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RACE TO CARBON NEUTRALITY. PROSPECTS OF PHASING OUT COAL

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Abstract
Carbon neutrality is necessary to address the global problem of climate change. The International Energy Agency has recognized coal as the largest source of anthropogenic carbon dioxide emissions. This article analyzes carbon dioxide emissions from coal and carbon dioxide emissions from energy for the major emitters of CO_2 emissions. As more than half of the world's Carbon dioxide emissions from coal come from China, the authors have analyzed the extreme situation that could arise in the carbon reduction market if China were to postpone its commitments to reduce coal consumption. The article calculates the time frame required for other coal-consuming countries to phase out coal to compensate for China's annual coal consumption. It demonstrates that without China transitioning from coal consumption to zero-carbon energy sources, other countries will not be able to achieve carbon neutrality by 2050. This proves that for the first time in history, the achievement of the goal set by the global community depends on the actions of a single country. The article outlines the goals set by China in its Nationally Determined Contribution and other government documents to reduce greenhouse gas emissions and achieve carbon neutrality. It also presents China's efforts to implement renewable energy sources, nuclear reactors, and energy storage.

Keywords: **Climate Change, Carbon Neutrality, Carbon Dioxide (CO_2) Emissions, Coal Combustion, Energy Sector, Coal Consumption, China.**

1. INTRODUCTION

Climate change is a global environmental problem of the 21st century. According to the global annual temperature forecast by the National Centers for Environmental Information [1], the year 2023 will be among the 10 warmest years on record. In May, 2021, the International Energy Agency (IEA) released a report, which highlighted the urgent need to stop investing in new coal power plants, fossil fuel extraction projects, and achieve zero emissions in the power sector by 2040 [2]. In November 2021, at the United Nations Framework Convention on Climate Change (UNFCCC) 26th Conference of the Parties (COP26), the Glasgow Climate Pact was adopted, which included a decision to gradually phase out the use of coal [3]. In April, 2022, in the Intergovernmental Panel on Climate Change (IPCC)'s Sixth Assessment Report (AR6), Climate Change 2022: Mitigation of Climate Change, it was concluded that to limit warming to no more than 1.5°C (2.7°F), coal consumption must be reduced by 95% by 2050 compared to the 2019 level, oil by 60%, and gas by 45% [4]. In March 2023, the Intergovernmental Panel on Climate Change (IPCC) released the AR6 Synthesis Report: Climate Change 2023 [5]. The AR6 states that only significant transformations in the energy sector with a rapid phased plan to phase out fossil fuel use can halt the climate crisis.

In the short-term perspective (2023–2030), the gradual reduction of coal usage as an energy source should be at the forefront of the attention of both energy experts and policymakers. Achieving carbon neutrality by the mid-century for carbon dioxide (CO_2) emissions from coal combustion in emitting countries requires an energy transformation involving the adoption of carbon-neutral energy sources and electric vehicles. The challenges of energy transition for many industrializing countries stem from the fact that coal is a locally cheap and competitive energy resource for them. This enables these countries to support economic growth and social stability. However, to fulfil their Nationally Determined Contributions (NDCs) under the Paris Agreement [6], economic growth in these nations must be accompanied by a gradual shift away from coal and a reduction in carbon emissions.

2. RESEARCH METHODS

The main objective of the article is to analyze coal consumption in the largest emitting countries to assess the potential for its reduction in line with the decisions of the Glasgow Climate Pact. 2019 was chosen as the baseline year because in AR6, quantitative commitments to reduce fossil fuel consumption compared to the baseline year of 2019 were provided. And 2019 was the last stable pre-pandemic (COVID-19) year. The atypical year of 2020, marked by the COVID-19 pandemic, was excluded from the analysis. The dynamics of CO_2 emissions from coal combustion in energy and metallurgical processes in the post-COVID-19 year of 2021 were compared to the baseline year of 2019. Due to the absence of statistical data on CO_2 emissions from coal combustion by country for the year 2022 as of the writing date of the article, no analysis was conducted for that year. To assess the impact of the crisis in energy markets caused by Russia's war against Ukraine, primary energy consumption by country and coal consumption by country in 2022 were compared to the baseline year of 2019. Statistical data from sources such as the "Statistical Review of World Energy", "Global CO_2 emissions from energy combustion and industrial processes", as well as reports from the International Energy Agency (IEA) and other sources were used for the analysis.

The authors use a comparative analysis method, constructing tables reflecting the dynamics of changes in CO_2 emissions from coal combustion and coal consumption by country. They also employ analytical methods, including statistical analysis of real data.

3. GLOBAL CARBON DIOXIDE EMISSION FROM COAL AND CARBON DIOXIDE EMISSIONS FROM ENERGY

In 2019 global carbon dioxide emissions from coal combustion accounted for approximately 43.2% of global carbon dioxide emissions from energy. The primary emitters of CO_2 emissions from coal combustion were 16 countries, whose combined emissions constituted around 91.9% of global CO_2 emissions from coal combustion (Table 1). These countries also contributed around 71.5% of global CO_2 emissions from energy (Table 2).

In 2021, global CO_2 emissions from coal combustion accounted for approximately 43.9% of global CO_2 emissions from energy. The combined country's CO_2 emissions from coal combustion by major emitters constituted 92.8% of global CO_2 emissions from coal combustion. The CO_2 emissions from energy in these countries amounted to 72.5% of global CO_2 emissions from energy (Table 2).

Global CO_2 emissions from energy decreased by 8 mln t (Mt) (0.02%) over the two analyzed years. However, CO_2 emissions from coal combustion increased by 240 Mt (1.6%). CO_2 emissions from energy in the 16 analyzed countries increased by 256 Mt (1%), while CO_2 emissions from coal combustion increased by 346 Mt (2.6%).

The analysis of Table 1 showed that the combined efforts of the major emitting countries to reduce CO_2 emissions from coal combustion (United States, Japan, South Africa, Russian Federation, South Korea, Indonesia, Germany, Turkey, Australia and Ukraine) 205 Mt (or 1.4% of global CO_2 emissions) in 2019 were unable to halt the increase in global CO_2 emissions from coal combustion. In 2021, the total CO_2 emissions from coal combustion for these 10 countries amounted to 3 402 Mt (or 22.8% of global CO_2 emissions from coal combustion).

As evident from Tables 1 and 2, the CO_2 emissions from coal combustion of some countries in the industrialization stage of their economies constituted a significant portion with a relatively small contribution to global carbon dioxide emissions from energy. For example, in 2019 CO_2 emissions from coal combustion in Vietnam accounted for approximately 1.3% of global CO_2 emissions from coal combustion, while Kazakhstan contributed about 1.2% of global CO_2 emissions from coal combustion. In contrast, their contributions to global

Table 1.
Carbon Dioxide Emissions from Coal Combustion by Country [7, 8]

Parameter	CO_2 emissions from coal combustion							CO_2 emissions from	
	country		Δ: country's - country's	country's / country's	country's / global			country's coal combustion / country's energy	
Year	2019	2021	2021 / 2019		Δ / 2021	2019 / 2019	2021 / 2021	2019 / 2019	2021 / 2021
Country ↓ Unit →	Mt	Mt	Mt	%	%	%	%	%	%
Global	14 710.00	14 950.00	240.00	1.63	1.61			43.21	43.90
China	7 540.00	7 960.00	420.00	5.57	2.81	51.26	53.24	75.94	75.32
India	1 680.00	1 800.00	120.00	7.14	0.80	11.42	12.04	69.69	73.12
United States	1 070.00	1 000.00	-70.00	-6.54	-0.47	7.27	6.69	21.49	21.02
Japan	432.25	418.82	-13.43	-3.11	-0.09	2.94	2.80	38.57	39.27
South Africa	394.35	370.27	-24.08	-6.11	-0.16	2.68	2.48	83.18	84.40
Russian Federation	390.37	380.23	-10.14	-2.60	-0.07	2.65	2.54	25.04	24.00
South Korea	321.61	283.91	-37.70	-11.72	-0.25	2.19	1.90	50.62	47.08
Indonesia	315.40	303.15	-12.25	-3.88	-0.08	2.14	2.03	56.05	58.34
Germany	240.09	230.22	-9.87	-4.11	-0.07	1.63	1.54	35.30	35.82
Vietnam	191.44	196.52	5.08	2.65	0.03	1.30	1.31	65.76	71.96
Poland	177.94	179.50	1.56	0.88	0.01	1.21	1.20	58.96	57.92
Kazakhstan	176.15	180.82	4.67	2.65	0.03	1.20	1.21	79.89	83.25
Turkey	164.97	162.56	-2.41	-1.46	-0.02	1.12	1.09	42.66	39.40
Australia	164.47	150.96	-13.51	-8.21	-0.09	1.12	1.01	40.39	40.76
Taiwan	154.56	154.89	0.33	0.21	0.002	1.05	1.04	55.34	55.28
Ukraine	114.05	101.83	-12.22	-10.71	-0.08	0.78	0.68	61.48	60.72
16 Countries	13 527.65	13 873.68	346.03	2.56	2.31	91.96	92.80		

Table 2.
Carbon Dioxide Emission from Energy by Country [8]

Parameter	CO_2 emissions from Energy						
	country		Δ: country's - country's	country's / country's	country's / global		
Year	2019	2021	2021 / 2019		Δ / 2021	2019 / 2019	2021 / 2021
Country ↓ Unit →	Mt	Mt	Mt	%	%	%	%
Global	34 044.0	34 052.2	8.2	0.02	0.02		
China	9 933.7	10 563.5	629.8	6.34	1.85	28.18	31.02
India	2 407.3	2 464.7	57.4	2.38	0.17	7.07	7.24
United States	4 981.6	4 768.4	-213.2	-4.28	-0.63	14.63	14.00
Japan	1 120.6	1 066.6	-54.0	-4.82	-0.16	3.29	3.13
South Africa	474.1	438.7	-35.4	-7.47	-0.10	1.39	1.29
Russian Federation	1 559.2	1 584.2	25.0	1.60	0.07	4.58	4.65
South Korea	635.3	603.0	-32.3	-5.08	-0.09	1.87	1.77
Indonesia	562.7	519.6	-43.1	-7.66	-0.13	1.65	1.53
Germany	680.1	642.8	-37.3	-5.48	-0.11	2.00	1.89
Vietnam	291.1	273.1	-18.0	-6.18	-0.05	0.86	0.80
Poland	301.8	309.9	8.1	2.68	0.02	0.89	0.91
Kazakhstan	220.5	217.2	-3.3	-1.5	-0.01	0.65	0.64
Turkey	386.7	412.6	25.9	6.70	0.08	1.14	1.21
Australia	407.2	370.4	-36.8	-9.04	-0.11	1.20	1.09
Taiwan	279.3	280.2	0.9	0.32	0.003	0.82	0.82
Ukraine	185.5	167.7	-17.8	-9.60	-0.05	0.54	0.49
16 Countries	24 426.7	24 682.6	255.9	1.16		71.45	72.48

CO_2 emissions from energy were around 0.9% for Vietnam and 0.7% for Kazakhstan. In 2021, Vietnam and Kazakhstan increased their CO_2 emissions from coal combustion by approximately 5 Mt each, representing around a 2.7% increase for each country.

However, India's CO_2 emissions from coal combustion in 2019 accounted for a significant 11.4% of global CO_2 emissions from coal combustion and 7.1% of global CO_2 emissions from energy. Meanwhile, China's CO_2 emissions from coal combustion constituted a substantial 51.2% of global CO_2 emissions from coal combustion and 29.2% of global CO_2 emissions from energy.

India, whose CO_2 emission from Coal combustion accounted for 12% of global CO_2 emission from coal combustion in 2021, increased emissions by 120 Mt (approximately 7.2% of India's CO_2 emission from coal combustion or 0.8% of the global CO_2 emission from coal combustion in 2021).

China, whose CO_2 emission from coal combustion represented about 53.2% of global CO_2 emission from coal combustion in 2021, increased emissions by 420 Mt (5.6%) in China's CO_2 emission from Coal combustion. This amounted to 2.8% of the global CO_2ded the combined CO_2 emission from coal combustion of Turkey, Taiwan and Ukraine (419 Mt).

The data from Tables 1 and 2 show that in 2021, the responsibility for carbon dioxide emissions from coal combustion in global emissions can be divided into four groups:

1. The most significant contribution is from China, accounting for approximately 53.2% of the global CO_2 emissions from coal combustion.
2. The high contributions of two countries (United States and India), whose combined CO_2 emissions from coal combustion amounted to approximately 2 800 Mt, accounting for around 18.7% of the global CO_2 emissions from coal combustion.
3. The significant contributions of 13 countries (Japan, South Africa, Russian Federation, South Korea, Indonesia, Germany, Vietnam, Poland, Kazakhstan, Turkey, Australia, Taiwan and Ukraine), whose combined CO_2 emissions from coal combustion amounted to approximately 3 114 Mt, accounting for approximately 20.8% of the global CO_2 emissions from coal.
4. A negligible contribution from the rest of the world's countries, whose combined CO_2 emissions from coal combustion amounted to only 1 076 Mt, making up approximately 7.2% of global CO_2 emissions from coal combustion.

Among the top three global emissions contributors (China, United States, India) responsible for approximately 17 797 Mt of CO_2 emissions from energy in 2021, accounting for 52.3% of global CO_2 emissions from Energy. Interestingly, these same countries are also among the top three emitters of carbon dioxide emissions from coal combustion. These three countries are responsible for approximately 10 760 Mt of CO_2 or about three-quarters (72.0%) of global CO_2 emissions from coal combustion. While China contributes 31.0% to global CO_2 emissions from energy, it accounts for a significant 53.2% of global CO_2 emissions from coal combustion.

This is the first time that the collective efforts of the world have resulted in less reduction in emissions than the efforts of a single country. These results underscore China's unique responsibility for reducing global CO_2 emissions from coal combustion. The second and third groups of countries cannot compensate for more than 50% of global carbon dioxide emissions from coal combustion due to China's emissions. Reductions in carbon dioxide emissions from coal combustion by the fourth group of countries do not have a significant impact on reducing anthropogenic carbon dioxide emissions from coal combustion.

4. CHINA'S COAL CONSUMPTION

4.1. Coal consumption by country

The 16 countries, major emitters of carbon dioxide emissions from energy, account for two-thirds of primary energy consumption. In 2022, primary energy consumption (PEC) increased by 16.7×10^{18} J (EJ) (2.8%) compared to the year 2019 (Table 3).

In 2019, the combined country coal consumption of these countries accounted for 144.8 EJ (91.9%) of global coal consumption, while their PEC represented 394.4 EJ (67.2%) of global PEC (as shown in Table 3). In the subsequent period, the combined coal consumption of these countries increased to 148.8 EJ (92.9%) of global coal consumption, and their PEC increased to 406.0 EJ (67.9%) of global PEC. Global coal consumption accounted for approximately 26.7% of PEC in 2022 (Table 4).

Analysis of Table 3 shows that the leader in PEC is China (approximately 26.4%) and PEC in China increased by 14.7 EJ (10.1%) from 2019 to 2022. Coal consumption represented nearly half of their PEC: 68.7% for South Africa, approximately 55% for

Table 3.
Primary Energy Consumption by Country [8]

Parameter	Primary Energy Consumption							
	country			Δ: country's - country's	country's / country's	country's / global		
Year	2019	2021	2022	2022 / 2019		Δ / 2022	2019 / 2019	2022/2022
Country ↓ Unit →	EJ	EJ	EJ	EJ	%	%	%	%
Global	587.39	597.41	604.04	16.65	2.83			
China	144.74	157.94	159.39	14.65	10.12	2.43	24.64	26.39
India	33.52	34.51	36.44	2.92	8.71	0.48	5.71	6.03
United States	95.67	93.40	95.91	0.24	0.25	0.04	16.29	15.88
Countries in group 2	129.19	127.91	132.35	3.16	2.45	0.52	21.99	21.91
Japan	18.51	17.94	17.84	-0.67	-3.62	-0.11	3.15	2.95
South Africa	5.33	5.00	4.82	-0.51	-9.57	-0.08	0.91	0.80
Russian Federation	30.16	31.48	28.89	-1.27	-4.21	-0.21	5.13	4.78
South Korea	12.48	12.56	12.71	0.23	1.84	0.04	2.12	2.10
Indonesia	8.22	7.76	9.77	1.55	18.86	0.26	1.40	1.62
Germany	13.31	12.78	12.30	-1.01	-7.59	-0.17	2.27	2.04
Vietnam	4.34	4.34	4.59	0.25	5.76	0.04	0.74	0.76
Poland	4.27	4.41	4.31	0.04	0.94	0.01	0.73	0.71
Kazakhstan	2.93	2.93	3.12	0.19	6.48	0.03	0.50	0.52
Turkey	6.60	6.96	7.01	0.41	6.21	0.07	1.12	1.16
Australia	6.05	5.73	5.98	-0.07	-1.16	-0.01	1.03	0.99
Taiwan	4.84	4.98	4.78	-0.06	-1.24	-0.01	0.82	0.79
Ukraine	3.45	3.36	2.33	-1.12	-32.46	-0.19	0.59	0.39
Countries in group 3	120.49	120.23	118.45	-2.04	-1.69	-0.34	20.51	19.61
Countries in group 4	192.97	191.33	193.85	0.9	0.46	0.15	32.85	32.09
16 Countries	394.42	406.08	410.19	15.77	4.00	2.61	67.15	67.91

Table 4.
Coal Consumption by Country [8, 9]

Parameter	Coal Consumption									
	country			Δ: country's - country's	country's / country's	Coal / Energy Consumption by country's		country's / global		
Year	2019	2021	2022	2022 / 2019		2019	2022	Δ / 2022	2019 / 2019	2022/2022
Country ↓ Unit →	EJ	EJ	EJ	EJ	%	%	%	%	%	%
Global	157.64	160.43	161.47	3.83	2.43	26.84	26.73			
China	81.79	87.54	88.41	6.62	8.09	56.51	55.47	4.10	51.88	54.75
India	18.60	19.30	20.09	1.49	8.01	55.49	55.13	0.92	11.80	12.44
United States	11.34	10.57	9.87	-1.47	-12.96	11.85	10.29	-0.91	7.19	6.11
Countries in group 2	29.94	29.87	29.96	0.02	0.07	23.18	22.64	0.01	18.99	18.55
Japan	4.91	4.93	4.92	0.01	0.20	26.53	27.58	0.01	3.11	3.05
South Africa	3.64	3.51	3.31	-0.33	-9.07	68.29	68.67	-0.20	2.31	2.05
Russian Federation	3.57	3.43	3.19	-0.38	-10.64	11.84	11.04	-0.24	2.26	1.98
South Korea	3.44	3.04	2.87	-0.57	-16.57	27.56	22.58	-0.35	2.18	1.78
Indonesia	3.41	2.75	4.38	0.97	28.45	41.48	44.83	0.60	2.16	2.71
Germany	2.25	2.24	2.33	0.08	3.56	16.90	18.94	0.05	1.43	1.44
Vietnam	2.07	2.16	2.05	-0.02	-0.97	47.70	44.66	-0.01	1.31	1.27
Poland	1.86	1.9	1.81	-0.05	-2.69	43.56	42.00	-0.03	1.18	1.12
Kazakhstan	1.66	1.40	1.44	-0.22	-13.25	56.66	45.15	-0.14	1.05	0.89
Turkey	1.76	1.74	1.75	-0.01	-0.57	26.67	24.96	-0.01	1.12	1.08
Australia	1.75	1.63	1.55	-0.20	-11.43	28.93	25.92	-0.12	1.11	0.96
Taiwan	1.67	1.68	1.58	-0.09	-5.39	34.50	33.05	-0.06	1.06	0.98
Ukraine	1.08	0.95	0.52	-0.56	-51.85	31.30	22.32	-0.35	0.69	0.32
Countries in group 3	33.07	31.36	31.70	-1.37	-4.14	27.45	26.76	-0.85	20.98	19.63
Countries in group 4	12.84	11.66	11.40	-1.44	-11.21	15.73	14.82	-0.89	8.15	7.06
16 Countries	144.80	148.77	150.07	5.27	3.64	36.71	36.59	3.26	91.85	92.94

China and India each, approximately 45% for Kazakhstan, Indonesia and Vietnam and 42% for Poland. Some countries had slightly lower coal consumption: Japan (27.6%), Australia and Turkey (approximately 25% each), South Korea and Ukraine (approximately 22% each) and Germany had approximately 19%. Russian Federation has a very low coal consumption rate of 11.0%, and the United States decreased to 10.3% during the same period.

The data in Tables 3 and 4 show that the responsibility of countries based on their share of Country Coal Consumption in Global Coal Consumption in 2022, can be divided into four groups:

1. Major contributors (88 EJ) China – approximately 55%.
2. High contributors (10 EJ < India, USA < 20 EJ) – approximately 18.6%.
3. Contributors (0.5 EJ < 13 countries < 5 EJ) – approximately 19.6%.
4. Minor contributors from other countries (<0.5 EJ) – approximately 7%.

Over the analyzed period, the main increase in Coal Consumption occurred in countries of the first and second groups: China and India (+5.0% Global Coal Consumption). In Germany a slight increase in coal consumption (+3.6% over two years) is attributed to the transformation of energy flows following the conflict between Russia and Ukraine. The significant decrease in energy consumption by 32.5% and coal consumption by 51.9% in Ukraine is due to the war with Russia, the loss of access to coal deposits in its territories, and a portion of its coal generation. All other countries experienced a decrease in coal consumption.

As evident from Tables 1–4, China is the global leader in CO_2 emissions and coal consumption. The increase in China's Coal Consumption from 2019 to 2022 by 6.6 EJ corresponds to approximately 4.1% of the Global Coal Consumption in the year 2022.

4.2. Compliance time interval between China's annual coal consumption and countries in groups 2, 3, and 4

According to the data in Tables 1–4, China leads the world in coal consumption and CO_2 emissions. The authors analyzed the timeline for the correspondence between China's annual coal consumption and the annual coal consumption of other countries to assess the contribution of major coal-consuming countries to Global Coal Consumption. They used a "business as usual" scenario for each country's coal consumption in 2022 as the baseline. They determined the time interval required for all countries in the world to compensate for China's annual coal consumption. The maximum scenario of complete abandonment of coal consumption, both by individual countries and groups of countries, was chosen as a marker for the fastest compensation (Table 5).

As evident from Table 5, China's annual coal consumption corresponds to:
- 3 years of coal consumption by the countries in the group 2 (India, USA);
- 2 years of coal consumption by the 13 countries in the group 3;
- 7 years of coal consumption by the countries in the group 4.

Alternatively, in terms of individual countries in the 2 and 3rd groups, China's annual coal consumption corresponds to a period ranging from 4…9 years (India, USA) to 38...49 years (Germany, Vietnam, Poland) and 51...61 years (Kazakhstan, Turkey, Australia, and Taiwan). And Ukraine needs to phase out coal for 170 years! The contribution of other countries in the fourth group is quite insignificant.

Since in reality, none of the listed countries can immediately abandon coal usage, the maximum scenario underscores the challenges of achieving the goals outlined by the International Energy Agency

Table 5.
The time interval of China's annual coal consumption and other countries

Parameter	China's coal consump-tion compared to		Parameter	China's coal consumption compared to	
	individual countries	the group of coun-tries		individual countries	the group of countries
Country	Year		*Country*	Year	
India	4		*Vietnam*	43	
United States	9		*Poland*	49	
All countries in group 2		3	*Kazakhstan*	51	
Japan	18		*Turkey*	57	
South Africa	27		*Australia*	56	
Russian Federation	28		*Taiwan*	61	
South Korea	31		*Ukraine*	170	
Indonesia	20		*All countries in group 3*		2
Germany	38		*All countries in group 4*		7

for carbon neutrality by 2050 [2], particularly without China abandonment or substantial reduction of coal consumption, which may not seem very realistic. To achieve the ambitious goal for reduction of coal consumption, China currently critically needs a rapid and comprehensive transformation of its energy system, and it would be beneficial for all other countries to provide extensive assistance. Next, we will explore what China is planning to do to achieve this ambitious task.

4.3. China's Climate Policy

China, a country rich in coal, recognizes its responsibility for increasing greenhouse gas emissions.

Nationally Determined Contribution

In 2021, China adopted its NDC [9]. The goals of China's NDC include:

- Achieving peak CO_2 emissions by 2030 and carbon neutrality by 2060.
- Reducing CO_2 emissions per unit of Gross domestic product (GDP) by more than 65% compared to the 2005 level.
- Increasing the share of non-fossil fuels in primary energy consumption to around 25%.
- Reaching a total installed capacity of wind and solar energy of over 1.2 billion kilowatts (TWh) by 2030.

The year 2005 serves as the base year for China, as it represents a period of rapid economic development for the country and several others. The choice of base year has an impact on China's targets for reducing CO_2 emissions from fuel combustion, as shown in Table 6. The CO_2 emissions from fuel combustion in Table 6 cover only emissions from the combustion of fossil fuels (coal, oil, and gas).

Data in Table 6 demonstrate that the abandonment of the base year 1990 in order to meet the country's obligations to reduce greenhouse gas emissions is more favorable for the country undergoing fast-paced economic development. The influence of the base year choice on countries' ambitions for reducing greenhouse gas emissions has been studied in works [11–13].

China's Approaches to NDC Implementation

China has adopted several documents to establish a low-carbon energy system:

- On March 12, 2021, the Outline of the People's Republic of China 14th Five-Year Plan for National Economic and Social Development and Long-Range Objectives for 2035 was released [14].
- On October 12, 2021, the "1+N" Roadmap for achieving carbon neutrality in all sectors was announced [15].
- On October 24, 2021, the general guidance document "Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy" was published [16].
- On October 26, 2021, the first "N" of the "1+N" system, the Action Plan for Carbon Dioxide Peaking Before 2030, was published [17].

The 14th FYP is the first Plan that includes much-awaited targets and guidelines on modernising the industrial system, including the energy system, along with promoting green development. The current targets on energy consumption and emissions intensity are broadly consistent with China's climate pledges and the Paris Agreement, strengthened front-loaded actions to realise the low-carbon transformation and ensure consistency between China's climate pledges and its development vision.

However, after the energy crisis in 2021, China stated that its top priorities are domestic energy security and economic development, even as the country strives for a "green transition" [18]. The energy market crisis, caused by Russia's war against Ukraine also slowed down China's plans to phase out to coal usage.

To strengthen its energy security, China increased its coal consumption. On April 20, 2022, during a State Council executive meeting, it was announced that coal would play a more significant role as a primary energy source [19]. The issuance of permits for coal-fired power plants, the commencement of construction, and announcements of new projects sharply accelerated in 2022, with the number of new permits reaching the highest level since 2015 [20].

According to the analysis by the E3G (Third Generation Environmentalism) analytical center, China has been accelerating approvals for new coal-fired power plants. As of January 2023, China accounted for 72% (250 GW) of global pre-construction coal capacity, while in July 2022, it was 66%. This contrasts sharply with the rest of the world, where the cumulative

Table 6.
China CO_2 emissions from fuel combustion [10]

CO_2, Mt	1990	2005	2019	2020	2021	2022
China	2 255	5 471	9 721	9 859	10 397	10 504

Table 7.
Coal Power Capacity in Development and Operating [22]

Country	Pre-construction	Construction	Shelved	Operating	Mothballed	Cancelled 2010-2022
World, GW	353.313	204.153	117.010	2 095.041	26 486	1 780.343
China, GW	255.463	136.237	50.930	1 108.908	2 045	601.762
Percent China	72%	67%	44%	53%	8%	34%

Table 8.
Coal consumption [25, 26]

Country	Parameter	2019	2021	2022	2025*
World	Total Coal Consumption, Mt	7 801	7 929	8 025	8 038
	Thermal coal and lignite consumption, Mt	6 667	6 820	6 945	6 960
	Metallurgical coal consumption, Mt	1 134	1 110	1 080	1 078
China	Total Coal Consumption, Mt	3 950	4 232	4 250	4 337
	Thermal coal and lignite consumption, Mt	3 206	3 511	3 542	3 643
	Metallurgical coal consumption, Mt	744	720	708	694
China / World	Total Coal Consumption, %	50.6	53.4	53.0	54.0
	Thermal coal and lignite consumption, %	48.1	51.5	51.0	52.3
	Metallurgical coal consumption, %	65.6	64.9	65.6	64.6
China coal / China total					
	Thermal coal and lignite consumption, %	81.2	83.0	83.3	84.0
	Metallurgical coal consumption, %	18.8	17.0	16.7	16.0

*2025 are forecasts IEA

Table 9.
The Dynamics of Coal Consumption Worldwide and in China

Parameter	World				China			
	2022/2019		2025/2022		2022/2019		2025/2022	
	ΔMt	%	Δ	%	ΔMt	%	Δ	%
Total Coal Consumption	224	2.87	13	0.16	300	7.59	87	2.05
Thermal coal and lignite consumption	278	4.17	15	0.22	336	10.48	101	2.85
Metallurgical coal consumption	-54	-4.76	-2	-0.19	-36	-4.84	-14	-1.98

capacity of pre-construction coal power plants has decreased to 97 GW during the same period [21].

The coal power capacity in development and operation is shown in Table 7. In July 2023 China's operating coal power capacity accounted for 53% of the world's operating coal power capacity (Table 7).

In its working plan for 2023, the government aims to further increase domestic coal production to support energy security [23]. The energy system still relies on the capacity of coal-fired power plants to meet peak electricity demand and manage the variability of supply and demand for clean energy [24].

The dynamics of coal consumption are shown in Tables 8 and 9.

According to the data in Tables 8 and 9, China's thermal coal consumption accounted for 81.2% of China's total coal consumption in 2019, while metallurgical coal consumption accounted for 18.8%. By 2022, China's coal consumption increased by 7.6%, with thermal coal consumption increasing by 10.5%, and metallurgical coal consumption decreasing by 4.8%. But World's coal consumption increased by 2.9%, with thermal coal consumption increasing by 4.2%, and metallurgical (or coking) coal consumption decreasing by 4.8%. According to IEA's forecast, by 2025, coal consumption will increase by 2% compared to 2022, thermal coal consumption will increase by 2.9%, and metallurgical (or coking) coal consumption will decrease by 2%. IEA forecast for China's coal demand through 2025 is underpinned by two key assumptions: growth in GDP and industrial production. IEA assume annual growth of ~4.7% on average for GDP and ~5% for industrial production. China's electricity demand is forecast to increase by ~5% [26].

China's carbon dioxide emissions from fuel combustion by sector are shown in Table 10. (Table 10).

The main consumption sector of thermal coal and lignite consumption is electricity and heat production.

China, the world's largest steel producer, is reducing its consumption of coking coal for steel production.

Table 10.
China's CO_2 emissions from fuel combustion by sector [27]

Parameter	Electricity and heat production	Other energy industry own use	Manuf. industries and construction	Transport	of which: road	Residential	Commercial and public services
unit	%	%	%	%	%	%	%
2019	53.0	3.5	28.1	9.1	7.4	3.4	1.2
2021	55.8	2.9	26.6	9.1	7.4	3.1	1.1%

Met coal demand fell by 2.5% (-20 Mt) as energy shortages and a weaker construction sector curbed steel output. To contribute to China's goal of decarbonizing the steel industry, the Ministry of Industry and Information Technology (MIIT) announced that the share of raw steel produced using electric arc furnaces (EAF) will exceed 15% by 2025 and reach 20% by 2030 [28]. China may reduce its consumption of coking coal in steel production by 20–25% by 2030 [29]. It is projected that the share of electric arc furnaces (EAF), primarily used for processing direct reduced iron (DRI), including scrap or environmentally clean DRI, in the total volume of raw steel production in China will increase to 22% by 2030 from the current 12%.

Zero Emissions Energy Sources in China

Despite the increase in fossil fuel consumption, China has set clear and detailed goals to facilitate the "green" transition of its energy sector towards carbon neutrality.

- On March 22, 2022, the National Development and Reform Commission (NDRC) and the National Energy Administration (NEA) issued the 14th Five-Year Plan (FYP) for the "Modern Energy System" [30].

Within the 14th FYP, China emphasizes ensuring energy security and sets key tasks and priorities for 2025 (compared to the end of 2020):

– Reduce energy intensity of Gross Domestic Product (GDP) by 13.5%.
– Reduce CO_2 intensity of GDP by 18%.
– Stabilize existing coal production and coal-fired power while fully leveraging their supporting role in the energy transition to new clean energy sources such as wind, solar, hydro, and nuclear. The goal is to increase the non-fossil fuel share of energy to 20%, the non-fossil fuel share of power to 39%, nuclear power to 70 GW, and hydro power (including pumped hydro) to 380 GW.
– Specific shares of coal in the total energy mix and share of coal-fired power in total power generation are no longer listed.

- On March 22, A Plan for New Energy Storage was published [31].
- On March 23, 2022, the NDRC and NEA published the Medium and Long-Term Plan for the Development of the Hydrogen Energy Industry (2021–2035) [32].
- On June 1, 2022, the NDRC published the 14th Five-Year Plan for the development of renewable energy (RE) (2021–2025) [33].

By 2025, as part of the 14th RE FYP, China has set the following goals:

- Renewable energy should account for 33% of the national energy consumption, compared to 28.8% in 2020.
- Non-hydro renewable energy (geothermal heating, biomass and fuel heating, and solar heating) should reach a share of 18%.
- Annual production of renewable energy should reach 3.3 TW-hours, compared to 2.2 TW-hours in 2020.

If the adopted plans are scaled up, new energy sources could replace coal as a cleaner and more flexible means of energy. China's emissions-peaking timetable will be dictated by when clean energy growth overtakes total energy demand growth.

The dynamics of installed capacity of power generation and electricity production in China are shown in Table 11 and 12.

According to the data in Table 11, in 2022 China added 26GW of thermal power from January to June in 2023, a 97% year-over-year (y-o-y) increase. Thermal Power installed capacity increased by 12%, while Zero-Emissions Power installed capacity higher by 51% than in 2019. In the first half of the calendar year 2023 (1HCY2023) China added 78 GW of solar power and 23 GW of wind power. Hydropower added only 5 GW during 1HCY2023. Total zero emissions capacity in 1HCY2023 increased by 115 GW. Coal remains the primary energy source for electricity production. In 2023, coal energy capacity accounted for 71%, while zero-emissions capacity accounted for 29% (Table 12).

Table 11.
China's Installed Generation Capacity [34, 35, 36]

Parameter	2019	2021	2022	July-2023	2022, %
Thermal Power, GW	1 190	1 297	1 332	1 364	52
Hydropower, GW	358	391	414	418	16
Nuclear Power, GW	49	53	56	57	2
Wind Power, GW	209	329	365	393	14
Solar Power, GW	204	307	393	491	15
Others (Biomass, Waste to Energy), GW	0.4	0.9	5	17	0.2
Total electric power, GW	2 010	2 378	2 564	2 740	100

Table 12.
China's Electricity Generation [8, 9, 36]

Parameter	2019	2021	2022	Jan-June 2023
Electricity Generation, TWh	7 503.4	8 534.3	8 848.7	4 168
Electricity generation by fuel, %				
Coal	64.63	62.44	61.00	70.68
Oil	0.14	0.14	0.13	
Gas	3.10	3.36	3.28	
Nuclear energy	4.65	4.77	4.72	5.09
Hydroelectric	16.96	15.23	14.73	10.80
Renewables	9.89	13.46	15.45	13.55
Other	0.63	0.59	0.68	0.00

As of January 2023, China had 57 nuclear power units in operation with a total capacity of 58.3 GW, ranked as third in the world (15% of Global Total) [37]. By 2030, China is expected to surpass the United States and become the world's largest nuclear power plant operator, according to the report, released by the China Nuclear Energy Association [38]. By 2035, China's nuclear power generation will account for 10 per cent of the country's electricity generation, according to the latest Blue Book of China Nuclear Energy Development Report [39]. According to the data in Table 12, China added 18% Electricity Generation from 2019 to 2022.

From Table 12, it can be observed that the share of coal, although slightly, is decreasing (approximately 1.3%), the share of nuclear energy is slightly increasing (approximately 2.5%), and the share of renewable energy sources in 2022 increased by 19% compared to 2021. Non-fossil fuel electricity production was 3 088 TWh, 8.1% higher than in 2021.

The National Energy Administration (NEA) reports that in the first quarter of 2023, pumped hydro storage (PHS) capacity increased by 1.5 GW, reaching a total of 47 GW. As a result, China has become the largest PHS operator in the world, more than doubling Japan, which is the second-largest with 22 GW, and the United States has the third place with 19 GW. PHS and batteries will play an increasingly important role in ensuring grid reliability as the penetration of variable renewable energy continues to grow. The NEA reports that new energy storage (principally batteries) reached 8.7 GW by the end of 2022 (+110% y-o-y). This puts China on track for its 50 GW of battery capacity by 2025 target, second only to the US [40].

While China has made remarkable progress in its renewable rollout, the country remains the world's largest polluter. Today China only gets 13.4% of its electricity from wind and solar, according to Chinese national statistics cited by GEM. The majority (65%) of its power comes from fossil fuels [41].

But in the first six months of 2023 China also has approved at least 50.4 GW of new coal power, new research from Greenpeace East Asia shows [42].

5. CONCLUSIONS

1. The analysis of carbon dioxide emissions from coal shows that 92% of emissions are attributed to 16 countries, with China accounting for 53% of the emissions.
2. Two countries, China and India, which are in the rapid industrialization phase of their economies and account for 67% of Global CO_2 emissions from Coal Combustion, increased their Coal Combustion by 8 EJ or 5% from 2019 to 2022.
3. Despite the world's efforts to reduce Coal

Consumption by 3.8 EJ or 2.4% of Global Coal Consumption, Global Coal Consumption increased by 4.75 EJ or 3.0%.

4. In the event of China extending the timeline for achieving its commitments to reduce coal consumption, other countries will not be able to achieve carbon neutrality even if they completely cease coal consumption for several years.
5. China's government plans for transitioning to carbon-free energy sources are optimistic. China is rapidly increasing its production of carbon-free electricity, and there are reasons to believe that it will be able to fulfil its crucial commitments to reduce coal consumption for the benefit of the world.

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