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Study on Measurement Index System of Carbon Emission Reduction Effect for Urban Rail Transit Based on LCA

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Abstract: *With the aim of effectively promoting the development of carbon trading markets and sustainable urban development, a reasonable quantification of the energy savings and emissions reduction effects of urban rail transit is of great practical importance. In this paper, we establish the carbon emissions model of urban rail transit baselines and project activities, which are based on life-cycle assessment theory (LCA) and account for differences in passenger travel mode choices before and after the construction of urban rail transit. In this model, urban rail transit data collection was accomplished in the baselines, project construction, and project activities. Metrics for each model component were calibrated against the data. The results of the metrics derived in this paper will be of use in the calculation of carbon emission models for urban rail transit systems.*

Keywords: *Urban rail transit, Carbon emission, LCA, Measurement Index System*

1. Introduction

Today, climate change has become a significant challenge for society. To deal with climate change, countries around the world have made commitments to carbon neutrality targets as well as specified times and actions[1]. In terms of the urban transportation structure framework, the proportion of urban rail transit increases year-on-year, which is conducive to solving the urban congestion problem, achieving transportation energy savings, and steadily improving the effect of reducing energy emissions. At the same time, compared to traditional road transport, which relies primarily on fossil energy as its energy source, urban rail transit uses electricity as its primary energy source, making it a good alternative energy technology advantage. As a result, the development of urban rail transit can effectively promote low carbon development in cities.

The measurement of carbon emissions is the fundamental support for research into spatio-temporal characteristics, impact factors, emissions reduction policies and scenarios. One of the most widely used methods for measuring carbon emissions is provided by the United Nations Intergovernmental Panel on Climate Change[2].

In the operational phase, the carbon emission factor refers to the average carbon emissions per kilometer from different modes of travel while driving as measured in gCO_2/km. The emission factor is a key parameter in mea suring total carbon emissions, and improving its accuracy and adaptability will help improve the accuracy of the results of the total computation. The carbon emission factor for different modes of transport is very different[3].

In this paper, the different modes of passenger travel and corresponding travel distances before and after the opening of urban rail transit were obtained through the formulation of a standard survey method. On the basis of relevant research literature, policy norms and Shijiazhuang's current situation, calibration of the parameters and algorithm for calculating urban rail transit carbon reduction was performed.

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2. Collection and analysis of information on passenger mode transfers based on surveys of willingness and behavior

2.1. Analysis of survey sample data

In this paper, Shijiazhuang Metro Line 3 Phase II is chosen as the base case . A total of 895 samples were collected over the course of the 1-week survey, including 16 fields such as survey time, IP address, sex, and age of respondents. Passenger traffic into and out of the station is mainly concentrated between 9 stations from Dongwang to Lexiang. Since the primary focus of this study is on the second phase of Shijiazhuang Metro Line 3, five stations from Xiyangling Station to Lexiang Station are set as the final starting station for the samples. 156 valid samples are cleaned and filtered.

Figure 1 shows the status of passengers entering and exiting the station. The number of passengers entering from Lexiang and Nanwang is higher while the number entering from Suncun and Xisanzhuang is lower; Most of the outward passenger traffic is concentrated in several stations, including Nandou, Taihang South Street, Xiyangling, and Zhongyangling, with fewer passengers coming out of Lexiang.

For the situation in which the metro line does not exist (given that the option for this problem is manifold, each sub item does not have a total proportion of 1), the results are presented in Figure 2. 40.37% of passengers are able to use electric vehicles or motorcycles for transportation, making up the largest proportion; With 33.56% of passengers able to choose high-carbon transport modes such as private cars and taxis, which also offers feasibility for this study to consider the reduction of carbon under the transfer of transport modes. Passenger journey paths are calculated based on online electronic maps, the bus network and stations, the urban rail transit system and stations, and the corresponding journey distance.

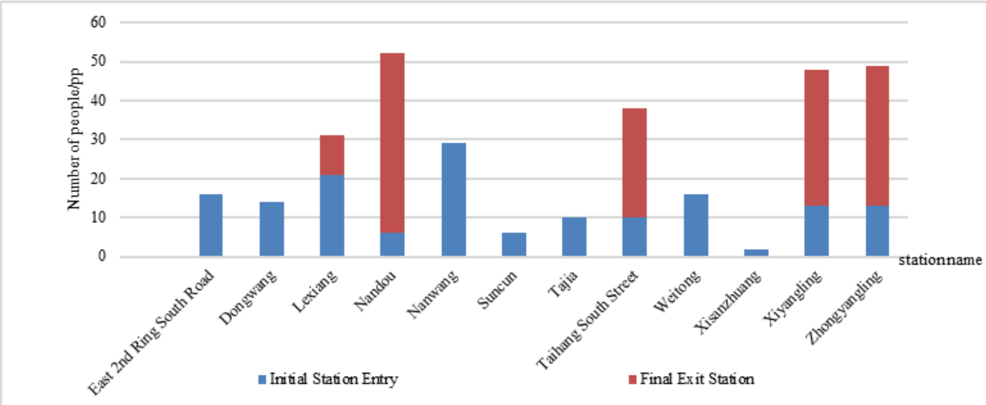

Figure 1: Passenger Entry and Exit Station Situation.

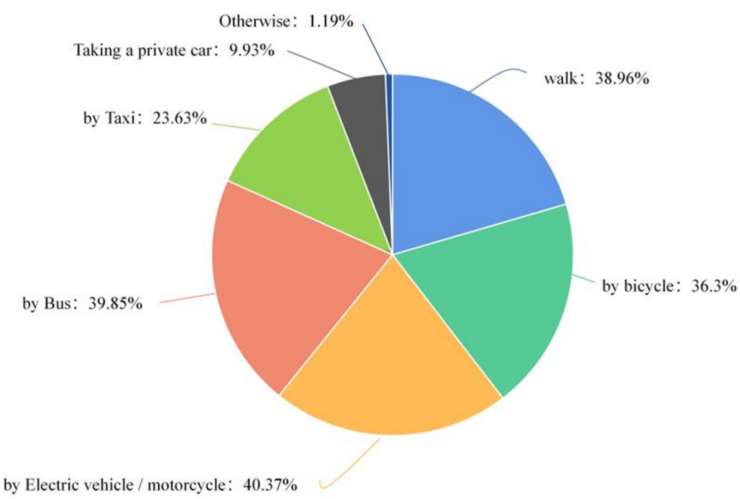

Figure 2: Proportion of Mode Shifts (When Subway Lines Do Not Exist).

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3. Benchmark carbon emission estimation model related index parameters

3.1. Grid carbon emissions coefficient

To facilitate the formulation of Clean Development Mechanism (CDM) projects in China's key emission reduction areas and the China Voluntary Greenhouse Gas Emission Reduction Project (CCER project), the Department of Climate Change of the Ministry of Ecology and Environment carried out a study to determine the baseline emissions factors for China's regional electricity distribution networks in 2019. In this process, relevant government departments and named operating entities (DOEs) were consulted. The boundaries of the power grid were evenly split, and the areas designated as North China included Beijing, Tianjin, Hebei, Inner Mongolia, Shandong and Shanxi. The baseline emissions factors for China's regional electricity networks in the 2019 (latest version) emissions reduction projects are shown in Table 1.

Table 1: Emission Factor Results of China's Regional Grid Baseline for 2019 Emission Reduction.

Title	$EF_{grid,OM}$(tCO_2/MWh)	$EF_{grid,BM}$(tCO_2/MWh)
North China Regional Power Grid	0.94	0.48
Northeast Regional Power Grid	1.08	0.24
East China Regional Power Grid	0.79	0.39
Central China Regional Power Grid	0.86	0.29
Northwest Regional Power Grid	0.89	0.44
Southern Regional Power Grid	0.80	0.21

Where, "OM" is the weighted average of marginal electricity emission factors from 2015 to 2017; "BM" is the marginal capacity emissions factor based on the 2017 statistics[4]. The baseline carbon emission factor is calculated as the average of the electricity marginal carbon emission factor and the capacity marginal carbon emission factor, as shown in equation (1).

$$EF_{grid,cm} = \frac{EF_{grid,OM} + EF_{grid,BM}}{2} \quad (1)$$

Where, $EF_{grid,cm}$ is the electricity carbon emission factor(tCO_2/MWh); $EF_{grid,OM}$ is the electricity marginal carbon emission factor(tCO_2/MWh); $EF_{grid,BM}$ is the Capacity marginal carbon emission factor(tCO_2/MWh).

Thus, as Shijiazhuang belongs to the regional electricity grid of North China, using formula (1), the city's reference carbon emission factor can be calculated to be 0.71 kg/kWh.

3.2. Fossil Fuel-Related Parameters Fossil Fuel-Related Parameters

Gasoline, liquefied natural gas (LNG) and compressed natural gas (CNG) are the main types of fuel used in Shijiazhuang for bus, taxi, private car, electric bicycle and motorcycle. These three fuels are expressed by different correlation coefficients. For ease of computational analysis, this study converts the fuel consumption of the different types to kilograms of standard coal[5]. The energy type conversion criteria are shown in Table 2, and the specific parameters of the energy type conversion standard are given in Table 3.

Table 2: Energy type conversion table.

Type fuel	Conversion units	Standard carbon/kg
Gasoline	1.00L	1.07
Liquefied natural gas	1.00kg	1.76
Compressed nature gas	1.00m^3	1.33

Table 3: Characteristics parameters of fossil fuels.

Type fuel	Low calorific value	Carbon content per calorific value (tC/GJ)	Fuel carbon oxidation rate
Gasoline	44.80GJ/t	18.90×10^{-3}	98.00%
Liquefied natural gas	41.87GJ/t	15.30×10^{-3}	99.00%
Compressed nature gas	3 893.10GJ/1 000Nm^3	15.30×10^{-3}	99.00%

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3.3. Carbon emission factor per person kilometer

Carbon emission factor per person kilometer represents the CO_2 emissions generated by the energy use consumed by each passenger during the 1 km operation of the vehicle[6]. This is an important parameter in the computational model of the baseline carbon emission effect. These metrics can be obtained through authoritative databases of relevant institutions, academic papers, publicly available government data, and so on, or can be measured using a "top down" or "bottom up" approach based on real-world situations.

Taking into account the issue of different carbon emission factors for different energy vehicles with different modes of transport, this study defines the weighted carbon emission factors for different modes of transportation based on the weight of different energy vehicles. Equation (2) shows the specific calculation formula.

$$EF_i = \frac{\sum_{ix} EF_{ix} \times Q_{ix}}{Q} \tag{2}$$

Where, EF_i is the weighted carbon emission factor of the i-th type of transportation mode ($kgCO_2/km$); Q_{ix} is the number of vehicles owned by the i-th type of transportation mode and the x-th energy type (vehicle); EF_{ix} is the carbon emission factor of the i-th type of transportation mode and the x-th energy type vehicles($kgCO_2/km$); Q is the e carbon emission factor of the i-th type of transportation mode and the x-th energy type vehicles($kgCO_2/km$); i is the different types of modes of transport(i=private cars, taxis, buses, etc.).

4. Relevant parameters of the carbon emission calculation model for project construction

This section has calibrated the parameters of the carbon emission calculation model for project construction, and parameters required for this model are summarised in Table 4. The quantity Q_n of subproject n is primarily determined based on the actual situation of the project and can be obtained through the relevant departments or metro design and construction companies. During the construction phase of the metro, the sub projects consist mainly of fence structures, open cut earthworks and main structures. Construction materials include primarily wood, steel, concrete, and other construct ion materials commonly used during the construction of open-cut subway stations.

Table 4: Parameters required for the carbon emission calculation model of project construction.

Parameters	Definition	Unit	Data sources
Q_n	Quantity of sub project n	per-unit	Subway construction company, etc
e,f,g	The number of materials, machinery, and personnel consumed to complete the unit sub project	m^3 or kg, machine shift, number of people	Relevant departments, subway construction companies, relevant research reports, literature, etc
$C_{cl,i}$	Carbon emission coefficient of material x	$tCO_2/(m^3)$ or $tCO_2/(kg)$	Related research reports, literature, etc
$C_{jx,j}$	Carbon emission coefficient of mechanical y	$tCO_2/(shift)$	
C_{rg}	Artificial carbon emission coefficient	$tCO_2/(per\ person)$	

5. Relevant parameters of carbon emission calculation model of project activities

This section calibrates the carbon emissions measurement model parameters of the project activities. Table 5 summarizes the parameters needed for the model at this point. We divide the model into several parts, fix most of the parameters based on the actual project situation, and refer the remaining part to the relevant literature report. A detailed description of the parameters for each part is provided, which effectively supports the calculation of carbon emissions in the following project activities.

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Table 5: Required parameters for the carbon emission calculation model of project activities.

Parameters	Definition	Unit	Data sources
Q_{qy}	Vehicle traction energy consumption	kWh	Subway operation company, related research reports, literature, etc.
Q_{zd}	Vehicle braking regenerative energy	kWh	
Q_{fz}	Vehicle auxiliary energy consumption	kWh	Relevant departments, research reports, literature, etc.
p	Regenerative braking absorption capacity ratio	-	
Y_i	Station escalator operation power	kW	Relevant departments, subway operating companies, etc.
h_i	Running time of escalator running in Yi at station	h	
LPD	Station lighting power density	W/m^2	
D	Public area of the station	m^2	
t	Station lighting duration	h	

6. Conclusions

The purpose of this paper is to sort out the index system in the urban rail transit carbon emission reduction effect model, and to calibrate the parameters in each model to different levels. In the baseline carbon emission measurement model, it is necessary to focus on the detailed analysis of the grid carbon emission factor, fossil fuel related parameters and man-kilometer carbon emission factor. Most of the parameters are calibrated for Shijiazhuang City where the project is situated. The parameters treated in this paper will be used in the calculation of the subsequent urban rail transit carbon emissions model.

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