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Vehicle Cycle Energy and Carbon Dioxide Analysis of Passenger Car in China

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Abstract

This study is aiming to assess the primary energy consumption, and the energy-related carbon dioxide (CO_2) emissions in vehicle cycle for a China passenger car powered by internal combustion engine. Meanwhile, this analysis concerns about the share of coal demand in the total primary energy use. The results show that the vehicle cycle energy consumption and CO_2 emissions of a China passenger car are about 91.13 GJ and 11.13 ton per vehicle, respectively. And coal accounting for about 84.5% of the vehicle cycle primary energy consumption is the key contributor to the CO_2 emissions in China. The processes of material production and vehicle assembly account for most of the vehicle cycle energy use and CO_2 emissions. There are four ways to reduce vehicle cycle environmental impacts: use clean energy, lower the weight of the vehicle under the condition of ensuring vehicle performance, adopt low energy-intensive and low emission-intensive materials in vehicle, and develop advanced vehicle propulsion systems.

Keywords: energy consumption; CO_2 emissions; vehicle cycle; China

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1. Introduction

The world energy-related carbon dioxide (CO2) emissions will increase from 30.2 billion metric tons in 2008 to 35.2 billion metric tons in 2020 (EIA, 2011). Much of the growth is attributed to non-OECD nations that depend heavily on fossil fuels to meet fast-paced growth in energy demand. Coal is the largest contributor to emissions growth in the non-OECD economies, and accounts for 54% of the projected non-OECD increase in total energy-related emissions. China's emissions account for more than two-thirds of the total increase in non-OECD Asia's emissions. China is one of the world's top three nations of coal-related emission.

Energy consumption of China road transport increased from 57 Mtoe (million tons of oil equivalent) in 2002 to 86 Mtoe in 2005 and the associated CO2 emissions grew from 169 to 255 million tons (Yan X., 2010).

This study is aiming to assess the primary energy consumption and the energy-related carbon dioxide emissions in vehicle cycle for a China passenger car powered by internal combustion engine with the life cycle assessment (LCA) methodology. Meanwhile, the share of coal in the total primary energy is concerned.

2. Methodology

2.1. Life Cycle Assessment

Life cycle assessment is an attempt to quantity the environmental aspects and potential environmental impacts (e.g. resources use and the environmental consequences of releases) over a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave) (ISO, 2004 and 2006).

There are four stages comprising a full life cycle approach: goal and scope definition, inventory analysis, impact assessment and results interpretation (ISO, 2006).

2.2. Vehicle Life Cycle

The vehicle cycle follows the sequences below during which the energy is consumed and emissions are released (N. Zamel et al., 2006 and Ben Lane 2006):

- Vehicle material production: production of automotive materials (e.g. steel, plastics, rubber, etc.)
- Vehicle assembly: assemble components and operate assembly line
- Vehicle distribution: the transportation of vehicles from the assembly line to the dealership
- Vehicle maintenance: maintenance and repair vehicle over its lifetime
- Vehicle disposal: dismantle and recycle of vehicles at the end of vehicle life

Since, there are many studies concerning life cycle assessment of vehicle technologies and fuels in western countries, few in China, especially the literatures about the vehicle cycle energy consumption and related emissions. In this paper, a special focus is put on the vehicle cycle total primary energy use, coal consumption and carbon dioxide emissions for a China passenger car powered by internal combustion engine.

3. Analysis

3.1. Data

In this analysis, the data for vehicle cycle assessment are acquired from the published literatures, the GREET model and the author's assumptions below.

Electricity in vehicle cycle is used for vehicle materials production, vehicle assembly and scraping at the end of lifetime. In this analysis, China electricity mix in 2009 is adopted from China electric power yearbook 2010, as shown in table 1. And the loss of electricity transmission and distribution is 6.7% (China electric power yearbook, 2010). From table 1, we can see that coal is the biggest contributor to the China electricity mix. The emissions and energy use associated with electricity generation from residual oil, natural gas, coal and uranium is calculated. And the electricity generations from the "other" group including hydropower (about 15.5%), wind (about 0.7%), geothermal energy and solar energy etc. are treated as zero emission.

Table 1. China electricity generation mix (China electric power yearbook, 2010)

Sources	Electricity mix (*%*)
Natural gas	0.1
Oil	0.5
Nuclear	1.9
Coal	77.9
Others	19.6

In this analysis, a vehicle with the mass of 1324 kg is chosen to be the representative of the mid-size passenger car. The vehicle material composition is shown in table 2. In this paper, the energy consumption and emissions associated with the steel and aluminum are assumed on the basis that 70% of the raw material is virgin, and the remaining is recycled. Other materials are all virgin. Coal is the main energy used in metallurgical industry of China. Coal and electricity are assumed as the main process energy of the metal material production. Based on the consumptions above, the primary energy densities and the energy-related CO_2 emission factors of automotive material and the share of coal in primary energy consumption are calculated, shown in table 2. The CO_2 emissions in table 2 are the CO_2 equivalent including the direct carbon dioxide, volatile organic compounds (VOCs) and carbon monoxide (CO). The VOCs and CO emissions are converted to CO_2 emissions based on the carbon ratios of their molecular weights.

Table 2. Data for material production

Material	Weight[a] (*kg*)	Energy (*kJ/kg*)	CO_2 emissions (*kg/kg*)	Coal share[b] (*%*)
Ferrous	886	38961	4.11	97.68
Aluminum	81	142282	8.89	81.81
Copper	9	107092	10.45	93.58
Zinc	7	102607	10.40	96.81
Magnesium	10	351868	33.60	91.40
Lead	10	26946	0.82	93.95
Glass	35	18659	2.01	96.32
Rubber	54	37054	3.80	98.15
Plastic	100	56708	4.51	29.66
Fluids	54	62733[a]	0[b]	0
Others	78	0[b]	0[b]	0

[a] From N. Zamel et al., 2006. [b] Assumed by the author. Other data are calculated by the author.

The energy consumption during the vehicle assembly is estimated as a linear function of the vehicle mass, ranging from 17.4 to 22.1 MJ/kg (N. Zamel et al., 2006 and Ben Lane 2006). The average of the two values is used in this analysis. The energy use of vehicle assembly is assumed 70% from China electricity and the remaining from coal directly. Based on this, the CO_2 equivalent emission factors for electricity and coal are calculated, are 257.2 kg/GJ and 104.4 kg/GJ respectively.

The energy use of vehicle distribution is estimated as a linear function of transportation distance and vehicle mass. The average transportation distance and the energy demand rate associated with the transportation of a car is assumed as 1600 km and 0.6 kJ/(kg·km) (N. Zamel et al., 2006). The vehicle disposal energy consumption is estimated as a linear function of vehicle mass, and is assumed as 370 kJ/kg (M. Schuckert et al., 1996). Since the energy-related carbon dioxide emissions data are not available during the vehicle distribution and disposal stages. And the emissions associated with the energy use in the two stages are puny comparing with the emissions from material production and vehicle assembly (N. Zamel et al., 2006). Therefore, they are neglected in this vehicle cycle analysis. Meanwhile, the shares of coal in total primary energy consumption of the two stages are not considered in this paper.

3.2. Equations

In this analysis, a large number of equations are used for the calculations of vehicle cycle energy use and carbon dioxide emissions. Parts of them are showed below.

The total energy use in the vehicle cycle is calculated by the following expression:

$$TE = \sum_i E_i \tag{1}$$

Where TE (kJ) is the total energy use of the vehicle life cycle, i is the vehicle cycle stages including material production, vehicle assembly, distribution and disposal, E_i (kJ) is the energy consumption of the vehicle cycle stage i.

The energy consumption for the material production stage is calculated by the following expression.

$$E_{material} = \sum_j (ED_j \times M_j) \tag{2}$$

Where $E_{material}$ (kJ) represents the energy consumption of the material production stage, j is the material type, ED_j (kJ/kg) represents the energy density of the material type j, M_j (kg) represents the mass of the material j in the evaluated vehicle.

The energy consumption for vehicle assembly stage is calculated by following expression.

$$E_{ass} = ED_{ass} \times M_{vehicle} \tag{3}$$

Where E_{ass} (kJ) is the energy use during the vehicle assembly process, ED_{ass} (kJ/kg) is the energy density for the vehicle assembly process and is assumed to be 19750 kJ/kg in this study, $M_{vehicle}$ (kg) reprensents the vehicle mass.

The energy consumption of vehicle distribution is calculated by following expression.

$$E_{distr} = ED_{distr} \times D_{distr} \times M_{vehicle} \tag{4}$$

Where E_{distr} (kJ) represents vehicle distribution energy consumption, ED_{distr} (kJ/(kg·km)) is the energy density for the vehicle distribution and is estimated to be 0.6 kJ/(kg·km) in this article, D_{distr} (km) is the vehicle distribution distance and is estimated to be 1600 km.

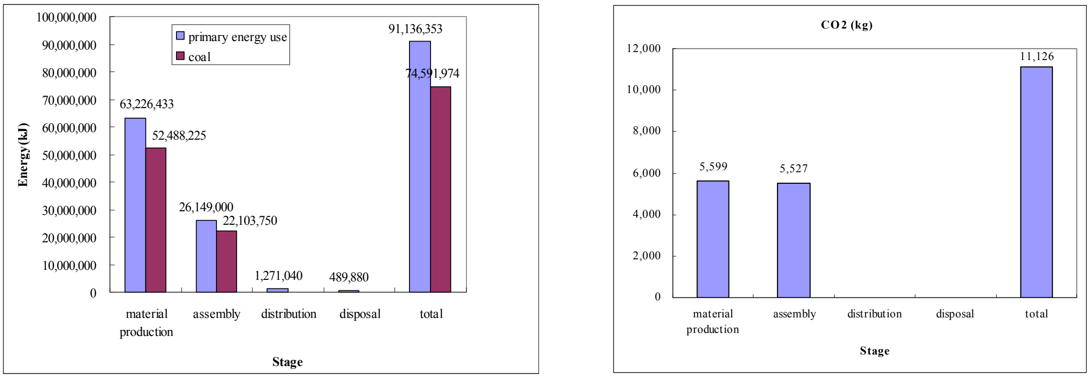
The energy demand during vehicle disposal at the end of vehicle lifetime is calculated by the following expression.

$$E_{disposal} = ED_{disposal} \times M_{vehicle} \tag{5}$$

Where $E_{disposal}$ (kJ) represents the energy consumption during the vehicle disposal stage, $ED_{disposal}$ (kJ/kg) is the energy density for the vehicle disposal and is estimated to be 370 kJ/kg.

The formulas of CO_2 emissions calculation in vehicle cycle are similar as the above formulas of the primary energy use.

4. Results



(a) Energy consumption (b) Carbon dioxide emissions

Fig. 1. Vehicle cycle energy consumption and carbon dioxide emissions

The results show that the vehicle cycle total primary energy consumption and CO_2 equivalent emissions of a China passenger car are about 91.13 GJ and 11.13 ton per vehicle, respectively. And the coal consumption accounts for about 81.8% of the total primary energy use, as illustrated in Fig. 1. Coal is the key energy source of vehicle cycle. Coal is the largest contributor to the carbon dioxide emissions in China.

From Fig. 1, we can find that the material production process is very energy-intensive and accounts for about 70% of the total vehicle cycle primary energy use, and generates over 50% of related CO_2 emissions. The coal consumption accounts for about 83% of the primary energy use in the material production process. Coal is the main contributor to the carbon dioxide emissions in this stage.

The assembly process accounts for about 29% of the vehicle cycle primary energy consumption, while the emissions of this stage accounts for about 49.7% of the total CO_2 emissions. It is very clear that the vehicle assembly line is emission-intensive, caused by painting process. Coal which accounts for about 84.5% of this stage energy demand is still the main contributor to the carbon dioxide emissions.

The stages of car transportation and disposal at the end of lifetime consume a small part of energy, comparing with the material production and vehicle assembly. And the emissions of the two stages are not considered in the study.

5. Conclusions

We have performed a vehicle cycle assessment of a mid-size passenger car for China with a focus on the energy consumption, coal demand and energy-related CO_2 equivalent emissions. The vehicle cycle primary energy use and CO_2 emissions are about 91.13 GJ and 11.13 ton per vehicle, respectively. Coal as the biggest contributor of environment impacts accounts for 84.5% of the vehicle cycle energy consumption.

The Material production consumes 63.2 GJ of energy about 70% of total primary energy consumption and releases over 50% of the total energy-related CO_2 emissions. The vehicle assembly stage accounts for 29% of the total energy consumption and releases 49.7% of the vehicle cycle CO_2 emissions. The energy demand and CO_2 emissions of the vehicle distribution and disposal generate puny environment impacts.

The results reveal that the material production process is very energy-intensive, and vehicle assembly is more emission-intensive. Coal as the main process fuel is the key contributor to the CO_2 emissions in China.

From the analysis above, we can find that there are four ways to reduce vehicle cycle environment impacts. First, lower the weight of the vehicle on the condition of ensuring vehicle performance. Second, adopt low energy-intensive and low emission-intensive materials. Third, substitute environment friendly energy for coal as the main process fuel in China. The last one, develop advanced vehicle propulsion system.

Acknowledgements

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