# Research on the Methods of Environmental Impact Analysis of Nuclear Power-Daya Bay in China as a Case

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**Abstract.** Nuclear energy, as a clean energy source, reduces reliance on fossil fuels and plays a key role in transforming the energy structure and achieving China's "carbon neutrality" and "carbon peak" goals. Using the Daya Bay Nuclear Power Station as a case study, this paper first calculates the carbon emission intensity of nuclear power through life cycle assessment and compares it with that of several renewable sources (hydropower, wind, and photovoltaic) and traditional thermal power. The findings show that: The carbon emission intensity of nuclear power is 10.42 $gCO_2e/kWh$, lower than thermal, hydropower, and photovoltaic generation, but slightly higher than wind power. About 83% of emissions occur during fuel extraction and waste disposal. Thus, the development of nuclear power is crucial for transforming China's energy structure and meeting carbon peaking and carbon neutrality goals.

**Keywords:** Nuclear energy; Environmental impacts; Carbon emission; Life cycle assessment

## 1 Introduction

The electricity industry is the primary source of carbon emissions in China [1]. To achieve sustainable development, China is exploring energy pathways that meet evolving demands. In 2020, China set carbon peak and carbon neutrality goals. By the end of 2023, clean energy generation reached 3.8 trillion kWh [2], with nuclear energy contributing 0.43 trillion kWh (4.86%). China's installed nuclear capacity remains well below the global average, indicating significant potential for further development [3].

With the development of nuclear power, its environmental impact has become a growing public concern. In response, numerous studies have employed life cycle assessment (LCA) methods to evaluate greenhouse gas emissions associated with nuclear power. Fthenakis VM et al. [4] calculated greenhouse gas emissions at each stage of the nuclear fuel cycle in the United States using the LCA. Siddiqui O et al. [5] compared the environmental impacts of nuclear power, wind power, and hydropower in Ontario, Canada through LCA. In China, Ma Zhonghai et al. [6] estimated the greenhouse gas


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emission coefficient of the nuclear power chain in 1999, and in 2001, conducted a comprehensive analysis of the greenhouse gas emissions across the entire nuclear energy chain using LCA [7]. In 2015, Jiang Ziying et al. [8] employed full energy chain analysis (PCA) and LCA methods to evaluate the life cycle greenhouse gas emissions in China's nuclear energy chain using updated data. In 2021, Wang Yanzhe et al. [9] conducted a quantitative analysis of $CO_2$ emission intensity per unit of electricity generation for nuclear, thermal, gas, hydro, photovoltaic, and wind power in China, based on LCA and segmented by stage.

Current foreign studies primarily focus on local conditions, while domestic studies need to align with the national context. Some domestic studies rely on earlier data, which should be updated with technological advancements. This paper calculates the carbon emission intensity of nuclear power throughout its life cycle, using the latest carbon emission factor data and life cycle assessment methods. A comparative analysis with other renewable and thermal power technologies evaluates nuclear power's emission reduction potential and environmental sustainability, providing a clearer basis for its role in the low-carbon energy system.

## 2 Methods

### 2.1 Life Cycle Assessment Methodology

Life Cycle Assessment (LCA) is a standardized methodology used to evaluate the environmental impacts of a product, process, or service across its entire life cycle, from cradle to grave [10]. LCA aims to identify and quantify the potential environmental impacts at each life cycle stage, including raw material extraction, production, use, disposal, and recycling. This approach helps decision-makers understand the cumulative environmental effects and supports the development of more sustainable choices. This study applies LCA to assess the greenhouse gas emissions of various power generation technologies over their life cycles and analyze their environmental impacts.

### 2.2 System Boundaries

The GHG emissions evaluation framework in this study follows the LCA model in [9], as shown in Fig. 1. It is divided into two cycles: the fuel cycle and the plant cycle. The evaluation boundary is defined based on the characteristics of different power generation methods, including only stages with significant GHG emissions contributions, while excluding stages with minimal impact (e.g., less than one-thousandth of a percent) [8] . This ensures consistency and comparability across evaluation frameworks for different power generation technologies.

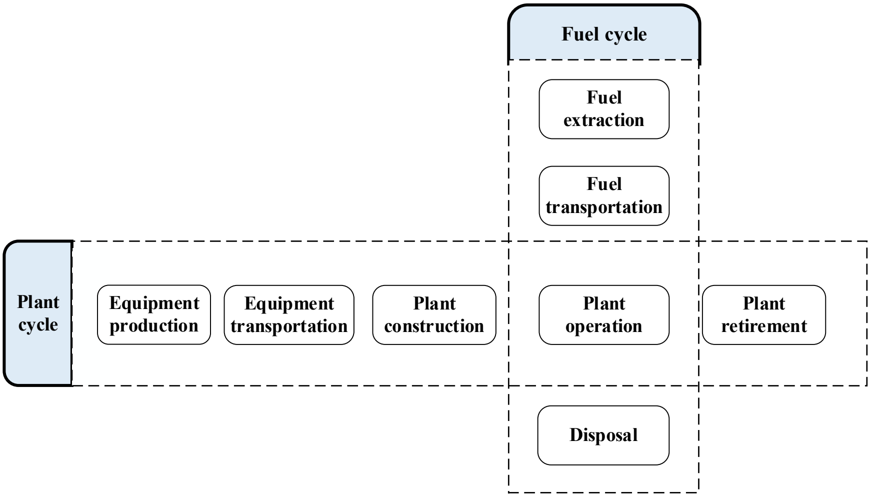



**Fig. 1.** Whole Life Cycle Assessment Framework.

(1) Nuclear Power: This study considers carbon emissions from fuel extraction and waste disposal within the fuel cycle, as these processes involve energy and material consumption. The contribution of fuel transportation to the nuclear power life cycle's carbon emissions is minimal and negligible. The plant operation stage focuses on GHG emissions associated with fuel during electricity generation. Since nuclear fuel does not emit GHGs during fission [11], nuclear power generation results in zero GHG emissions during operation [12].

In the plant cycle, the production of equipment, plant construction, and operation are considered. The first two stages involve material and energy consumption, while the plant requires electricity for operations and residential use during its operation [12], necessitating the inclusion of carbon emissions from these stages. Carbon emissions from equipment transportation are negligible. Due to the lack of detailed energy consumption data, emissions from the decommissioning stage are not considered.

(2) Renewable Energy Power: This includes hydropower, wind power, and photovoltaics, which have no fuel cycle. In the plant cycle, hydropower covers equipment production, transportation, plant construction, and operation. As most of China's hydropower plants are already operational, data on decommissioning is limited, and carbon emissions from this stage are not considered. Wind power is evaluated across all five stages. Photovoltaic power considers equipment production, transportation, and plant construction, with minimal energy consumption during operation and a long lifespan. Due to limited data on energy consumption during decommissioning and recycling, carbon emissions from these stages for wind power are not included in the analysis.

(3) Thermal Power: The system boundary includes both the fuel cycle and plant cycle segments, as described in Figure 1.

### 2.3 Methodologies for Calculating Greenhouse Gas Emissions

(1) Total Life-Cycle Power Generation

$$E = 8760 \cdot T \cdot C \cdot \delta \tag{1}$$

where 8760 is the number of hours in a year; $T$ is the operating life of the unit; $C$ is the installed capacity of the unit; $\delta$ The average annual load factor of the unit.

(2) Carbon Emission Intensity per Unit of Electricity Generation

$$C_n \begin{cases} \frac{\sum_{j=1}^{2}\sum_k\sum_i m_{ijk}\sigma_i(t)}{E}, & \text{n is nuclear power or coal power;} \\ \frac{\sum_k\sum_i m_{ijk}\sigma_i(t)}{E}, & \text{n is renewable energy generation，j = 1.} \end{cases} \tag{2}$$

where $n$ is the mode of power generation; $m_{ijk}$ is the material or energy source $i$ in the $j$ cycle $k$ cycle. When $j = 1$ is the power plant cycle, and $j = 2$ is the fuel cycle; $\sigma_i(t)$ is the amount of material or energy$i$ in the$t$ carbon emission factor for the time period.

### 2.4 Research Population and Data Sources

(1) Nuclear power: The Daya Bay Nuclear Power Plant in China, with two units and a total capacity of 1,968 MW, is the study's objective, referencing energy and material consumption data from [8] .

(2) Hydropower: A typical hydropower plant in China is studied, with greenhouse gas emission data from each stage as detailed in [13] .

(3) Wind power: An onshore wind power project in China, consisting of 50 1 MW turbines, is examined, using greenhouse gas emission data from [13] .

(4) Photovoltaic: A 10 MW PV grid-connected power plant with a 25-year operational life is studied, referencing energy consumption data from [14] .

(5) Thermal power: A domestic power plant with an installed capacity of 600MW is studied, with energy consumption data from [15] .

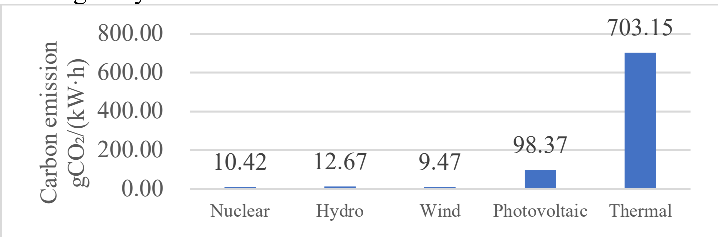
The main parameters of different power generation methods are shown in Table 1, with carbon emission factor data from the China Carbon Emission Factor Database.

**Table 1.** Main parameters of different power generation methods

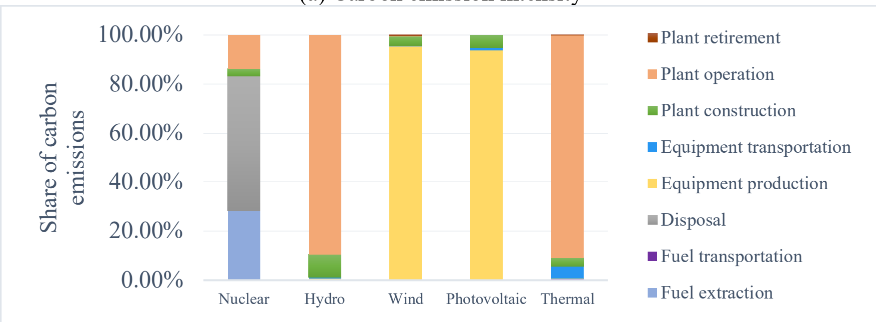
| Type of power | Installed capacity/MW | Operating life/year | Average annual power generation hours/h |
|---|---|---|---|
| Nuclear | 2*984 | 40 | 7430 |
| Hydro | 22500 | 150 | 3567.6 |
| Wind | 1*50 | 20 | 2585 |
| Photovoltaic | 10 | 25 | 1691 |
| Thermal | 60 | 30 | 4293 |

## 3 Results

Fig. 2(a) shows the carbon emission intensity per unit of electricity generation across different power generation modes. The values are 10.42, 12.67, 9.47, 98.37, and 703.15 $gCO_2e/kWh$ for nuclear, hydropower, wind, photovoltaic, and thermal power, respectively. Nuclear and renewable energy modes exhibit much lower carbon emissions than thermal power, with nuclear and wind having the lowest intensity and best environmental performance. Although photovoltaic power generation has a higher carbon intensity, it remains significantly lower than thermal power. Overall, nuclear and renewable energy generation greatly reduce carbon emissions.




(a) Carbon emission intensity




(b) The contribution of each life cycle stage

**Fig. 2.** Carbon emission intensity of different electricity generation methods across the entire life cycle and the contribution of each life cycle stage.

As shown in Fig. 2(b), carbon emissions from nuclear power primarily arise from the waste disposal and fuel extraction stages, accounting for approximately 83%. The disposal phase includes spent fuel reprocessing and waste disposal. Reprocessing, especially through high-temperature chemical treatments and physical separation, relies on fossil fuels, resulting in carbon emissions. Similarly, transportation and storage of spent fuel, particularly in long-term geological disposal and deep burial, require significant energy and contribute to the carbon footprint. The long-term management of high-level radioactive waste demands specialized storage facilities, further increasing energy consumption and emissions. Carbon emissions from fuel extraction primarily stem from uranium ore mining and processing, where heavy machinery using and energy-intensive refining, lead to substantial $CO_2$ emissions. Hydropower exhibits the highest proportion of carbon emissions during the operational phase (about 89%), primarily due to water impoundment and reservoir formation, which submerge land and vegetation. The submerged organic matter undergoes anaerobic decomposition, releasing greenhouse gases. For wind and photovoltaic power, the highest emissions occur during equipment production, accounting for about 95% and 94%, respectively. Manufacturing key components like turbine blades, solar panels, and mounting structures involves processing large quantities of raw materials, including metals and glass, which leads to significant energy consumption, primarily from fossil fuels or electricity, resulting in $CO_2$ and other greenhouse gas emissions. In thermal power generation, about 91% of carbon emissions occur during operation, primarily from the combustion of large quantities of fossil fuels. Additionally, thermal power plants emit pollutants such as nitrogen oxides and sulfur oxides, further contributing to environmental degradation. In summary, while promoting nuclear power, China should address carbon emissions in waste disposal and fuel extraction, exploring green and low-carbon technologies. Wind and photovoltaic power generation should reduce their carbon footprint by optimizing production processes and using clean energy. Hydropower should focus on carbon emissions during water storage and adopt environmentally friendly designs. Thermal power generation needs technological transformation, developing cleaner combustion technologies to cut greenhouse gas emissions. Overall, China's power development should foster low-carbon innovation and strengthen carbon emission control throughout the energy life cycle.

## 4 Conclusion

This paper examines the environmental impacts of nuclear power in China, focusing on carbon emission. Using the Daya Bay Nuclear Power Station as a case study, a life cycle assessment (LCA) approach is employed to calculate the greenhouse gas emission intensity of nuclear power, comparing it with other renewable energy sources and conventional thermal power. The main findings are as follows:

In this study, the carbon emission intensities per unit of electricity generation for nuclear power, hydropower, wind power, photovoltaic power, and thermal power in China are 10.42, 12.67, 9.47, 98.37, and 703.15 $gCO_2e/kWh$, respectively. The carbon emission intensities of nuclear and renewable energy sources are significantly lower than those of thermal power generation. For nuclear power, emissions primarily result from fuel extraction and waste disposal. Wind and photovoltaic power emissions are mainly associated with equipment production. Carbon emissions from hydropower and thermal power primarily arise from plant operations, albeit for different reasons. Overall, fostering the synergistic development of nuclear power and renewable energy generation will play a crucial role in reducing greenhouse gas emissions and advancing the achievement of China's carbon neutrality goal. In conclusion, this study requires improvements in data completeness, which should be addressed in future work.

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