Study on energy consumption index system and calculation method of highway transportation infrastructure in Qinghai Province

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Abstract. In view of the lack of mandatory statistics on energy consumption of transportation infrastructure at the national level, the energy consumption index system of Qinghai highway transportation infrastructure was established based on the analytic hierarchy process by using fuzzy synthetic evaluation method. And the calculation method of Qinghai highway transportation infrastructure was established based on the calculation results of the unit energy consumption coefficient of each classification index. This work offers reference for the rapid evaluation of the energy consumption of Qinghai highway transportation infrastructure.

1. Introduction
According to the mandatory energy consumption assessment for transportation industry in the latest national policy of China, the index systems including operating buses, operating trucks and urban passenger transport are required. However, that only contains the energy consumption of motor vehicles. On the contrary, the energy consumption for the operation and maintenance of highway infrastructure, as well as road construction, belong to the key energy consumption unit of the transportation industry [1]. Therefore, the establishment of the energy consumption statistics and calculation index system is an urgent issue to be solved [2]. In this paper, the fuzzy comprehensive evaluation model based on the Analytic Hierarchy Process (AHP) is employed to study the energy consumption index system of highway transportation infrastructure in Qinghai highway, and the calculation methods of each index are established by calculating the unit energy consumption coefficients.

2. Study on energy consumption index system of highway transportation infrastructure in Qinghai province
Based on the investigation of the current key energy consumption units of the highway transportation infrastructure in Qinghai Province, and the analysis of the energy consumption during the highway construction period, the energy consumption index system of the highway transportation infrastructure in Qinghai Province was established. Methods combined with the index setting categories reported in the reference [3] and expert suggestions were performed. The comprehensiveness of the system was fully considered. Specifically, the energy consumption index system of highway transportation infrastructure in Qinghai Province was divided into five classified evaluation indexes (Table 1).
Based on the AHP method [4] and the above classification indicators, the expert scoring table was set thus the expert survey results can be obtained. Then the judgment matrix corresponding to the indicator system was sorted out. After the eigenvalues and eigenvectors of the judgment matrix were calculated, the weight vectors were obtained through normalization and consistency test. Finally, the weight values of each single indicator were acquired thus the total hierarchy ranking was listed in Table 1.

### Table 1. Final weight-rank and the index system of transportation infrastructure energy consumption of Qinghai highway

| Indicator categories | Index name                                      | Overall ranking levels |
|----------------------|-------------------------------------------------|------------------------|
| Infrastructure       | total comprehensive energy consumption of service area | 0.1073                 |
| Infrastructure       | total comprehensive energy consumption of toll station | 0.0741                 |
| Infrastructure       | total comprehensive energy consumption of tunnel | 0.2848                 |
| Infrastructure       | total comprehensive energy consumption of transportation office building | 0.0460                 |
| Infrastructure       | total comprehensive energy consumption of construction period of new road | 0.4878                 |

### 3. Calculation of unit energy consumption coefficient of classified index of highway transportation infrastructure energy consumption in Qinghai province

#### 3.1. Study of conversion coefficient of energy consumption per building area of service area

According to the field investigation and statistical data collection of Qinghai highway service area, the conversion coefficient of energy consumption per building area of service area was calculated based on the energy consumption data of service area on all known building area [5].

Coefficient of energy consumption per building area of service area = The total annual electricity consumption of all highway service areas / Total construction area of all highway service areas

#### 3.2. Study of conversion coefficient of energy consumption for the number of lanes of entrance and exit of toll station

According to the field investigation and statistical data collection of Qinghai highway toll station, the conversion coefficient of energy consumption for the number of lanes of entrance and exit of toll station was calculated based on the energy consumption data of Qinghai highway toll station [6].

Coefficient of energy consumption for the number of lanes of entrance and exit of toll station = The total annual electricity consumption of all highway toll stations / The total number of lanes of all highway toll stations

#### 3.3. Study of conversion coefficient of energy consumption per unit length of tunnel

According to the field investigation and statistical data collection of Qinghai highway tunnel, the conversion coefficient of energy consumption per unit length of tunnel was calculated based on the energy consumption data of tunnel on all known length [7].

Coefficient of energy consumption per unit length of tunnel = Total annual electricity consumption of all highway tunnels / All highway tunnel mileage×2

#### 3.4. Study of conversion coefficient of energy consumption per building area of office building

According to the field investigation and statistical data collection of transportation office building, the conversion coefficient of energy consumption per building area of office building was calculated based on the energy consumption data of office building [8].
Coefficient of energy consumption per building area of office building = The total annual electricity consumption of all transportation office buildings / Total construction area of all traffic office buildings

3.5. Study of conversion coefficient of energy consumption of the classified project for each unit during the construction period of Qinghai highway

“Xiaoda” highway is the representative construction highway of Qinghai province. Therefore, “Xiaoda” highway is selected as the typical project to study the energy consumption calculation system of highway construction period. The operational quantities of the classification of construction machinery are supposed to be the calculation unit for total energy consumption [9].

Table 2. Energy consumption during the construction period of “Xiaoda” highway in Qinghai province

| Classification of construction machinery | Highway construction mileage (km) | Operational quantities of highway construction | Types of energy | Total energy consumption (L, kW·h, m³) |
|------------------------------------------|----------------------------------|-----------------------------------------------|-----------------|--------------------------------------|
| earthwork machinery                      | 5.759 km (K79+168-K85+000)      | earthwork transshipment: 2200,000 m³           | diesel          | 1,160,000 L                         |
| compact machinery                        | 5.759 km (K79+168-K85+000)      | compaction mileage: 5.759 km                   | diesel          | 80,000 L                            |
| piling and road machinery                | 46.39 km                        | mileage of road surface operation: 46.39 km    | electricity     | 138,890,000 kW·h                    |
|                                          |                                 |                                               | natural gas     | 12,150,000 m³                       |
| bridge opening machinery                 | 5.759 km                        | bridges and culverts build mileage: 5.759 km   | electricity     | 7,200,000 kW·h                      |
| asphalt concrete machinery               | 5.759 km (K79+168-K85+000)      | asphalt concrete mixing capacity: 100,000 m³   | diesel          | 120,000 L                           |
|                                          | 5.759 km (K79+168-K85+000)      | mileage of road construction: 5.759 km         | electricity     | 2,880,000 kW·h                      |
| lifting and transporting machinery       | 5.759 km (K79+168-K85+000)      | mileage of road construction: 5.759 km         | electricity     | 2,880,000 kW·h                      |
| tunnel and general machinery             | 15.081 km                       | mileage of tunnel construction: 15.081 km      | electricity     | 6,560,000 kW·h                      |

Coefficient of energy consumption of the classified project for each unit during the construction period of Qinghai highway = Total energy consumption of classified construction machinery / Corresponding classified of engineering assessment work

Table 3. Calculation coefficient of energy consumption of the classified project for each unit during the construction period of Qinghai highway

| Classification of construction machinery | Operational quantities of highway construction | Conversion coefficient of unit energy consumption during highway construction period |
|------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| earthwork machinery                      | earthwork transshipment                        | 0.653 tce/10,000 m³                           |
| compact machinery                        | total mileage of road construction             | 1.72 tce/km                                  |
| piling and road machinery                | total mileage of road construction             | 403.97 tce/km                                 |
| bridge opening machinery                 | bridges and culverts build mileage             | 153.65 tce/km                                 |
| asphalt concrete machinery               | asphalt concrete mixing capacity               | 54,579 tce/10,000 m³                          |
| lifting and transporting machinery       | total mileage of road construction             | 61.46 tce/km                                  |
| tunnel and general machinery             | mileage of tunnel construction                 | 60.03 tce/km                                  |
Energy consumption calculation system of highway construction period was established based on the conversion coefficients in Table 3. Thus after a new highway is built, the total energy consumption can be evaluated on the basis of the classified operational quantities of highway construction.

4. Study on calculation method of energy consumption of highway transportation infrastructure in Qinghai Province

Table 4. Energy consumption coefficient for per unit of Qinghai highway transportation infrastructure

| Categories of unit energy consumption coefficient                                      | Numerical value |
|-------------------------------------------------------------------------------------|-----------------|
| conversion coefficient of energy consumption for per building area of service area   | 6.32 (kgce/m²)  |
| conversion coefficient of energy consumption for the number of lanes of entrance and exit of toll station (tce/unit) | 6.10 |
| conversion coefficient of energy consumption for per unit length of tunnel (kgce/m) | 24.39 |
| conversion coefficient of energy consumption for per building area of office building (kgce/m²) | 32.53 |

Based on the calculation coefficients of unit energy consumption of transportation infrastructure and highway construction period listed in Table 3 and Table 4, a simple and replicable calculation method of energy consumption of transportation infrastructure in Qinghai province was established. According to the size of new infrastructures, such as building area, mileage and different kinds of engineering machinery production, measurable amounts of comprehensive energy consumption of transportation industry in Qinghai Province highway infrastructure can be calculated using classification coefficient conversion, which can provide data support for energy conservation and emissions reduction of the transportation industry.

5. Conclusion

On the basis of energy consumption status evaluated by the site investigation and AHP, the key transportation-infrastructure energy-using units of energy consumption index in Qinghai province are studied. Therefore, the comprehensive energy consumption index system is established which includes total 5 classification evaluation index arranged by new road construction, tunnel, service area, toll station and then transportation building from the evaluation results. In conclusion, the importance degree of the energy consumption statistical work for above indicators is in that order.

According to current status of transportation infrastructure energy consumption in Qinghai province and statistical data collection, the energy consumption calculation coefficients including per unit building area of service area, per unit exit lanes number in toll station, per unit length of the tunnel, per unit building area of transportation building are studied. Meanwhile, the comprehensive energy consumption calculation method of road construction including classified coefficients based on the operational quantities for the machinery in the highway construction is proposed. Then a simple and replicable system is formed to measure the comprehensive energy consumption level of the highway infrastructure of the transportation industry in Qinghai province, which can provide data support for energy conservation and emission reduction of the transportation industry.

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References

[1] Liu Z, Guan D, Wei W, et al. Reduced carbon emission estimates from fossil fuel combustion and cement production in China[J]. Nature, 2015, 524(7565):335-338.

[2] Andres R J, Boden T A, F.-M. Bre’ on, et al. A synthesis of carbon dioxide emissions from fossil-fuel combustion[J]. Biogeosciences, 2012, 9(5).

[3] Andres R J, Boden T A, Higdon D. A new evaluation of the uncertainty associated with CDIAC estimates of fossil fuel carbon dioxide emission[J]. Tellus B, 2014, 66.

[4] Xiao-Qing S, Xiao-Nuo L I, Jian-Xin Y. Research on Carbon Reduction Potential of Electric Vehicles for Low-Carbon Transportation and Its Influencing Factors[J]. Environmental Science, 2013.

[5] Aini M S, Chan S C, Syuhaily O. Predictors of technical adoption and behavioural change to transport energy-saving measures in response to climate change[J]. Energy Policy, 2013, 61:1055-1062.

[6] Xie R, Fang J, Liu C. The effects of transportation infrastructure on urban carbon emissions[J]. Applied Energy, 2017, 196:199-207.

[7] Liu C. Transport Energy-Saving Emission Reduction Countermeasures under the Concept of Sustainable Development[C]// International Conference on Modeling. 2010.

[8] Zhang M, Li H, Zhou M, et al. Decomposition analysis of energy consumption in Chinese transportation sector[J]. Applied Energy, 2011, 88(6):2279-2285.

[9] Achtymichuk D. Investigating the Effects of Transportation Infrastructure Development on Energy Consumption and Emissions[C]// Transportation Research Forum, Arlington, Virginia, March. 2010.