



Analysis of Carbon Accounting during the Construction Period of Power Transmission and Transformation Infrastructures

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Abstract. The escalating scale of power transmission and transformation infrastructure construction each year has led to a substantial increase in the consumption of materials and energy. This article proposes methods for calculating carbon emissions during the different construction stages of power transmission and transformation infrastructures, including the production and transportation of raw materials and the engineering construction period. The calculation methods are subsequently validated through their application in the construction of a 500 kV transmission line infrastructure in a province in China. According to our findings, the top three contributors to carbon emissions are the production of metals for conductors and towers and the construction of foundations. During construction, the emissions from basic engineering projects are the highest, whereas the emissions from grounding and debugging projects are the lowest. An accurate carbon accounting of power transmission and transformation infrastructures helps grasp the key compositions of carbon emissions in the construction process of power transmission and transformation infrastructures, thereby baking the formulation of effective emission reduction measures and helping power grid infrastructures achieve the goals of "carbon peaking and carbon neutrality".

Keywords: Power transmission and transformation infrastructures, Carbon emissions.

1 Introduction

According to the *Annual Report on Development of China's Power Industry 2023* released by the China Electricity Council, the national power grid construction registered an investment of 500.6 billion yuan in 2022, an increase of 1.8% compared to the previous year [1]. The carbon emissions of power grid infrastructures are generally included in the life cycle assessment of the power supply chain or as specific components of the transmission network. However, such assessments are primarily focused on Europe. Accurately accounting for the carbon emissions during the construction period of power transmission and transformation infrastructures in the power grids will help us

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foster a deeper understanding of the composition of carbon emissions in the construction process, ushering in effective emission reduction measures based on the carbon emission levels of each stage, and achieving the ultimate goal of "carbon peaking and carbon neutrality" in the power grid infrastructure construction.

Currently, the low-carbon construction of China's power grid engineering is still in its infancy, with most of the research centered on the carbon emissions of the power system, as well as macro research on the carbon emissions of power grid enterprises. On the contrary, carbon accounting during the construction period of power grid engineering is unreported. Turconi, R. thinks in future electricity systems the impacts of distribution network equipment are expected to increase, and as renewable sources will provide lower impacts, those caused by infrastructure may become comparable to those associated with electricity generation itself[2]. Jorge, R.S. et al. uses process LCA to evaluate the impacts in each life cycle stage of the components of power grids and the contribution of the different processes related to infrastructure to the components impacts[3][4]. Zhang et al. collected field construction data from fifteen 500 kV transmission line infrastructures and applied the field data in a life cycle assessment framework, the results of which revealed that the infrastructure-induced emissions of nine recently constructed ultra-high voltage direct current infrastructures in China amounted to 16.7 Mt CO₂[5]. Wei et al. combined input-output analysis with process analysis to reveal the significant energy consumption and carbon dioxide emissions of typical ultra-high voltage substations in China [6].

However, the accounting data on carbon emissions from China's power transmission and transformation infrastructures are limited. To navigate this problem, carbon accounting methods for the construction period of power transmission and transformation infrastructures are proposed in this article based on existing research results, and the specific calculation process is presented with practical instances. The proportion of carbon emissions in each of construction period of power transmission and transformation infrastructures is analyzed, and the key stages of low-carbon emission reduction are summarized.

2 Carbon accounting methods for the construction of power transmission and transformation infrastructures

Carbon accounting during the construction period of power transmission and transformation infrastructures mainly includes the production and transportation of building materials and equipment and the engineering construction period. Among these, the construction process consists of the carbon emissions generated by the completion of various projects and those produced by the implementation of various measures. The construction of substations mainly encompasses sub-infrastructure such as site transportation, earthwork engineering, foundation engineering, masonry engineering, concrete and steel reinforcement engineering, metal structure engineering, ground and floor engineering, roofing and waterproofing engineering, water supply and sewerage engineering, lighting and lightning protection and grounding engineering, and fire protec-

tion engineering. The construction of transmission lines mainly incorporates sub-infrastructures such as site transportation, earthwork engineering, foundation engineering, tower engineering, overhead line engineering, accessory engineering, and auxiliary engineering. The carbon emissions during the construction stage stem from the energy consumption of construction machinery involved in each sub-infrastructure, the construction water usage, and the on-site personnel's utilization of water, electricity, and gas in their lives and work.

2.1 Calculation of carbon emissions

The formula for calculating the total carbon emissions during the construction period of power transmission and transformation infrastructures is as follows:

$$C_{inf} = C_m + C_{mtr} + C_f + C_e + C_w + C_{wtr} \quad (1)$$

In this formula, C_{inf} represents the total carbon emissions during the construction period of the power transmission and transformation infrastructures (kg CO₂e); C_m represents carbon emissions generated during the physical and chemical stages of building materials and equipment used in the construction (kg CO₂e); C_{mtr} represents carbon emissions generated from the transportation of building materials and equipment used in the construction (kg CO₂e); C_f represents carbon emissions generated by the combustion of fossil fuels used in mechanical equipment during the construction (kg CO₂e); C_e represents implicit carbon emissions from the use of purchased electricity during the construction (kg CO₂e); C_w represents carbon emissions incurred by water usage at the construction site (kg CO₂e); C_{wtr} represents carbon emissions generated from waste treatment at the construction site (kg CO₂e).

1) Calculation of carbon emissions from the production of building materials and equipment for power transmission and transformation engineering construction:

$$C_m = \sum_{i=1}^n (M_i \times MF_i) + \sum_{j=1}^m (E_j \times EF_j) \quad (2)$$

Here M_i represents the total amount of Class i building material used in the construction of power transmission and transformation infrastructures (t); MF_i represents the carbon emission factor for Class i building material, wherein the utilization of recycled raw materials results in a 50% reduction in carbon emission level compared to using the replaceable primary raw materials; E_j represents the total amount of Class j equipment used in the construction (t); EF_j represents carbon footprint of Class j equipment during the manufacturing stage (kg CO₂e/t); i represents the serial number of building materials; j represents the device serial number.

2) Calculation of carbon emissions generated by the transportation of building materials and equipment used in power transmission and transformation engineering construction:

The transportation stage mainly includes the off-site transportation of large power transmission and transformation equipment, construction equipment and facilities, and

building materials. Large power transmission and transformation equipment mainly involve transformers, switch gears, insulators, lightning arresters, transmission lines, and secondary equipment. The carbon emissions during the transportation stage derive from the fuel consumption of vehicles during off-site transportation.

$$C_{mr} = \sum_{i=1}^n \sum_{j=1}^m (MT_i \times D_{i,j} \times EF_j) + \sum_{i=1}^n \sum_{j=1}^m (ET_i \times D_{i,j} \times EF_j) \quad (3)$$

Here MT_i represents the consumption of Class i building material used in the construction of power transmission and transformation infrastructures (t); ET_i represents the load capacity of Class i equipment in construction (t); $D_{i,j}$ represents the transportation distance of Class i building materials or equipment using Class j transportation method (km); EF_j represents the carbon emission factor per unit weight transportation distance under Class j transportation mode (kg CO₂e/t·km); i represents the serial number of building materials; j represents the serial number of the transportation method.

3) Calculation of carbon emissions generated by fuel combustion at the construction site of power transmission and transformation infrastructures:

$$C_f = \sum_{i=1}^n \left(P_i \times \sum_{j=1}^m (T_{i,j} \times F_j \times EF_j) \right) \quad (4)$$

$$EF_j = NCV \times CC \times OF \times \frac{44}{12}$$

Within this formula, P_i represents the engineering quantity (unit of measurement) for Class i sub infrastructure of the power transmission and transformation infrastructures; $T_{i,j}$ represents the total number of Class j construction machinery shifts per unit quantity of Class i sub infrastructure (shift/unit infrastructure); F_j represents the fossil fuel consumption of Class j construction machinery per unit shift (kg/shift); EF_j represents the carbon emission factor of fossil fuels or electricity used for Class j construction machinery (tCO₂e/t); NCV represents the low calorific value of fossil fuels (GJ/t); CC represents the carbon content per unit calorific value of fossil fuels (tC/GJ); OF represents the carbon oxidation rate of fossil fuels (%); 44/12 is the relative molecular weight ratio of carbon dioxide to carbon; i represents the infrastructure serial number; j represents the serial number of construction machinery.

4) Calculation of carbon emissions induced by the use of purchased electricity during the construction process of power transmission and transformation infrastructures:

$$C_e = \sum_{i=1}^n E_i \times EF \quad (5)$$

Here E_i represents the electricity consumption of Class i infrastructure, excluding clean electricity (MWh); EF represents the carbon emission factor of the corresponding regional power grid.

5) Calculation of carbon emissions generated by construction water usage for power transmission and transformation infrastructures:

$$C_w = \sum_{i=1}^n W_i \times WF_i \quad (6)$$

Here W_i represents the construction water consumption (t) for Class i infrastructure; WF_i indicates the carbon emission factor of water (kg CO₂/t) is generally taken as 0.168; i represents the infrastructure serial number.

6) Calculation of carbon emissions generated by the transportation of construction waste in power transmission and transformation infrastructures:

$$C_{wtr} = \sum_{i=1}^n CW_i \times D_i \times CWF_i \quad (7)$$

In this formula, CW_i represents the amount of waste generated for Class i power transmission and transformation infrastructure (m³ or t); D_{ij} denotes the transportation distance for Class i waste using Class j transportation method (km); CWF_i denotes the carbon emission factor per unit weight transportation distance under Class i transportation method (kg CO₂e/t·km); i represents the waste serial number.

2.2 Carbon emission factor

The carbon emission factors of energy are taken from the *China Energy Statistical Yearbook 2021*, the *Provincial Greenhouse Gas Inventory Compilation Guidelines*, and the *China Greenhouse Gas Inventory Research*. The carbon emission factors for raw material production and transportation mainly come from the *Building Carbon Emission Calculation Standards* released by the Ministry of Housing and Urban Rural Development in 2019 and the Chinese Life Cycle Database, and the energy consumption coefficient of construction machinery is taken from the *Electricity Construction Engineering Construction Machinery Unit Fee Quota* (CEC, 2018).

3 Instance validation

A 500 kV overhead transmission line project in a Chinese province is selected as a practical instance, which is equivalent to a single circuit extending 88.274 km. According to the carbon accounting methods mentioned above, the carbon emission intensities are calculated and analyzed in Tables 1 – 3.

Table 1. Carbon emission intensities for different stages of the transmission infrastructure.

Number	Stage	Carbon emission sion (tCO ₂ e)	Proportion	Carbon emission intensity (tCO ₂ e/km)
1	Production of raw materials	62743.0533	96.23%	710.7761
2	Transportation of raw materials	549.1264	0.84%	6.2207
3	Construction	1906.9362	2.92%	21.6025
Total		65199.1159	100%	738.5993

Table 2. Carbon emission intensities for different items of the transmission infrastructure.

Number	Item	Carbon emission (tCO ₂ e)	Proportion	Carbon emission intensity (tCO ₂ e/km)
1	Production of metals for conductors	33160.9140	52.85%	375.6589
2	Production of metals for towers	21030.2400	33.52%	238.2382
3	Construction of foundations	8990.9304	14.33%	101.8525
4	Others	439.0311	0.70%	4.9735
Total		62743.0533	100%	710.7761

Table 3. Carbon emission intensities for different items for construction of the transmission infrastructure

Number	Item	Carbon emission (tCO ₂ e)	Proportion	Carbon emission intensity (tCO ₂ e/km)
1	Basic engineering	1369.8002	71.83%	31.0352
2	Tower engineering	344.5322	18.07%	7.8060
3	Grounding engineering	1.1097	0.06%	0.0251
4	Wiring engineering	101.8084	5.34%	2.3066
5	Attachment installation engineering	87.9710	4.61%	1.9931
6	Debugging engineering	1.7146	0.09%	0.0388
Total		1906.9361	100%	21.6025

It can be seen from Table 1 that the carbon emissions from the production of raw materials account for the largest proportion at 96.23%, whereas transportation accounts for the smallest proportion at merely 0.84%. Table 2 indicates the top three contributors to raw material carbon emissions, which are the production of metals for conductors and towers, followed by the construction of foundations. During the construction period, the carbon emissions of basic engineering projects are the highest at 71.83%, whereas those of grounding and debugging projects are the lowest at 0.06% and 0.09%, respectively, as detailed in Table 3. Given the above analysis, it is feasible to utilize novel renewable building materials to lower raw material carbon emissions and embrace innovative prefabricated foundations to reduce carbon emissions in the foundation construction process. Moreover, enhancing the adoption of clean energy among raw material manufacturers and construction sites also provides an avenue to cut down carbon emissions.

4 Conclusion

This article zooms in on the characteristics of carbon emissions in the construction process of power transmission and transformation infrastructures, provides calculation methods for carbon emissions in each stage, and verifies their operability through the example of a 500 kV transmission line infrastructure. Our study enables power transmission and transformation infrastructure builders to grasp the key composition of carbon emissions in the construction process of power transmission and transformation

infrastructures, laying the groundwork for formulating carbon emission plans and determining quotas for engineering construction. In the subsequent engineering construction, it is imperative to direct attention towards researching high-emission aspects within the infrastructures and reasonably curb carbon emissions through construction technology innovation and clean energy substitution.

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