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China's Strategic Response to Climate Change: Policies, Challenges, and Pathways to Carbon Neutrality

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Abstract

Climate change, driven by greenhouse gas (GHG) emissions, poses a significant threat to China's environment, economy, and society. This review paper examines China's evolving response to this challenge. It explores China's international commitments, including the Paris Agreement and its Nationally Determined Contributions (NDCs) aiming for carbon neutrality by 2060. Additionally, the paper analyzes domestic policies like the 1+N Climate Policy framework, the 14th Five-Year Plan (FYP) for Energy, and the National Emissions Trading Scheme. These policies highlight China's multi-pronged approach, focusing on GHG reduction and a comprehensive energy sector transformation. The paper emphasizes the importance of evaluating these policies for effectiveness and acknowledges the challenges China faces, such as balancing climate goals with economic growth. Ultimately, the paper argues that China's strategic approach signifies a growing recognition of the need for climate action. The success of this approach, coupled with continued advancements in clean energy technologies and international collaboration, will be paramount in achieving carbon neutrality and securing a sustainable future.

Keywords: Climate Change, Greenhouse Gas Emissions (GHGs), China, Carbon Neutrality, Sustainable Development, Environmental Polic

1. Introduction:

The Earth's climate is demonstrably changing at an alarming rate [1]. Although natural fluctuations in climate have always existed, the current pace of warming is unusual, with anthropogenic activities as primary driver, particularly the release of greenhouse gases (GHGs) like carbon dioxide, methane, and nitrous oxide [2], [3]. These GHGs trap heat in the atmosphere, causing a gradual warming effect that disrupts established weather patterns and leads to a rise in extreme weather events [4]. Heatwaves, droughts, floods, and intensified storms are becoming more frequent and severe, impacting ecosystems, natural resources, and human societies across the globe [3].

China, a nation with a vast and diverse landscape, is experiencing these changes firsthand. Rising temperatures are disrupting weather patterns, leading to more frequent and intense heat waves, droughts, floods, and storms [5]. These extreme weather events not only pose a significant threat to China's agricultural sector, a cornerstone of national food security but also strain water resources and damage critical infrastructure [6]. The changing climate presents a multifaceted challenge to China's long-term stability and prosperity.

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However, China is not standing idly by. Recognizing the urgency of the situation, the country has actively pursued diverse policies aimed at mitigating climate change and adapting to its effects. This review paper delves into China's evolving response to the climate crisis. It will explore China's commitment to international agreements like the Paris Agreement and its subsequent Nationally Determined Contributions (NDCs), which focus on reducing GHG emissions and achieving carbon neutrality by 2060.

Furthermore, the paper will examine the development and implementation of domestic policies like the 1+N Climate Policy framework, the 14th Five-Year Plan (FYP) for Energy, and the National Emission Trading Scheme (ETS). These policies represent a multi-pronged approach, targeting not just carbon emissions reduction but also a comprehensive transformation of China's energy sector.

Moreover, China is not standing idly by. Recognizing the urgency of the situation, the country has actively pursued diverse policies aimed at mitigating climate change and adapting to its effects. This includes not only policy-based mitigation and adaptation but also considerations of technological solutions like geo-engineering [7]. This review paper aims to provide a comprehensive understanding of China's efforts to combat climate change. It will assess the effectiveness of these policies, identify potential challenges and opportunities, and explore the path towards achieving carbon neutrality by 2060. In doing so, this paper seeks to contribute to the ongoing global conversation on climate change mitigation and adaptation strategies.

2. China's Status of Greenhouse Gas (GHG) Emissions:

China's rapid economic growth (i.e., the country's GDP has increased by 10% annually on average for more than a decade) has accelerated its GHG emissions significantly. China has emitted more GHGs per year than any other country in the world over the last ten years, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). In 2020, it was evident that China is the top contributor with a share of approximately 30.65% followed by the United States, the European Union, India, Germany, South Africa, and the United Kingdom which contributed 13.58%, 7.47%, 7.02%, 1.85%, 1.30%, and 0.95%, respectively. Also, China surpassed the United States as the leading emitter of CO_2 in 2005 [8]. China has one of the highest energy usage per unit of GDP among nations of the Organization of Economic Cooperation and Development (OECD) and Brazil, Russia, India, China, and South Africa (BRICS). Since 2006, ithas become the world's greatest emitter of CO_2 and a producer of massive amounts of various pollutants. The yearly comparison (2010-2019) of China, the United States, and the European Union for CO_2 emissions in million tonnes is presented in Figure 1.

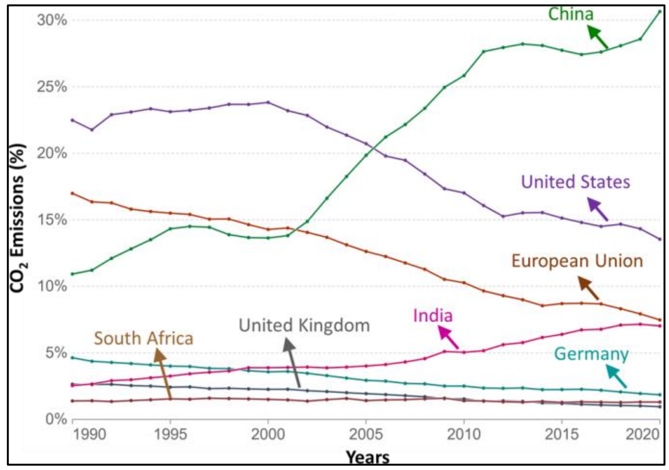

Figure 1: CO_2 emission profiles of the top seven countries over the last three decades [8].

The driving factor of China's industrialization and urbanization is coal utilization which accounts for 75% of China's carbon emissions [9], [10], [11]. China being the largest coal consumer across the globe, consumes over half of annual global coal consumption. During 2013-2016, there appeared to be a decline in coal consumption. For instance, a 2.9% and 3.7% decrease in coal consumption was observed in 2014 and 2015, respectively. However, coal consumption bounced back by 0.8% per year during 2017-2020 [12], [13]. Between 1998 and 2018, China's CO_2 emissions increased significantly, mostly due to an increase in industrial activities and transportation needs. Along with a noticeable rise in emissions by the transport sector, the industrial sector, encouraged by economic prosperity, contributed considerably to the increase in emissions. The overall emissions trended upward, despite relatively stable sectors like construction and agriculture & forestry. The evolving trends of CO_2 emissions in industrial, transportation, and other sectors from 1998 to 2018 are presented in Figure 2.

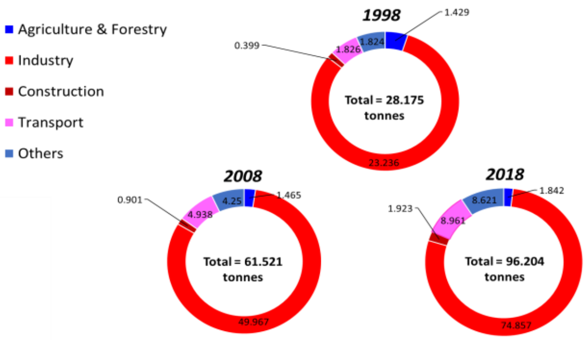

Figure 2*:* Sectoral Division of China's CO_2 Emissions.

As a primary source, China's power generation and manufacturing sectors generate 44% and 38% of total CO_2 emissions, respectively. In addition to the differences in technology, energy, and economic structure between regions within China, the uneven distribution of CO_2 emissions among China's provinces is influenced by the sectoral breakdown of emissions, the areas near the industrial clusters proclaim a higher proportion of CO_2 emissions [14], [15]. For instance, from 1997 to 2017, CO_2 emissions in Inner Mongolia increased six times from 97 megatonnes to 639 megatonnes of CO_2. Consequently, the top six polluters in China in 2017 accounted for more than 40% of the country's CO_2 emissions, including energy-based provinces such as Hebei, Inner Mongolia, and Henan, as well as eastern coastline provinces such as Shandong, Jiangsu, and Guangdong [9], [10].

The Chinese central government authorized the provincial government to install new power plants between 2014 and 2016. A stated 250 GW of additional electricity capacity was added to the grid between 2014 and 2018 as a result of this reform, with 78% of the projects being coal-fired thermal power plants. This increase is nearly equal to the US's total fleet of coal-fired power plants (266 GW) in 2018 [16]. The Chinese government further suggested a series of stimulus projects to increase economic growth in reaction to the COVID-19 outbreak, investing more than 30 trillion Chinese Yuan (US$ 4.5 trillion). After that, China's economy bounced back rapidly, growing by 2.3% in 2020. Moreover, annual CO_2 emissions in 2020 increased to about the same amount as those in 2019 [17], [18]. However, it is critical for China to achieve a 'green recovery' in the post-pandemic era, decoupling economic recovery from emissions resumption.

In 2022, China experienced a slight decrease of 0.2% in its energy-related emissions bringing the total to approximately 12.1 gigatonnes. This decrease occurred despite the additional use of coal, which led to an increase of 88 megatonnes in emissions solely from energy combustion activities. However, this rise in emissions was counteracted by a reduction in emissions from industrial processes. Overall, although the emissions from coal usage increased, however, other factors, particularly improvements in industrial processes, contributed to keeping China's energy-related emissions relatively stable. Coal made up almost three-fifths of the fuel mix used to generate energy, but this was somewhat offset by a significant growth in solar PV and wind power. Demand for power as a whole increased far more slowly than it had on average during the previous ten years. As a result, emissions from coal-fired power rose by about 3%. This increase was partly caused by the coal power plants' increased output during heat waves and by the growing use of coal-fueled district heating and electricity.

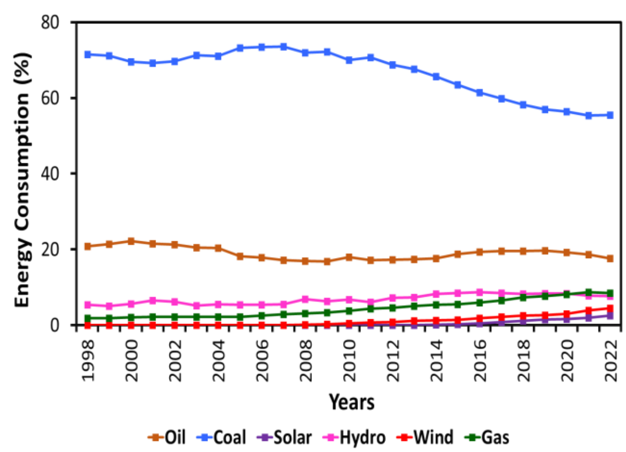

Figure 3: Temporal Profile of China's Percentage Energy Mix.

The gains in energy and carbon intensity (-13%) and total CO_2 emissions (-79%) that occurred between 1978 and 2018 were completely negated by the rise in emissions caused by GDP per capita growth (176% of the entire change in CO_2 emissions) [19]. Emissions from the industrial sector decreased in 2022, however, the consequences of China's crackdown on debt-financed real estate and the prolonged real estate crisis were not entirely reflected in those emissions. Although there was a 40% decrease in new construction starts year over year, there was only a 2% and 10% decrease in steel and cement production compared to 2021. Consequently, China's industrial sector reduced its emissions by 161 Mt over the previous year, primarily due to process emissions. Global industry emissions decreased as a result of China's historically significant year-over-year fall. From the 1980s to the 2000s, China's GDP grew at an average yearly rate of about 10%, which is thirty times higher than in previous years [20]. The growth rates of CO_2 emissions averaged 7.4% in the 2010s. Since 2011, economic growth has shown a notable slowdown, primarily due to economic restructuring. The growth rates of CO_2 emissions have also slowed during this period, with a brief decline observed in emissions between 2013 and 2016 [21], [22], [23].

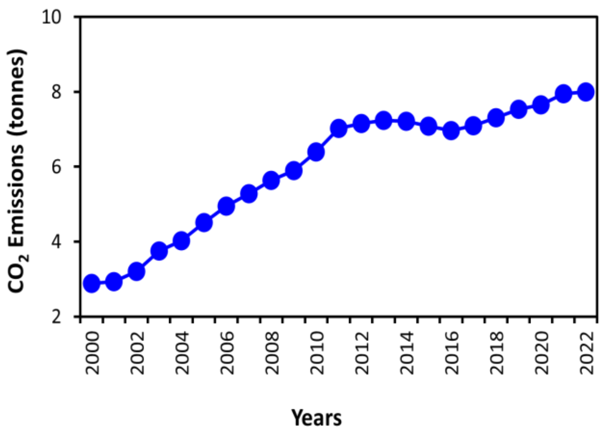

Figure 4: Annual China's per Capita CO_2 Emissions from 2000-2022

Infrastructure and the real estate sectors are examples of fixed asset capital investments that have grown quickly, with annual growth rates of 21% in the 2000s and 9% in the 2010s [23]. In line with this, there was an increase in the consumption of fossil fuels (coal and thermal electricity) as well as industrial materials such as steel and cement. As a result, this sector accounted for 61% and 71% of the increase in emissions from 2005 to 2007 and 2007 to 2010, respectively [24], [25]. A 4 trillion Chinese Yuan stimulus plan was introduced in the aftermath of the 2008 financial crisis to promote infrastructure development across the country. Consequently, the yearly production of crude steel, cement, and energy consumption rose by 14%, 15%, and 5%, respectively, in 2009, as compared to 3%, 5%, and 3% in 2008. Correspondingly, CO_2 emissions rose by 8.5% in 2009, a significant rise over the 3.3% recorded in 2008. Due to this rise in domestic CO_2 emissions, despite the effects of the global financial crisis, worldwide emissions increased in 2008–2009 [26], [27].

China's living standards have increased significantly since the 1970s. In 2017, the country's per capita disposable income was 22.8 times more than it was in 1978 [28]. Hence, lifestyle changes have led to a sharp rise in home energy demand and emissions [29], [30], [31]. For example, in 2012, the overall household carbon footprint accounted for 34% of the total national footprint, including direct emissions from household fuel consumption and indirect emissions from the supply chain of household goods and services [32]. Furthermore, from 1981 to 2002, more than half of the increasing emissions linked to urban home consumption came from the use of energy and the service sector [33].

Household carbon footprints in the cities of Eastern coastal provinces are comparatively high throughout China. In the case of China, the top 5% of earners account for around 20% of the total household carbon footprint. In other words, the emissions associated with 5% earners are equivalent to 6.4 tonnes of CO_2 per capita, which is substantially more than the average of 1.7 tonnes of CO_2 per capita for all houses in 2012. Furthermore, consumption in urban regions accounted for 72% of China's household carbon footprint between 2007 and 2012 [32], [34], [35]. China’s national emissions are also influenced by government consumption. 10% of the overall rise in CO_2 emissions between 1981 and 2002 came from government use [33]. In 2002, 2007, 2012, and 2017, government consumption-related CO_2 emissions were 7%, 5%, 5%, and 6% of the country's total CO_2 emissions [36].

China's transport sector emissions decreased by 3.1% in 2022 compared to the global increase in emissions. In contrast to 2021, COVID-19 measures were heavily enforced, including as complete lockdowns in large cities and prohibitions on traversing prefecture or province boundaries. In 2022, six million electric cars were sold, averting further emissions from gasoline and diesel vehicles [37]. China emitted 12.3 billion tonnes of CO_2 equivalent, about 27% of global GHG emissions in 2022, as demonstrated by the Climate Analysis Indicators Tool (CAIT) database maintained by the World Resources Institute (WRI) [38].

3. China’s Climate Change & Its Impact:

The climate on Earth is changing, and it is expected that it will do so for the rest of this century and beyond. The amount of GHG released into the atmosphere globally and the degree of uncertainty around the climate's sensitivity to these emissions will be the key determinants of the extent of climate change after the next several decades. The annual average rise in global temperature might be kept to 2°C or below with considerable reductions in GHG emissions. By the end of this century, the yearly average global temperature increase over preindustrial levels might rise by 5°C or more if significant reductions in these emissions are not implemented [39].

Since the 19th century, the global average surface temperature has risen by 0.3-0.6ºC, whereas China had an average increase of 0.5-0.8ºC. The trend of increasing surface temperatures in China is particularly evident in the Himalayan Mountains. As estimated the Tibetan Plateau's air temperature is presently rising at a pace of 0.3ºC per 10 years, significantly faster than the global average. The quick shift in temperature has a direct and significant influence on glaciers. According to projections, a temperature elevation of 4ºC could result in the fast melting of glaciers globally [40], [41], [42].

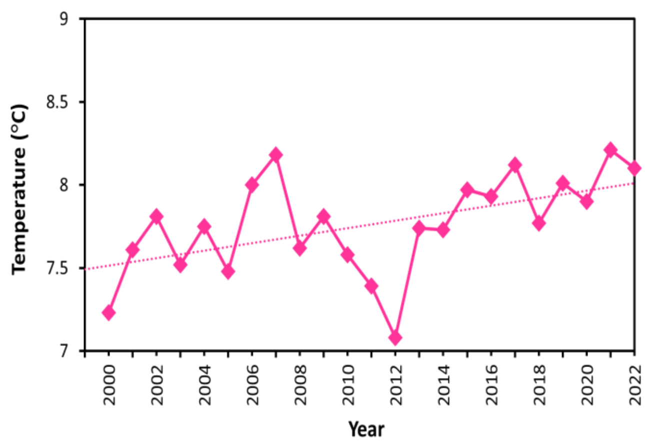

Figure 5: Annual Average Temperature of China 2000-2022

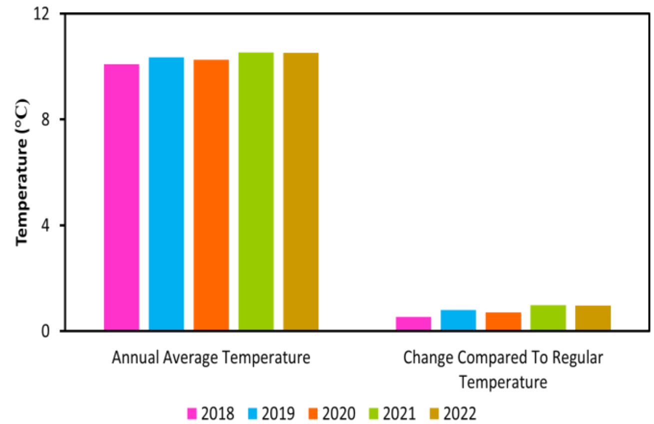

Figure 6: Annual Average Temperature Change 2018-2022

In 2004, rapid landslides along with substantial flooding from the River Yi'ong Zangbo on the Tibetan Plateau devastated vital roadways and bridges that connected surrounding regions. The enormous flood in Tibet destroyed around ten bridges, fifty miles of roads, and hundreds of dwellings [43]. In its third assessment report, the Intergovernmental Panel on Climate Change (IPCC) stated that severe weather events, including heat waves, extratropical and tropical cyclones, droughts, torrential rains, thunderstorms, snow avalanches, and dust storms, are on the rise across Asia, specifically China. The 2004 State of the Environmental Report in China found an increase in peculiar natural catastrophes such as droughts, tropical cyclones, rainstorms, dust storms, and thunderstorms. According to the Chinese government's white paper, China's Policies and Actions for Addressing Climate Change (issued on October 29, 2008), extreme climate phenomena such as high temperatures, heavy rain and snow, and severe droughts have grown more prevalent and intense in the country. The most prominent climatic trend in coastal regions is the rise in sea surface temperatures, leading to more intense tropical cyclones [44].

In 2022, China's annual Surface Air Temperature (SAT) reached 10.51ºC, a 0.62ºC rise from the norm and the second-highest since 1961. Most locations observed SAT near or above norms, particularly in the middle and lower regions of the Yangtze River and regions in northwest China, that were 1-2ºC warmer than typical. Six regions reported above-average SAT with the northwest hitting 9.74ºC, the highest since 1961. The middle and lower sections of the Yangtze River reached 17.81ºC, higher than average, and was recorded as second-highest. Southwest China had the third-highest SAT, at 15.63ºC.

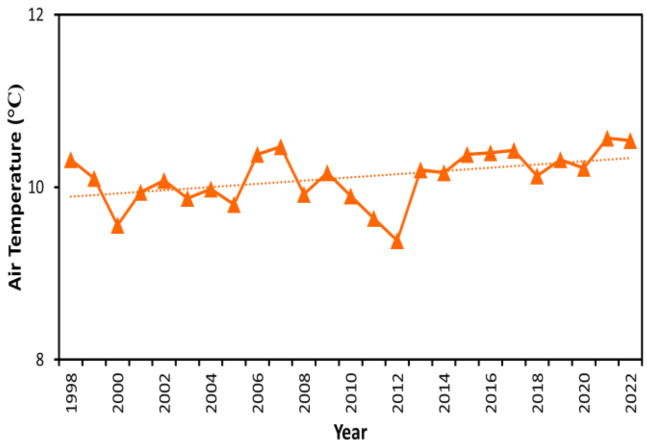

Figure 7: Annual Average SAT of China 1998-2022

During the winter of 2021/22, the seasonal SAT was -0.2ºC lower than average, accompanied by significant intra-seasonal variations. Spring, summer, and fall observed SAT levels increased by 1.2ºC, 1.1ºC, and 0.9ºC, respectively, establishing new records. The number of hot days exceeded average norms by 7.3ºC, with regions such as the middle and lower Yangtze River Valley suffering extended hot weather. This shattered China's previous record for the frequency of intense heat waves, which had been maintained since 1961. Maximum daily SATs approached the severe threshold of heat-wave, with records broken at 366 sites, including Chongqing Beibei's peak SAT of 45.0ºC.

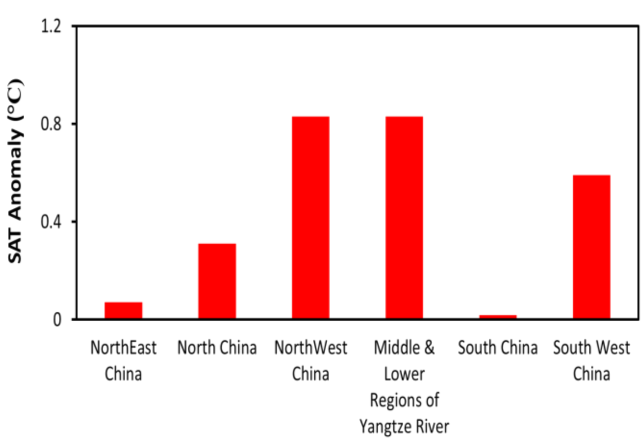

Figure 8: Regional SAT Anomalies in 2022

In the same year, China witnessed its lowest national average rainfall of 606.1 mm, a 5% drop from 2012. Rainfall patterns differed by location, with greater amounts in Eastern and Northern China and significant decreases in Southern parts. The average number of rainy days fell to 94.3, the lowest level since 1961, with a notable decrease in the middle and lower Yangtze River basins. Seasonal rainfall varied significantly, with above-normal values from January to June and November, and decreases from July to October and December. Rainfall rose throughout the winter and spring but decreased during the summer and autumn. The national average rainfall from May to September was 411.5 mm, a decline of 11.9% and the third lowest since 1961. The rainy season began early in 2022, with varying rainfall quantities throughout areas. Despite the early commencement, rainfall levels varied significantly, notably in South, North, and Northeast China.

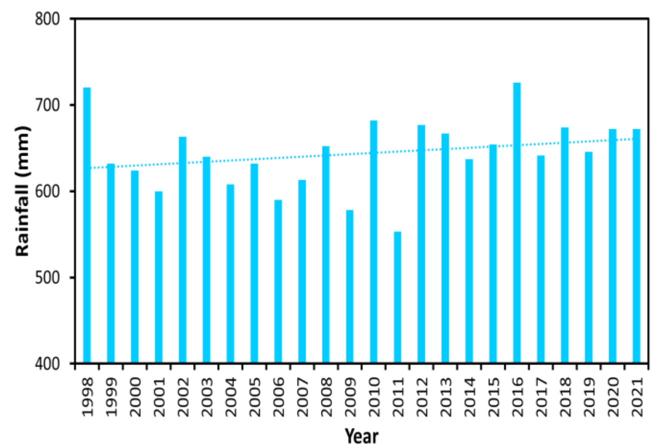

Figure 9: Annual Average Amount of Rainfall in China from 1998-2021

During the spring and summer, China had extensive droughts in North China, the Huang-Huai and Jiang-Huai areas, as well as severe droughts in Southern China. Despite these problems, the country observed 38 heavy rainfall events, particularly in the Pearl River Basin, which caused serious flooding in Northeast China's Song-Liao River in June and July. Although 25 typhoons formed in the Northwest Pacific and South China Sea, only four made landfall in China, the lowest number since 1949. In the summer, China experienced the most severe heat wave in the central and eastern areas since 1961. There were 35 cold air processes, including 11 cold surge outbreaks, representing six more than the typical number [45].

Nearly 25% of China's glacial area has already vanished [46]. Many of Asia's major rivers originate from these glaciers and run as far as Afghanistan, Vietnam, and southern India. They make up over half of "Asia's Water

Tower," the biggest freshwater concentration found outside of the Polar Regions [47]. Since the early 1950s, the average annual temperature has risen by 3ºC or more in various regions of western China. A glacial lake outburst was observed by Greenpeace East Asia in August 2018 in a region where average yearly temperatures have risen by 3 to 3.5ºC since 1951[48]. Since the 1950s, over 82% of China's glaciers have melted away due to rising temperatures [49]. China's cryosphere experienced a more than 50% rise in glacier meltwater volume between 1960 and 2006, which had an effect on agriculture and led to flooding and the creation of catastrophic glacial lakes. It is estimated that by the end of the century, almost two-thirds of the glaciers in High Mountain Asia would disappear unless significant steps were taken to prevent the rise in temperatures. If the increase in world temperature is limited to 1.5 degrees, two-thirds can be preserved [50]. Once "peak water" is reached, the amount of meltwater reduces sharply as glaciers recede. The flow of meltwater from glaciers in western China rose by 53.5% between 1960 and 2006. In the years 2040 to 2070, the majority of China's glaciers will achieve "peak water," if the increase in global average temperature is limited to 2 degrees Celsius [51]. Subsequently, there will be significant water shortages throughout the region as a result of the abrupt reduction in meltwater levels. Rapid glacier melt is already causing seasonal water fluctuations in some areas of western China. The Kumarak and Tailan rivers, which supply the Aksu River Basin in Xinjiang, receive 52.4% and 69.7% of their water from glacier runoff, respectively [52]. Even though the basin is normally extremely dry, beginning in the 1980s, increased runoff from glacier melt allowed for fast development in the region. The Aksu River Basin's vegetation covering increased by 19.03% between 2000 and 2018, from 10976.13 km² to 13065.00 km² [53]. Crops have been impacted by spring flooding and summer water shortages brought on by glacier melt. The Aksu River Basin's altogether annual water use reached 10.848 billion m^3, surpassing water resources by 72.9% in 2016 [54].

One of the most important human-induced changes to the earth's surface climate is the urban heat island (UHI), a widespread phenomenon where metropolitan areas tend to have higher atmospheric or surface temperatures than the surrounding rural areas. UHI has changed the biophysical process and surface energy balance, as well as having various unfavorable effects on the environment. China's urbanization trend has resulted in an enormous rise in the urban built-up area and a loss in the amount of water and vegetation. This leads to a decline in the habitable degree, a worsening of the urban thermal environment, and an increasing severity of the urban heat island effect [55]. China's metropolitan areas experience higher temperatures as a result of the UHI effect, which raises the energy required for cooling and raises electricity consumption and greenhouse gas emissions. The UHI impact in Beijing might lead to a 40% increase in the energy needed for cooling [56]. It intensifies the development of smog and other pollutants, worsening air pollution in metropolitan areas. Higher concentrations of air pollutants such as $PM_{2.5}$ and ozone are a result of the UHI impact in Chinese cities. This degradation in air quality contributes to respiratory disease and cardiovascular problems. It also contributes to heat-related illnesses, such as heatstroke and dehydration due to high temperatures, leading to increased healthcare costs [57], [58]. Increased death rates during heat waves are just one of the serious health effects that can arise from the elevated temperatures linked to the UHI impact. Climate change is expected to significantly increase heat-related mortality in China, with an estimated 1.4% increase in death for every 1°C rise in temperature above a threshold [59]. Heatwaves have been responsible for tens of thousands of deaths in China over the past few decades, with urban areas experiencing higher mortality rates due to the Urban Heat Island effect [60]. Local hydrological cycles are altered by urbanization and the UHI effect, which increases water demand and puts stress on water supplies. This is especially troublesome in areas where there is already a scarcity of water, as it increases competition for scarce water supplies and may even spark conflicts over water resources. Water supplies in cities such as Beijing, Shanghai, Guangzhou, Shenzhen, Chengdu, Chongqing, and Xi'an, are severely impacted by the Urban Heat Island (UHI) effect. The consequences of UHI are intensified by urbanization and large-scale development, which modifies precipitation patterns, increases surface runoff, and impacts groundwater recharge. Research has demonstrated the relationship between urbanization, UHI intensity, and modifications to the local hydrology, underscoring the difficulties these communities encounter in conserving and managing their water resources [55], [61].

Extreme rains and flooding following strong typhoons caused China's direct economic losses from natural disasters in July and August 2023 to rise by 75.37 billion Chinese Yuan (US$ 10.31 billion), almost twice as much as losses in the first half of the year. According to figures released by China's Ministry of Emergency Management, the country suffered losses of 34.19 billion Chinese Yuan in August, on top of sharp losses of 41.18 billion Chinese Yuan in July [45]. In 2020, severe flooding in southern China's Yangtze River basin resulted in direct economic losses of approximately 199.38 Chinese Yuan (US$ 29 billion), according to official estimates from the Ministry of Emergency Management [62]. One of the strongest tropical cyclones ever recorded, Typhoon Haiyan in 2013, made landfall in multiple nations, including China. It seriously damaged the southern regions of China's infrastructure, agriculture, and coastal towns, causing enormous financial losses. Economic loss was estimated to be billions of Chinese Yuan [63].

In China, severe droughts damage livelihoods, water supplies, and agricultural output, which results in economic losses. For instance, millions of hectares of agriculture were impacted by the severe drought that struck in 2010–2011, which had a major financial impact [64], [65]. According to China's Ministry of Emergency Management, the drought crisis in July 2022 alone affected 33.85 million people and resulted in a direct economic loss of 128.9 billion Chinese Yuan.

4. China's Strategic Approach to Mitigate Climate Change:

China's economy has expanded at an extraordinary rate since 1978. With an average growth rate of 9.22%, the real GDP grew from 367.87 billion Chinese Yuan to 14,944.05 billion Chinese Yuan between 1978 and 2020 [66]. China's economy has grown swiftly, consuming large amounts of fossil fuels and producing large amounts of carbon emissions. China became the world's largest emitter of CO_2 after 2006, as its annual emissions surged from 1.49 billion tonnes to 10.67 billion tonnes at a pace of 4.80% annually between 1978 and 202. China's CO_2 emissions in 2020 were higher than those of the US, India, Russia, Japan, and Germany combined [8]. Mitigating global warming will remain unattainable even if developed countries make substantial reductions in emissions without the active participation and efforts of China [67].

Industrial development contributes significantly to pollution, greenhouse gas emissions, and waste generation, negatively influencing human health and the environment. These consequences have huge economic costs and are a major public concern. Energy, materials, and other natural resources are extensively utilized by industry. The way these resources are used impacts short-term internal and external costs and thus affects the long-term sustainability prospects of the global and local Chinese economy. Environmental concerns from rapid industrial expansion became a key policy issue after the turn of the twentieth century. Consequently, air, water, and soil pollution have reached worrisome levels.

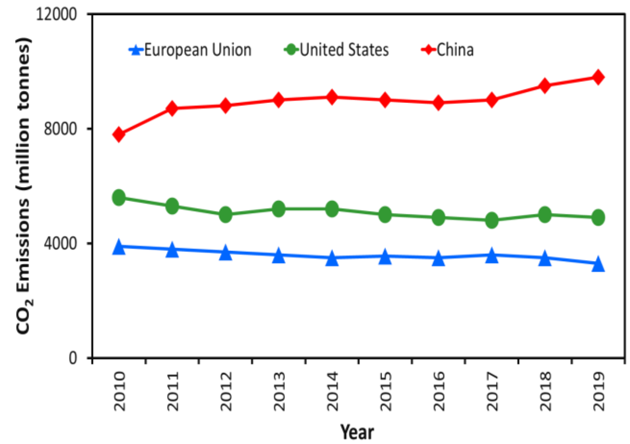

Figure 10: Yearly comparison of CO_2 emission in million tonnes from 2010 to 2019 of China, the United States, and the European Union.

Between 2005 and 2021, China's primary energy usage more than doubled. In 2021, gas was used for 8.6% of China's energy consumption, oil for 19.4%, and coal for 54.7%. Even if coal's percentage decreased from 73% to 55%, the amount consumed in total increased by 55% as a result of increasing energy demand. In 2021, China added 25.2 GW of coal power capacity, accounting for more than half of the global total. Between 2005 and 2021, the share of renewable energy sources (RES) climbed from 5.5% to 15%, with total RES production increasing by 462%. Despite tremendous development in renewable energy, fossil fuel demand has increased faster.

China's wind power industry governs the global market for photovoltaic solar panels. Hydropower is an essential part of China's energy system. Before the COP27 climate change summit, China suggested a worldwide clean energy cooperation to boost investment and connect supply chains. China is a net energy consumer. China imports liquefied natural gas from Australia, Qatar, Malaysia, and other nations, accounting for two-thirds of the total. China presented its mid-century long-term low greenhouse gas emission development strategy and updated NDC in October 2021, ahead of COP26. The plan aims to achieve carbon neutrality by 2060 and peak CO_2 emissions by 2030 [68].

4.1. From INDC to "Dual Carbon Goals": China's Evolving Climate Pledges and International Collaboration:

On June 30, 2015, China submitted its inaugural "intended nationally determined contribution" (INDC), committing to peak CO_2 emissions "around 2030" and exerting its "best efforts to peak early." As one of the pioneering nations, China swiftly ratified the Paris Agreement. Although China considers itself a developing country, it did not request funding for climate action from developed-country parties in its INDC. Instead, it launched a "south-south cooperation fund" in 2015, committing 20 billion Chinese Yuan (US$ 3.1 billion) to help other developing countries combat climate change. The fund was launched in 2015, as part of the Obama-Xi Joint Statement before the Paris climate talks [69].

In May 2017, the Chinese government unveiled plans to replenish the South-South Cooperation Assistance Fund with US $1 billion during a Belt and Road Forum for International Cooperation. By the conclusion of 2017, China had forged collaborative partnerships with 15 prominent international organizations, including the World Food Programme, the United Nations Development Programme, and the World Health Organization. This collaboration led to the implementation of nearly 200 development cooperation initiatives spanning 27 countries and regions across Asia, Africa, and Latin America.

These initiatives encompassed diverse sectors such as food safety, post-disaster reconstruction, refugee assistance, healthcare provision, maternal and child welfare, poverty reduction, education, training, and facilitation of trade and investment. As a result of these efforts, approximately 5 million individuals in developing nations benefited from the programs [70]. China also stated clearly that it will not join the Green Climate Fund (GCF) for developing countries, whether as a donor or a beneficiary.

On September 22, 2020, Xi Jinping, China's leader, unexpectedly declared that China would intensify its Nationally Determined Contributions (NDC), striving to reach the peak of CO_2 emissions before 2030 and attain carbon neutrality by 2060. These targets, known as the "30-60 goals" or "dual-carbon goals" in China, signify a significant commitment towards environmental sustainability.

During the UN Climate Ambition Summit 2020, Xi Jinping elaborated that China would implement more robust policies and measures by 2030. These measures include reducing CO_2 intensity by over 65% compared to 2005 levels, raising the proportion of non-fossil fuels in primary energy consumption to approximately 25%, and augmenting forest stock volume by 6 billion cubic meters, equivalent to 46% [71], [72].

China formalized these objectives in its revised Nationally Determined Contributions (NDC), submitted to the UNFCCC just ahead of the Glasgow COP26 climate talks in late 2021. Alongside reinforcing the goals established in 2015, the updated NDC pledges to achieve a minimum of 1,200 gigawatts (GW) of installed wind and solar power capacity by 2030, a milestone anticipated to be reached well in advance of the deadline [73].

Table 1: China's NDC Goals: 2016 vs. 2021 & Progress Updates [74].

Indicator	Target for 2030		Achieved	Current Status
	NDC 2015	NDC 2021	2020	
Reduced CO_2 emissions per unit of GDP (relative to 2005 levels)	60-65%	More than 65%	48.40%	50.3% (end of 2021)
Non-fossil energy share in primary energy consumption.	Around 20%	Around 25%	15.90%	17.5% (end of 2022)
Increase in forest stock volume (relative to 2005)	Around 4.5 billion cubic meters	6 billion cubic meters	4.6 billion cubic meters	6.5 billion cubic meters (end of 2021)
Wind and solar power installed capacity	-	More than 12,00 GW	543 GW	760 GW (end of 2022)

In 2021, the United States and China released additional joint climate statements, including an unexpected announcement during the COP26 summit. They affirmed their commitment to collaborating in addressing the "climate crisis" during this pivotal decade. This collaboration entails focusing on mitigating methane emissions, gradually reducing coal usage, and preserving forests, highlighting shared efforts to combat climate change. In November 2023, another joint statement was issued, supporting a worldwide objective to triple renewable energy capacity by 2030. This initiative aims to expedite the transition away from coal, oil, and gas generation, anticipating substantial absolute emission reductions in the power sector following its peak. Notably, the statement lacked agreed-upon language regarding the gradual phase-out or elimination of fossil fuels [75]. While China's updated 2021 NDC didn't elevate its primary ambition, the amalgamation of its objectives could prompt earlier attainment of a lower emissions peak than the officially stated goal of "before 2030”. The International Energy Agency's World Energy Outlook 2023 projected that China's fossil fuel utilization would culminate in 2024, followed by a structural downturn, implying a decline in energy-related CO_2 emissions.

Despite Climate Action Tracker acknowledging China's revised NDC targets as "slightly more ambitious" than the original version, it still categorizes them as "highly insufficient" for surpassing China's "fair share" range and for being inconsistent with the 1.5°C and 2°C climate objectives.

4.2. China's 14th FYP for Energy: Balancing Decarbonization with Energy Security:

Despite undergoing major economic reforms, China still heavily relies on Soviet-style economic planning to guide its social and economic development. Central to this planning are the "five-year plans" (FYPs) and "action plans," which exert significant influence over the country's climate policies. In the latest 14th five-year plan unveiled in March 2021, China introduced the concept of a "CO_2 emissions cap", although the specific limit was not specified. Notably, this plan marked the first time climate goals for 2030 and 2060 were incorporated into a five-year plan, underscoring China's commitment to long-term climate action. The plan also aims to reduce CO_2 intensity and energy intensity levels by 18% and 13.5%, respectively, over the next five years, mirroring targets set in the previous plan. However, this consistency raised concerns internationally about China's commitment to its dual-carbon goals, suggesting a potential lack of ambition. Further details and policy directions were outlined in the central government's 14th five-year plan for the energy sector, released in March 2022. Referred to as the "14FYP for a modern energy system", the plan focuses on accelerating the development of a clean, low-carbon, secure, and efficient energy system. It emphasizes five main goals, including enhancing energy security, transitioning to low-carbon energy, improving energy efficiency, fostering innovation, and enhancing energy services.

The plan sets a target for non-fossil sources to contribute around 39% of electricity generation by 2025 and aims for electricity to account for approximately 30% of final energy consumption by the same year. However, it does not specify caps for total energy or coal consumption, unlike the previous plan. Instead of phasing out coal, the plan emphasizes retrofitting existing coal plants to accommodate more renewable energy generation. Additionally, it prioritizes enhancing the stability and security of energy supply chains, increasing gas supply capabilities, and utilizing coal to ensure basic energy needs and provide flexible peaking services to the grid [76].

Table 2: Evolution of Climate Control Targets in China's Five-Year Plans (FYPs) [77].

	11th FYP (2006-2010)	12th FYP (2011-2015)	13th FYP (2016-2020)	14th FYP (2021-2025)
Coal	-	New benchmark set for limiting coal use within primary energy consumption	Coal share transitions to a mandated level New aspirational target set for total coal use	-
Non-fossil Fuels	Revised target for renewables in primary energy use	Mandated increase in the share of non-fossil fuels in primary energy consumption	-	-
Energy	Ambitious goal set for energy efficiency improvement	Introduced 'Dual Energy Goals': Mandatory energy efficiency target alongside a non-binding cap on total energy consumption	-	-
CO_2 Emissions	New metric tracks CO_2 savings from energy efficiency	Enforced goal set to decrease CO2 emissions intensity	-	CO_2 emissions capped (specific level to be set)

4.3. "1+N" Climate Policy Framework: A Multi-Pronged Approach to Decarbonization:

In October 2021, China's central government released "working guidance" outlining the country's strategies to peak carbon emissions and achieve carbon neutrality, along with an action plan aimed at reaching peak CO_2 emissions before 2030 [78], [79]. These documents marked the inception of China's "1+N" climate policy system, representing a significant development that will provide direction and political guidance for the nation's decarbonization efforts [80]. The "1" component of the system refers to the working guidance, which operates under the "new development philosophy" endorsed by Xi Jinping. This theoretical framework sets overarching objectives for China's future development within the context of its "dual-carbon" goals. The "N" component encompasses action plans and measures tailored for key sectors. These plans are designed to address specific challenges and opportunities within each sector and are integral to achieving China's climate targets. According to a National Development and Reform Commission (NDRC) official, the 1+N system allows for flexibility in implementing policies and measures across diverse sectors [81]. The NDRC has been tasked with the authority to formulate policies as part of the 1+N design, working in collaboration with local authorities and government departments to ensure coordinated implementation of the action plans. The system covers ten key sectors, including energy structure, industrial transition, energy efficiency and low-carbon buildings, green transportation, circular economy, technology innovation, green finance, economic reforms, carbon markets and pricing, and nature-based solutions [77].

This comprehensive approach underscores China's commitment to addressing climate change through a multi-faceted strategy that integrates policy development, sector-specific initiatives, and collaborative governance mechanisms. By adopting the 1+N climate policy system, China aims to navigate the complexities of decarbonization while advancing sustainable economic development.

4.4. National Emissions Trading Scheme: A Slow Start with Ambitious Plans:

China's national emission trading scheme (ETS), launched in July 2021, marked a significant step towards curbing carbon emissions. Discussions for an ETS began in 2011, with pilot programs running in seven local regions from 2013 onward. The initial phase focuses solely on the power generation sector, responsible for over 40% of China's energy-related CO_2 emissions. This makes it the world's largest ETS by covered emissions, despite lacking a fixed cap, unlike other "cap-and-trade" systems. Instead, facilities receive free allowances based on output and emission intensity benchmarks, varying across unit types and sizes [77]. Two years after its launch (July 2023), the national ETS generated a cumulative turnover of 11.03 billion Chinese Yuan ($1.54 billion) and traded 239.9 million tons of carbon allowances. These figures pale in comparison to the established EU ETS, which in 2022 alone recorded transactions of 12.5 billion tonnes and a turnover of €865 billion ($958 billion) [82], [83]. China's ETS launch coincided with the EU's approval of a carbon border adjustment mechanism (CBAM). This policy aims to prevent "carbon leakage" by imposing a carbon price on imported goods entering the EU unless they come from regions with equivalent carbon pricing mechanisms. Starting October 2023, importers will be required to report emissions, with payments mandated in 2026. As a major exporter to the EU, China stands to be significantly impacted by this policy, particularly in targeted industries like cement, iron, steel, aluminum, fertilizers, electricity, and hydrogen. China's ETS initially planned to expand to other energy-intensive sectors like petrochemicals, chemicals, building materials, and aviation. However, progress has reportedly been delayed due to unreliable emissions data [83], [84], [85].

4.5. China's Power Sector Transformation:

Over the past two decades, China has embarked on a significant transformation of its electricity sector by implementing a series of power market reforms. These reforms aim to introduce competition, improve efficiency, and facilitate the integration of renewable energy sources. In 2002, China initiated a critical step by separating power generation companies from grid utilities responsible for transmission, distribution, and retail [86]. This dismantled the previous state-owned monopoly control over the entire electricity sector, paving the way for competition among independent power producers. A new wave of reforms in 2015 further separated the transmission, distribution, and retail sectors, fostering competition within each segment. Crucially, these reforms allowed diverse retail entities to participate in the market and most importantly, enabled generation and retail prices to be determined by market forces [87]. This shift towards market-based pricing mechanisms is crucial for efficient resource allocation and attracting investment in renewable energy sources. The reforms actively supported the creation of electricity spot markets for real-time trading based on supply and demand fluctuations. Provincial-level pilot programs kicked off in 2018, allowing for dynamic price adjustments that reflect real-time market conditions [88]. Spot markets are particularly well-suited for integrating renewable energy sources due to their variable nature, such as wind and solar power.

The National Development and Reform Commission (NDRC) and the National Energy Administration (NEA) have set ambitious goals to establish a unified national power market by 2030, with a preliminary structure in place by 2025 [89]. This signifies a significant shift towards a more interconnected and market-driven electricity sector, fostering competition and potentially leading to lower electricity prices for consumers. In September 2023, the

NDRC and NEA released "basic" rules for China's spot market. These rules promote the construction of inter-provincial, provincial, and regional markets, ultimately aiming to integrate them into a cohesive national network [90]. Energy experts believe that spot trading will improve cost-effectiveness and facilitate the integration of renewable energy sources due to their variable nature. These reforms, coupled with China's national control plan for methane emissions released in November 2023, demonstrate the country's commitment to a cleaner and more efficient energy sector that fosters competition and embraces renewable sources.

5. Achieving Carbon Neutrality by 2060:

China's target to attain carbon neutrality by 2060 is under the sustainable climate goals of the Paris Agreement to limit the rise in the temperature of the globe to 2°C. China has a keen eagerness to combat climate change primarily because of domestic environmental issues including the effect of climate change on food and water security. China has also a long-term strategic aim to become a global technological industrial leader in the 21st century [91]. Furthermore, this is also strong opposition within China including governmental enterprises, which highly rely on coal and associated industries. For instance, as of 2020, the solar power generation capacity of China is 281 GW, which significantly increased over the last few years by 20% annually. During times of COVID-19, solar and wind power capacities were increased by 49 GW and 71 GW, respectively. However, increasing the share of renewable energy from 17% to nearly 85% (more than 6 times) in a short span of 30 to 40 years is a hectic task under the given constraints of solar and wind energy associated with seasonal change and weather patterns. Additionally, reducing coal share from 70% (as of 2020) to 10% by 2050 would require a rapid phase-out of coal-based power generation facilities and would render them stranded assets. Furthermore, unemployment would be an issue that would arise in this quick phasing out of coal power plants. Despite the crucial issues described above, the following section highlights the key steps either taken by the Chinese government or proposed by the researchers and the climate change-based scientific community for rapidly achieving carbon neutrality by 2060 [92].

A three-stage/four-step strategy: Climate change poses a threat to all of humanity. China has established a long-term ambition of becoming carbon-neutral by 2060, but there are numerous hurdles ahead. Zhao and colleagues proposed that China should explore developing a three-stage/four-step strategy to attain carbon neutrality. The first stage would last from 2021 to 2030, with the main aim of reaching the carbon peak; the second stage (from 2031 to 2040), with the major goal of achieving carbon slowdown; and the third stage (from 2041 to 2060), with the main goal of achieving carbon neutrality. The third stage is further split into two sub-steps: the first (from 2041 to 2050) is to achieve zero-carbon emissions in China's main industries, and the second (from 2051 to 2060) is to achieve net-zero CO_2 emissions and fully realize the dissociation of economic development and carbon emissions [93].

Environmental decentralization in China: Environmental management is extremely crucial in controlling environmental pollution. Because of China's extensive economic growth, Wu and coworkers studied the effect of environmental decentralization in 30 different provinces of China on its green development using a dynamic model of panel vector autoregressive (PVAR). It was found that environmental decentralization (partitioning of environmental managerial powers between local and central governments) and environmental administrative decentralization (splitting of authorities associated with environmental administration) assisted China's green development. Whereas, decentralization of environmental supervision (i.e., environmental rules, laws, and regulations) and monitoring (processes and techniques to assess the quality of air, water, soil, etc.) resulted in adverse implications for China's green development. The cumulative result of the partitioning of environmental managerial powers between local and central governments and local government competition induces a "race to the bottom" that negates China's regional green development [94]. In addition, they proposed the following policy recommendations;

- Significant autonomy should be provided to the local government by the central government to effectively utilize funds in environment-relevant agencies. This will help local governmental bodies to augment their environmental services. Additionally, it will induce healthy competition among various local bodies to provide the best environmental services. Consequently, it will aid regional economic development [94].

- Also, the resource allocation should be based on the nature of the respective areas as economic growth is not balanced in all regions of China. For instance, the eastern regions of China have strong environmental management and supervision systems. Therefore, eastern regions do not further require improvement concerning environmental management. However, the central government can increase the allocation of environmental supervision and management systems since these areas have limited resources concerning environmental management [94].

Economic development based on clean and green initiatives: Equal emphasis should be placed on economic development and environmental protection; strengthening top-level design; improving energy efficiency through technological reform and innovation, establishing clean energy; boosting the process of energy conservation, emission reduction, and energy transformation; and applying negative emission technology to promote low-carbon and zero-carbon economic and social development. Simultaneously, it is critical to enhance China's green financial system, promote the transformation and upgrading of industrial structure, improve the national carbon emissions trading market, fully exploit the market's role in green resource configuration, and provide complete support to localities where conditions allow achieving their carbon peak and carbon neutrality, which will accelerate China's carbon peak and carbon neutrality [93]. Furthermore, speeding the development of climate change legislation, enhancing key legal rules, and undertaking broad interaction with the international community would assist ensure China's carbon-neutral aim is met smoothly. All of this might help China to meet its carbon neutrality commitment on time and make a big contribution to the fight against global warming.

Presently, reducing China's GHG emissions is extremely essential and critical in determining the sustainable future of the world. However, few internationally recognized authorities outside of the Chinese government can investigate the true sources of this global warming pollution. According to a Rhodium Group study, China's companies drove the country's greenhouse gas emissions over that of all developed nations altogether in 2019. To meet President Xi Jinping's promise of zero emissions by 2060, these same companies will have to abandon dirty energy, embrace new technologies, and change their business models. “Emissions of numerous state-owned enterprises in the power, steel, cement, oil refining, and other major emitting sectors are equal to those of entire nations,” says Lauri Myllyvirta, an analyst with the Centre for Research on Energy and Clean Air. “Once these enterprises align their investments and business plans with the emissions-neutrality target, they can make an enormous contribution, if they choose to.” [91].

6. Conclusion:

China's response to the intertwined challenges of greenhouse gas (GHG) emissions and climate change presents a critical case study for the world. This review paper has explored China's evolving strategic approach, encompassing both international commitments and ambitious domestic initiatives. Here are the main conclusions:

- On the international stage, China's adherence to the Paris Agreement and its subsequent Nationally Determined Contributions (NDCs) represent a significant commitment to reducing GHG emissions and achieving carbon neutrality by 2060.
- Domestically, China's multi-pronged strategy tackles climate change head-on. The 14th Five-Year Plan (FYP) for Energy emphasizes clean energy development, while the National Emissions Trading Scheme incentivizes industries to curb emissions. The 1+N Policy framework fosters regional collaboration on climate action, and the ongoing power sector transformation prioritizes renewable energy sources.
- However, achieving carbon neutrality by 2060 hinges on the effectiveness of these policies. Carefully analyzing their implementation and impact will be crucial. China faces challenges, such as balancing climate goals with economic growth and ensuring a just transition for workers in carbon-intensive industries.
- Despite these hurdles, China's strategic approach demonstrates a growing recognition of the urgency of climate action. Continued advancements in clean energy technologies, coupled with international collaboration and knowledge sharing, will be essential for China's success. Ultimately, the effectiveness of China's climate strategy will not only benefit its own citizens but also contribute

significantly to global efforts in mitigating climate change and building a more sustainable future for all.

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