Planning and Energy-Economy-Environment-Security Evaluation Methods for Municipal Energy System in China under Targets of Peak Carbon Emissions and Carbon Neutrality

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Calculations and method

The general expression of energy demand can be determined by the product of an activity level and an annual energy intensity, which is a bottom-up analysis model. The formula is shown below:

$$E_i = \sum_s \sum_t EAL_{s,t} \cdot EI_{i,s,t} \quad (1)$$

Where E_i means energy demand of fuel type i, $EAL_{s,t}$ is the energy activity level of technology t in sector or sub-sector s, $EI_{i,s,t}$ is the energy intensity. Based on department analysis method used in LEAP, the total energy demand is calculated in industry, transportation, buildings, agriculture and power, each of which might be broken down into different sub-sectors[1]. The detailed expressions in sectors are illustrated as follows.

(1) Industry

There are two approaches to calculate the energy demand in industry. The one is unit consumption analysis of industrial product and the other one is unit consumption analysis of output value[2], as shown in Equation (2) and Equation (3). The unit consumption will be influenced by product mix, industrial structure, energy-saving measures, product price and production conditions.

$$E_{i,t,s,industry} = P_{t,s} \cdot EF_{i,t,s} \quad (2)$$

Where, $P_{t,s}$ is annual productions of technology t in sub-sector s, and $EF_{i,t,s}$ is energy use per unit output of fuel type i.

$$E_{i,t,s,industry} = GOV_{t,s} \cdot EFV_{i,t,s} \quad (3)$$

Where, $GOV_{t,s}$ is industrial output value of technology t in sub-sector s, and $EFV_{i,t,s}$ is energy use per unit output value of fuel type i.

According to the industrial development and structure in China, the industry is usually divided into 41 sub-sectors, which are also classified as mining, manufacturing, production and supply industries[3].

(2) Transportation

The transportation sector can be divided into road, rail, waterborne and air sub-

sectors. The energy use of road transportation mainly comes from various vehicles, including public vehicles, road wagons, passenger vehicles and etc. And all road vehicles are driven by gasoline, diesel oil, natural gas, electricity and hydrogen. The rail transportation mainly consists of high-speed rail and ordinary railway. Now, high-speed railway electrification is fully realized in China[4]. While some ordinary railways are still driven by diesel internal combustion engines. Therefore, the energy demand in this sector can be expressed as Equation (4) [5].

$$E_{i,t,s,transportation} = (P_{s,turnover} + F_{s,turnover}) \cdot FE_{t,s} \cdot \rho_{i,t,s} \cdot \delta_{i,t,s} \tag{4}$$

$$F_{s,turnover} = \lambda \cdot P_{s,turnover} \tag{5}$$

Where, $P_{s,turnover}$ is the passenger turnover of sub-sector s, $F_{s,turnover}$ is the freight turnover, $FE_{t,s}$ is fuel economy of vehicle type t, $\rho_{i,t,s}$ is the density of fuel i, $\delta_{i,t,s}$ is the conversion coefficient of standard coal. The data of passenger turnover and freight turnover in base year is usually from statistical yearbook, and the future data refers to traffic planning. In each sub-sector, the passenger turnover can be converted to the relevant freight turnover, as shown in Equation (5). The conversion factor λ of road, rail, waterborne and air are 10, 1, 3, 13.89 respectively[6].

(3) Buildings

The energy consumption of building sector can be divided into public building, residential building and construction. The energy demand of public and residential can be calculated by building area and energy consumption per unit area, as illustrated in Equation (6).

$$E_{i,t,s,buildings} = S_{t,s} \cdot EFA_{i,t,s} \tag{6}$$

Where, $S_{t,s}$ is the building space of building type t in sub-sector s and building type consists of new buildings and existing buildings, $EFA_{i,t,s}$ is the energy consumption per unit area of fuel type i.

Besides, the energy use in construction means that the energy consumption in the process of survey, design, construction and installation in new buildings as well as maintenance of existing buildings, which is affected by the area the new buildings and the maintenance cycle of old buildings.

(4) Agriculture

The agriculture energy consumption mainly refers to energy activities generated by mechanical farming and improvement of planting environment. The expression is:

$$E_{i,t,s,agriculture} = A_{t,s} \cdot EFI_{i,t,s} \tag{7}$$

Where, $A_{t,s}$ is the the area of agricultural production activity, $EFI_{i,t,s}$ is the energy use coefficient per unit area.

(5) Power

Unlike other sectors, power sector consumes energy and produces electricity for other sectors. The coal-fired and gas-fired power plants consume coal and natural gas to generate electricity, which constitute almost all CO_2 emissions in power sector. The energy

consumption of power sector can be illustrated as:

$$E_{i,t,s,power} = ELE_i \cdot \lambda_{ele,i} \quad (8)$$

Where, ELE_i is electricity generation by fuel i fired power plant mainly including coal and gas, $\lambda_{ele,i}$ is consumption of fuel i for power supply.

Electricity demand is sum of electricity demand of all sectors, as demonstrated in Equation (9).

$$ELED = \sum_s \sum_t ELE_{s,t} \quad (9)$$

Where, $ELED$ is the total electricity demand of a city, $ELE_{s,t}$ is the electricity consumption of technology t in sector s.

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