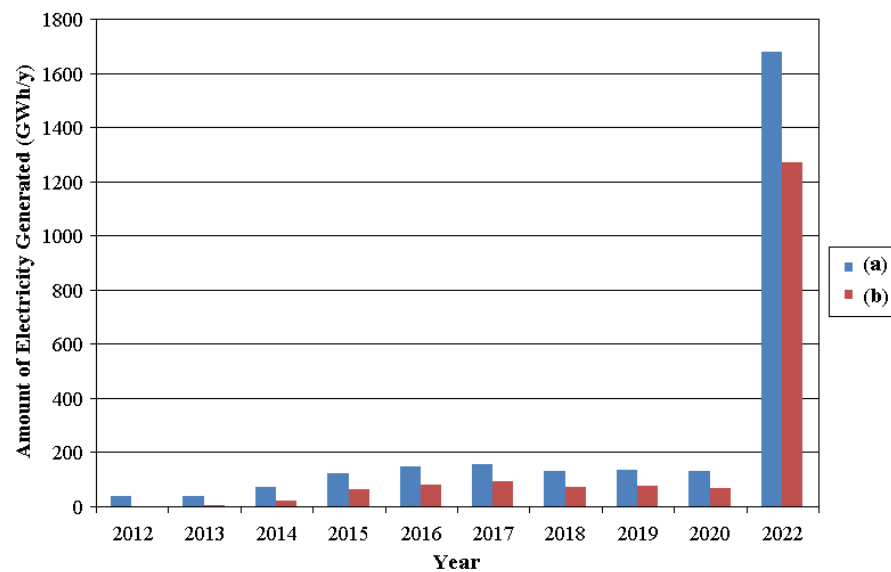
Figure 9. Actual annual amounts and projections of electricity generated by NIS [91]: (**a**) total generation of electricity, and (**b**) electricity sold.

Based on all the considerations, a set of applicable measures to ensure that Serbia will remain independent in terms of the electricity supply and at the same time maximally reduce CO_2 emissions from its electricity generation sector is as follows:

- The share of CPPs in the total annual amount of electricity consumed in Serbia should be 28%. It should also be ensured that this share can be additionally increased by up to the share of NGPPs (i.e., by up to 24%), if necessary.
- The construction of planned HPPs with lager generation capacities must be carried out simultaneously with the construction of RESs and completed as soon as possible. This measure has no alternative.
- The construction of RESs should be continued according to the trend from 2020 or intensified even more. If possible, the share of RESs in the total annual amount of electricity consumed in Serbia should be increased up to 27% (of course, without taking into account the share of larger HPPs).
- The annual gross electricity consumption of Serbia should be reduced by up to 20% by means of the implementation of projects in the areas of smart cities, smart infrastructure, and energy-efficient industries.

5. Conclusions

Compared to CO_2 emissions from the Serbian electricity generation sector for 1990, CO_2 emissions obtained under Scenarios 1 and 2 could be reduced by 10.94% and by up to 74.44%, respectively. In addition, for the same annual number of operation hours, the replacement of each old CPP by a new NGPP of the same generation capacity can reduce the corresponding annual CO_2 emissions by at least 50%. Moreover, new large players have been appearing in the Serbian electricity generation sector, which represents the next logical step in the deregulation of the local electricity market. In connection with this, it was found that, by 2034, the share of NGPPs owned by these players in the total annual amount of electricity consumed in Serbia can reach 24%. Furthermore, if Serbia relies unreservedly on the generation of electricity in NGPPs, giving up the technology of conventional CPPs, then its electricity generation sector could, for the first time, be dependent on the import of NG. Accordingly, Serbia can remain independent in terms of the electricity supply only if the share of CPPs in the total annual amount of electricity consumption amounts between 28% and 52%.

The proposed methodology combining the Kaya identity with the emission factor method was developed and successfully applied in order to estimate the potential annual

CO_2 emissions from the Serbian electricity generation sector by the end of 2050. According to the proposed methodology, the future CO_2 emissions were probably underestimated by less than 10%, which is reasonable because such differences result from the use of the default CO_2 emission factors (taken from the 2006 IPCC Guidelines) instead of the country-specific ones. In addition to this, the EU's "20-20-20" targets are achievable in the case of the Serbian electricity generation sector by 2050 while zero CO_2 emissions are not. The proposed methodology was successfully verified based on historical data for 2020, and it was pointed out that the CO_2 emissions for 2020 correspond to Sub-scenario 1-1.

It was also found that the annual CO_2 emissions from the Serbian electricity generation sector were reduced by 12.65% in the period 2011–2019 and that they did not reach the 1990 level. Moreover, it was established that the share of RESs in the annual amount of electricity generated in Serbia reached 4.21% for the first time in 2020. Undoubtedly, the reduction in CO_2 emissions coincided with the increase in electricity generation from RESs. However, it is possible that the unusually mild winters in the period 2011–2020 also contributed to this outcome. Finally, having in mind the need to ensure that Serbia should remain independent in terms of the electricity supply, a set of measures necessary for the reduction of CO_2 emissions from the Serbian electricity generation sector was also identified.

Future research directions are a direct comparison of the proposed methodology to that used by the PE EPS, a study of the country-specific CO_2 emission factors including the generation of electricity and heat, and overviews of possible scenarios for reducing other energy-related GHG emissions in Serbia.

Nomenclature

CCHP	Combined cooling, heating, and power
CHP	Combined heating and power
CPP	Coal-fired power plant
EU	The European Union
GDP	Gross domestic product
GHG	Greenhouse gas
HPP	Hydro power plant
IEA	The International Energy Agency
IPAT	The impact by population, affluence, and technological development
IPCC	The Intergovernmental Panel on Climate Change
KC	Clinical Center (or Klinički Centar, in Serbian)

LMDI	Logarithmic Mean Divisia Index
NATO	North Atlantic Treaty Organization
NIS	The Petroleum Industry of Serbia
NG	Natural gas
NGPP	Natural gas-fired power plant
PE EPS	The Public Enterprise Electric Power Industry of Serbia
PESTEL	P–political, E–economic, S–social, T–technological, E–environmental, and L–legal
PUC	Public Utility Company
PV	Photovoltaic
RES	Renewable energy source
STEEP	S–social, T–technological, E–economic, E–environmental, and P–political
UK	The United Kingdom
UN	The United Nations
USA	The United States of America
USD	United States Dollar
BUSD	Billion of current USD
GJ/GWh	Gigajoule per gigawatt-hour
GJ/Sm^3	Gigajoule per standard cubic meter
GJ/t	Gigajoule per ton
Gt CO$_2$	Gigaton of CO$_2$
GWh/y	Gigawatt-hour per year
g CO$_2$/kWh	Gramme of CO$_2$ per kilowatt-hour
h/y	Hour per year
kt CO$_2$/y	Kiloton of CO$_2$ per year
kUSD/y	Thousand of current USD per year
k 2010 USD	Thousand of constant 2010 USD
Mt CO$_2$	Megaton of CO$_2$
Mt CO$_2$/TWh	Megaton of CO$_2$ per terawatt-hour
Mt CO$_2$/y	Megaton of CO$_2$ per year
MW	Megawatt
MW$_{th}$	Thermal megawatt
Sm^3	Standard cubic meter
Sm^3/h	Standard cubic meter per hour
Sm^3/y	Standard cubic meter per year
TJ	Terajoule
TWh	Terawatt-hour
TWh/BUSD	Terawatt-hour per billion of current USD
TWh/y	Terawatt-hour per year
t CO$_2$/GJ	Ton of CO$_2$ per gigajoule
t CO$_2$/y	Ton of CO$_2$ per year
t/h	Ton per hour
t/y	Ton per year

Appendix A. Calculation of CO$_2$ Emissions

For the calculation of the annual direct CO$_2$ emissions from stationary combustion of fuels, and associated annual CO$_2$ emission intensities, the following performance indicators of CPPs and NGPPs were used: Q_{el}—the annual electricity generation in GWh/y, LHV_i—the lower heating value of a specific fuel type in GJ/t or GJ/Sm^3, M_i—the annual fuel consumption in t/y or Sm^3/y, $F_{E,i}$—the default value of direct CO$_2$ emission factor for stationary combustion of a specific fuel type in the electricity generation sector in t CO$_2$/GJ, and m_i—the hourly fuel consumption in t/h or Sm^3/h. In addition, the subscript $i = L, M, N$, or NG represents a specific fuel type, namely: the subscripts L, M, N, and NG stand for lignite (or coal), mazut (i.e., residual fuel oil), naphtha, and NG, respectively. The actual values for $Q_{el}, LHV_i, M_i, F_{E,i}, m_L$, and m_{NG} are taken from [6,49,57,70,71] and from the

official web page of the PE EPS while the values for m_M and m_N are estimated based on the known actual values in the following manner:

$$m_i = \frac{M_i}{t_{op}} \text{ for } i = M \text{ and } i = N,$$

(A1)

where:

$$t_{op} = \frac{M_i}{m_i} \text{ for } i = L \text{ and } i = NG$$

(A2)

represents the estimated annual number of operation hours for a specific CPP or NGPP in h/y.

For Serbian CPPs, lignite is the basic fuel while mazut and naphtha are secondary. In order to accelerate combustion processes, the secondary fuels are added to the basic fuel, before being fed to the combustion system. Although Serbian NGPPs do not need any secondary fuel for electricity generation, two of them can use mazut instead of NG (as an alternative fuel), and one simultaneously uses biomass for the generation of heat. The lower heating values for mazut, naphtha, and NG are LHV_M = 40.86, LHV_N = 42.1, and LHV_{NG} = 0.0342 GJ/Sm^3, respectively. The lower heating values for different types of lignite used in Serbian CPPs are given in Table A1, Appendix B. The default values of direct CO_2 emission factors for stationary combustion of lignite, mazut, naphtha, and NG are based on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories [49]. According to [49], the direct CO_2 emission factors for lignite, mazut, naphtha, and NG are $F_{E,L}$ = 0.101, $F_{E,M}$ = 0.0774, $F_{E,N}$ = 0.0733, and $F_{E,NG}$ = 0.0561 t CO_2/GJ, respectively. The required values for the hourly consumptions of lignite/coal, mazut, naphtha, and NG are given in Tables 1, 2 and A1–A3; that is, in Section 2 and Appendix B.

The annual direct CO_2 emissions from stationary combustion of a combination of fuels (lignite and mazut; lignite and naphtha; lignite, mazut and naphtha; NG only; or coal and mazut) for a specific CPP or NGPP in t CO_2/y are calculated by means of [49]:

$$E_{a,t} = \sum_i E_{a,i} = \sum_i LHV_i \cdot M_i \cdot F_{E,i}$$

(A3)

or:

$$E_{a,t} = \sum_i E_{a,i} = \sum_i LHV_i \cdot m_i \cdot t_{op} \cdot F_{E,i},$$

(A4)

where $E_{a,i}$ represents the annual direct CO_2 emissions from stationary combustion of a specific fuel type in t CO_2/y, M_i is the annual consumption of a specific fuel type in t/y or Sm^3/y, m_i is the hourly consumption of a specific fuel type in t/h or Sm^3/h, and t_{op} is the estimated annual number of operation hours for the CPP or NGPP under consideration in h/y.

The annual amount of heat released from stationary combustion of a combination of fuels in GWh/y is:

$$Q_f = \sum_i Q_{f,i} = \frac{1}{3600} \cdot \sum_i LHV_i \cdot M_i$$

(A5)

or:

$$Q_f = \sum_i Q_{f,i} = \frac{1}{3600} \cdot \sum_i LHV_i \cdot m_i \cdot t_{op},$$

(A6)

where $Q_{f,i}$ is the annual amount of heat released from stationary combustion of a specific fuel type in GWh/y.

In Equations (A3)–(A6), the estimated, average, or potential values for $E_{a,t}$, $E_{a,i}$, Q_f, and $Q_{f,i}$ are required to be calculated using the corresponding values of M_i, m_i, and t_{op}.

Moreover, the average values for m_i and t_{op} are obtained based on the five corresponding estimates relating to the years (t) from 2015 to 2019, i.e.,

$$m_i = \frac{1}{5} \cdot \sum_{t = 2015}^{2019} m_i(t) \text{ for } i = M \text{ and } i = N \tag{A7}$$

and:

$$t_{op} = \frac{1}{5} \cdot \sum_{t = 2015}^{2019} t_{op}(t), \tag{A8}$$

respectively, while the average value for M_i is estimated as:

$$M_i = m_i \cdot t_{op} \text{ for } i = M \text{ and } i = N. \tag{A9}$$

Furthermore, the actual and average values of m_L for a specific CPP, or of m_{NG} for a specific NGPP, are assumed to be constant and mutually equal.

Accordingly, the electrical efficiency for a specific CPP or NGPP in percent is:

$$\eta_{el} = \frac{Q_{el}}{Q_f} \cdot 100, \tag{A10}$$

where Q_{el} is the annual electricity generation in GWh/y, and Q_f is the annual amount of heat released from stationary combustion of a combination of fuels in GWh/y. In this case, the values for η_{el}, Q_{el}, and Q_f may be the actual, average, or potential. The average value for Q_{el} is obtained based on five appropriate actual values relating to the years (t) from 2015 to 2019, i.e.,

$$Q_{el} = \frac{1}{5} \cdot \sum_{t = 2015}^{2019} Q_{el}(t). \tag{A11}$$

Finally, for a CPP or NGPP in the case when heat generation is not taken into account, an annual CO_2 emission intensity IE_a in g CO_2/kWh (estimated, average, or potential) is calculated as the ratio of the corresponding annual direct CO_2 emissions from stationary combustion of a combination of fuels $E_{a,t}$ in t CO_2/y, and the corresponding annual electricity generation Q_{el} in GWh/y [72], i.e.,

$$IE_a = \frac{E_{a,t}}{Q_{el}}. \tag{A12}$$

If a CPP or NGPP uses only one type of fuel, Equation (A12) reduces to the following form:

$$IE_a = \frac{36 \cdot 10^4 \cdot F_{E,i}}{\eta_{el}}, \tag{A13}$$

where $F_{E,i}$ is in t CO_2/GJ, and η_{el} in percent. In particular, this equation can be obtained by substituting Equations (A3), (A5) and (A10) into (A12), or by substituting Equations (A4), (A6) and (A10) into (A12).

Appendix B. CO_2 Emissions from the Existing CPPs and NGPPs

Overviews of the actual, estimated, and average values for the performance indicators, annual CO_2 emissions, and annual CO_2 emission intensity of existing CPPs and NGPPs in Serbia are given in this appendix. Table A1 shows a periodic overview of the actual and estimated data on the CPPs and NGPPs built before 2000 while Tables A2 and A3 show overviews of the average data on all existing CPPs and all existing NGPPs, respectively.

Table A1. A periodic overview of the actual performance indicators, estimated annual CO_2 emissions, and estimated annual CO_2 emission intensities for Serbian CPPs and NGPPs built before 2000 [6] *.

CPP or NGPP and LHV_i **	Parameter		Unit	2015	2016	2017	2018	2019	2020
Nikola Tesla A which uses the lignite having $LHV_L = 6.7$ GJ/t		Q_{el}	GWh/y	9693.3	10,844	8357.098	7878	8571.08	9075.7
	Fuel	m_L	t/h	2510	2510	2510	2510	2510	2510
		m_M	t/h	2.552	1.312	1.511	3.614	3.01	3.119
	t_{op}		h/y	5831.4	6635.1	5732.4	5529.7	5862.4	6243.8
	η_{el}		%	35.36	34.87	31.09	30.28	31.03	30.88
	$E_{a,t}$		Mt CO_2/y	9.952	11.297	9.764	9.445	10.024	10.667
	IE_a		g CO_2/kWh	1026.7	1041.8	1168.3	1198.9	1169.6	1175.3
Nikola Tesla B which uses the lignite having $LHV_L = 6.7$ GJ/t		Q_{el}	GWh/y	8196.2	6418	7750.348	7733.1	7937.29	7960.86
	Fuel	m_L	t/h	1770	1770	1770	1770	1770	1770
		m_M	t/h	1.747	3.979	3.058	1.585	2.486	1.634
	t_{op}		h/y	6709.9	5403.1	6843.8	7115.2	7223.3	7225
	η_{el}		%	36.86	35.57	34.02	32.71	32.95	33.26
	$E_{a,t}$		Mt CO_2/y	8.074	6.54	8.263	8.578	8.688	8.691
	IE_a		g CO_2/kWh	985.1	1019	1066.2	1109.3	1094.6	1091.7
Kolubara A which uses the lignite having $LHV_L = 6.28$ GJ/t		Q_{el}	GWh/y	803.1	706	780.746	560.1	560.15	560.24
	Fuel	m_L	t/h	493.5	493.5	493.5	493.5	493.5	493.5
		m_N	t/h	1.26	0.499	0.45	0.725	0.741	0.88
	t_{op}		h/y	2999.5	2742.2	2960.1	2230.5	2242.2	2093.4
	η_{el}		%	30.58	29.7	30.45	28.88	28.74	30.72
	$E_{a,t}$		Mt CO_2/y	0.951	0.863	0.931	0.703	0.707	0.661
	IE_a		g CO_2/kWh	1183.6	1221.8	1192	1255.6	1261.9	1179.8
Morava which uses the lignite having $LHV_L = 7.78$ GJ/t		Q_{el}	GWh/y	335.4	294	390.184	443.5	453.86	491.93
		m_L	t/h	170	170	170	170	170	170
	Fuel	m_M	t/h	0.578	0.571	0.567	0.208	0.37	0.162
		m_N	t/h	0.218	0.195	0.103	0.096	0.084	0.063
	t_{op}		h/y	2441.1	2238.1	2941.6	3478.6	3712.9	3749
	η_{el}		%	36.49	34.92	35.37	34.22	32.96	35.47
	$E_{a,t}$		Mt CO_2/y	0.332	0.304	0.399	0.47	0.5	0.503
	IE_a		g CO_2/kWh	990.4	1035.3	1023	1059	1100.6	1023.4
Kostolac A which uses the lignite having $LHV_L = 7.8$ GJ/t		Q_{el}	GWh/y	1742.9	2042	2063.031	2010.4	2070.76	1671.07
	Fuel	m_L	t/h	410	410	410	410	410	410
		m_N	t/h	0.192	0.181	0.188	0.242	0.35	0.443
	t_{op}		h/y	6544.2	7103.5	7513.1	6979.5	7145.4	5933.6
	η_{el}		%	29.9	32.28	30.83	32.32	32.47	31.52
	$E_{a,t}$		Mt CO_2/y	2.118	2.298	2.431	2.26	2.316	1.925
	IE_a		g CO_2/kWh	1215	1125.5	1178.4	1124	1118.3	1151.8
Kostolac B which uses the lignite having $LHV_L = 7.8$ GJ/t		Q_{el}	GWh/y	4245.9	4711	4798.8	4329.3	3575.74	4571.73
	Fuel	m_L	t/h	800	800	800	800	800	800
		m_M	t/h	1.053	0.65	0.56	0.751	0.868	0.692
	t_{op}		h/y	6958.8	7496.6	7738.7	6862.4	5546.7	6941.5
	η_{el}		%	34.96	36.1	35.64	36.22	36.98	37.83
	$E_{a,t}$		Mt CO_2/y	4.409	4.74	4.891	4.341	3.511	4.39
	IE_a		g CO_2/kWh	1038.4	1006.2	1019.2	1002.8	981.9	960.3

Table A1. *Cont.*

CPP or NGPP and LHV_i **		Parameter	Unit	2015	2016	2017	2018	2019	2020
Sum		$E_{a,t}$	Mt CO$_2$/y	**25.835**	**26.052**	**26.679**	**25.797**	**25.745**	**26.837**
Novi Sad		Q_{el}	GWh/y	44.9	90	185.359	238.3	336.65	192.19
	Fuel	m_{NG}	Sm^3/h	53047.7	53047.7	53047.7	53047.7	53047.7	53047.7
		t_{op}	h/y	360.6	700.3	1425	1837.9	2485.7	1406.1
		η_{el}	%	24.71	25.5	25.81	25.73	26.87	27.12
		$E_{a,t}$	Mt CO$_2$/y	0.0367	0.0713	0.145	0.1871	0.253	0.143
		IE_a	g CO$_2$/kWh	817.3	791.9	782.4	785	751.5	744.6

* The NGPPs Zrenjanin and Sremska Mitrovica are excluded from this table because they did not generate electricity during the period from the beginning of 2015 to the end of 2019. ** LHV_L stands for the lower heating value of lignite.

Table A2. An overview of the average performance indicators, average annual CO$_2$ emissions, average annual CO$_2$ emission intensities, and some other related information for the existing Serbian CPPs [6].

No.	CPP * and Commence-ment of Operation	Installed Electricity Generation Units and Their Powers	Average Electrical Efficiency	Thermal Energy	Average Fuel Consumption			Average Annual Number of Operation Hours	Average Annual CO$_2$ Emis-sions **	Average Annual CO$_2$ Emission Intensity **
					Basic	Secondary				
					Lignite	Mazut	Naphtha			
					m_L	m_M	m_N			
		MW	%	MW$_{th}$	t/h	t/h	t/h	h/y	Mt CO$_2$/y	g CO$_2$/kWh
1	Nikola Tesla A, 1970–1979	2 × 210 + 1 × 329 + 1 × 308.5 + 1 × 340 + 1 × 347.5 = 1745	32.61	197.6	2510	2.4	0	5918.2	10.097	1113.4
2	Nikola Tesla B, 1983–1985	2 × 650 = 1300	34.37	0	1770	2.571	0	6659.1	8.03	1055.6
3	Kolubara A, 1956–1979	3 × 32 + 1 × 65+ 1 × 110 = 271	29.77	120	493.5	0	0.735	2634.9	0.831	1218.1
4	Morava, 1969	1 × 125 = 125	34.58	0	170	0.459	0.139	2962.5	0.401	1046.7
5	Kostolac A, 1967–1980	1 × 100+1 × 210 = 310	31.58	130	410	0	0.231	7057.1	2.284	1150.4
6	Kostolac B, 1987–1991	2 × 348.5 = 697	35.93	0	800	0.776	0	6920.6	4.379	1010.7
	Sum	4448	–	447	6153.5	6.206	1.105	–	26.022	–

* All CPPs listed in this table belong to the PE EPS. ** For each CPP, it is assumed that the average annual CO$_2$ emissions and average annual CO$_2$ emission intensity for any future year shall correspond to the averages obtained for the period from the beginning of 2015 to the end of 2019, using the proposed calculation method.

According to Table A2, the average values of IE_a for the existing Serbian CPPs range between 1010.7 (in the case of CPP Kostolac B) and 1218.1 g CO$_2$/kWh (in the case of CPP Kolubara A). In addition, according to Table A3, the average values of IE_a for the existing Serbian NGPPs range between 459 (in the case of NGPP Zapad) and 774.2 g CO$_2$/kWh (in the case of NGPP Novi Sad). It is also evident that these increases in IE_a coincided with a reduction in the electrical efficiency η_{el} of the CPPs in Table A2 and of the NGPPs in Table A3, regardless of the commencement date of operation. When definition (A12) takes into account heat generation, it becomes apparent that IE_a can have a significantly lower value when compared to the corresponding value from Table A2 or Table A3. This applies to each CPP or NGPP that generates both electricity and heat. This could certainly be the topic of a future study.

Table A3. An overview of the average performance indicators, average annual CO_2 emissions, average annual CO_2 emission intensities, and some other related information for the existing Serbian NGPPs [6,73].

No.	NGPP * and Commencement of Operation	Installed Electricity Generation Units and Their Powers	Average Electrical Efficiency	Thermal Energy	Average Fuel Consumption NG m_{NG}	Average Annual Number of Operation Hours	Average Annual CO_2 Emissions	Average Annual CO_2 Emission Intensity
		MW	%	MW$_{th}$	Sm^3/h	h/y	kt CO_2/y	g CO_2/kWh
1	Sremska Mitrovica, 1977	$1 \times 32 = 32$	30	33	9453 **	0 ****	0 ****	673.2
2	Novi Sad, 1981–1984	$1 \times 135 + 1 \times 110 = 245$	26.09	355	53047.7 ***	1361.9	138.612 *****	774.2 *****
3	Zrenjanin, 1989	$1 \times 120 = 120$	32	140	19693.8 ***	0 ****	0 ****	631.1
4	Toplana KC (heating plant in the City of Belgrade), 2008 ******	$1 \times 1.819 = 1.819$	43.3	1.807	466.3	7500	6.7099	466.4
5	Imlek (dairy company in Padinska Skela), 2011	$1 \times 1.415 = 1.415$	41.9	1.492	374.5	7500	5.3889	482
6	Sirakovo, Aug 2013	$1 \times 0.85 = 0.85$	39.9	0.904	181.4	7500	2.6103	506.2
7	Kikinda, Nov 2013	$1 \times 0.995 = 0.995$	41.3	1.1	254.2	7500	3.6578	489
8	Velebit 1, Dec 2013	$1 \times 0.995 = 0.995$	42.6	1.04	270.1	7500	3.8866	474.1
9	Velebit 2, Dec 2013	$1 \times 0.995 = 0.995$	42.6	1.04	270.1	7500	3.8866	474.1
10	Srbobran 1, Aug 2014	$1 \times 0.995 = 0.995$	41.5	1.1	474.7	7500	6.8308	486.7
11	Srbobran 2, Aug 2014	$1 \times 0.995 = 0.995$	41.5	1.1	474.7	7500	6.8308	486.7
12	Boka, Sep 2014	$1 \times 0.329 = 0.329$	41.4	0.37	81.2	7500	1.1684	487.8
13	Turija, Dec 2014	$1 \times 0.995 = 0.995$	40.6	1.118	206.8	7500	2.9758	497.4
14	Bradarac, Dec 2014	$1 \times 0.3 = 0.3$	40.9	0.345	60.1	7500	0.8648	493.8
15	Velebit 3, Jan 2015	$1 \times 1 = 1$	41.2	–	415.6	7500	5.9803	490.2
16	Velebit 4, Jan 2015	$1 \times 1 = 1$	41.2	–	415.6	7500	5.9803	490.2
17	Sirakovo 2-1, Jun 2015	$1 \times 1 = 1$	43.1	–	207.8	7500	2.9902	468.6
18	Sirakovo 2-2, Jun 2015	$1 \times 1 = 1$	43.1	–	207.8	7500	2.9902	468.6
19	Majdan, Aug 2016	$1 \times 2.41 = 2.41$	39.5	–	1250.1	7500	17.9885	511.3
20	Zapad (heating plant in the City of Novi Sad), Oct 2016	$3 \times 3.328 = 9.984$	44	10.035	2541.3	7500	36.5684	459
	Sum	424.077	–	549.451	90,346.8	–	255.9206	–

* NGPPs 1-3 belong to the PE EPS, NGPP 4 belongs to the Clinical Center of Serbia (Srb. *Klinički Centar Srbije*), NGPP 5 belongs to the dairy company Imlek, NGPPs 6-19 belong to NIS, and NGPP 20 belongs to the PUC Novosadska Toplana Novi Sad. NGPPs 1-3 are equipped with typical steam turbines while the other NGPPs use internal combustion engines that operate at fixed rotational speeds. ** The NGPP Sremska Mitrovica simultaneously uses NG for the generation of electricity and biomass for the generation of heat. *** The NGPP Novi Sad and NGPP Zrenjanin can use mazut as fuel instead of the typically used NG. **** During the period from 2015 to 2019, only heat was generated in the NGPP Zrenjanin and NGPP Sremska Mitrovica. ***** For the NGPP Novi Sad, it is assumed that the average annual CO_2 emissions and average annual CO_2 emission intensity for any future year shall correspond to the averages obtained for the period from the beginning of 2015 to the end of 2019, using the proposed calculation method. ****** The NGPP Toplana KC can use mazut as fuel instead of the typically used NG. Since 2011, the Clinical Center of Serbia has been selling electricity generated from this NGPP to the PE EPS.

In addition, there are CO_2 emission intensities, whose values are usually obtained by conducting experiments for different CPPs. In the EU member countries, a CPP with an assumed 40% efficiency generates electricity with an average annual CO_2 emission intensity of about 850 g CO_2/kWh [74]. This is unfortunately not the case with the existing CPPs in Serbia, whose average annual CO_2 emission intensity, according to [30,74,75], ranges between 880 and 1340 g CO_2/kWh. The lower and upper bounds of this range correspond to the lignite types from the Kostolac and Kolubara basins, respectively. The CPP Kostolac

A and CPP Kostolac B use lignite from the Kostolac basin while the others use lignite from the Kolubara basin. Accordingly, an average annual CO_2 emission intensity that can be used for a Serbian CPP is 1150 g CO_2/kWh [30]. This certainly agrees with the results obtained using the proposed calculation method.

Appendix C. An Overview of Some Possible Sub-Scenarios

Scenario 1 or Scenario 2 from Section 2.3, for example, are divided into six possible sub-scenarios. Accordingly, six possible sub-scenarios within Scenario 1 are as follows:

Sub-scenario 1-1: From 2019 to the end of 2040, electricity generation in CPPs should be at the level of the average electricity generation in CPPs for the period 2015–2019, and after 2040, it should start to decrease by 3% annually until it reaches 70% of the given average.

Sub-scenario 1-2: From 2019 to the end of 2030, electricity generation in CPPs should be at the level of the average electricity generation in CPPs for the period 2015–2019, and after 2030, it should start to decrease by 2% annually until it reaches 70% of the given average, and then it should not change by the end of 2050.

Sub-scenario 1-3: From 2019 to the end of 2030, electricity generation in CPPs should be at the level of the average electricity generation in CPPs for the period 2015–2019, and after 2030, it should start to decrease by 3% annually until it reaches 70% of the given average, and then it should not change by the end of 2050.

Sub-scenario 1-4: From 2019 to the end of 2050, electricity generation in CPPs should be reduced by 1% annually until it reaches 70% of the average electricity generation in CPPs for the period 2015–2019.

Sub-scenario 1-5: From 2019 to the end of 2035, electricity generation in CPPs should be reduced by 2% annually until it reaches 70% of the average electricity generation in CPPs for the period 2015-2019, and then it should not change by the end of 2050.

Sub-scenario 1-6: From 2019 to the end of 2030, electricity generation in CPPs should be reduced by 3% annually until it reaches 70% of the average electricity generation in CPPs for the period 2015-2019, and then it should not change by the end of 2050.

In addition, six possible sub-scenarios within Scenario 2 are:

Sub-scenario 2-1: In 2020, electricity generation in CPPs should be at the level of the average electricity generation in CPPs for the period 2015-2019, and then it should be reduced annually by the amount of electricity generated in the planned NGPPs (Table 3).

Sub-scenario 2-2: In the period 2020-2050, electricity generation from RESs should be at the corresponding level of 2019 and should amount to 3.79% of the average annual gross electricity consumption of Serbia for the period 2006-2019 (i.e., 3.79% of 33.481 TWh/y). In the same period, electricity generation in CPPs should be reduced annually by the amounts of electricity generated in the planned NGPPs and RESs.

Sub-scenario 2-3: In the period 2020-2050, in regard to the corresponding level of 2019, electricity generation from RESs should be additionally increased, on an annual basis, by 0.2% of the average annual gross electricity consumption of Serbia for the period 2006-2019. This should be an RES share of 10% in the average annual gross electricity consumption. In the same period, electricity generation in CPPs should be reduced annually by the amounts of electricity generated in the planned NGPPs and RESs.

Sub-scenario 2-4: According to this sub-scenario, the share of RESs in the average annual gross electricity consumption of Serbia should be 20% by the end of 2050, and everything else is the same as in the case of Sub-scenario 2-3.

Sub-scenario 2-5: According to this sub-scenario, the annual gross electricity consumption of Serbia should be reduced by 20% (or 0.645% annually) by the end of 2050 (in the period from 2020 until the end of 2050). In addition, electricity generation in CPPs should be reduced annually by the amounts of the electricity generated in the planned NGPPs and RESs, and by the amount of the decline in the annual gross electricity consumption of Serbia. Everything else remains the same as in the case of Sub-scenario 2-4.

Sub-scenario 2-6: According to this sub-scenario, the annual gross electricity consumption of Serbia should be increased by 20% (or 0.645% annually) by the end of 2050 (in the period from 2020 until the end of 2050). In addition, electricity generation in CPPs should be reduced annually by the amounts of the electricity generated in the planned NGPPs and RESs and increased by the amount of the rise in the annual gross electricity consumption of Serbia. Everything else remains the same as in the case of Sub-scenario 2-4.

These sub-scenarios, that is, the projections of the annual CO_2 emissions from the Serbian electricity generation sector corresponding to Scenarios 1 and 2, are illustrated in Figures A1 and A2, respectively. The appropriate upper and lower limits of uncertainty for each of the projections are also shown in Figures A1 and A2. Each uncertainty region between two corresponding limits is colored light grey.
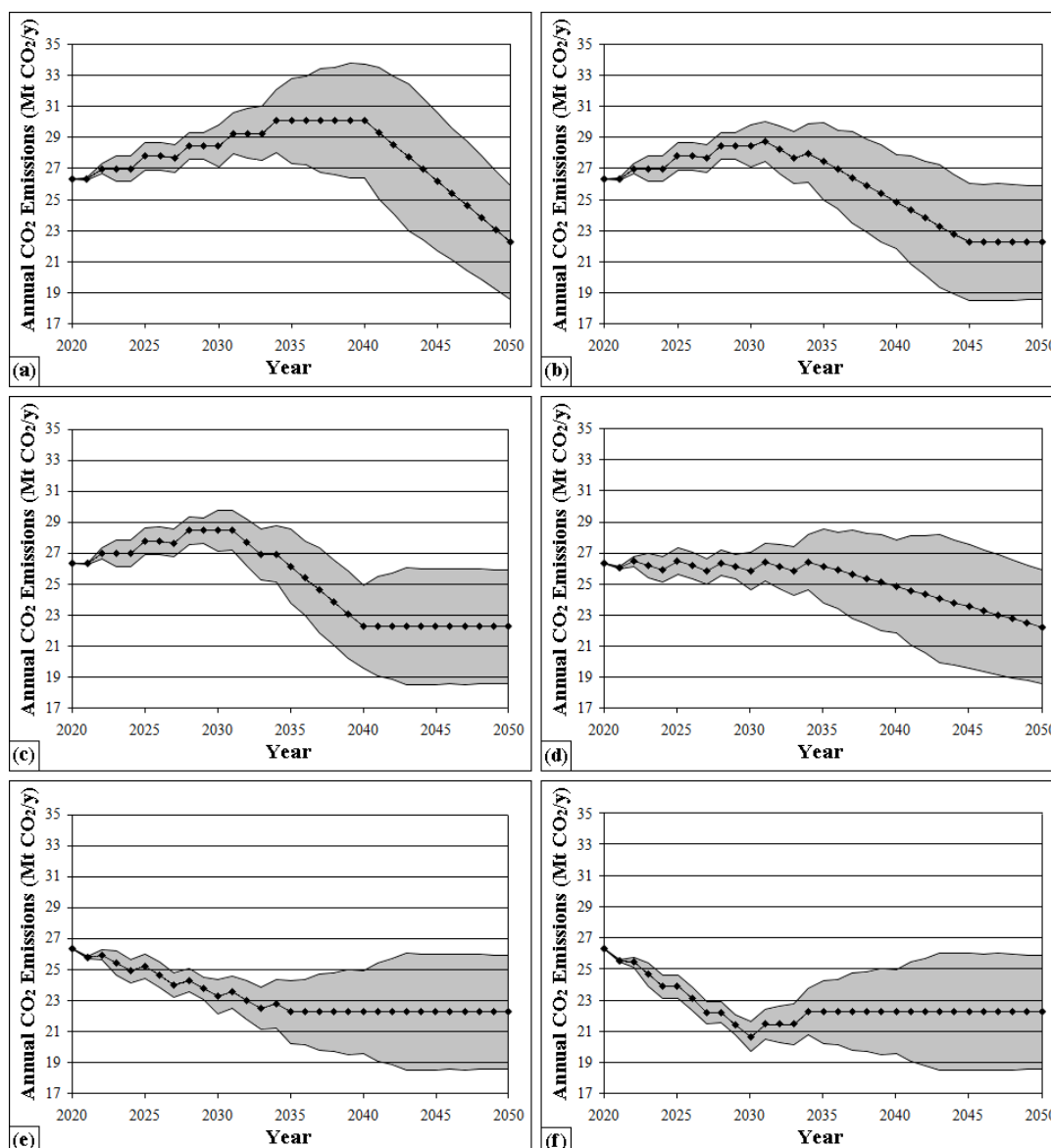
Figure A1. Projections of annual CO_2 emissions from the Serbian electricity generation by the end of 2050, taking into account national targets relating to the independence of the electricity supply, that is, Scenario 1, namely: (**a**) Sub-scenario 1-1; (**b**) Sub-scenario 1-2; (**c**) Sub-scenario 1-3; (**d**) Sub-scenario 1-4; (**e**) Sub-scenario 1-5; and (**f**) Sub-scenario 1-6.
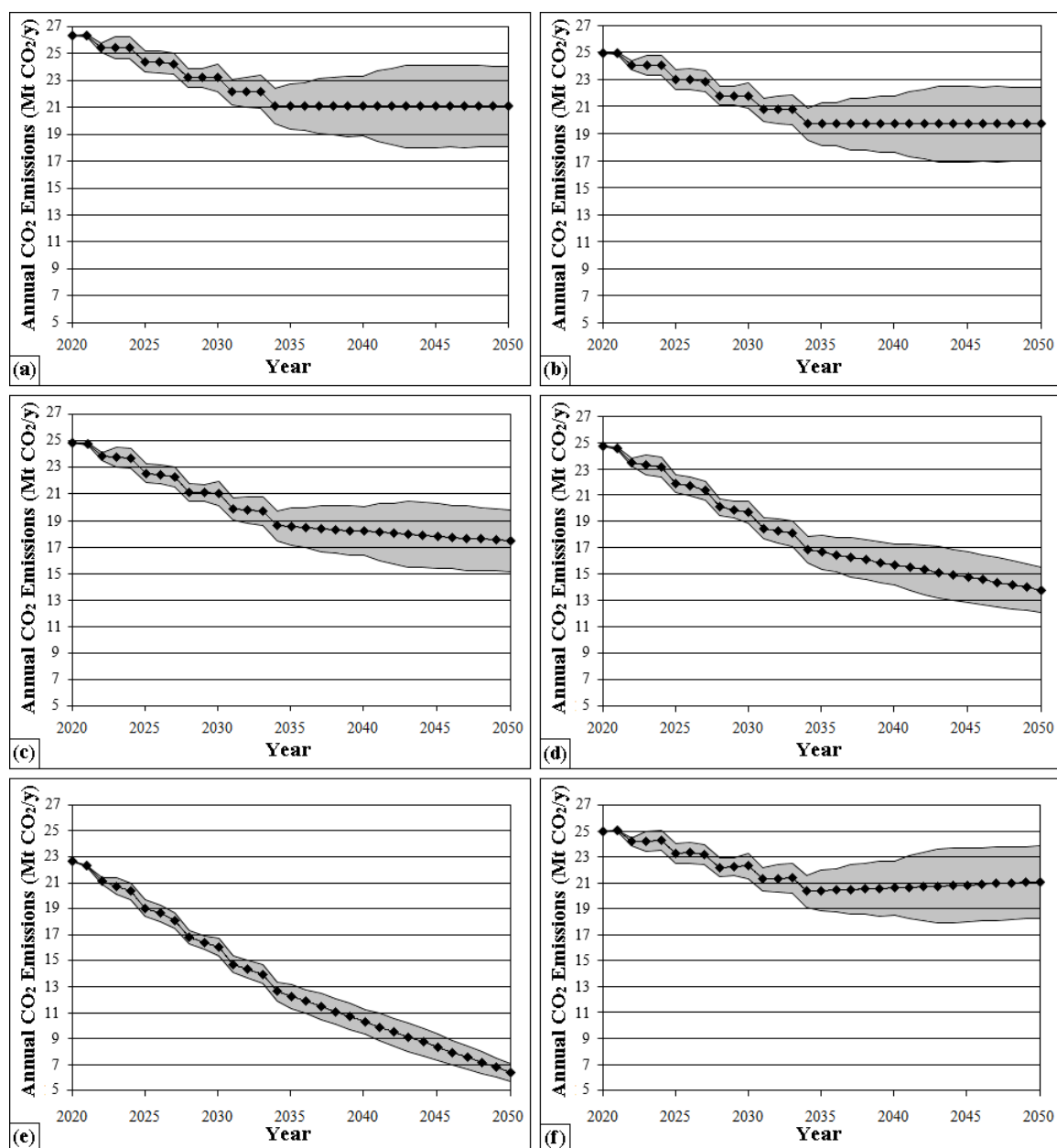
Figure A2. Projections of annual CO_2 emissions from the Serbian electricity generation sector by the end of 2050, taking into account the EU's "20-20-20" targets, that is, Scenario 2, namely: (**a**) Sub-scenario 2-1; (**b**) Sub-scenario 2-2; (**c**) Sub-scenario 2-3; (**d**) Sub-scenario 2-4; (**e**) Sub-scenario 2-5; and (**f**) Sub-scenario 2-6.

References

1. International Energy Agency (IEA). Global Energy Review: CO_2 Emissions in 2020. 2 March 2021. Available online: https://www.iea.org/articles/global-energy-review-co2-emissions-in-2020 (accessed on 1 June 2022).
2. World Health Organization (WHO). Influenza A (H1N1) Outbreak. 2009. Available online: https://www.who.int/emergencies/situations/influenza-a-(h1n1)-outbreak (accessed on 18 June 2022).
3. International Energy Agency (IEA). CO_2 Emissions from Fuel Combustion: Overview. July 2020. Available online: https://www.iea.org/reports/co2-emissions-from-fuel-combustion-overview (accessed on 1 June 2022).
4. EMBER. 2020 Global Electricity Review. March 2020. Available online: https://ember-climate.org/wp-content/uploads/2020/03/Ember-2020GlobalElectricityReview-Web.pdf (accessed on 1 June 2022).
5. International Energy Agency (IEA). Global CO_2 Emissions in 2019. 11 February 2020. Available online: https://www.iea.org/articles/global-co2-emissions-in-2019 (accessed on 1 June 2022).

6. Public Enterprise Electric Power Industry of Serbia (PE EPS). Reports on the State of the Environment in the PE 'Electric Power Industry of Serbia' for 2010–2020. 2011–2021. Available online: http://www.eps.rs/cir/Pages/Sredina.aspx (accessed on 1 June 2022). (In Serbian language).

7. International Energy Agency (IEA). Country Profile: Serbia. 2020. Available online: https://www.iea.org/countries/serbia (accessed on 1 June 2022).

8. Dastan, S.A. Negotiation of a cross-border natural gas pipeline: An analytical contribution to the discussions on Turkish Stream. *Energy Policy* **2018**, *120*, 749–760. [CrossRef]

9. Nalbandian, H. *Climate Implications of Coal-to-Gas Substitution in Power Generation*; IEA Clean Coal Centre: London, UK, 2015. Available online: https://usea.org/sites/default/files/042015_Climate%20implications%20of%20coal-to-gas%20substitution%20in%20power%20generation_ccc248.pdf (accessed on 1 June 2022).

10. Traber, T.; Fell, H.-J. *Natural Gas Makes No Contribution to Climate Protection*; Energy Watch Group—EWG: Berlin, Germany, 2019. Available online: http://energywatchgroup.org/wp-content/uploads/EWG_Natural_Gas_Study_September_2019.pdf (accessed on 1 June 2022).

11. Cowern, N.; Russell-Jones, R. *Global Warming Impact of a Switch from Coal to Gas-Fired Electricity Generation in the UK: Evidence Towards a Better Solution*; The Climate Change Committee: London, UK, 2016. Available online: https://www.theccc.org.uk/wp-content/uploads/2016/07/Onshore-petroleum-evidence-submitted-by-Cowern-and-Russell-Jones.pdf (accessed on 1 June 2022).

12. Dong, K.; Sun, R.; Li, H.; Liao, H. Does natural gas consumption mitigate CO_2 emissions: Testing the environmental Kuznets curve hypothesis for 14 Asia-Pacific countries. *Renew. Sustain. Energy Rev.* **2018**, *94*, 419–429. [CrossRef]

13. Maamoun, N.; Kennedy, R.; Jin, X.; Urpelainen, J. Identifying coal-fired power plants for early retirement. *Renew. Sustain. Energy Rev.* **2020**, *126*, 109833. [CrossRef]

14. European Environmental Bureau. Serbia's Public Electricity Company Faces Court for Breaching Toxic Emission Limits. 26 January 2021. Available online: https://eeb.org/serbias-public-electricity-company-faces-court-for-breaching-toxic-emission-limits/?fbclid=IwAR3hJDWH7TQ3L26ZxvX5R-IGdyIGcBQn7E4N0sFDsPZ0GZ-Efp61fvkfAVY (accessed on 1 June 2022).

15. Center for Investigative Journalism of Serbia. Investigative Stories: New EU Tax that Affects Serbia—Citizens and Businesses Will Lose. 25 March 2021. Available online: https://www.cins.rs/en/new-eu-tax-that-affects-serbia-citizens-and-businesses-will-lose/ (accessed on 1 June 2022).

16. Eguchi, S.; Takayabu, H.; Lin, C. Sources of inefficient power generation by coal-fired thermal power plants in China: A metafrontier DEA decomposition approach. *Renew. Sustain. Energy Rev.* **2021**, *138*, 110562. [CrossRef]

17. Heggelund, G.M. China's climate and energy policy: At a turning point? *Int. Environ. Agreem. Politics Law Econ.* **2021**, *21*, 9–23. [CrossRef]

18. Qin, Y. Natural gas in China's power sector: Challenges and the road ahead. *Energy Insight* **2020**, *80*, 1–15.

19. Yang, Y.; Campana, P.E.; Yan, J. Potential of unsubsidized distributed solar PV to replace coal-fired power plants, and profits classification in Chinese cities. *Renew. Sustain. Energy Rev.* **2020**, *131*, 109967. [CrossRef]

20. Wang, S. Current status of PV in China and its future forecast. *CSEE J. Power Energy Syst.* **2020**, *6*, 72–82. [CrossRef]

21. Yu, X.; Qu, H. Wind power in China—Opportunity goes with challenge. *Renew. Sustain. Energy Rev.* **2010**, *14*, 2232–2237. [CrossRef]

22. Dai, J.; Yang, X.; Wen, L. Development of wind power industry in China: A comprehensive assessment. *Renew. Sustain. Energy Rev.* **2018**, *97*, 156–164. [CrossRef]

23. Li, Y.; Xia, Y. DES/CCHP: The best utilization mode of natural gas for China's low carbon economy. *Energy Policy* **2013**, *53*, 477–483. [CrossRef]

24. Yan, B.; Xue, S.; Li, Y.; Duan, J.; Zeng, M. Gas-fired combined cooling, heating and power (CCHP) in Beijing: A techno-economic analysis. *Renew. Sustain. Energy Rev.* **2016**, *63*, 118–131. [CrossRef]

25. Zhang, R.; Wang, G.; Shen, X.; Wang, J.; Tan, X.; Feng, S.; Hong, J. Is geothermal heating environmentally superior than coal fired heating in China? *Renew. Sustain. Energy Rev.* **2020**, *131*, 110014. [CrossRef]

26. Feng, Y.; Chen, X.; Xu, X.F. Current status and potentials of enhanced geothermal system in China: A review. *Renew. Sustain. Energy Rev.* **2014**, *33*, 214–223. [CrossRef]

27. Lazarevic, A.; Karamarkovic, V.; Lazarevic, D.; Karamarkovic, R. Potentials and opportunities to reduce energy-related greenhouse gas emissions in Serbia. *Energy Sources Part A Recovery Util. Environ. Eff.* **2017**, *39*, 712–719. [CrossRef]

28. Cvetković, S.M.; Kaludjerović Radoičić, T.S.; Kragić, R.B.; Kijevčanin, M.L. Electricity production from biogas in Serbia—Assessment of emissions reduction. *Therm. Sci.* **2016**, *20*, 1333–1344. [CrossRef]

29. Stefanović, P.L.; Marković, Z.J.; Bakić, V.V.; Cvetinović, D.B.; Spasojević, V.D.; Živković, N.V. Evaluation of Kolubara lignite carbon emissions characteristics. *Therm. Sci.* **2012**, *16*, 805–816. [CrossRef]

30. Jović, M.; Laković, M. Carbon Footprint method—A case study for thermal power plants in Republic of Serbia. *Acta Tech. Corviniensis-Bull. Eng.* **2018**, *11*, 127–129.

31. Pietrapertosa, F.; Khokhlov, V.; Salvia, M.; Cosmi, C. Climate change adaptation policies and plans: A survey in 11 South East European countries. *Renew. Sustain. Energy Rev.* **2018**, *81*, 3041–3050. [CrossRef]

32. Batas Bjelić, I.; Rajaković, N.; Ćosić, B.; Duić, N. A realistic EU vision of a lignite-based energy system in transition: Case study of Serbia. *Therm. Sci.* **2015**, *19*, 371–382. [CrossRef]

33. Batas Bjelic, I.; Ciric, R.M. Optimal distributed generation planning at a local level—A review of Serbian renewable energy development. *Renew. Sustain. Energy Rev.* **2014**, *39*, 79–86. [CrossRef]

34. Dunjic, S.; Pezzutto, S.; Zubaryeva, A. Renewable energy development trends in the Western Balkans. *Renew. Sustain. Energy Rev.* **2016**, *65*, 1026–1032. [CrossRef]

35. Siva Reddy, V.; Kaushik, S.C.; Panwar, N.L. Review on power generation scenario of India. *Renew. Sustain. Energy Rev.* **2013**, *18*, 43–48. [CrossRef]

36. Gonzalez-Salazar, M.A.; Kirsten, T.; Prchlik, L. Review of the operational flexibility and emissions of gas- and coal-fired power plants in a future with growing renewables. *Renew. Sustain. Energy Rev.* **2018**, *82*, 1497–1513. [CrossRef]

37. Şevik, S. An analysis of the current and future use of natural gas-fired power plants in meeting electricity energy needs: The case of Turkey. *Renew. Sustain. Energy Rev.* **2015**, *52*, 572–586. [CrossRef]

38. Antonanzas, J.; Alia-Martinez, M.; Martinez-de-Pison, F.J.; Antonanzas-Torres, F. Towards the hybridization of gas-fired power plants: A case study of Algeria. *Renew. Sustain. Energy Rev.* **2015**, *51*, 116–124. [CrossRef]

39. Clark, R.; Zucker, N.; Urpelainen, J. The future of coal-fired power generation in Southeast Asia. *Renew. Sustain. Energy Rev.* **2020**, *121*, 109650. [CrossRef]

40. Ali, H.; Phoumin, H.; Weller, S.R.; Suryadi, B. Cost–Benefit Analysis of HELE and Subcritical Coal-Fired Electricity Generation Technologies in Southeast Asia. *Sustainability* **2021**, *13*, 1591. [CrossRef]

41. Seo, S.-J.; Kim, J.-H.; Yoo, S.-H. Public Preference for Increasing Natural Gas Generation for Reducing CO_2 Emissions in South Korea. *Sustainability* **2020**, *12*, 2636. [CrossRef]

42. Abdel-Hameed, A.; Kim, J.; Hyun, J.-H.; Ramadhan, H.H.; Joseph, S.R.; Nandutu, M. Optimization of Electricity Generation Technologies to Reduce Carbon Dioxide Emissions in Egypt. *Appl. Sci.* **2021**, *11*, 8788. [CrossRef]

43. Kaya, Y. Impact of Carbon Dioxide Emission Control on GNP Growth: Interpretation of Proposed Scenarios. In Proceedings of the IPCC Energy and Industry Subgroup, Response Strategies Working Group, Paris, France, 9 May 1990.

44. Yamaji, K.; Matsuhashi, R.; Nagata, Y.; Kaya, Y. A study on economic measures for CO_2 reduction in Japan. *Energy Policy* **1993**, *21*, 123–132. [CrossRef]

45. Kaya, Y.; Yokobori, K. *Environment, Energy, and Economy: Strategies for Sustainability*, 1st ed.; United Nations University Press: Tokyo, Japan, 1997.

46. Kirby, P.; O'Mahony, T. *The Political Economy of the Low-Carbon Transitions: Pathways beyond Techno-Optimism (International Political Economy Series)*, 1st ed.; Springer International Publishing AG: Cham, Switzerland, 2018.

47. Hwang, Y.-S.; Um, J.-S.; Hwang, J.-H.; Schlüter, S. Evaluating the causal relations between the Kaya identity index and ODIAC-based fossil fuel CO_2 flux. *Energies* **2020**, *13*, 6009. [CrossRef]

48. Schröder, E.; Storm, S. Economic growth and carbon emissions: The road to "Hothouse Earth" is paved with good intentions. *Int. J. Political Econ.* **2020**, *49*, 153–173. [CrossRef]

49. Gómez, D.R.; Watterson, J.D.; Americano, B.B.; Ha, C.; Marland, G.; Matsika, E.; Namayanga, L.N.; Osman-Elasha, B.; Saka, J.D.K.; Treanton, K.; et al. Chapter 2: Stationary Combustion. In *2006 IPCC Guidelines for National Greenhouse Gas Inventories—Volume 2: Energy*, 1st ed.; Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K., Eds.; Institute for Global Environmental Strategies (IGES): Hayama, Japan, 2006; pp. 2.1–2.47.

50. Nielsen, O.-K.; Plejdrup, M.S.; Winther, M.; Hjelgaard, K.; Nielsen, M.; Fauser, P.; Mikkelsen, M.H.; Albrektsen, R.; Gyldenkærne, S.; Thomsen, M. *Projection of Greenhouse Gases 2017–2040 (Scientific Report from DCE—Danish Centre for Environment and Energy No. 294)*; Aarhus University, DCE—Danish Centre for Environment and Energy: Aarhus, Denmark, 2018. Available online: https://dce2.au.dk/pub/SR294.pdf (accessed on 1 June 2022).

51. Chong, C.H.; Tan, W.X.; Ting, Z.J.; Liu, P.; Ma, L.; Li, Z.; Ni, W. The driving factors of energy-related CO_2 emission growth in Malaysia: The LMDI decomposition method based on energy allocation analysis. *Renew. Sustain. Energy Rev.* **2019**, *115*, 109356. [CrossRef]

52. Kamjou, A.S.; Miller, C.J.; Rouholamini, M.; Wang, C. Comparison between Historical and Real-Time Techniques for Estimating Marginal Emissions Attributed to Electricity Generation. *Energies* **2021**, *14*, 5261. [CrossRef]

53. Ofosu-Adarkwa, J.; Xie, N.; Javed, S.A. Forecasting CO_2 emissions of China's cement industry using a hybrid Verhulst-GM(1,N) model and emissions' technical conversion. *Renew. Sustain. Energy Rev.* **2020**, *130*, 109945. [CrossRef]

54. Energy Agency of the Republic of Serbia (AERS). Annual Reports for 2005–2020. 2006–2021. Available online: https://www.aers.rs/Index.asp?l=1&a=53 (accessed on 1 June 2022)(In Serbian language).

55. Public Enterprise Electric Power Industry of Serbia (PE EPS). Annual Reports for 1997–2020. 1998–2021. Available online: http://www.eps.rs/cir/Pages/tehnicki-izvestaji.aspx (accessed on 1 June 2022). (In Serbian language).

56. Balkan Green Energy News. In 2019, the Generation of Electricity from Renewables in Serbia was Doubled. 2020. Available online: https://balkangreenenergynews.com/rs/u-2019-duplirana-proizvodnja-elektricne-energije-iz-obnovljivih-izvora-u-srbiji/ (accessed on 1 June 2022). (In Serbian language).

57. Public Enterprise Electric Power Industry of Serbia (PE EPS). Green Book. 2009. Available online: http://www.eps.rs/cir/Pages/Sredina.aspx (accessed on 1 June 2022). (In Serbian language).

58. Country Economy. Serbia GDP—Gross Domestic Product. 1999. Available online: https://countryeconomy.com/gdp/serbia?year=1998 (accessed on 1 June 2022).

59. International Monetary Fund. Federal Republic of Yugoslavia: Membership and Use of Fund Resources—Request for Emergency Post-Conflict Assistance. 8 January 2001. Available online: https://www.imf.org/en/Publications/CR/Issues/2016/12/30/Federal-Republic-of-Yugoslavia-Membership-and-Use-of-Fund-Resources-Request-for-Emergency-3875 (accessed on 1 June 2022).

60. Republic of Serbia, Ministry of Mining and Energy. Energy Sector Development Strategy of the Republic of Serbia for the Period by 2015. 2005. Available online: https://www.mre.gov.rs/doc/efikasnost-izvori/01%20Strategija%20razvoja%20energetike%20Republike%20Srbije%20do%202015%20godine.pdf (accessed on 1 June 2020)(In Serbian language).

61. Trading Economics. Serbia GDP 1995–2019 Data. 2020. Available online: https://tradingeconomics.com/serbia/gdp (accessed on 1 June 2022).

62. Trading Economics. Serbia GDP per Capita 1995–2018 Data. 2020. Available online: https://tradingeconomics.com/serbia/gdp-per-capita (accessed on 1 June 2022).

63. The World Bank. The World Bank in Serbia—Overview for 2019. 2020. Available online: https://www.worldbank.org/en/country/serbia/overview (accessed on 1 June 2022).

64. The World Bank. The World Bank in Serbia—Overview for 2020. 2021. Available online: https://www.worldbank.org/en/country/serbia/overview (accessed on 1 June 2022).

65. The World Bank. Serbia. 2020. Available online: https://data.worldbank.org/country/serbia (accessed on 1 June 2022).

66. Trading Economics. Serbia Population 1995–2020 Data. 2021. Available online: https://tradingeconomics.com/serbia/population (accessed on 1 June 2022).

67. Republic of Serbia, Ministry of Mining and Energy. Energy Sector Development Strategy of the Republic of Serbia for the Period by 2025 with Projections by 2030. 2016. Available online: http://meemp-serbia.com/wp-content/uploads/2018/09/Legislative-Energy-Sector-Development-Strategy-of-the-Republic-of-Serbia-for-the-period-by-2025-with-projections-by-2030.pdf (accessed on 1 June 2022).

68. Balkan Energy. Country Report on Energy Business in Serbia. December 2020. Available online: https://balkanenergy.com/files/Country_report_on_energy_business_in_Serbia_April_2019.pdf (accessed on 1 June 2022).

69. UN Economic and Social Commission for Western Asia. United Nations Development Account Project on Promoting Renewable Energy Investments for Climate Change Mitigation and Sustainable Development: Case Study on Policy Reforms to Promote Renewable Energy in Serbia. 2018. Available online: https://www.unescwa.org/sites/default/files/pubs/pdf/policy-reforms-promote-renewable-energy-serbia-english.pdf (accessed on 1 June 2022).

70. Knežević, D.; Kolonja, B.; Stanković, R.; Tomašević, A.; Nišić, D. Sizing of Coal Storage Yards. In Proceedings of the 11th International Conference on Surface Mining OMC, Zlatibor, Serbia, 15–18 October 2014; pp. 225–236, (In Serbian language).

71. CEE Bankwatch Network. Carbon Costs for Planned Coal Power Plants in the Western Balkans and the Risk of Stranded Assets. 29 March 2017. Available online: http://www.cekor.org/documents/pages/649_2.pdf (accessed on 1 June 2022).

72. Graus, W.; Worrell, E. Methods for calculating CO_2 intensity of power generation and consumption: A global perspective. *Energy Policy* **2011**, *39*, 613–627. [CrossRef]

73. Vignjević, D. Construction of Small Power Plants at Oil and Gas Fields. 2017. Available online: https://www.energy-community.org/dam/jcr:290c4795-7e7e-424f-9eca-97c684b558eb/OF2017_NIS.pdf (accessed on 1 June 2022).

74. International Renewable Energy Agency (IRENA). Renewable Energy Prospects for the European Union. February 2018. Available online: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Feb/IRENA_REmap-EU_2018_summary.pdf?la=en&hash=818E3BDBFC16B90E1D0317C5AA5B07C8ED27F9EF (accessed on 1 June 2022).

75. Marković, Z.; Erić, M.; Cvetinović, D.; Stefanović, P.; Spasojević, V.; Škobalj, P. Determination of the Specific Carbon Dioxide Emission Factor from Thermal Power Plants Nikola Tesla A and B. *Termotehnika* **2016**, *42*, 25–36. [CrossRef]

76. Official Journal of the European Communities. Directive 2001/80/EC of the European Parliament and of the Council of 23 October 2001 on the Limitation of Emissions of Certain Pollutants into the Air from Large Combustion Plants. 2001. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32001L0080&from=EN (accessed on 1 June 2022).

77. Official Journal of the European Union. Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on Industrial Emissions (Integrated Pollution Prevention and Control). 2010. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010L0075&from=en (accessed on 1 June 2022).

78. Brnabić, A.; Turković, M. *A Roadmap for Deploying Renewable Energy Sources in Serbia and the Regional Perspective: Renewable Energy Policy Considerations*; Center for International Relations and Sustainable Development (CIRSD): Belgrade, Serbia, 2015; (In Serbian language).

79. University of Belgrade, Faculty of Mechanical Engineering. Environmental Impact Assessment Study for the Project of Constructing the Cogeneration Plant "TE-TO Pančevo" at the KP 3523/11 K.O. Vojlovica Site. 2018. Available online: http://www.ekourbapv.vojvodina.gov.rs/wp-content/uploads/2019/01/Procena_uticaja_TE-TO_Pancevo_08_01_2019.pdf (accessed on 1 June 2022)(In Serbian language).

80. Anadolu Agency. Is TurkStream's Second Line to Europe Decided? 2018. Available online: https://www.aa.com.tr/en/info/infographic/12295 (accessed on 1 June 2022).

81. World News. Gazprom Chose the Route of "Turkish Stream" to Europe Bypassing Ukraine. 2018. Available online: https://sevendaynews.com/2018/11/22/gazprom-chose-the-route-of-turkish-stream-to-europe-bypassing-ukraine/ (accessed on 25 August 2021).

82. Hydrocarbons Technology. Gas Interconnection Bulgaria—Serbia (IBS) Pipeline. 2020. Available online: https://www.hydrocarbons-technology.com/projects/gas-interconnection-bulgaria-serbia-ibs-pipeline/ (accessed on 1 June 2022).

83. Republic of Serbia, Ministry of Environmental Protection, Directorate for Environmental Protection. National Environmental Strategy. 2004. Available online: https://www.asser.nl/media/2271/cms_eel_id109_1_neap-eng.pdf (accessed on 1 June 2022).

84. Republic of Serbia, Ministry of Environmental Protection, Environmental Protection Agency. Environment in Serbia: 2004–2019—Extended Summary. 2019. Available online: http://www.sepa.gov.rs/download/ENG_FIN_JubilarnaPublikacija.pdf (accessed on 1 June 2022).

85. Republic of Serbia, Ministry of Energy, Development and Environmental Protection. Report on Strategic Environmental Assessment for the Energy Sector Development Strategy of the Republic of Serbia by 2025 with Projections until 2030, for the Period 2017–2023. 2017. Available online: https://www.mre.gov.rs/doc/efikasnost-izvori/SEA_PROGRAM%20FOR%20THE%20IMPLEMENTATION%20ENERGY%20STRATEGY%20%20FOR%20THE%20PERIOD%20FROM%202017%20UNTIL%202023.pdf (accessed on 25 August 2021).

86. Andrijašević, M.; Pašić-Tomić, V. Environment in Serbia in Figures. In Proceedings of the 9th International Symposium on Natural Resources Management (ISNRM 2019), Zaječar, Serbia, 31 May 2019; pp. 1–8.

87. Balkan Green Energy News. PM10 Concentration in Serbia 10 Times Above Limit, as Region Fills Most Polluted Cities Lists. 2019. Available online: https://balkangreenenergynews.com/pm10-concentration-in-serbia-10-times-above-limit-as-region-fills-most-polluted-cities-lists/ (accessed on 1 June 2022).

88. Balkan Green Energy News. Citizens of Serbia Breathe Polluted Air—Particle Pollution Several Times Higher Than Allowed. 2019. Available online: https://balkangreenenergynews.com/citizens-of-serbia-breathe-polluted-air-particle-pollution-several-times-higher-than-allowed/ (accessed on 1 June 2022).

89. Official Gazette of the Republic of Serbia—International Agreements, No. 3/2013-1. The Law on Confirmation of the Intergovernmental Agreement between the Government of the Republic of Serbia and the Government of the Russian Federation for the Supply of Natural Gas. 15 March 2013. Available online: https://www.pravno-informacioni-sistem.rs/SlGlasnikPortal/eli/rep/mu/skupstina/zakon/2013/3/1/reg (accessed on 1 June 2022).

90. Safari, A.; Das, N.; Langhelle, O.; Roy, J.; Assadi, M. Natural gas: A transition fuel for sustainable energy system transformation? *Energy Sci. Eng.* **2019**, *7*, 1075–1094. [CrossRef]

91. Petroleum Industry of Serbia (NIS). Annual Reports on Sustainable Development for 2012–2020. 2013–2021. Available online: https://www.nis.eu/odrzivi-razvoj (accessed on 1 June 2022). (In Serbian language).