# SUSTAINABLE ENERGY AND ENABLING NET ZERO EMISSIONS

## Final term project by Group-02

## Developing net zero $CO_2$ emissions (by 2050) plan for China

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### Abstract

China, the world's largest emitter, contributes nearly 30% of global carbon dioxide emissions, totaling approximately 14 gigatonnes annually [1]. Although China has committed to achieving carbon neutrality by 2060 under its Nationally Determined Contribution (NDC), reaching net zero emissions by 2050 is crucial to align with the 1.5°C global warming limit recommended by the IPCC AR6 report [2].

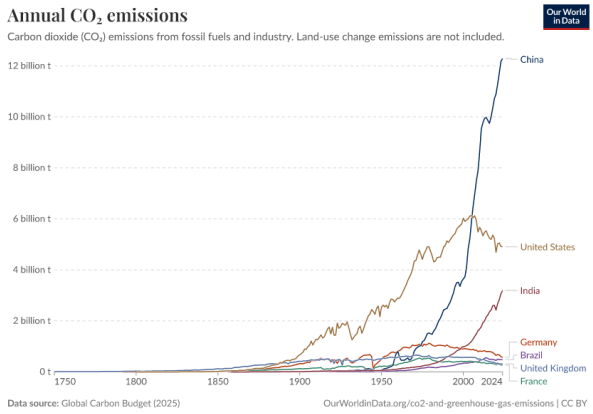



Figure1: annual $CO_2$ emissions [1]

This report presents a comprehensive, quantitative roadmap for China to achieve this accelerated 2050 net-zero target [2][3]. The strategy is founded on deep electrification, significant expansion of renewable energy, industrial sector transformation, deployment of carbon capture technologies, and structural policy reforms. By integrating sectoral decarbonization strategies, energy system modeling, and carbon removal mechanisms, the proposed framework demonstrates both the technical and economic feasibility of the transition within a sustainable development context [3].

### Introduction

China's rapid industrial growth over the last thirty years has heavily relied on coal, making it the world's largest consumer of primary energy [4]. Coal dominates China's energy mix, accounting for about 56% of primary energy consumption, with oil and natural gas contributing approximately 18% and 9%, respectively [4]. This reliance has caused a significant rise in the country's annual $CO_2$ emissions since 2000, primarily driven by the power generation (nearly 40% of total emissions), heavy industry (approximately 30%), and construction sectors [1]. Transport contributes about 10%, with buildings and other sectors making up the rest [1][4].

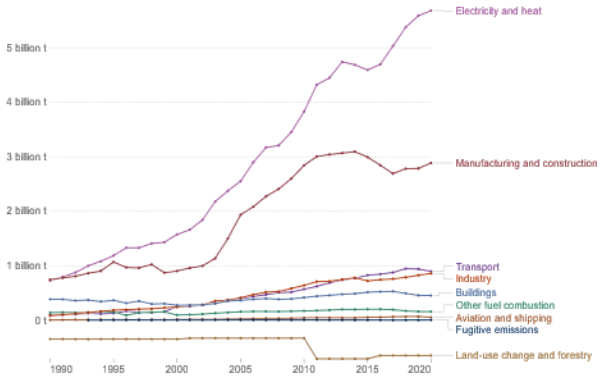



Figure2. $CO_2$ emissions from different sectors [1]

Despite these high emissions, China has also emerged as the global leader in renewable energy deployment, installing more solar and wind capacity than any other nation in recent years [5]. Leveraging this leadership in renewables could accelerate China's transition pathway, potentially enabling it to achieve net-zero emissions by 2050, a decade earlier than its current 2060 target [2][5].

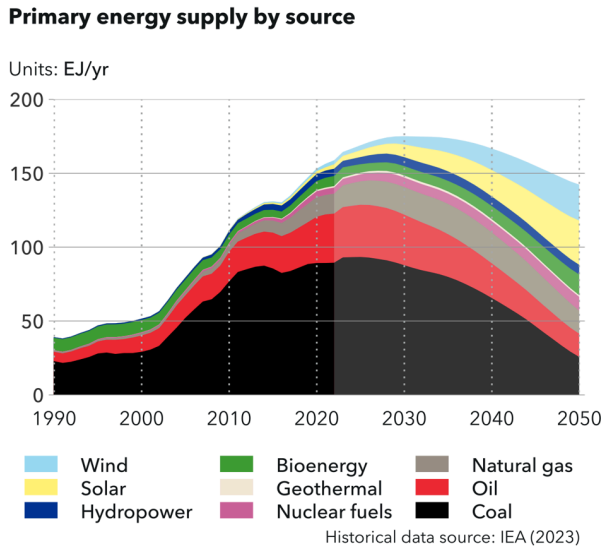
### Methodology

The study employs a scenario-based energy systems approach, drawing on publicly available data from sources including the International Energy Agency (IEA), IPCC, Energy Transitions Commission, Climate Action Tracker, and China Energy Outlook reports [2][3][4]. The analysis is benchmarked against a 2022 baseline, where total

emissions were estimated at approximately 14 $GtCO_2$ and electricity generation was around 7000 TWh [1][4].
A key element is the accelerated net-zero scenario, which incorporates several assumptions: annual energy intensity improvements of 3–4%, the progressive electrification of various end-use sectors, and a projected carbon price of about $150 per tonne by 2045 [2][6]. Furthermore, renewable capacity factors are set at 20% for solar PV and 30% for wind, reflecting global averages documented in IRENA and IEA datasets [4][5]. Economic growth is assumed to slow to an annual rate of 3–4% by 2040, aligning with projections from the China Energy Outlook 2050 [7].

### Energy Demand Outlook to 2050

China's total final energy demand is projected to decrease from its current level of nearly 88 EJ to an estimated 64–70 EJ by 2050, primarily driven by structural shifts in the economy and improved efficiency [4][7]. However, despite this overall decline in energy use, electricity demand is anticipated to rise substantially. It is expected to almost double from 7000 TWh in 2022 to nearly 15,000 TWh by 2050 [3][4].




This significant increase is attributed to the increasing electrification of key sectors, including transport, heating, and industry [3][4]. Electrification contributes to improved system efficiency because electric technologies, such as heat pumps and electric vehicles (EVs), convert energy more effectively than traditional fossil fuel systems [2]. Consequently, electricity's share of final energy consumption is forecasted to jump from approximately 28% in 2022 to nearly 70% by 2050 [3][4].

### Power Sector Transformation

Decarbonizing the power sector is the central pillar of China's net zero transition because it enables emissions reduction across other sectors through electrification [2]. To generate approximately 15,000 TWh by 2050, installed renewable capacity must increase significantly [3]. Solar PV capacity would need to reach roughly 2.7 TW, which at a 20% capacity factor would generate approximately 4700–4800 TWh annually [3][5]. Wind capacity would need to reach approximately 2.4 TW, which at a 30% capacity factor would generate roughly 6200–6300 TWh annually [3][5]. Hydropower capacity is expected to reach around 550 GW contributing approximately 2000 TWh annually, while nuclear capacity of around 100 GW would contribute approximately 800 TWh annually [3][4]. Together, these sources would provide more than 85% of total electricity generation, significantly reducing coal-based generation [3].

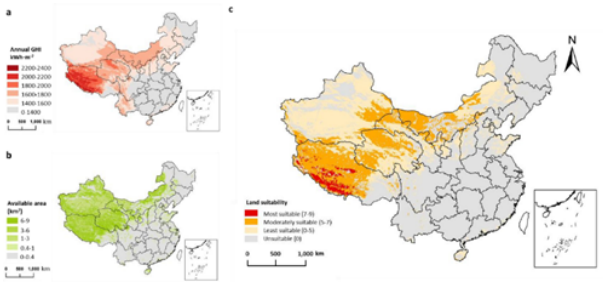


Figure: Available and Favorable area for solar PV.

To maintain grid stability with high renewable penetration, China would require large-scale energy storage including approximately 140 GW of pumped hydro storage and between 800–1000 GWh of battery storage capacity

[3][5]. Ultra-high voltage transmission expansion would also be necessary to integrate renewable resources from western provinces into eastern industrial demand centers [5].

### Industrial Decarbonization

China's industrial sector contributes an estimated 4–5 $GtCO_2$ to annual global emissions, with the primary sources being steel, cement, and chemical production [1][4]. Significant emissions reduction can be achieved in steelmaking by switching from the conventional blast furnace-basic oxygen furnace (BF-BOF) method to electric arc furnaces (EAF) powered by renewable energy [3]. Furthermore, eliminating fossil-based inputs is possible through the adoption of green hydrogen in direct reduced iron (DRI) processes [3][8].

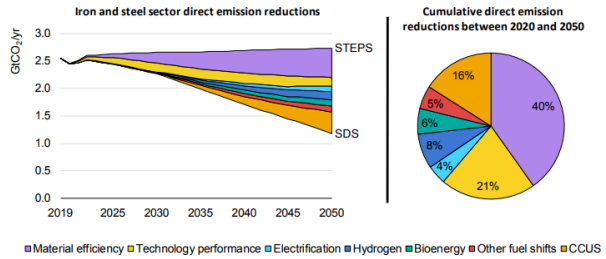



figure: Iron & steel $CO_2$ cuts in SDS by mitigation.

For the cement industry, emissions can be lowered through strategies like clinker substitution, the electrification of process heat, and the implementation of carbon capture and storage (CCS) technologies [2][8]. Overall, these industrial decarbonization initiatives have the potential to collectively reduce annual $CO_2$ emissions by approximately 3 $GtCO_2$ by the year 2050 [3].

### Transport Sector Transformation

China's transport sector is currently responsible for about 10% of the nation's total emissions, with road transport being the primary contributor [1]. Significant emissions and oil demand reductions could be achieved by nearly complete electrification of passenger vehicles by 2045 [6]. Decarbonization strategies for the hard-to-electrify segments include the transition of heavy-duty transport to cost-competitive hydrogen fuel cells or battery-electric systems [2] [6], and the use of sustainable aviation fuels and green ammonia-based marine fuels for aviation and shipping, respectively [2]. Overall, these measures across the transport sector are projected to reduce annual $CO_2$ emissions by approximately 2 $GtCO_2$ by 2050 [2] [3].

### Hydrogen Economy

China's hydrogen demand is expected to significantly increase under deep decarbonization strategies, rising from about 33 million tonnes in 2020 to an estimated 80–100 million tonnes by 2050 [4][8]. This growing demand would be met by green hydrogen, generated via electrolysis powered by renewable electricity, which would replace fossil-based hydrogen in industrial use and offer seasonal energy storage [2][3]. Meeting this projected green hydrogen need would necessitate a substantial addition of approximately 3500–4000 TWh of new renewable electricity generation capacity [3].

### Carbon Capture and Negative Emissions

Even with widespread electrification and efficiency improvements, residual emissions from sectors such as cement, chemicals, and aviation are likely to persist [2]. To address these, a combination of negative emission technologies is necessary to achieve net-zero goals by offsetting these residual emissions [2]. Specifically, Carbon Capture and Storage (CCS) technologies in industrial clusters could potentially capture up to 2 $GtCO_2$ annually by 2050 [2][8]. Furthermore, Bioenergy with Carbon Capture and Storage (BECCS) and afforestation programs are projected to contribute approximately 1 $GtCO_2$ of annual carbon removal [2].

## Economic Considerations

China's net-zero transition between 2025 and 2050 is estimated to require a total cumulative investment of approximately $6–7 trillion, aligning with projections from the Energy Transitions Commission [3]. This investment, representing roughly 1.5–2% of China's projected annual GDP over the transition period, is considered economically manageable due to the country's significant capacity for infrastructure investment [3][7]. Furthermore, carbon pricing mechanisms within China's national emissions trading system are expected to provide the necessary economic signals to accelerate low-carbon investments [6].

## Conclusion

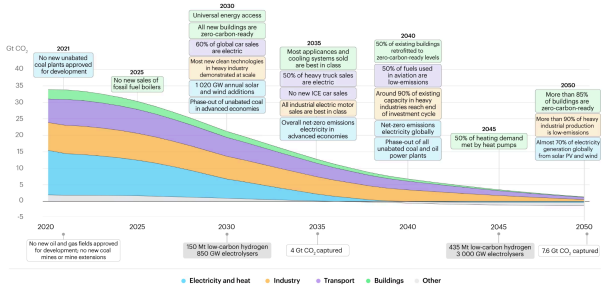



Fig: Netzero pathway by 2050 [8]

Achieving net zero emissions in China by 2050 is technically feasible and economically viable if supported by strong policy frameworks, rapid renewable expansion, industrial transformation, and deployment of carbon removal technologies [2][3]. The transition requires increasing electricity generation to approximately 15,000 TWh, expanding renewable capacity to multi-terawatt levels, electrifying transport and industry, and scaling CCS deployment [3][4]. Early and accelerated action reduces long-term transition costs and aligns China with global 1.5°C climate objectives [2]. With coordinated implementation, China can shift from being the largest emitter to becoming a global leader in deep decarbonization [5].

## References


[1] Our World in Data, "$CO_2$ and Greenhouse Gas Emissions."

[2] IPCC, AR6 Working Group III Report, 2022.

[3] Energy Transitions Commission, "China 2050: A Fully Developed Rich Zero-Carbon Economy," 2020.

[4] International Energy Agency (IEA), World Energy Outlook 2023; China Country Data.

[5] International Renewable Energy Agency (IRENA), Renewable Capacity Statistics 2023.

[6] Climate Action Tracker, China Policy Assessment 2023.

[7] China Energy Outlook 2050 Report.

[8] IEA, "Net Zero by 2050 Roadmap," and Industrial Decarbonisation Reports.