

COMPARATIVE STUDY OF THE MAIN SOURCES OF CO₂ EMISSIONS IN CHINA: SECTOR REVIEW

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Naskah Diterima: Maret 2025/Revisi: Mei 2025 /Disetujui: Juni 2025

ABSTRACT

Climate change poses severe threats to ecosystems, economic activities, and human health, primarily due to increased greenhouse gas concentrations, especially carbon dioxide (CO₂). China, being one of the largest contributors to global CO₂ emissions, faces the significant challenge of peaking its CO₂ emissions before 2030 and achieving carbon neutrality by 2060. In 2022, China accounted for 31.1% of global CO₂ emissions from combustible fuels, totaling 10,613.17 Mt CO₂. This study aims to analyze the main sources of CO₂ emissions in China and identify key sectors contributing to these emissions. The research employs both qualitative and quantitative methods, using secondary data from the International Energy Agency (IEA) and the Chinese National Bureau of Statistics, and applying the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. The results reveal that China's CO₂ emissions from fuel combustion increased significantly from 2000 to 2022, with coal combustion being the largest source, accounting for 79% of total emissions. The electricity and heat production sector is the largest contributor, followed by the industrial and transportation sectors. Per capita CO₂ emissions also showed a significant increase, reaching 7.51 tCO₂ per capita in 2022. China's efforts to control and reduce CO₂ emissions through measures such as Carbon Capture and Storage (CCS) technology, improving the efficiency of coal-fired power plants, and promoting reforestation and sustainable agricultural practices are crucial for addressing the challenges posed by climate change. The integration of renewable energy sources and the transition to cleaner technologies will be vital for mitigating future emissions and fostering a sustainable future.

Keywords: Climate Change, Carbon dioxide, Greenhouse, Fuel Combustion, Carbon Capture and Storage (CCS), The Belt and Road Initiative

INTRODUCTION

The effects of climate change are very hazardous, among others, they can disrupt ecosystems (G. Klein, et al. 2022), economic activities (M. Waldinger. 2022), and human health (C. Mora. et al. 2022). It has been broadly accepted that the increase in greenhouse gas concentrations, especially carbon dioxide (CO₂), in the atmosphere is the main reason for climate change (M. Filonchyk, M.P. et.al. 2024). Therefore, to mitigate climate change, which is inevitable, carbon neutrality is needed, namely net zero CO₂ emissions (C. Zhao. 2022).

Carbon dioxide (CO₂) emissions have become one of the most significant environmental concerns globally, with profound implications for climate change and global sustainability (J. Min. et al. 2022). China is one of the largest contributors to carbon dioxide (CO₂) emissions in the world. One of China's efforts is to reduce CO₂ emissions by making international commitments. China submitted its Nationally Determined Contribution (NDC) in preparation for the Conference of Parties 21 (COP21) On 30 June 2015 (NDRC. 2024). China's NDC was used as a handler at the United Nations Framework Convention held in December 2015. NDC is expected to reduce carbon dioxide (CO₂) emissions per unit of GDP from 2005 until 2030 by 60% to 65%. (R. Xing. et al. 2021). The toughest challenge for China is to attain the peak of carbon dioxide (CO₂) emissions before 2030 and reach carbon neutrality within 40 years (J. He. et al. 2022). Therefore the Chinese government strives to reduce greenhouse gas emissions from energy consumption (Y. Huang. et al. 2022).

The main sources of CO₂ emission in China have been driven by rapid industrialization, urbanization, and fuel combustion over the past few decades (X. Yu. et al. 2023). China's CO₂ emissions are distributed across various sectors, with certain industries and activities contributing disproportionately to the national total. A review of the primary sectors highlights the key sources and their respective impacts (T. Shao. et al. 2022). Energy production, particularly coal, plays a dominant role in China's emissions profile. The heavy reliance on fossil fuels, coupled with rising energy demands from manufacturing and urban expansion, has positioned China as a focal point for global climate policy discussions. Moreover, industrial processes, transportation, and residential energy consumption further contribute to the country's growing carbon footprint (I. Renewable and E. Agency. 2022).

A review of the primary sectors highlights key sources and their respective impacts. Energy production, particularly from coal, plays a dominant role in China's emissions profile. The heavy reliance on fossil fuels, coupled with rising energy demands from manufacturing and urban expansion, positions China as a focal point for global climate policy discussions. Additionally, industrial processes, transportation, and residential energy consumption contribute significantly to the country's growing carbon footprint (X.H. Chen. et al. 2023).

Additionally, industrial processes such as steel, cement, and chemical manufacturing are significant sources of emissions, driven by the country's rapid industrialization. The transportation sector, which includes road, rail, and air transport, is also a growing contributor, particularly as urbanization leads to increased vehicle usage. Residential energy consumption, while smaller in comparison, still represents a notable portion of emissions, primarily due to heating and cooking (S. Mehmood. et al. 2024).

This paper compares and analyzes the primary sources of CO₂ emissions in China, identifying key sectors responsible for the highest outputs. By evaluating the underlying factors driving these emissions, seek to provide insights into potential mitigation strategies and their implications for sustainable development and climate goals. The research objectives of this paper are to analyze sectoral contributions of CO₂ emission, compare emission trends across key industries, and provide recommendations for emission reduction.

METHODOLOGY

This research activity uses qualitative and quantitative methods to produce the right conclusions and recommendations. A qualitative method refers to a type of research approach that focuses on understanding phenomena in a deeper, more descriptive way. It is used primarily in social sciences, humanities, and other disciplines where the aim is to explore complex concepts, behaviors, or experiences that are difficult to quantify. Qualitative methods are used to explain the phenomenon that occurs in the data on emission sources of each sector and fuel consumption in China. Quantitative research refers to a research method that focuses on gathering numerical data and applying statistical analysis to understand patterns, relationships, or phenomena. It is used primarily in fields such as natural sciences, social sciences, economics, and healthcare, where the goal is to quantify the problem by way of generating numerical data or data that can be transformed into usable statistics. Quantitative methods are used to produce the right conclusions from the calculation data of China's CO₂ emission sources (N. Simister. et al. 2020). The qualitative methods use secondary data from the International Energy Agency (IEA) and the Chinese National Bureau of Statistics. Emission data from 2000 – 2022 are analyzed using a comparative approach and examined with sectoral review. The quantitative method is carried out through an internationally agreed calculation method. Emission data refers to guidelines that have been agreed upon internationally and apply in all countries, namely the 2006 IPCC (Intergovernmental Panel On Climate Change) Guideline for National Greenhouse Gas Inventories for Energy. In it, there are emission factors and absorption factors that cover all anthropogenic emissions generated within an administrative boundary territorial scope due to energy consumption (Y. Shan. et al. 2020).

In the IPCC, there is a division of greenhouse gas emission calculation methods based on their level of accuracy (tier).

- a) Tier 1, Estimates based on IPCC default activity and emission factors data.
- b) Tier 2, Estimates are based on more accurate activity data and IPCC default

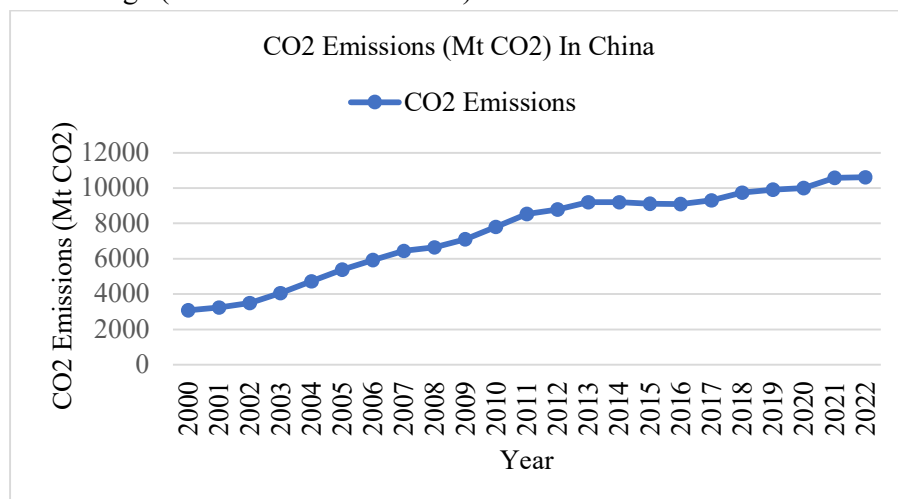
- emission factors or country-specific/plant-specific emission factors.
- c) Tier 3, Estimation based on a country-specific method with more accurate activity data (direct measurement) and country-specific/plant-specific emission factors. (O. V. Lapshin. 2017)

In this paper, the calculated greenhouse gas emissions only come from two categories, namely emissions from fuel combustion and fugitive emissions from production activities. Emission sources from fuel combustion are grouped into eight categories: electricity and heat producers, industry, transport, residential, commercial and public services, agriculture, final consumption not elsewhere specified and other energy industries.

RESULT

3.1 Total CO₂ Emission

The burning of fossil fuels as an energy source is largely responsible for climate change and greenhouse gas emissions. Despite efforts to reduce emissions, the total amount of CO₂ emissions globally remains much higher than necessary to avoid the worst effects of climate change (K. A. Nitesh. et al. 2021).



Source : The International Energy Agency (IEA), 2022

Figure 1 Trend CO₂ Emissions In China From 2000 to 2022

China emit a share of global emissions of 31,1% of CO₂ emissions from combustible fuels in 2022. Total CO₂ emissions from fuel combustion in 2022 was 10.613,17 Mt CO₂. According to IEA data, the total CO₂ Emissions in China are ranked first in the world and the Asia Pacific region. Figure 1 shows the trend of increasing CO₂ emissions in China from 2000 to 2022. Emissions started at 3078,4 Mt CO₂ in 2000 and increased significantly, surpassing 10.613,17 Mt CO₂ in 2022. A significant spike was seen between 2000 and 2013, during which emissions growth was rapid until 198,74%. From about 2014 to 2019, the increase in emissions which is 7,73% looks more stable compared to the previous period. The emissions in 2020 are 10.004,8 MtCO₂, there were indications of a slight slowdown (no major spike as before), likely

due to a reduction in industrial activity during the COVID-19 pandemic. After 2020, there was an increase again until 2022, reflecting the post-pandemic economic recovery. So the trend is increasing from 2000 to 2022 by 245%.

1.2 Per Capita CO2 Emissions

CO2 emissions per capita in developed economies tend to be higher than in developing countries which varies depending on the economic structure and energy system in the country. For example, countries that rely on carbon-intensive modes of transportation such as land transportation and air transportation will have higher per capita emissions. Likewise, countries that have higher energy-intensive industries such as the steel industry or chemical industry and are highly dependent on fossil fuels for their power generation will have higher emissions per capita as well (M. A. Gonzalez-Alvarez. 2023).

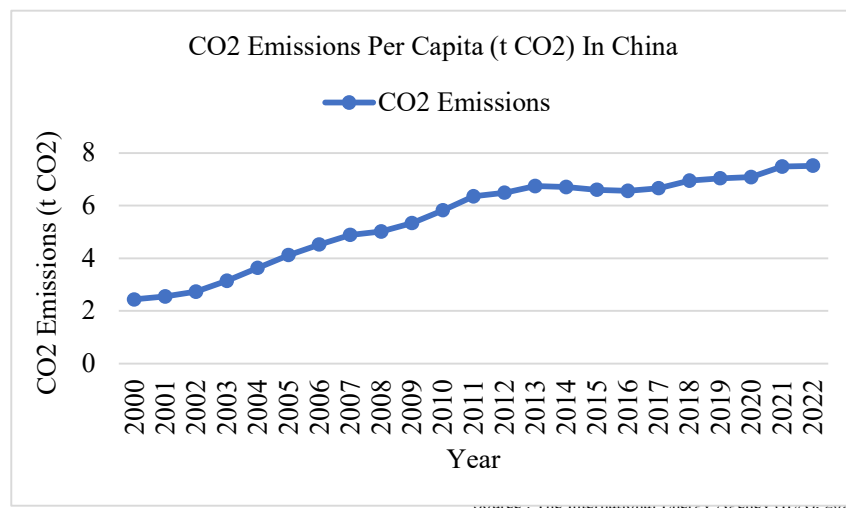


Figure 2 Trend CO2 Emissions Per Capita In China From 2000 to 2022

A general analysis of CO2 emissions per capita in China from 2000 to 2022 based on Figure 2 shows a sharp upward trend in CO2 emissions per capita in China from 2000 to 2013. After a period of sharp gains, the charts from 2014 to 2020 appear to show a more stable trend with little fluctuation. In the last years from 2021 to 2022, there has been a resurgence in CO2 emissions per capita. Total CO2 emission per capita in 2022 was 7,51 tCO2 per capita with a 208% increasing trend from 2000.

3.3. CO2 Emission by Fuel Combustion

Most CO2 emissions in the energy sector come from the burning of fossil fuels such as coal, oil, and natural gas for power generation or for fueling vehicles and engines (X. Ma. et al. 2022). Current carbon dioxide removal technologies, excluding nature-based means such as reforestation, account for only about a millionth of the CO2 emissions generated from fossil fuels (J. Samaniego. et al. 2023).

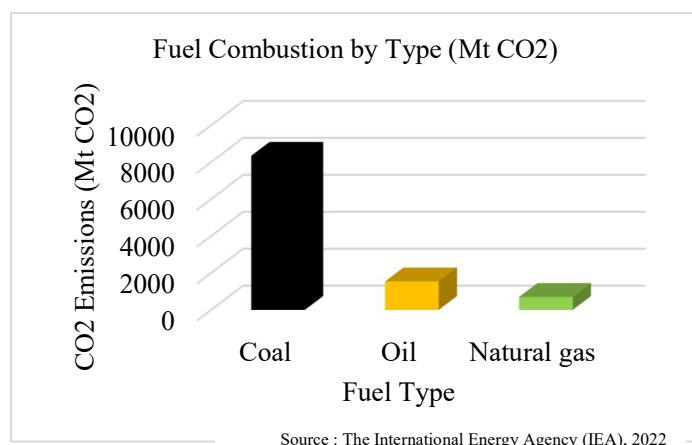
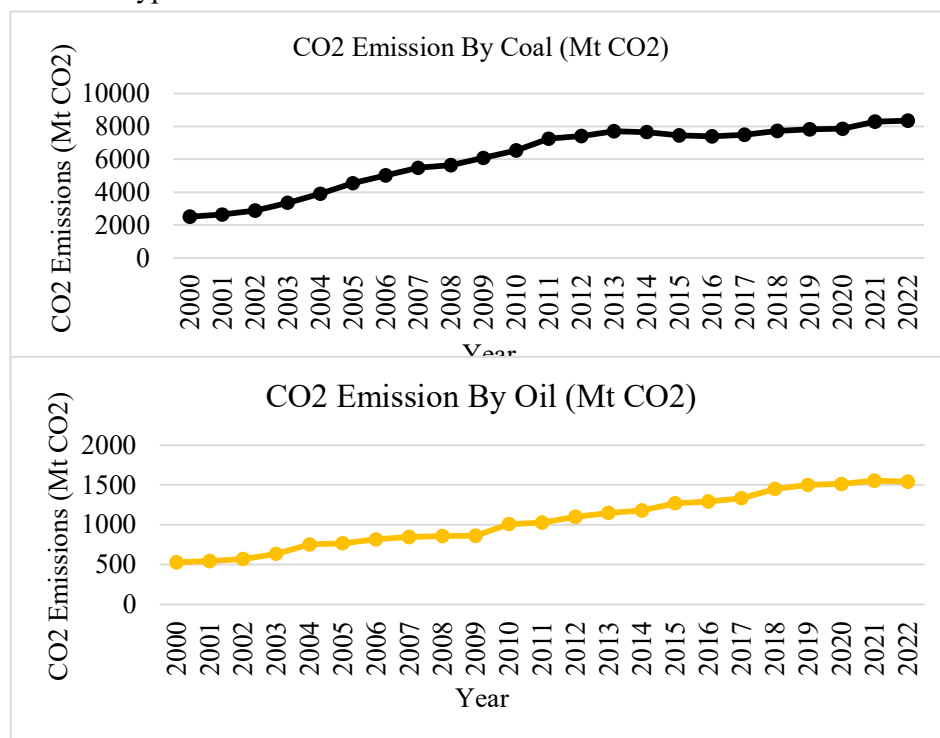


Figure 3 Fuel Combustion by Fuel Type

Figure 3 shows CO₂ emissions from fuel combustion in China divided by fuel type, namely coal, petroleum, and natural gas. Coal is the main source of CO₂ emissions, with much higher figures than petroleum and natural gas. The second largest source of emissions is petroleum. Natural gas is a lower source of emissions than coal and petroleum. The emissions from coal is 8347,5 Mt CO₂ representing coal accounts for 79% of total CO₂ emissions from fuel combustion. This is significantly higher than the others, indicating that coal combustion is the largest source of CO₂ emissions among the three fuel types shown.



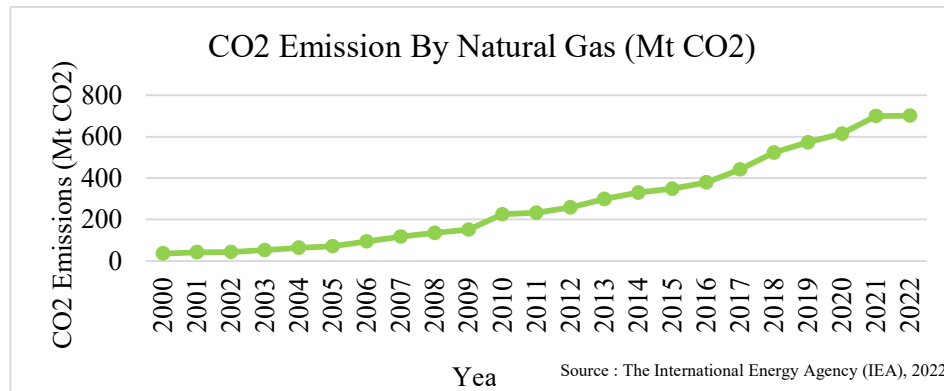


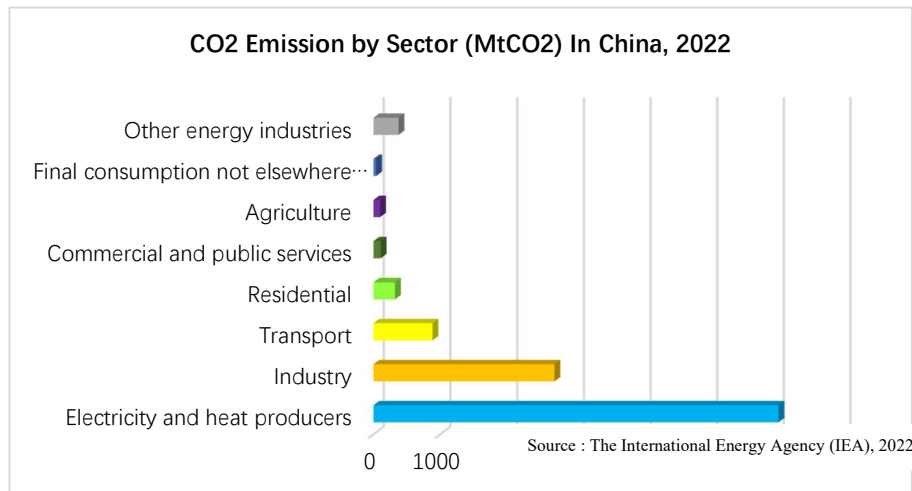
Figure 4 CO2 Emissions By (a) Coal (b) Oil (c) Natural Gas From 2000 to 2022

A significant surge was seen from 2000 to 2013, as China's industrialization and economic growth accelerated. After 2013, emissions from coal were relatively stable but remained the largest compared to other sources. Petroleum had a steady growth from 2000 to 2022. Natural gas showed a gradual increase, especially after 2010.

3.4 CO2 emissions by Sectoral

The economic structure and energy system are related to the details of CO2 emissions in the energy sector. Burning fuel to generate electricity and heat in power plants will produce emissions. In transportation, although the rapid growth of EVs is still highly dependent on oil-based fuels, therefore most CO2 emissions in most countries come from motor vehicles. The main source of emissions that the residential sector produces in most countries is the burning of fossil fuels.

The burning of fossil fuels is also still common in the industrial sector to generate heat in industrial processes such as paper or steel manufacturing. Noteworthy that CO2 emissions produced appropriate by particular processes, like cement manufacturing, are not input here, and can be substantial.



The graph above shows the distribution of CO₂ emissions by sector in China in 2022. Electricity and Heat Producers The largest contributor to CO₂ emissions is 6071,90 MtCO₂. The industrial sector accounts for the second largest CO₂ emissions, around 2710,32 MtCO₂. This transportation sector contributes 885,43 MtCO₂. Residential and Commercial contribute fewer emissions than other sectors but remain significant.

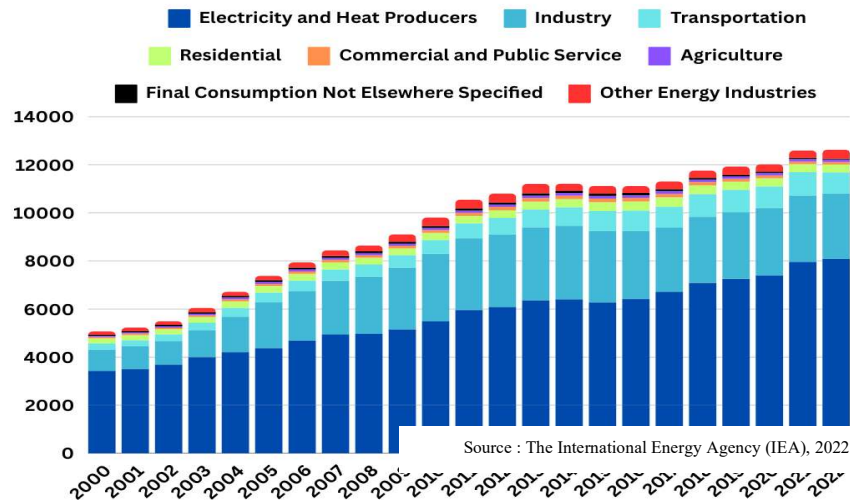


Figure 6 illustrates the annual carbon dioxide (CO₂) emissions in China, breakdown by sector from the year 2000 to 2022. Each bar represents the total CO₂ emissions for a given year, with different colors indicating the proportion of emissions from various sectors. Electricity and Heat Producers are the largest segment in each bar, indicating that this sector is the largest contributor to CO₂ emissions throughout the years shown. The second-largest segment is industry, which shows the significant contribution of industrial activities to CO₂ emissions. Transportation sector's contribution is smaller compared to electricity and heat production and industry but still substantial. The commercial and Public Service sector's contribution is similar to the transportation sector. The residential sector's emissions are relatively minor in comparison to the other sectors. The agricultural sector's emissions are a small part of the total emissions. Final Consumption Not Elsewhere Specified category includes emissions that do not fall into the other specified sectors. Other Energy Industries are the smallest segment in each bar, indicating a minimal contribution to the total emissions.

Figure 6 shows an overall increasing trend in CO₂ emissions from 2000 to 2022, with some fluctuations. The electricity and heat producers sector consistently accounts for the largest share of emissions, followed by the industry sector. The transportation sector also shows a noticeable increase over the years, reflecting the growth in vehicle use and related emissions. Figure 6 provides a visual representation of the changes in CO₂ emissions by sector over time, which can be useful for policymakers, researchers, and the public to understand the main sources of emissions and to target efforts for emission reductions.

DISCUSSION

China, as the country with the largest carbon emitters in the world, has taken various policies and strategic steps to reduce carbon dioxide (CO₂) emissions and achieve carbon neutrality targets by 2060. In 2020, President Xi Jinping announced that China is committed to peaking carbon emissions before 2030 and achieving carbon neutrality by 2060. Energy transition policies have also been carried out by developing renewable energy. The target renewable energy capacity will reach 1,200 GW from wind and solar energy by 2030. In addition, developing nuclear power plants is part of the clean energy blend.

Renewable energy, natural gas, and electricity are the energy needs in China which are presently adding. The scale of China's future electricity demand and the challenge of decarbonizing the power force help explain why global investment in electricity caught that of oil and gas for the first time in 2016. Electricity safety emphasized with state regulations and programs enforced to support energy sustainability in China. That said, bring reductions for renewables are not sufficient on their own to secure efficient decarbonization or dependable force.

China will expand its renewable energy capacity globally encyclopedically from 2019 to 2024 by 40% by increasing system integration, lower situations of restriction and increasing the competitiveness of solar PV and onshore wind. Over the same period, China is expected to account for nearly half of global distributed PV growth, overtaking the EU to become the world leader in installed capacity by 2021. The blending of ethanol in further businesses and increased investment in biofuel product capacity in China is anticipated to make China a country leading global growth in biofuel product. However, China's coal demand and product capacity remain high. Presently, to induce electricity in China requires one of every four tons of coal used globally. Thus, to support programs by perfecting the effectiveness of coal-fired power plants and committing to stop the construction of new coal-fired power plants abroad. One of the government's programs is to encourage emission reduction and air quality improvement by switching to gas in the industrial and residential sectors, but China's coal fleet is young, efficient, and still ten times larger than its gas-fired fleet. The operational cost of building a new combined-cycle gas turbine (CCGT) to generate electricity is more expensive than the prevailing price of gas, new onshore wind, and solar photovoltaic (PV). Under these conditions, the main contribution of gas-fired power plants to replace coal will be an indirect contribution, by helping the integration of renewable energy.

The transportation sector's policy to support carbon neutrality is to provide subsidies for new energy vehicles (NEVs) and target 40% of new vehicles in China to be electric vehicles by 2030. The development of transportation infrastructure carried out by the government is expanding the EV charging network throughout the country and encouraging low-emission public transportation such as high-speed trains and electric buses.

To control and reduce CO₂ emissions, China is taking measures, to improve energy

efficiency in steel, cement, and petrochemical industries, including the application of Carbon Capture and Storage (CCS) technology in new power and artificial installations. CCS technology can effectively reduce carbon dioxide emissions. For example, a study shows that coal-fired power plants with CCS technology are competitive in cost compared to natural gas power plants, especially when the carbon price reaches a certain level. The economic feasibility of CCS technology is crucial for its large-scale adoption. As the technology evolves, financial factor analysis of capital investment, operational expenditure, and long-term benefits becomes increasingly important. Challenges faced by CCS technology include cost, technical difficulty, safety, storage capacity, and regulatory requirements. Although CCS technologies have shown significant efficiency and cost improvements in laboratories or on-site, the development and implementation of these technologies remain crucial given the urgent challenges of global warming and climate change.

Reforestation and sustainable agricultural management programs are policies carried out in the agricultural and forestry sectors. Increasing carbon sequestration capacity through massive tree planting, China has the world's largest reforestation program targeting an increase in forest cover by up to 25% by 2030. Sustainable agricultural management by reducing emissions from fertilizers and livestock waste through environmentally friendly technology.

In 2021, China launched the world's largest national carbon market, which includes the power generation sector. High-emitting companies are required to buy emission permits or invest in low-carbon technologies. In addition, China is committed to assisting developing countries in the transition to clean energy through projects such as the Belt and Road Initiative (BRI) Green Development.

CONCLUSIONS

The effects of climate change pose significant hazards, disrupting ecosystems, economic activities, and human health. As one of the largest contributors to carbon dioxide (CO₂) emissions globally, China faces the formidable challenge of peaking its CO₂ emissions before 2030 and achieving carbon neutrality by 2060. In 2022, China accounted for 31.1% of global emissions from combustible fuels, totaling 10,613.17 Mt CO₂, with a per capita emission of 7.51 tCO₂, marking a 208% increase since 2000. Coal remains the primary source of CO₂ emissions in China, contributing 79% of total emissions from fuel combustion. The electricity and heat production sector is the largest contributor, followed by industrial activities and transportation. While emissions from coal have stabilized after 2013, the transportation sector continues to grow due to increased vehicle usage.

To control and reduce CO₂ emissions, China has implemented several measures, including the adoption of Carbon Capture and Storage (CCS) technology and improvements in the efficiency of coal-fired power plants. The government is also

promoting reforestation and sustainable agricultural practices, alongside its commitment to the Belt and Road Initiative (BRI) Green Development project. These efforts are crucial for addressing the urgent challenges posed by climate change and achieving sustainable development goals. As China advances towards its emission reduction targets, the integration of renewable energy sources and the transition to cleaner technologies will be vital for mitigating future emissions and fostering a sustainable future.

Acknowledgment

The author would like to express sincere thanks to the Metallurgical Resource and Engineering lecturers at The School of Metallurgy and Environment (SME), for their guidance and direction throughout this paper. Special thanks are also extended to the Central South University in China for granting permission to Study in this university.

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