Study on the Influencing Factors of Carbon Emission in the Production Stage of Building Materials and the Countermeasures for Reducing Carbon Emission

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Abstract. At present, the carbon emissions of the construction industry still account for a large proportion. This paper starts with the energy consumption of the main building materials in the production stage of the building, analyses the carbon dioxide emissions of common building materials, and combines the total amount of building materials used in the total construction area of Yangzhou City in Jiangsu Province in 2017 to utilize energy consumption carbon. The emission formula approximates the amount of carbon emissions used in building materials in Yangzhou City for the whole year, and proposes corresponding emission reduction measures based on the analysis of the main influencing factors of carbon emissions in the production stage of building materials, thus providing corresponding theory for the current carbon reduction in construction industry.

1. Introduction
In recent years, carbon emission reduction has become the focus of attention. In 2007, the Ministry of Science and Technology of China issued ‘the Circular on Issuing Comprehensive Work Program on Energy Conservation and Emission Reduction’, and began to evaluate the energy efficiency of new buildings. Those who fail to meet the standards are not allowed to go through the formalities of start-up and completion acceptance registration. In 2008, the Law of the People's Republic of China on Energy Conservation was promulgated, which strengthened industry supervision and emphasized that building energy conservation is the only way for civil construction projects. In 2009, the executive meeting of the State Council proposed that the carbon emissions per unit GDP of our country will decrease by 40% - 45% by 2020 compared with 2005. In 2015, Chinese government proposed a new emission reduction target to the United Nations, that is, the carbon emissions per unit GDP of 2030 will decrease by 60% - 65% [1]. At present, China is in the rapid development stage of urbanization, the construction scale is huge, and the construction industry is still in the development status of high energy consumption and high emissions. Some studies show that the CO₂ emissions of construction industry account for 28-34% of the total national emissions. Gasoline, coal and electricity are the main energy sources of carbon emissions. Therefore, the control of energy consumption and CO₂ emissions in construction industry is of great significance to promote energy conservation and emission reduction and social sustainable development in China.
2. Energy Consumption and Carbon Emission Analysis of Common Building Materials in Production Stage

Energy consumption and carbon emissions of construction industry are mainly concentrated in the production and transportation of materials. The CO₂ in the production stage of building materials mainly comes from two aspects: one is the CO₂ produced by burning or generating electricity or coal when calcined at high temperature in the production process; the other is the CO₂ produced by chemical reaction in the manufacturing process of building materials. Therefore, the carbon emissions in the production process of building materials can be estimated according to the energy consumption and the corresponding carbon emission coefficient. The formula for calculating carbon emissions from energy consumption is [2]:

\[ \text{CEE} = \sum (Q_{Ei} \times \gamma_i \times a_i) \]

CEE: carbon emissions from energy consumption. \( Q_{Ei} \): Consumption of type i Energy. \( \gamma_i \): Converted standard coal coefficient of type i Energy. The low calorific value of standard coal is 29271KJ/kg, and the CO₂ emission factor is 2.7725 t CO₂/tce. Different energy sources can be converted into standard coal unit calorific value according to their respective calorific value. \( a_i \): Carbon Emission Coefficient of Unit Standard Coal of type i Energy.

The main energy consumption and carbon emission in the process of production are analyzed by taking the main building materials commonly used in engineering as an example.

2.1 Steel

Iron and steel industry is one of the most important basic industries in China. The energy consumption of iron and steel industry accounts for about 10% of the national energy consumption, while the amount of steel used in construction accounts for about 20-25% of the total steel output. Steel structures and structures are mainly made of steel, various steel bars in reinforced concrete, steel doors and windows, steel wires and strands. Taking steel for steel structure and steel for reinforced concrete as examples, the energy input and CO₂ emission of four commonly used steels in the process of refining are shown in Table 1.

### Table 1 Unit Energy Consumption and Carbon Emission for Production of Common Steel Products

| Steel                  | Unit energy consumption/ KJ/ Kg | Unit CO₂ emissions/ Kg/Kg |
|------------------------|---------------------------------|---------------------------|
| Large steel            | 26341                           | 1.721                     |
| Medium and small steel | 21225                           | 1.381                     |
| Hot rolled ribbed steel| 33906                           | 2.208                     |
| Cold-rolled ribbed steel| 43072                           | 2.758                     |

Steel production belongs to energy-intensive industry, but in the construction industry, its recovery rate is higher, and the recovery rate of scrap steel products is more than 85%. In the ironmaking process of large iron and steel enterprises, energy consumption and pollution emissions are mainly concentrated in ironmaking and the previous processes, which generally account for 60% of the total energy consumption, from iron ore entering the plant to coking-sintering-ironmaking-steelmaking process. That is to say, compared with iron ore, direct steelmaking with scrap steel can save about 60% [3] of energy, 1 ton less pig iron per ton of scrap steel, and 0.4 tons of coke can be saved.

2.2 Cement

Cement production mainly includes the extraction and mixing of raw materials, raw meal grinding, firing, clinker grinding, slag grinding, gypsum preparation and so on. CO₂ in cement production mainly comes from the energy consumption of electricity, coal and chemical reaction of lime decomposition during high temperature calcination. Data show that the production of 1 ton of P.O.42.5 cement requires about 80-110 kilowatt-hour electricity. If thermal power is used, about 0.86 kilograms of CO₂ will be generated per kilowatt-hour electricity. In addition, about 110 kg of standard coal is needed to produce 2.46 kg of CO₂ per kg of standard coal. About 1.55 tons of raw materials are consumed in the production of 1 ton of cement. The weight loss of 550 kg is mainly due to the decomposition of calcium carbonate, a component of lime, into carbon dioxide during high temperature calcination. If a ton of cement contains 60% clinker, the CO₂ emissions from the
production of a ton of cement are as follows:

\[
\text{CO}_2 \text{ emissions} = \text{thermal power generation carbon emissions} + \text{coal combustion carbon emissions} + \text{lime decomposition}
\]

\[
= 110 \times 0.86 + 0.6 \times (110 \times 2.46 + 550) = 586.96 \text{ kg}
\]

The production of cement varieties, labels, clinker content is different, unit cement energy consumption and carbon emissions are also different. CO\(_2\) emissions from high-temperature calcination energy use are mainly coal and electricity consumption. Unit energy consumption and CO\(_2\) emission of cement production process with different varieties and clinker content are shown in Table 2. The influence of cement label and clinker content on carbon emissions is obvious.

| Building material | Unit energy consumption/ KJ/ Kg | Unit CO\(_2\) emissions/ Kg/ Kg |
|-------------------|---------------------------------|--------------------------------|
| P.I.52.5          | 4464                            | 0.89                           |
| P.O.42.5          | 3972                            | 0.79                           |
| P.S.32.5          | 2987                            | 0.63                           |

2.3 Concrete and concrete blocks

Commodity concrete commonly used in engineering is made up of cement, gravel, sand, admixture, admixture and water in a certain proportion. In the concrete production process, most of the environmental load comes from the cement production and the grinding of admixtures. According to statistics, about 350 kg of cement is needed to produce 1 m\(^3\) commercial concrete. The average energy consumption per kilogram of cement is 3808KJ. It consumes about 1332800KJ and emits about 270Kg of CO\(_2\). According to the local standard, the energy consumption per cubic autoclaved aerated concrete block is 819588KJ and the carbon emission is 291kg.

2.4 Glass

Glass is an amorphous silicate material formed by melting, forming and quenching of quartz sand, limestone and feldspar, soda ash and some auxiliary materials at high temperature. The glass commonly used in engineering includes flat glass, decorative glass, safety glass and energy-saving glass. Glass energy consumption is calculated by comprehensive coal consumption and electricity consumption, that is, energy consumption of processing, melting, forming and annealing for producing qualified glass fuel per ton (or per weight box). Taking the flat glass commonly used in engineering as an example, the calculation shows that the energy consumption per kilogram of flat glass is about 33060 KJ, and the CO\(_2\) emission is about 2.91 kg.

2.5 Ceramics

Ceramics and glass are two indispensable decorative materials in modern architecture. Ceramic products are easy to clean, wear-resistant, corrosion-resistant and low maintenance cost, so they are widely used in engineering. Architectural sanitary ceramics are mainly made of pure kaolin and roasted at relatively high temperature, so they belong to high energy consumption industry. According to the relevant provisions of the national standard "Energy Consumption Limit of Building Sanitary Ceramics Unit Products", the average energy consumption per square meter of building sanitary ceramics is calculated according to 197579 KJ, and the carbon emission is about 18.7 kg.

2.6 Brick masonry materials

Brick masonry materials mainly include sintered ordinary bricks, sintered hollow bricks, sintered porous bricks and so on. The production process of sintered brick mainly includes excavation, transportation, billet making, forming, drying and roasting. Because of its good strength and durability, good thermal stability and simple technology, it is widely used as wall material, brick column, brick arch and foundation. However, sintered bricks need to dig a large number of good fields to make billets, and the sintering energy consumption is high. The roasting temperature should generally be controlled between 900-1100-degree C, so that the brick billets can be burned to partial melting and sintered. According to different raw materials, bricks can be divided into sintered clay bricks, sintered
fly ash bricks, sintered shale bricks, sintered gangue bricks and so on. According to whether there are holes or not, it can be divided into ordinary brick, hollow brick, porous brick and so on. Referring to the standard calculation of comprehensive energy consumption quota per unit product of sintered brick, the unit energy consumption of hollow clay brick, solid clay brick and solid lime-sand brick are 4061565 KJ/1000 pieces, 1170840 KJ/1000 and 349633 KJ/1000 respectively, and their CO₂ emissions per unit are 418 kg/1000, 503 kg/1000 pieces and 460 kg/1000 pieces respectively.

2.7 Coatings
Architectural coatings refer to the materials which are coated on the surface of the object and have good bonding with the matrix material to form a complete and tough protective film [4]. Its production process mainly includes grinding dispersion, paint mixing, deforming and viscosity adjustment. According to the data, the energy consumption per kilogram of building coatings is about 5836KJ, and the carbon emission is about 0.9kg.

2.8 Stone
There are two kinds of stones commonly used in architecture: natural rock and man-made stone. Natural rock is a block material which is manually mined and processed. Artificial stone is made from natural marble, calcite, dolomite and other inorganic powders by forming and solidifying with binder according to certain processing technology. Artificial stone can make comprehensive use of resources, and it is a green building material with environmental protection and energy saving. Therefore, when considering energy consumption and carbon emissions, natural stone should be taken into account. The comprehensive energy consumption per kilogram of stone is about 12942 KJ, and the carbon emission is about 2.32 kg.

2.9 Wood
Wood has the advantages of light weight, high strength, good elasticity and toughness, and low thermal conductivity, so it has been widely used in building structure and decoration. Wood waste can also be processed and utilized comprehensively to make plywood, plywood sandwich board, fiberboard and so on. Wood is a kind of green environmental protection material. It can absorb carbon dioxide in the growth process, but there will be different degrees of carbon emissions in the storage and processing process, that is, the emissions from fossil fuel combustion in the production and processing process. Generally speaking, the energy consumption per cubic meter of wood is about 522700 KJ, and the CO₂ emission per cubic meter is about 30 kg [5].

3. Composition of Carbon Emissions in Construction Material Production Stage
According to the energy consumption and carbon emissions of the main building materials described above, the summary is shown in Table3.

Table 3 Unit Energy Consumption and Carbon Emission in Construction Material Production Stage

| Construction Material          | Unit | Construction Material Production Stage |     |     |
|-------------------------------|------|----------------------------------------|-----|-----|
|                               |      | Unit energy consumption KJ             | Average unit energy consumption KJ | Unit CO₂ emissions kg | Average Unit CO₂ emissions kg |
| Large steel products          | kg   | 26341                                  | 2.63 | 1.721 |
| Small and Medium-sized Steel  | kg   | 21225                                  | 2.12 | 1.381 |
| Hot-rolled steel bar          | kg   | 33906                                  | 3.39 | 2.208 |
| Cold rolled steel wire        | kg   | 43072                                  | 4.30 | 2.758 |
| Cement P.I.52.5              | kg   | 4464                                   | 0.45 | 0.894 |
| Cement P.O.42.5              | kg   | 3972                                   | 0.40 | 0.792 |
| Cement P.S.32.5              | kg   | 2987                                   | 0.30 | 0.63  |
| Solid clay brick              | 1000 pieces | 4893450                               | 4.89 | 503  |
|                               |      |                                        |     | 460  |
Hollow clay brick: 1000 pieces = 4061565 kg
Solid Gray Sand Brick: 1000 pieces = 3496633 kg
Concrete: 1 m^3 = 1332800 kg
Concrete block: 1 m^3 = 2750000 kg
Wood: 1 m^3 = 52270 kg
Architectural glass: 1 kg = 33060 kg
Thermal insulation material: 1 kg = 90353 kg
Coating: 1 kg = 5836 kg
Stone material: 1 m^2 = 12942 kg
Autoclaved aerated concrete blocks: 1 m^3 = 819588 kg
Ceramics: 1 m^2 = 197579 kg

Taking Yangzhou City, Jiangsu Province as an example, the total building area of this city in 2017 is 393,000 square meters, in which the use of various building materials is huge. If the hollow clay brick is calculated by 175 pieces of 1 cubic meter and the flat glass is calculated by 2.7 kg of 1-millimeter thick and 1 square meter weight, and the energy consumption and carbon emission per unit of five kinds of steel and three kinds of sintered bricks are averaged, the energy consumption of 10 main building materials used in Yangzhou construction project in 2017 can be roughly calculated by using the formula of carbon emission of energy consumption, as is shown in Table 4.

Table 4 Total usage of building materials in Yangzhou

| Building materials       | Unit | Amount  | Energy consumption /KJ | CO2 emission /t |
|--------------------------|------|---------|------------------------|----------------|
| Steel type               | t    | 4540000 | 1.41357×10^14          | 9.1572×10^6    |
| Cement type              | t    | 9560000 | 3.64×10^13             | 7.3803×10^6    |
| Concrete                 | m^3  | 960000  | 1.2795×10^10           | 2.592×10^6     |
| Concrete block           | m^3  | 275000  | 2.2539×10^12           | 8.003×10^4     |
| Wood type                | m^3  | 765000  | 3.9987×10^11           | 2.295×10^4     |
| Glass type               | m^2  | 480000  | 4.285×10^10            | 3771.36        |
| Hollow clay brick        | m^3  | 1400000 | 9.9508×10^11           | 10240          |
| Coatings                 | Kg   | 1200000 | 7.0032×10^9            | 10800          |
| Stone materials          | m^2  | 400000  | 5.1768×10^9            | 928            |
| Building ceramics        | m^2  | 3100000 | 6.1249×10^11           | 57970          |

Note: Data are from Yangzhou Statistical Bureau

4. Suggestions on Carbon Emission Reduction

4.1 Promoting the use of low-carbon environmental protection building materials
The carbon emissions of steel, cement, concrete and concrete blocks are relatively high in the production stage. Every 1 kg of steel consumes nearly 1.06 kg of standard coal and emits about 2 kg of CO2. Ceramics, as a common household decoration material, are also used in a large amount. Nearly 7 kg of standard coal will be used for each 1 m2 ceramic production, and 16.9 kg of CO2 will be discharged. The source of wood is trees, which have carbon sequestration effect in the process of tree growth. Every reduction of 1 m3 wood use will reduce the use of about 25 kg of standard coal and 30 kg of carbon dioxide emissions. In view of these building materials which are widely used in engineering and have high carbon emission in production, green, low energy consumption and low carbon emission in production can be selected to replace them, so that the carbon emission of these building materials is at a lower level, such as GFRP (Fiber Reinforced Plastics, also known as FRP) for building steel. Carbon emissions in cement production are mainly concentrated in the clinker burning process, accounting for about 80% of the total carbon emissions of cement production. In addition, the higher the cement label, the greater the carbon emissions. Therefore, when concrete or
mortar is prepared with cement in engineering, low clinker and low grade cement are selected as far as possible under the condition of meeting the strength and durability, or a large number of mineral admixtures are added to replace cement clinker equally in the preparation of composite materials such as concrete, so as to reduce the carbon emissions in the cement production process.

4.2 Ensuring the Service Life of Buildings
The relevant standards of China stipulate that the design life of ordinary houses and structures is 50 years, and that of important buildings is 100 years. However, due to various reasons, a large number of buildings were demolished abnormally. According to the statistics of relevant departments, the average service life of demolition of many buildings in China is less than 30 years [6]. The service life of rural residential buildings is shorter than that of cities and towns, and in some areas it is less than 20 years. The shortening of building life not only increases the waste of materials, but also directly increases the carbon emissions of the construction industry. If buildings or structures can be used normally within the prescribed reasonable service life, it will reduce the use of a large number of building materials, thereby reducing carbon dioxide emissions in the production process of materials.

4.3 Strengthen the reuse of construction waste
At present, the utilization of resources in the construction process is not high, there are some problems such as waste of resources, neglect of management and recycling of construction wastes, etc. [2]. In the process of construction management, the disassembled waste should be treated in different ways according to whether it can be recycled or not. Waste building materials are usually transported by construction companies to specialized recycling departments for recycling, or to processing sites for treatment and reuse. Some construction waste can be used as general backfilling materials after sorting on site; others can also be used as basic materials for buildings or roads, such as bricks and other waste can be used as fillers in low-lying areas or roadbed; concrete fragments can be used as recycled aggregate after processing in treatment plants. Re-smelting recycled steel can greatly reduce energy consumption and carbon dioxide emissions.

4.4 Accelerating the Progress of Construction Technology
At present, some domestic construction enterprises still have the problems of backward technology, outdated equipment and high energy consumption of raw materials. If we can speed up the innovation and development of construction technology, improve the technical assembly rate of construction industry, realize the industrialization and mechanization of construction in an all-round way, and complete the mechanical prefabrication of all construction components in the prefabrication yard, the construction in the near future will reduce the dependence on building resources and the emission of carbon dioxide quantity.

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