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Development of a Low-Carbon Indicator System for China

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November 2011

This work was supported by the China Sustainable Energy Program of the Energy Foundation through the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

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Abstract

In 2009, China committed to reducing its carbon dioxide intensity (CO_2/unit of gross domestic product, GDP) by 40 to 45 percent by 2020 from a 2005 baseline and in March 2011, China's 12th Five-Year Plan established a carbon intensity reduction goal of 17% between 2011 and 2015. The National Development and Reform Commission (NDRC) of China then established a Low Carbon City policy and announced the selection of five provinces and eight cities to pilot the low carbon development work. How to determine if a city or province is "low carbon" has not been defined by the Chinese government.

Macro-level indicators of low carbon development, such as energy use or CO_2 emissions per unit of GDP or per capita may be too aggregated to be meaningful measurements of whether a city or province is truly "low carbon". Instead, indicators based on energy end-use sectors (industry, residential, commercial, transport, electric power) offer a better approach for defining "low carbon" and for taking action to reduce energy-related carbon emissions.

This report presents and tests a methodology for the development of a low carbon indicator system at the provincial and city level, providing initial results for an end-use low carbon indicator system, based on data available at the provincial and municipal levels. The report begins with a discussion of macro-level indicators that are typically used for inter-city, regional, or inter-country comparisons. It then turns to a discussion of the methodology used to develop a more robust low carbon indicator for China. The report presents the results of this indicator with examples for six selected provinces and cities in China (Beijing, Shanghai, Shanxi, Shandong, Guangdong, and Hubei). The report concludes with a discussion of data issues and other problems encountered during the development of the end-use low carbon indicator, followed by recommendations for future improvement.

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1. Overview and Objectives

In 2009, China committed to reducing its carbon dioxide intensity (CO_2/unit of gross domestic product, GDP) by 40 to 45 percent by 2020 from a 2005 baseline. In August 2010, after receiving permission from the State Council, the National Development and Reform Commission (NDRC) of China established a Low Carbon City policy and announced the selection of five provinces and eight cities to pilot the low carbon development work (NDRC 2010). The five provinces are: Guangdong, Liaoning, Hubei, Shaanxi and Yunnan; and the eight cities are Chongqing, Tianjin, Shenzhen, Xiamen, Hangzhou, Nanchang, Guiyang, and Baoding. In March 2011, China's 12th Five-Year Plan established a carbon intensity reduction goal of 17% between 2011 and 2015.

Given these various CO_2 intensity reduction goals, it is important to develop a clear definition of "low carbon", which is now a popular term in China. In addition to defining "low carbon", indicators to determine if a city or region meets the definition must be developed in order to evaluate the current situation and measure progress toward more low-carbon activities.

Macro-level indicators of low carbon development, such as energy use or CO_2 emissions per unit of GDP or per capita may be too aggregated to be meaningful measurements of whether a city or province is truly low carbon and do not provide any indication of where the inefficiencies occur or where action is needed. Instead, indicators based on energy end-use sectors (industry, residential, commercial, transport, electric power) could offer a better approach for defining low carbon and for taking action to reduce energy-related carbon emissions.

The objective of this work is to develop a methodology for a low carbon indicator system at the provincial and city level. This report outlines a proposed methodology and provides initial results for an end-use low carbon indicator and ranking system based on data available at the provincial and municipal levels. The report begins with a discussion of macro-level indicators that are typically used for inter-city, regional, or inter-country comparisons. It then turns to a discussion of the methodology used to develop a more robust low carbon indicator for China. The report presents the results of this indicator with examples for six selected provinces and cities in China (Beijing, Shanghai, Shanxi, Shandong, Guangdong, and Hubei). The report concludes with a discussion of data issues and other problems encountered during the development of the end-use low carbon indicator, followed by recommendations for future improvement.

2. Macro-Level Indicators

Macro-level indicators for measuring the carbon intensity of a city, region, or country are typically based on either CO_2 emissions per unit of GDP or CO_2 emissions per capita.

2.1 Macro-Level Economic (GDP) Indicators

An economic-based carbon intensity indictor, or CO_2 emissions/unit of GDP, is comprised of two elements: (1) energy intensity, defined as the amount of energy consumed per unit of economic activity; and (2) carbon intensity of energy supply, defined as the amount of carbon emitted per unit of energy (EIA 2004). As illustrated by the formula below, the multiplication of these two elements produces a country's carbon intensity, defined as the amount of CO_2 emitted per dollar of economic activity:

Energy Intensity x Carbon Intensity of Energy Supply = Carbon Intensity of the Economy

or *(Energy/GDP) x (Carbon Emissions/Energy) = (Carbon Emissions/GDP)*

With regard to energy intensity, it needs to be noted that the scope of energy included in the calculation of energy intensity can render different results. Specifically, it is important to distinguish between final energy and primary energy for the purposes of both data collection and construction of the indicator. Final energy, or end-use energy, refers to energy delivered at the end-use site and does not account for electricity generation efficiency and energy losses during transmission and distribution (T&D). Primary energy includes final energy as well as energy consumed during the generation and T&D of electricity. The relation between primary energy and final energy is illustrated by the formulas below:

Final Energy = *Fuel Use + Electricity Use*

Primary Energy = *Final Energy + Electricity Generation and T&D Losses*

In China, electricity (in kWh) is converted to energy (in kilograms coal equivalent, kgce) using 0.404 kgce/kWh for primary energy and 0.1229 kgce/kWh for final energy.[1]

Table 1 compares China's four large municipalities (Beijing, Tianjin, Shanghai, and Chongqing), four of the five autonomous regions (Xinjiang, Inner Mongolia, Ningxia, and Guangxi; data are not available for Tibet), and 22 provinces using three macro-level economic indicators: primary energy/GDP, final energy/GDP, and end-use CO_2 emissions/GDP. Focusing just on the four large municipalities, Table 1 shows that using these indicators, Beijing, Tianjin, and Shanghai could all be considered "low-carbon" cities because their energy use and emissions per unit of GDP are lower than those of Chongqing and most of China's provinces and autonomous regions.

[1] To accurately convert electricity to primary energy, a conversion factor that reflects the efficiency of power generation combined with electricity T&D losses should be calculated. For 2008, a conversion factor of 3.11 is equivalent to China's national average efficiency of thermal power generation of 32.15%, including T&D losses (NBS 2008; Anhua and Xingshu 2006; Kahrl and Roland-Holst 2006).

Table 1. Comparison of Macro-Level Economic Indicators For China's Large Municipalities, Autonomous Regions, and Provinces, 2008.

Region	Primary Energy Use	Region	Final Energy Use	Region	Consumption-Based Carbon Emissions
	Primary Energy Consumption/GDP		Final Energy Consumption /GDP		End-Use CO2/GDP
	kgce/RMB		kgce/RMB		kgCO2/RMB
Beijing	0.07	Beijing	0.05	Beijing	0.16
Guangdong	0.08	Guangdong	0.05	Guangdong	0.16
Shanghai	0.08	Zhejiang	0.05	Fujian	0.17
Jiangsu	0.08	Jiangsu	0.05	Hubei	0.17
Zhejiang	0.08	Fujian	0.05	Zhejiang	0.18
Jiangxi	0.08	Shanghai	0.06	Guangxi	0.18
Fujian	0.09	Jiangxi	0.06	Hainan	0.19
Tianjin	0.09	Tianjin	0.07	Jiangsu	0.19
Hainan	0.09	Hainan	0.07	Sichuan	0.19
Heilongjiang	0.10	Guangxi	0.07	Shanghai	0.19
Shandong	0.10	Shandong	0.07	Jiangxi	0.21
Shaanxi	0.10	Anhui	0.07	Tianjin	0.23
Guangxi	0.10	Heilongjiang	0.07	Hunan	0.24
Anhui	0.10	Henan	0.07	Shaanxi	0.25
Hunan	0.11	Shaanxi	0.07	Yunnan	0.25
Sichuan	0.11	Hunan	0.07	Chongqing	0.25
Chongqing	0.11	Sichuan	0.08	Anhui	0.26
Henan	0.11	Chongqing	0.08	Shandong	0.27
Jilin	0.12	Hubei	0.09	Heilongjiang	0.27
Hubei	0.12	Jilin	0.09	Henan	0.29
Liaoning	0.13	Liaoning	0.10	Jilin	0.30
Yunnan	0.15	Yunnan	0.10	Liaoning	0.34
Hebei	0.16	Inner Mongolia	0.12	Qinghai	0.37
Xinjiang	0.16	Hebei	0.12	Xinjiang	0.37
Inner Mongolia	0.16	Gansu	0.12	Guizhou	0.37
Guizhou	0.19	Xinjiang	0.13	Gansu	0.40
Gansu	0.19	Guizhou	0.13	Inner Mongolia	0.41
Shanxi	0.21	Shanxi	0.15	Hebei	0.43
Qinghai	0.25	Qinghai	0.15	Shanxi	0.54
Ningxia	0.29	Ningxia	0.17	Ningxia	0.73
avg-unweighted	0.127		0.088		0.286

Sources: NBS 2009; NBS 2010; IPCC 1996.
Notes: Data are only for mainland China; data are not available for Tibet.
Primary energy: total end-use energy consumption of each province with electricity converted at 0.404 kgce/kWh.
Final energy: total end-use energy consumption of each province with electricity converted at 0.1229 kgce/kWh.
Consumption-based carbon emissions: Emissions from electricity are counted where the electricity is consumed. Emissions data include the sequestered carbon in non-energy use petroleum products such as asphalt and lubricants, which total about 150 million tonnes CO_2 (Fridley, et al. 2011).

While this comparison is informative from the point of view of how municipalities, autonomous regions, and provinces compare internally in China, it does not provide any indication of how these regions compare globally. Table 2 provides indicators with which to compare the four large cities in China with other large cities around the world.[2] This comparison shows that all four Chinese municipalities, including the three that appeared to be "low-carbon" when compared with other cities, regions, and provinces in China, have significantly higher final energy and CO_2 intensities than the other selected cities from around the world.

Table 2. Comparison of Macro-Level Economic Indicators For Selected Cities Around the World and China's Four Large Municipalities, 2008

City	Final Energy/GDP *kgce/RMB*	City	CO2/GDP *kg CO2/RMB*
Oslo	0.005	Oslo	0.004
Helsinki	0.006	Brussels	0.008
Amsterdam	0.006	Stockholm	0.009
Brussels	0.006	Tokyo	0.010
Tokyo	0.006	Helsinki	0.011
Copenhagen	0.006	Zurich	0.011
Lisbon	0.007	Copenhagen	0.012
Vienna	0.008	Rome	0.012
Hong Kong	0.008	Taipei	0.013
Taipei	0.008	Paris	0.014
Osaka	0.008	Vienna	0.014
London	0.008	Amsterdam	0.016
New York	0.009	Osaka	0.016
Stockholm	0.009	London	0.024
Paris	0.009	Yokohama	0.025
Zurich	0.010	New York	0.026
Rome	0.010	Hong Kong	0.027
Yokohama	0.012	Seoul	0.028
Berlin	0.012	Lisbon	0.030
Singapore	0.015	Singapore	0.030
Seoul	0.016	Berlin	0.030
Beijing	**0.045**	Los Angeles	0.037
Shanghai	**0.057**	**Beijing**	**0.160**
Tianjin	**0.065**	**Shanghai**	**0.193**
Chongqing	**0.082**	**Tianjin**	**0.228**
Los Angeles	N/A	**Chongqing**	**0.253**

Sources: NBS 2009; NBS 2010; IPCC 1996; Economist Intelligence Unit 2011; Economist Intelligence Unit 2009; World Bank 2010.

Notes: Data for international cities are for the 2008-2009 period; NYC data are for 2005; London data are for 2006. The two exchange rates used for the international indicators are: 1) 2010 average exchange rate of 0.147679 2010 US$ per RMB to convert US$ to RMB for the Asian Green City Index. 2) 2008 average exchange rate of 0.098443 2008 Euro per RMB to convert Euros to RMB for the European Green City Index. Both exchange rates were taken from the Bank of Canada's historical exchange rates database at: http://www.bankofcanada.ca/rates/exchange/

[2]Note that this comparison is complicated by factors that might potentially affect the accuracy of such comparisons such as exchange rates between different currencies (purchasing power parity could be used instead).

2.2 Macro-Level Population-Based Indicators

Similar to the economic-based macro-level indicators, indicators using population as the denominator instead of GDP can also be used to compare cities, regions, and provinces. Table 3 shows the comparison using primary energy use/capita, final energy use/capita, and end-use CO_2 emissions/capita for the 30 provinces, autonomous regions, and cities in China in 2008.

Table 3. Comparison of Macro-Level Per Capita Indicators For China's Large Municipalities, Autonomous Regions, and Provinces, 2008.

Region	Primary Energy Use	Region	Final Energy Use	Region	Consumption-based Carbon Emissions
	Primary Energy Consumption /capita		Final Energy Consumption /capita		End-use CO2/capita
	tce/person		tce/person		tCO2/person
Jiangxi	1.11	Hainan	0.80	Henan	2.13
Anhui	1.25	Chongqing	0.85	Xinjiang	2.47
Guangxi	1.26	Shandong	0.87	Gansu	2.62
Hainan	1.36	Liaoning	0.99	Hunan	2.73
Sichuan	1.37	Hebei	0.99	Jilin	2.77
Guizhou	1.47	Gansu	1.01	Shandong	2.85
Yunnan	1.52	Inner Mongolia	1.06	Qinghai	2.91
Hunan	1.58	Hubei	1.12	Tianjin	3.09
Shaanxi	1.66	Shaanxi	1.16	Heilongjiang	3.67
Henan	1.73	Xinjiang	1.19	Hebei	3.99
Heilongjiang	1.80	Guizhou	1.22	Guizhou	4.02
Chongqing	1.83	Guangxi	1.31	Yunnan	4.13
Gansu	1.89	Heilongjiang	1.35	Liaoning	4.28
Hubei	1.96	Yunnan	1.39	Shaanxi	4.66
Fujian	2.18	Sichuan	1.44	Jiangsu	4.92
Jilin	2.31	Jilin	1.50	Chongqing	5.26
Guangdong	2.46	Anhui	1.70	Inner Mongolia	5.59
Xinjiang	2.64	Henan	1.74	Sichuan	5.87
Shandong	2.76	Jiangxi	1.81	Ningxia	6.09
Jiangsu	2.77	Hunan	1.97	Jiangxi	6.11
Zhejiang	2.88	Ningxia	2.07	Shanghai	6.38
Hebei	3.02	Beijing	2.25	Anhui	7.29
Liaoning	3.48	Shanxi	2.36	Guangdong	8.19
Beijing	3.57	Guangdong	2.48	Beijing	8.69
Shanxi	3.71	Shanghai	2.60	Zhejiang	8.98
Qinghai	3.84	Jiangsu	2.72	Guangxi	9.59
Tianjin	4.28	Qinghai	2.81	Fujian	10.82
Ningxia	4.66	Zhejiang	3.09	Shanxi	11.85
Inner Mongolia	4.74	Fujian	3.36	Hainan	11.95
Shanghai	5.08	Tianjin	3.50	Hubei	12.06
avg -unweighted	2.539		1.757		5.866

Sources: NBS 2009; NBS 2010; IPCC 1996.
Notes: Data are only for mainland China; data are not available for Tibet.
Primary energy: total end-use energy consumption of each province with electricity converted at 0.404 kgce/kWh.
Final energy: total end-use energy consumption of each province with electricity converted at 0.1229 kgce/kWh.
Consumption-based carbon emissions: Emissions from electricity are counted where the electricity is consumed. Emissions data include the sequestered carbon in non-energy use petroleum products such as asphalt and lubricants, which total about 150 million tonnes CO_2 (Fridley, et al. 2011).

The results for the four large municipalities in China using the per capita indicators differ from the results using GDP as the denominator. On a per capita basis, Chongqing has the lowest energy use and CO_2 emissions per capita of the four cities, while Shanghai, Beijing, and Tianjin cannot be defined as low-carbon cities. When China's four large municipalities are compared to selected world cities using both the final energy/capita and CO_2 emissions/capita indicators, Chongqing has the lowest per capita energy consumption of all of the cities, but a number of world cities have lower per capita CO_2 emissions, most likely due to a more decarbonized fuel mix. Beijing's per capita final energy consumption is also relatively low when compared to the selected international cities, but again the per capita CO_2 emissions of China's capital city are higher than most other cities in the comparison due to the heavy reliance on coal in China's fuel mix. Nonetheless the Chinese cities are still of a similar magnitude as other international best practice cities, unlike the GDP based indicator which shows that Chinese cities are 20 times more carbon intensive than the selected international cities. The comparison demonstrates that the choice of indicators is crucial in determining whether a city or province is low carbon.[3]

Table 4. Comparison of Macro-Level Per Capita Indicators For Selected Cities Around the World and China's Four Large Municipalities, 2008

City	Final Energy per capita *tce/person*	City	CO2/capita *t CO2/person*
Chongqing	**1.38**	Oslo	2.19
Hong Kong	1.54	Rome	3.50
Lisbon	1.66	Stockholm	3.62
Seoul	2.14	Seoul	3.70
Yokohama	2.48	Zurich	3.70
Taipei	2.48	Brussels	3.91
Amsterdam	2.55	Taipei	4.20
London	2.55	**Chongqing**	**4.28**
Beijing	**2.56**	Tokyo	4.80
Berlin	2.65	Paris	5.04
Vienna	2.69	Vienna	5.19
Copenhagen	2.75	Yokohama	5.20
Rome	2.89	Copenhagen	5.38
Tokyo	2.90	Hong Kong	5.40
Brussels	2.97	London	5.90
New York	3.03	Helsinki	6.01
Helsinki	3.03	New York	6.50
Tianjin	**3.10**	Berlin	6.57
Zurich	3.24	Amsterdam	6.66
Oslo	3.24	Singapore	7.40
Paris	3.30	Lisbon	7.47
Stockholm	3.58	Osaka	7.60
Singapore	3.74	**Beijing**	**8.69**
Shanghai	**3.79**	Los Angeles	9.60
Osaka	3.88	**Tianjin**	**10.82**
Los Angeles	N/A	**Shanghai**	**11.95**

Sources: City of New York, 2011; Economist Intelligence Unit 2011; Economist Intelligence Unit 2009; NBS 2009; NBS 2010; IPCC 1996; World Bank 2010.
Notes: Data for international cities are for the 2008-2009 period; NYC data are for 2010.

[3] There are a number of efforts to compare CO_2 emissions/capita for the world's cities (Carbon Disclosure Project, 2011; City of New York, 2011; KPMG, 2010) which emphasize the importance of data quality, boundary definitions, conversion factors, etc. All of these issues also apply to the use of a CO_2 emissions/capita indicator in China.

Issues with Macro-Level Indicators

Based on the discussions above, there are many issues and underlying factors with these two macro-level indicators that make them less desirable for use in defining "low carbon" cities or provinces. In the case of the 30 Chinese provinces and cities, the issues include:

- Macro-level indicators do not accurately reflect end-use (e.g. buildings, transport, industry) energy or carbon intensities since they are created based on a top-down approach for the purpose of providing a general, overall picture of a country's situation.
- Migrant/transient populations were not included in official population data until the 2010 Census which could result in over-accounting of energy use per capita in large coastal cities and provinces that have significant migrant populations, such as Beijing and Shanghai, and possible under-accounting of energy use per capita in other areas.
- Cross-country comparisons have additional issues due to differing data sources, definitions, exchange rates, conversion factors, etc. which often make it difficult to ensure that the results are comparable.

The underlying factors include:

- Provinces and cities are varied in their economic structure (i.e. primary, secondary, and tertiary industry); a more fair comparison would account for these structural differences.
- Income levels vary by location, with generally higher incomes in the cities and provinces in Eastern China, leading to higher car ownership and fuel use, higher residential energy consumption, etc.
- Building energy consumption is highly dependent on the weather conditions of a region, and the macro level indicators ignore these differences, which could lead to inaccurate results.

Economic energy intensity (i.e. energy/GDP or CO_2/GDP) is a mixed indicator, accounting for both physical energy efficiency and economic structure that influences energy consumption. As economic development proceeds, the economic energy intensity typically declines yet absolute energy and carbon emissions can still increase. Although per capita indicators may provide a more equitable basis for comparison across cities, provinces, and countries, highly aggregated per capita indicators (i.e. total energy/capita or CO_2/capita), should still be used with caution. A city with heavy industry and a small population, which supplies other cities with cement and steel, would result in high energy consumption per capita even though the people of the city might use relatively little energy in their residences. Similarly, a city in the cold region will always have higher energy consumption than cities in moderate climate.

It is important to develop an accurate indicator and associated sub-indicators because there could be significant implications related to mislabeling a city or region as low carbon when it is not (or vice versa) such as inappropriate use of funds for development, misguided efforts to influence development and behavior that are not conducive to actually reducing energy use or CO_2 emissions, and missed opportunities to focus on specific areas that could have the most impact in actually making a specific location low carbon.

3. Sectoral End-Use Low Carbon Indicator for China

The goal of this study is to develop a methodology for a low carbon indicator system for municipalities, autonomous regions, and provinces in China. To address some of the issues with the macro-level indicators described above, a composite sectoral end-use low carbon indicator is developed for this purpose.

The advantages of using this indicator include:

- Its development is based on international experience (ICLEI 2009; IEA 2010; Zhou et al. 2011), while factoring in data availability in China and applicability to the Chinese situation.
- It is constructed using the underlying contributors to the overall level of energy use or CO_2 emissions of a city or province - the energy and emissions of the main energy-consuming end-use sectors: residential, commercial, industry, transportation and power.[4]
- It indexes the energy consumption and CO_2 emissions of the five major energy end-use sectors so that they can be weighted and combined.
- It applies a weighting factor for the five major energy end-use sectors to account for their contribution to the overall energy use or CO_2 emissions within the province or city.
- It also applies climate adjustment factor for the buildings sector that is based on the weather data of each province, to ensure the comparison among cities is fair and consistent.
- It is operation- and goal-oriented, providing measurability and comparability and can be used to define low carbon, rank cities by energy use and CO_2 emissions levels, track progress in energy efficiency and emission reductions, and establish benchmarks.

This section begins with a description of the methodology for development of the sectoral end-use low carbon indicator. This is followed by a presentation of the results for China's 30 selected provinces and cities after applying the methodology, including more detailed discussion of the results for six Chinese provinces and cities (Beijing, Shanghai, Shanxi, Shandong, Guangdong, and Hubei). The section ends with a discussion of identified issues and areas for improvement of the new low carbon indicator.

3.1. Methodology

There are four key steps in the development of the end-use low carbon indicator:

- Identify end-use sectors
- Identify indicators for each end-use sector identified (based on available data)
- Gather indicator data for each province/city
- Calculate the end-use low carbon indicator value by indexing and weighting end-use indicators

[4] Residential includes buildings energy use as well as the energy use of appliances and equipment in the buildings. Commercial includes wholesale, retail trade, catering, construction, and other commercial services. Agricultural energy use is not included in the calculations presented in this report.

Identify End Use Sectors

The first step in developing the low carbon indicator is to identify key end-use energy-consuming sectors of the economy for which data are available. For China, five sectors were identified that cover virtually every aspect of China's modern living and activities: residential buildings, commercial buildings, industry, transportation, and power generation. These five sectors combine to account for all energy use and related CO_2 emissions in China.

Identify Indicators for Each End-Use Sector

The second step in developing the low carbon indicator is to identify indicators for each of the end-use sectors that were defined in the first step. Again, it is essential that the data required for development of each indicator are available.

Residential Buildings Sector

For China, the end-use low carbon indicator for the residential buildings sector is defined as weather-corrected residential buildings final energy[5]/capita. This indicator should be weather-adjusted to account for the differing demands on energy use in residential buildings in various climatic zones in order for the indicator to be comparable across cities and provinces. For example, non-weather-adjusted residential energy intensity in a severely cold zone such as Harbin is not directly comparable to the non-weather-adjusted residential energy intensity of a mild-weathered city such as Kunming since overall lower energy intensity doesn't necessarily imply higher energy efficiency without taking the weather into consideration. Weather variation can be accounted for by calculating cooling degree-days (CDD) and heating degree-days (HDD). HDDs and CDDs are measures of how cold/warm a location is over a period of time relative to a base temperature, most commonly specified as 18 °C. Heating degree days are the summation of the negative differences between the mean daily temperature and the 18 °C base; cooling degree days are the summation of the positive differences (Zhou et al. 2011).

Commercial Buildings Sector

The end-use low carbon indicator for China's commercial buildings sector is defined as commercial buildings final energy/tertiary sector employees.[6] Data on the number of employees are more readily available than data on commercial buildings floor area (m^2). However, an indicator based on energy use per square meter would be more comparable for commercial buildings since the number of employees per meter can vary significantly.[7] If data are available broken out by types of buildings, then more detailed comparisons could be provided as the energy consumption patterns are very different among the different building types such as retail, office, hotel, education, health care, etc.

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[5] Final energy was used for the development of these indicators; a comparison of the results using primary energy showed little difference in the overall ranking order. Final energy was chosen as the method to present here since most cities and provinces cannot influence the efficiency of the generation or T&D of the electricity they consume.

[6] Commercial building sector energy data were not weather-corrected for this analysis due to lack of data; such a correction should be done, if possible, for more accurate results.

[7] For the commercial building sector, floor space data may be collected through the local taxation office through properties taxes. Or, the building construction commission or the planning bureau often has a record of the building construction area. Such data could be used instead of commercial building employees for this indicator.

Industry Sector

The end-use low carbon indicator for the industry sector in China is defined as industrial final energy per /industrial share of regional GDP (NBS 2010). This indicator is at a highly aggregated level, combining all industrial energy consumption (and carbon emissions) activities and dividing by the industrial share of regional GDP. It would be ideal to have industrial value added data instead of the industrial share of regional GDP, but this value is only available at the national level in China. This indicator can also be developed at a sub-sectoral level, for example, to compare the intensity of overall cement production in a city with the intensity of other industrial sub-sectors such as chemicals and steel, depending upon data availability.

Transportation Sector

The end-use low carbon indicator for China's transportation sector is defined as transportation final energy/capita. This indicator provides a measure of the energy or carbon intensity of moving people and goods around a city. This indicator can also be developed for individual transportation modes, but this is challenging, since it requires knowing the usage (passenger-kilometers, freight-kilometers) of all public transportation modes (buses, light rail, subway, trucks, etc.), total person-trip-kilometers for all private travel in cars and taxis as well as the total energy consumption of these travel modes.

Power Sector

The end-use low carbon indicator for power sector is defined as CO_2 per unit of power produced. CO_2 emissions per unit of generated electricity is a common indicator for tracking the de-carbonization of electricity supply. Expressed as kg CO_2/kWh, this indicator can be used to track the reduction in use of carbon-intensive coal and the impact of the use of renewable, natural gas, and nuclear energy sources in the power generation mix. This indicator also serves as an emission factor for determining carbon emissions from electricity use for each of the end-use sectors.

Gather Indicator Data for Each Province/City

The next step in the construction of the sector-based end-use low carbon indicator is to identify and gather the required data for each province or city. For China, the data for the development of the indicators outlined above was all collected from published data provided by Chinese government statistical offices. When collecting such data, it is important to understand the data definitions and boundaries in order to ensure that the indicators are comparable.

For example, it is important to understand if electricity is presented as final or primary energy when total energy values are provided. The end-use low carbon indicator uses final energy so that an indicator for the electricity sector can be presented along with indicators for each end-use sector.[8] It is also important to ensure that economic data are presented in the same base year. The energy data used for the development of the Chinese indicators presented in this report are from the *China Energy Statistical Yearbook 2009* of the China National Bureau of

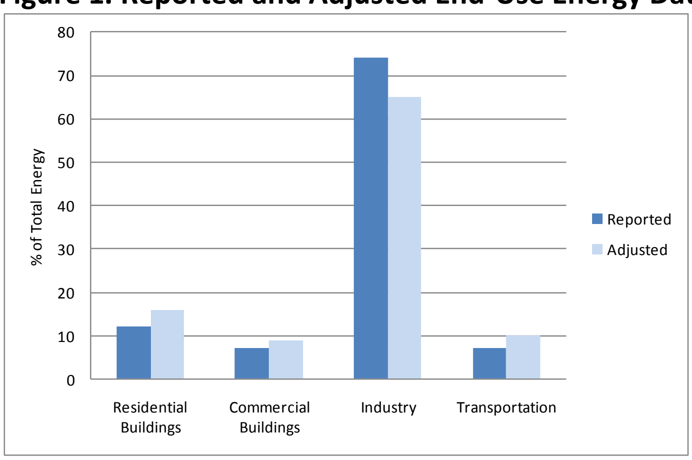
[8] A comparison of the LCI calculated using primary energy to the LCI results presented in this report using final energy showed that there was very little difference in the resulting indicator values.

Statistics (NBS) (NBS 2009). The economic data are from the *2010 China Statistical Yearbook* of NBS (NBS 2010), and the economic data are converted to 2005 RMB based on the price indices provided by NBS. The CO_2 emission factors are from the Intergovernmental Panel on Climate Change (IPCC) (IPCC 1996).

Depending upon the quality and comparability of the data, some adjustments to the data may be needed. For example, for the residential sector in China, adjustments to the data may be needed to ensure that the energy use of all residences is included in this indicator. Often, residential energy use in industrial units is accounted for within the industrial energy use category. Like the residential buildings sector, energy use for transportation within industrial units may also need to be removed from industrial sector data and added to transportation sector data in order to more accurately reflect the energy use of this end-use sector. Figure 1 shows the results when such an adjustment was made to China's 2000 energy data (Zhou et al. 2007). Such adjustments were not, however, made for this report because this report relies solely on published data from China.

Adjustments of the usage of oil products were made in the industrial, residential, commercial, and transport. Gasoline usage that was reported under the industrial, residential, commercial and agriculture sectors was reallocated to transport sector. Kerosene and fuel oil consumption in the transport sector was reduced to take into account the inter-provincial and international use of jet fuel in airplanes and fuel oil in ships, respectively. Due to a lack of detailed data, a reduction factor of 50% was applied.[9]

Figure 1. Reported and Adjusted End-Use Energy Data for China, 2000.



Source: Zhou et al. 2007.

[9] The reduction factor of 50% derives from an analysis of China's jet fuel and marine fuel oil usage in 2009. In that year, 94% of China's kerosene consumption was jet kerosene and 49% of China's fuel oil was used for transportation. The statistics do not distinguish between domestic and international bunkers for either jet fuel or fuel oil. Considering that some air flights are within provinces (though most are not), and that some marine fuel oil is used for ships moving within provinces (though most is not), it was estimated that 80% of each was in interprovincial/international travel. This assumption results in a total of 20.7 Mt of total kerosene and fuel oil for interprovincial/international travel, out of a total of 39.7 Mt total consumption, or about 50% of the total.

Calculate the End-Use Low Carbon Indicator Value by Indexing and Weighing End-Use Indicators

Once the end-use sectors and their indicators have been identified and data have been collected and modified, if necessary, the final steps for the calculation of the end-use local carbon indicator are to index each end-use sector's low carbon indicator and multiply it by a weighting factor and add the results of that calculation to the indexed and weighted power sector indicator. This indexing and weighting is done for each of the large municipalities, autonomous zones, and provinces.

The weighting factor for the end-use sectors is the share of each individual end-use sector in the combined total residential, commercial, industrial, and transportation energy use. In this way, the energy use for each end-use sector reflects the significance of that sector in the city or province's overall energy use. The weighting factor for power generation is the share of electricity in the total city or provincial energy use. Equation (1) provides the calculation details for the provincial level low carbon indicator (LCI). Figure 2 illustrates this calculation.

(1) $$LCI = \left\{\left(\frac{PR/Cap}{NR/Cap}\times 100\right)\times\frac{PR}{PT}\right\} + \left\{\left(\frac{PC/E}{NC/E}\times 100\right)\times\frac{PC}{PT}\right\} + \left\{\left(\frac{PI/I\ GDP}{NI/I\ GDP}\times 100\right)\times\frac{PI}{PT}\right\} + \left\{\left(\frac{PTr/Cap}{NTr/Cap}\times 100\right)\times\frac{PTr}{PT}\right\} + \left\{\left(\frac{PCO2/Pp}{NCO2/Pp}\times 100\right)\times\frac{PElec}{PT}\right\}$$

Where:

PR = Provincial Residential final energy use
NR = National Residential final energy use
Cap = capita
PT = Provincial Total end-use energy
PC = Provincial Commercial final energy use
NC = National Commercial final energy use
E = employee
PI = Provincial Industrial final energy use
NI = National Industrial final energy use
I GDP = Industrial share of gross domestic product
PTr = Provincial Transport final energy use
NTr = National Transport final energy use
PCO_2 = Provincial CO_2 emissions
NCO_2 = National CO_2 emissions
Pp = Power produced
PElec = Provincial Electricity use

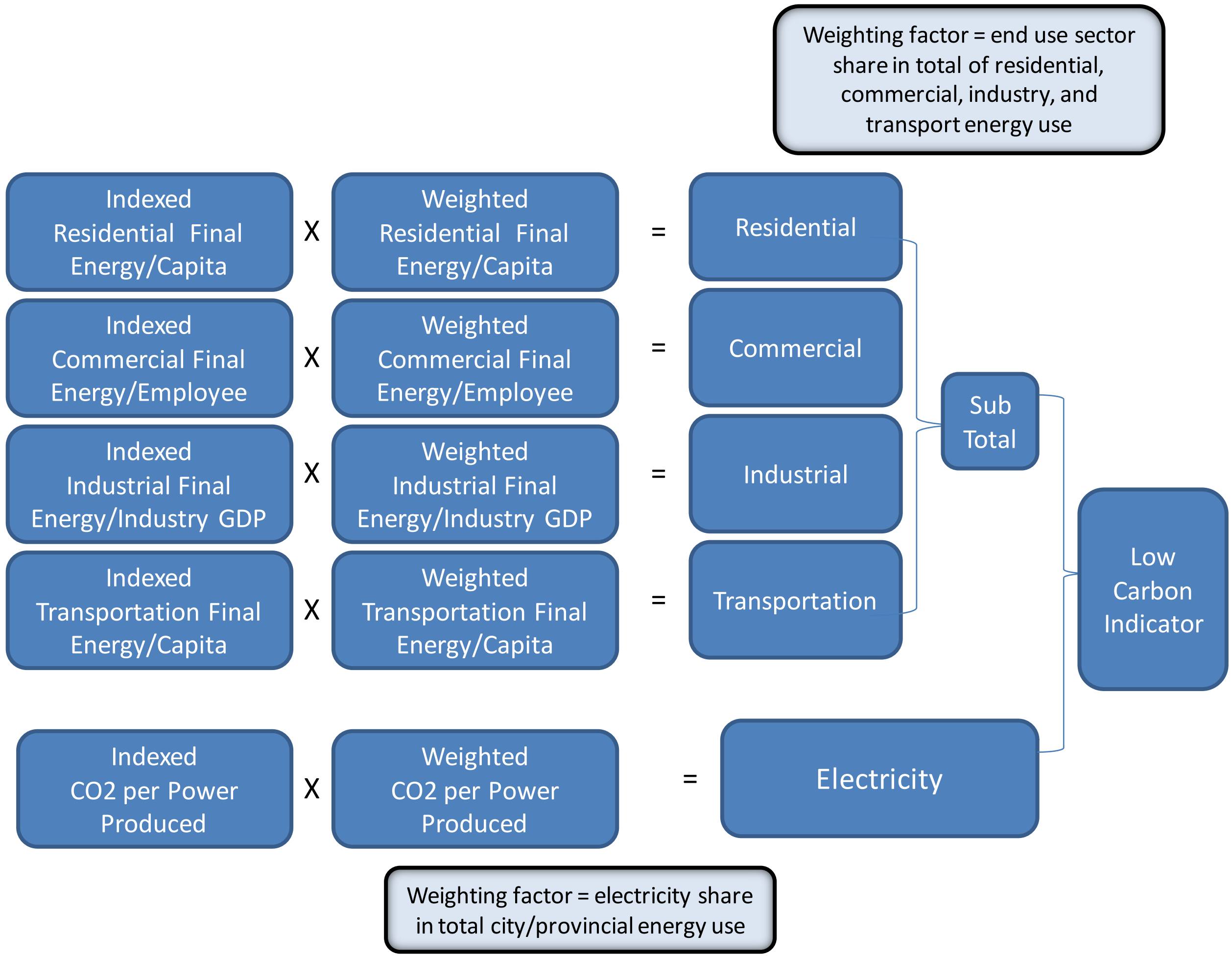


Figure 2. Calculation of the Aggregated Low Carbon Indicator

3.2 End-Use Low-Carbon Indicator Calculation Results

This section provides a description of the results of the calculation of the sector-level end-use low carbon indicator for China based on 2008 data. Table 5 shows the 2008 indicator value for each of the end-use sector-specific indicators for China's large municipalities, autonomous regions, and provinces.

Table 5. End-Use Sectoral Indicators for China's Large Municipalities, Autonomous Regions, and Provinces, 2008

Region	Electric Power	Residential	Commercial	Industrial	Transportation
	CO2 per Power Produced	Residential final energy/capita (weather corrected)	Commercial final energy/tertiary sector employees	Industrial final energy/Industry GDP	Transportation final energy/capita
	kgCO2/kWh	tce/cap	tce/cap	tce/10,000 RMB (2005 yuan)	tce/cap
Beijing	0.664	0.385	0.978	0.908	0.584
Tianjin	0.899	0.318	1.396	0.828	0.390
Hebei	0.995	0.214	0.661	1.871	0.122
Shanxi	0.958	0.308	0.681	2.091	0.255
Inner Mongolia	1.231	0.642	1.661	1.652	0.444
Liaoning	1.039	0.301	0.496	1.420	0.335
Jilin	1.256	0.246	0.668	1.517	0.243
Heilongjiang	1.040	0.364	0.479	0.962	0.155
Shanghai	0.829	0.280	1.572	0.796	0.728
Jiangsu	0.803	0.095	0.345	0.828	0.178
Zhejiang	0.695	0.153	0.430	0.678	0.245
Anhui	0.890	0.084	0.169	1.372	0.083
Fujian	0.563	0.145	0.426	0.804	0.217
Jiangxi	0.882	0.087	0.184	1.115	0.087
Shandong	0.975	0.134	0.884	0.983	0.229
Henan	0.981	0.128	0.160	1.066	0.083
Hubei	0.321	0.156	0.374	1.453	0.253
Hunan	0.596	0.124	0.380	1.398	0.114
Guangdong	0.659	0.228	0.463	0.631	0.260
Guangxi	0.371	0.063	0.266	1.296	0.141
Hainan	0.566	0.069	0.457	1.793	0.248
Chongqing	0.797	0.147	0.249	1.584	0.173
Sichuan	0.440	0.149	0.243	1.296	0.115
Guizhou	0.690	0.115	0.592	2.162	0.116
Yunnan	0.558	0.059	0.241	1.958	0.161
Shaanxi	0.847	0.170	0.546	0.931	0.214
Gansu	0.640	0.207	0.221	2.219	0.121
Qinghai	0.314	0.448	0.926	2.512	0.220
Ningxia	1.022	0.215	0.735	3.369	0.254
Xinjiang	0.808	0.304	0.756	1.962	0.280

Sources: NBS 2009; NBS 2010; IPCC 1996.

Notes: Data are only for mainland China; data are not available for Tibet.

Primary energy: total end-use energy consumption of each province with electricity converted at 0.404 kgce/kWh.

Final energy: total end-use energy consumption of each province with electricity converted at 0.1229 kgce/kWh.

Consumption-based carbon emissions: Emissions from electricity are counted where the electricity is consumed.

Emissions data include the sequestered carbon in non-energy use petroleum products such as asphalt and lubricants, which total about 150 million tonnes CO_2 (Fridley, et al. 2011).

According to formula (1), in order to construct a single end-use low carbon indicator, the values shown in Table 5 need to be indexed so that they can be compared. Each indicator is indexed to its un-weighted average national value in order to aggregate the disparate values. Table 6 presents the results of the indexing step. Indexed values below 100 indicate that for that specific indictor, the province or city is below the national average. Indexed values above 100 indicate that the indicator is higher than the national average.

Table 6. Indexed End-Use Sectoral Indicators for China's Large Municipalities, Autonomous Regions, and Provinces, 2008

Region	Residential final energy/capita (weather corrected)	Commercial final energy/tertiary sector employees	Industrial final energy/Industry GDP	Transportation final energy/capita	Electric Power CO2/kWh
	Index	Index	Index	Index	Index
Beijing	182	166	63	249	85
Tianjin	151	237	57	166	116
Hebei	101	112	129	52	128
Shanxi	146	116	144	108	123
Inner Mongolia	304	282	114	189	158
Liaoning	143	84	98	143	134
Jilin	117	114	105	103	161
Heilongjiang	173	81	66	66	134
Shanghai	132	267	55	310	107
Jiangsu	45	59	57	76	103
Zhejiang	73	73	47	104	89
Anhui	40	29	95	35	114
Fujian	69	72	55	92	72
Jiangxi	41	31	77	37	113
Shandong	63	150	68	97	125
Henan	60	27	74	35	126
Hubei	74	64	100	108	41
Hunan	59	65	97	49	77
Guangdong	108	79	44	111	85
Guangxi	30	45	89	60	48
Hainan	33	78	124	105	73
Chongqing	69	42	109	74	102
Sichuan	70	41	89	49	57
Guizhou	54	101	149	50	89
Yunnan	28	41	135	69	72
Shaanxi	80	93	64	91	109
Gansu	98	38	153	51	82
Qinghai	212	157	173	94	40
Ningxia	102	125	233	108	131
Xinjiang	144	129	135	119	104
National Average	100	100	100	100	100

The values in Table 6 do not fully explain the situation in each province or city, though, because they do not take into account the share of each end-use sector's energy use in the province. Thus, the next step is to calculate weighting factors based on the share of energy use in each of the four end-use sectors (residential buildings, commercial buildings, industry and transportation) as well as the share of provincial/city electricity use of total provincial/city energy are calculated (as shown in Table 7). These weighting factors are then multiplied by the indexed values for each end use sector.

Table 7. Weighting Factors for End-Use Sectoral Indicators for China's Large Municipalities, Autonomous Regions, and Provinces, 2008

Region	Share of Residential Sector Energy in Total End-Use Energy	Share of Commercial Sector Energy in Total End-Use Energy	Share of Industrial Sector Energy in Total End-Use Energy	Share of Transportation Sector Energy in Total End-Use Energy	Share of Provincial Electricity of Total Provincial Energy
	%	%	%	%	%
Beijing	0.15	0.20	0.41	0.24	0.19
Tianjin	0.10	0.09	0.69	0.13	0.17
Hebei	0.09	0.04	0.81	0.06	0.14
Shanxi	0.11	0.04	0.76	0.10	0.16
Inner Mongolia	0.12	0.08	0.67	0.14	0.18
Liaoning	0.10	0.04	0.73	0.13	0.15
Jilin	0.10	0.06	0.71	0.14	0.12
Heilongjiang	0.16	0.05	0.66	0.12	0.16
Shanghai	0.08	0.12	0.59	0.21	0.20
Jiangsu	0.06	0.04	0.80	0.10	0.26
Zhejiang	0.09	0.07	0.70	0.15	0.31
Anhui	0.10	0.03	0.77	0.10	0.20
Fujian	0.09	0.06	0.68	0.16	0.27
Jiangxi	0.09	0.04	0.76	0.11	0.17
Shandong	0.07	0.08	0.73	0.12	0.17
Henan	0.10	0.02	0.80	0.07	0.21
Hubei	0.11	0.05	0.66	0.18	0.16
Hunan	0.10	0.06	0.73	0.11	0.17
Guangdong	0.11	0.07	0.65	0.18	0.28
Guangxi	0.07	0.05	0.71	0.17	0.21
Hainan	0.05	0.08	0.61	0.26	0.17
Chongqing	0.10	0.04	0.72	0.13	0.14
Sichuan	0.15	0.05	0.68	0.12	0.17
Guizhou	0.15	0.13	0.61	0.12	0.20
Yunnan	0.08	0.03	0.72	0.16	0.19
Shaanxi	0.14	0.08	0.59	0.18	0.17
Gansu	0.13	0.03	0.74	0.10	0.22
Qinghai	0.12	0.07	0.72	0.09	0.28
Ningxia	0.06	0.04	0.81	0.09	0.28
Xinjiang	0.11	0.05	0.70	0.14	0.11
National Total	0.10	0.06	0.71	0.13	0.19

Note: The shares for the end-use sectors add to 100%, while the share for electricity is the share of electricity versus other energy sources (e.g. coal, natural gas) used in the province.

Table 8 shows the aggregated end-use low-carbon indicator results for each of the 30 Chinese large municipalities, autonomous regions, and provinces. The results are presented in typical order as shown in Chinese publications on the left side of the table as well as in ascending order on the right side of the table. The lower end-use low carbon indicator value denotes a more "low carbon" ranking. The large municipalities of Chongqing, Tianjin, Beijing and Shanghai are ranked 15, 16, 26, and 29, respectively, among the 30 cities, regions, and provinces evaluated. Since the results take into account all energy use sectors as well as the power sector and are energy consumption based (exported energy is excluded and imported energy is included), "carbon leakage" that often results from using final energy values is avoided.

Table 8. End-Use Low Carbon Indicator for China's Large Municipalities, Autonomous Regions, and Provinces, 2008

Region	End Use Low Carbon Indicator	Region	End Use Low Carbon Indicator
Beijing	163	Fujian	83
Tianjin	115	Jiangsu	85
Hebei	140	Jiangxi	87
Shanxi	159	Zhejiang	87
Inner Mongolia	188	Guangdong	88
Liaoning	127	Guangxi	88
Jilin	126	Sichuan	89
Heilongjiang	107	Shaanxi	92
Shanghai	161	Henan	95
Jiangsu	85	Hunan	99
Zhejiang	87	Shandong	100
Anhui	104	Hubei	103
Fujian	83	Anhui	104
Jiangxi	87	Heilongjiang	107
Shandong	100	Chongqing	112
Henan	95	Tianjin	115
Hubei	103	Hainan	123
Hunan	99	Jilin	126
Guangdong	88	Yunnan	126
Guangxi	88	Liaoning	127
Hainan	123	Guizhou	135
Chongqing	112	Hebei	140
Sichuan	89	Xinjiang	145
Guizhou	135	Gansu	150
Yunnan	126	Shanxi	159
Shaanxi	92	Shanghai	161
Gansu	150	Beijing	163
Qinghai	180	Qinghai	180
Ningxia	247	Inner Mongolia	188
Xinjiang	145	Ningxia	247

Note: The lower end-use low carbon indicator value denotes a more "low carbon"ranking.

These results can be used to define what qualifies as a "low-carbon" municipality, autonomous region, or province. Based on the results presented in Table 8, one option would be to define all regions that have a low-carbon indicator value of less than 100 as "low carbon." Another option would be to designate the five or ten regions with the lowest indicator value as "low carbon." Since this methodology is applied in this analysis to a mix of cities, autonomous regions, and provinces, a specific value is not recommended here. Application of this methodology to a more homogenous set (e.g. only cities) could provide results that can be used to delineate a specific value for qualification as "low-carbon."

Figure 3 provides a graphical representation of the results of the end-use CO_2 emissions per capita indicator showing that CO_2 emissions per capita are the highest in the northern, industrial provinces of China, followed by neighboring provinces in the east as well as Xinjiang province in the far west. The indicator, however, doesn't provide a fair comparison among provinces with different economic structures or climate conditions.

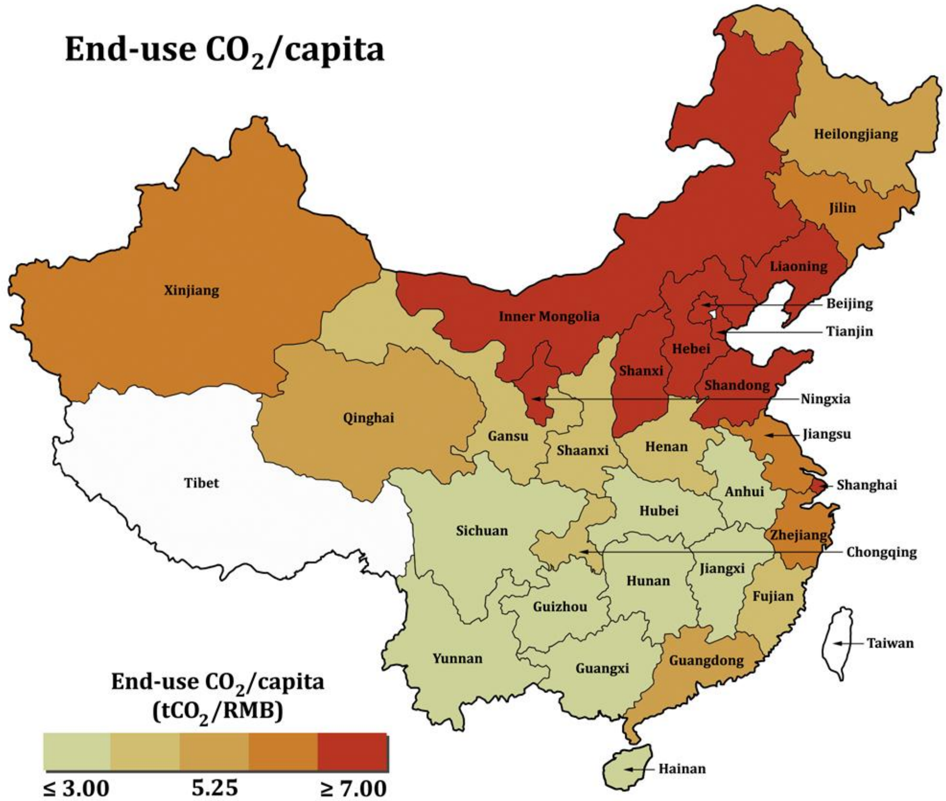


Figure 3. Results of the End Use CO_2/Capita Indicator

Figure 4 shows end-use CO_2 emissions per unit of GDP. The highest CO_2 emissions per unit of GDP are concentrated in the west and northern regions, with relatively low CO_2 emissions per unit of GDP in the coastal and southern regions of China. This economic-based indicator favors the economically more developed regions or energy-consumption-based regions with "low carbon" status, rather than energy-producing regions.

Figure 5 provides the results of the low carbon indicator (LCI). This indicator shows that China's eastern and southern provinces have the lowest carbon ranking, with the exception of Shanghai. Shanghai has a very high carbon using the composite indicator, due to the dominance of some carbon-intensive sectors. This is explained further below. With few exceptions, the east and south of China rank as lower carbon than the north and west of China using the low carbon indicator.

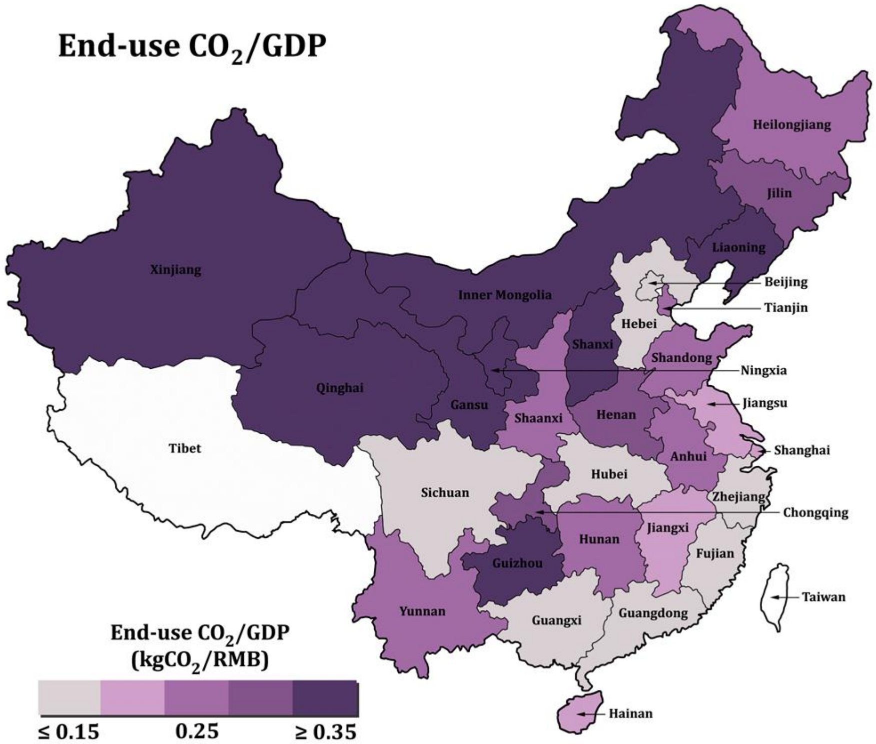


Figure 4. Results of the End Use CO_2/GDP Indicator

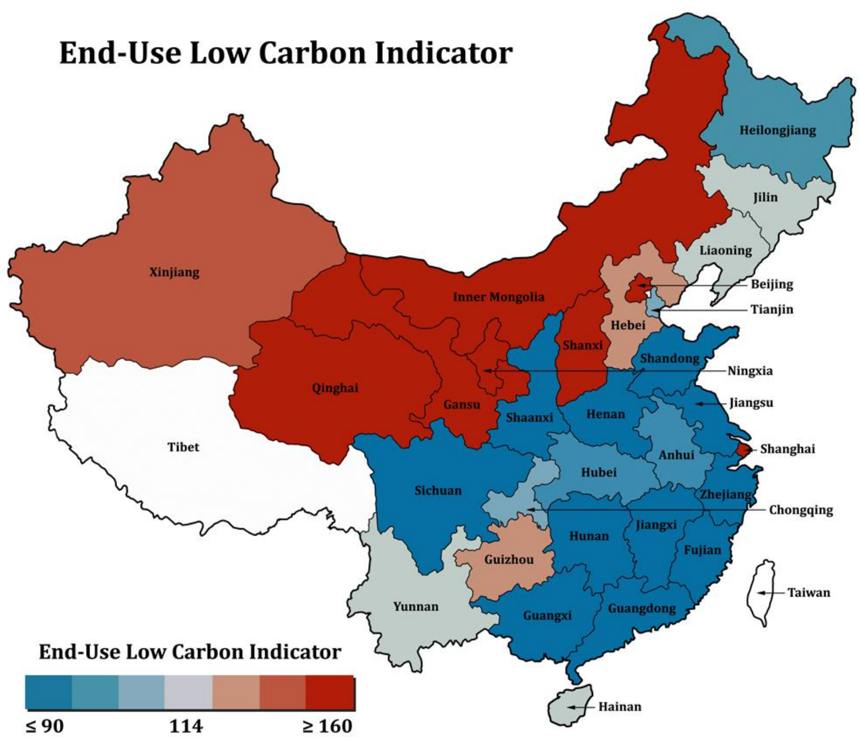


Figure 5. Results of the End Use Low Carbon Indicator

To understand how the sectoral end-use low carbon indicator compares to the two more commonly used macro-level indicators (economic- and population-based) and the five individual end-use sector-level indicators, six Chinese provinces and cities (Beijing, Shanghai, Shanxi, Shandong, Guangdong, and Hubei) that represent various types of economic development were selected for more detailed evaluation. For each province/city selected, a brief explanation of the overall ranking in the end-use sectoral indicators is provided.

Beijing

Of the 30 large municipalities, autonomous regions, and provinces evaluated, Beijing ranks very high in terms of being "low carbon" using metrics that are based on GDP: 1st in primary energy consumption/GDP, 1st in end-use CO_2/GDP, and 1st in final energy consumption/GDP (see Table 9). As the nation's capital, with a highly-developed, economically-productive commercial sector, this is not a surprise. Alternatively, Beijing does not appear to be "low carbon" when indicators based on population are used, ranking 24th in primary energy use/capita, final energy use/capita, and end-use CO_2/capita. Again, as a densely populated urban area, this also is not surprising. Beijing's ranking using a per capita based indicator will most likely improve after 2010 when migrant workers, who were previously not included in the national census and are not included in the denominator for the values reported here, are included in the city's population.

Looking at the end-use sector-level indicators, Beijing again fares well (7th) with the one indicator that is GDP-based (industrial final energy/industry GDP) and ranks relatively well at 11th in kilograms (kg) CO_2 emitted per kilowatt hours (kWhs) of electricity produced. Overall, when the end-use sector-level indicators are combined into the end-use low carbon indicator, Beijing ranks 27th of 30 due to high energy use per capita for residential buildings, high energy use per employees for commercial buildings, and high energy use per capita for transportation, despite the rapid growth in the subway system and the introduction of bus rapid transit.

Table 9. Beijing Ranking in Macro- and Sector-Level Indicators

Macro-level indicators	Beijing Ranking	End-use sector-level indicators	Beijing Ranking
Primary Energy Consumption/GDP	1	Residential final energy/capita	28
Final Energy Consumption/GDP	1	Commercial final energy/tertiary sector employees	27
End-use CO_2/GDP	1	Industrial final energy/industry GDP	7
Primary Energy Consumption/capita	24	Transportation final energy/capita	29
Final Energy Consumption/capita	24	CO2 per power produced	11
End-use CO_2/capita	24	**End-Use Low Carbon Indicator**	**27**

Shanghai

Similar to Beijing, Shanghai – China's financial hub - ranks well (3rd) in terms of low carbon when the indicator is based on GDP (see Table 10). Also similar to Beijing, this densely populated urban area does not rank well in terms of energy consumption and CO_2 emissions per capita (29th and 30th). Shanghai's voracious development into China's top transshipment hub has no doubt driven up its ever-increasing energy consumption in transportation, leading it to trail all the other 29 provinces and cities in the transportation sector indicator. Shanghai also ranks poorly in terms of energy use per capita or per employee for residential and commercial buildings, respectively. However, industry in Shanghai is relatively low carbon ranking 3rd lowest in industrial final energy use per unit of industrial GDP produced. Even though CO_2 emissions per unit of power produced were in the mid-range (17th), Shanghai's overall end-use low carbon indicator value was 26th, making it one of the least low-carbon areas in China.

Table 10. Shanghai Ranking in Macro- and Sector-Level Indicators

Macro-level indicators	Shanghai Ranking	End-use sector-level indicators	Shanghai Ranking
Primary Energy Consumption/GDP	3	Residential final energy/capita	22
Final Energy Consumption/GDP	6	Commercial final energy/tertiary sector employees	29
End-use CO_2/GDP	10	Industrial final energy/industry GDP	3
Primary Energy Consumption/capita	30	Transportation final energy/capita	30
Final Energy Consumption/capita	30	CO_2 per power produced	17
End-use CO_2/capita	29	**End-Use Low Carbon Indicator**	**26**

Shanxi Province

Shanxi Province, with abundant coal reserves and a huge coal mining industry, ranks poorly in terms of "low carbon" using both the GDP and per capita based macro-level indicators (see Table 11). The end-use sector-level indicators also reveal that Shanxi Province ranks in the lower half of China's large municipalities, autonomous areas, and provinces in terms of energy use per capita for residential buildings and transportation, energy use per employee for commercial buildings, energy use per unit of industrial GDP, and CO_2 emissions per unit of electricity produced. This indicates that not only is more effort needed for improving energy efficiency, but a shift to developing other secondary industries with lower carbon intensity could reduce energy use, CO_2 emissions, and associated environmental strain resulting from years of natural resource exploitation.

Table 11. Shanxi Province Ranking in Macro- and Sector-Level Indicators

Macro-level indicators	Shanxi Ranking	End-use sector-level indicators	Shanxi Ranking
Primary Energy Consumption/GDP	28	Residential final energy/capita	25
Final Energy Consumption/GDP	28	Commercial final energy/tertiary sector employees	22
End-use CO_2/GDP	29	Industrial final energy/industry GDP	26
Primary Energy Consumption/capita	25	Transportation final energy/capita	23
Final Energy Consumption/capita	26	CO_2 per power produced	22
End-use CO_2/capita	26	**End-Use Low Carbon Indicator**	**25**

Shandong Province

Shandong Province ranks relatively well (11th) in terms of energy use/GDP and slightly worse than average (18th) in terms of end-use CO_2 emissions/GDP (see Table 12). The Province's ranking drops further (to 19th, 20th, and 22nd) for primary energy use, final energy use, and end-use CO_2 emissions per capita. When broken down into the end-use sector-level indicators, it can be seen that Shandong Province's residential and industrial sectors are relatively "low carbon" (both ranking 10th), while the commercial buildings, transportation, and electricity generation sectors rank lower. As one of the largest heavy industrial provinces in China, Shandong Province ranks as relatively low-carbon in the industrial sector indicator, predominately due to the Province's focus and vigorous promotion of industrial energy efficiency. Since the industrial sector accounts for 74% of the provincial energy use, high industrial energy efficiency clearly contributes to the overall relatively low carbon ranking of 11th among China's large municipalities, autonomous zones, and provinces.

Table 12. Shandong Province Ranking in Macro- and Sector-Level Indicators

Macro-level indicators	Shandong Ranking	End-use sector-level indicators	Shandong Ranking
Primary Energy Consumption/GDP	11	Residential final energy/capita	10
Final Energy Consumption/GDP	11	Commercial final energy/tertiary sector employees	25
End-use CO_2/GDP	18	Industrial final energy/industry GDP	10
Primary Energy Consumption/capita	19	Transportation final energy/capita	17
Final Energy Consumption/capita	20	CO_2 per power produced	23
End-use CO_2/capita	22	**End-Use Low Carbon Indicator**	**11**

Guangdong Province

As with Shandong Province, the industrial sector of Guangdong Province represents the largest share (64%) of overall provincial energy use. Industrial production in Guangdong Province is focused on high value-added products, so Guangdong ranks very well (2nd, 2nd, and 2nd, for final energy use, primary energy use, and end-use CO_2 emissions, respectively) when measured by the overall energy consumption and end-use CO_2 emissions per unit of GDP. The rankings drop to 16th and 17th when measured on a per capita basis (see Table 13).

On an end-use sector-level basis, Guangdong Province is not low carbon in the residential buildings (20th) or transportation (24th) sectors. The rankings for commercial buildings (15th) and power production (10th) are much better. Interestingly, Guangdong ranks the best of all large municipalities, autonomous regions, and provinces in terms of industrial final energy use/industry GDP. Since industry represents 66% of total energy use in the province, this ranking heavily influences Guangdong's overall low-carbon ranking (5th in China).

Table 13. Guangdong Province Ranking in Macro- and Sector-Level Indicators

Macro-level indicators	Guangdong Ranking	End-use sector-level indicators	Guangdong Ranking
Primary Energy Consumption/GDP	2	Residential final energy/capita	20
Final Energy Consumption/GDP	2	Commercial final energy/tertiary sector employees	15
End-use CO_2/GDP	2	Industrial final energy/industry GDP	1
Primary Energy Consumption/capita	17	Transportation final energy/capita	24
Final Energy Consumption/capita	16	CO_2 per power produced	10
End-use CO_2/capita	16	**End-Use Low Carbon Indicator**	**5**

Hubei Province

Hubei Province ranks in the middle in primary and final energy use/GDP (20th and 19th, respectively) as well as per capita (14th and 15th, respectively) (see Table 14). However, due to its abundant water supply from a few great lakes that provides rich sources for hydropower, Hubei Province has significantly lower CO_2 emissions per kWh for power generation, ranking 2nd lowest of China's cities, regions, and provinces. As a result, the CO_2/GDP and CO_2/capita rankings are 4th and 6th, respectively.

Despite the 2nd lowest ranking of CO_2 per kWh for electricity production, Hubei's overall end-use low carbon indicator value of 12 is due to the higher rankings for the other end-use sectors, especially transport (21st) and industry (18th).

Table 14. Hubei Province Ranking in Macro- and Sector-Level Indicators

Macro-level indicators	Hubei Ranking	End-use sector-level indicators	Hubei Ranking
Primary Energy Consumption/GDP	20	Residential final energy/capita	15
Final Energy Consumption/GDP	19	Commercial final energy/tertiary sector employees	10
End-use CO_2/GDP	4	Industrial final energy/industry GDP	18
Primary Energy Consumption/capita	14	Transportation final energy/capita	21
Final Energy Consumption/capita	15	CO_2 per power produced	2
End-use CO_2/capita	6	**End-Use Low Carbon Indicator**	**12**

3.3 Issues with the Sector-Level End-Use Low Carbon Indicator

Although the sector-level end-use low carbon indicator presented here represents an improvement over the more simplified energy or CO_2/GDP and energy or CO_2/capita indicators, there are a number of issues that arose during the development of this indicator for China.

For the commercial buildings sector, the ideal indicator would be weather-adjusted energy use per unit of commercial floor space (m^2). However, for China, information on commercial floor space at the local level does not exist, so the number of tertiary employees was used for this calculation. In addition, more detailed indicators based on commercial building types would be more helpful in understanding commercial building energy use and tracking progress. This information, however, is also not readily available at the provincial and city level for China.

For the industrial sector, the industrial share of regional GDP was used as the denominator, but a better value would be provincial or city industrial sector value added. However, for China, industrial sector value added is only available at the national level.

For the transport sector, it would be helpful to have more detailed information on usage (passenger-kilometers) of all public transportation modes (buses, light rail, subway, etc.), and the total person-trip-kilometers for all private travel in cars and taxis, as well as the total energy consumption of these travel modes in order to develop more detailed indicators and metrics. This information, however, is also not readily available at the provincial and city level for China.

For the power sector, the indicator used is calculated based on total power production by province expressed in terms of CO_2/kWh. This approach favors large hydropower producers and exporters such as Hubei province (ranked 2nd), which emits insignificant CO_2 compared with coal-based power-generating provinces such as Shandong province (ranked 23rd). A preferred approach would be to base this indicator on power production by grid. Strengths and weaknesses of this approach include:

- It accords more closely with supply region for consumption. Nearly every province both imports electricity from and exports electricity to the regional grid. The current province-based calculation, however, does not exclude carbon emissions from generation of power that is exported, nor does it include the carbon emissions of imported power. Consequently the power sector indicator may not accurately reflect the actual end-use consumption within a given province, resulting in overstating of emissions for major exporters of power, and understating of emissions for major power importers. Expansion of the boundary from province to the regional grid could thus better reflect the emissions profile of actual power use within provincial boundaries.
- A grid-based calculation would reduce the disparity between provinces with a high proportion of renewable power generation and with those with a high proportion of fossil power generation. As evident in the cases of Shanxi and Hubei, provinces using more fossil fuels to generate the same amount of electricity emit much more CO_2 than provinces using more renewable energy. Measurement by power grid thus could help smooth out this disparity.
- A challenge to this approach is that grid-based calculations are more difficult than province-based calculations because some grid boundaries do not accord to provincial boundaries. As a result, in the cases where provincial and grid boundaries do not coincide, additional sub-provincial data would be needed to effect the grid calculation, or grid-wide calculations would need to be provided from other sources. NDRC does publish grid emission factors, but these figures are based on thermal generation only, so do not reflect the contribution of non-fossil generation.

4. Conclusion and Recommendations

The results presented above for China illustrate that single indicators based on energy or CO_2 emissions per unit of GDP or per capita do not fully explain or reflect the end-use energy consumption and emissions situation in a given city or province. Such macro-level indicators can lead to inaccurate or confusing comparisons and conclusions about whether certain cities or provinces are or are not low carbon which could in turn lead to inappropriate use of funds for development, misguided efforts to include development and behavior that are not conducive to actually reducing energy use or CO_2 emissions, and missed opportunities to focus on specific areas that could have the most impact in actually making a specific location low carbon.

The sectoral end-use low carbon indicator developed in this report has been constructed using the underlying contributors to the overall level of energy use or CO_2 emissions of a city or province - the energy and emissions of the main energy-consuming end-use sectors: residential buildings, commercial buildings, industry, transportation and power. As such, it provides a more robust indication of where energy use is inefficient as well as where actions can be targeted so that a city or province can become more "low carbon". Such an operation- and goal-oriented indicator can provide a means for measuring and comparing and can be used to define low carbon, rank cities by energy use and CO_2 emissions levels, track progress in energy efficiency and emission reductions, and establish benchmarks

Although the composite sectoral end-use low carbon indicator can reflect energy use of a province or a city more accurately than the macro-level indicators, to increase its recognition and adoption by the Chinese government, additional efforts are needed in the following areas.

- Gather more city-level data. From the tables presented in this report, it is obvious that energy use data at the city-level are limited to only a few large Chinese cities. It is recommended that the central and provincial governments encourage city governments to collect the required data through developing a clear set of policies, edicts and standardized statistics system, and providing necessary funding for these efforts.
- Gather data on preferred indicators, such as energy/m^2 of commercial buildings sector and grid-based power sector emission factors. As discussed, replacing tertiary sector employee with per square meter is more meaningful for commercial buildings indicator as energy use is generally used at the level of floor space. For the industrial sector indicator, it is better to replace industrial share of regional GDP with industrial sector value added.
- Once the necessary data has been gathered, calculate indicators and rankings for more cities.
- Use the sector-level end-use low carbon indicator to rank cities by energy use and CO_2 emissions levels, track progress in energy efficiency and emission reductions, and establish benchmarks.
- Develop policies and programs to promote low carbon development at the sector and end-use level.
- If data can be gathered, more disaggregated indicators within a sector can also be developed to provide the basis for more specific status assessments and policy

recommendations. For example, for the power sector, the efficiency of coal-power plants and the share of renewable energy could be used. For the buildings sector, the share of more efficient buildings/low energy buildings such as LEED-certified or green buildings could also be used (Zhou, et al. 2011).

There are many resources available for government officials, urban planners, and researchers to use to help in the development of low carbon cities or regions. Many of these resources have been gathered in Zhou et al. (2011) which draws from both international and Chinese domestic experience to provide information on successful policies and measures for local governments in China to create low carbon plan or climate action plans.

Acknowledgments

The authors would like to thank Hu Min at the Energy Foundation for her significant contribution to this report. We also want to thank Adam Hinge of Sustainable Energy Partnerships, Liu Feng of the World Bank's Energy Sector Management Assistance Program (ESMAP), Xu Huaqing and Hu Xiulian at the Energy Research Institute of NDRC, Zhuang Guiyan at China Academy of Social Science, Su Mingshan at Tsinghua Univerisity, Song Guojun from Renmin University, Julia Currie of Johnson Controls' Institute for Building Efficiency, and Bo Shen of Lawrence Berkeley National Laboratory's China Energy Group, for their comments and review. We would also like to extend our thanks to Tiffany Tona of the University of San Francisco for the indicator map graphics.

This work was supported by the China Sustainable Energy Program of the Energy Foundation through the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

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