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Development of an End-Use Sector-Based Low-Carbon Indicator System for Cities in China

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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. In March 2011, China's 12th Five-Year Plan established a carbon intensity reduction goal of 17% between 2011 and 2015. China's National Development and Reform Commission (NDRC) then announced the selection of five provinces and eight cities to pilot low carbon development work. 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) offer a better approach for defining "low carbon" and for taking action to reduce energy-related carbon emissions.

This paper presents and tests a methodology for the development of an end-use sector-based low-carbon indicator system at the city level, providing initial results for an end-use low carbon indicator system based on data available at the municipal levels. The paper consists of a discussion of macro-level indicators that are typically used for inter-city, regional, or inter-country comparisons; the methodology used to develop a more robust low carbon indicator system for China; and the results of this indicator system. The research concludes with a discussion of issues encountered during the development of the end-use sector-based low-carbon indicator, followed by recommendations for future improvement.

Introduction

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, China's National Development and Reform Commission (NDRC) established a Low Carbon City policy and announced the selection of five provinces (Guangdong, Liaoning, Hubei, Shaanxi and Yunnan) and eight cities (Chongqing, Tianjin, Shenzhen, Xiamen, Hangzhou, Nanchang, Guiyang, and Baoding) to pilot the low carbon development work (NDRC 2010). 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.

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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 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) could offer a better approach for defining low carbon and for taking action to reduce carbon emissions.

The objective of this work is to develop a methodology for a low carbon indicator system at the city level. This paper outlines a proposed methodology and provides initial results for an end-use low carbon indicator and ranking system based on data available at the municipal level. The paper begins with a discussion of macro-level indicators that are typically used for inter-city comparisons. It then turns to a discussion of the methodology used to develop a more robust low carbon indicator for China. The paper presents the results of this indicator with examples for four large municipalities in China (Beijing, Shanghai, Tiajin, and Chongqing). The paper 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.

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. An economic-based carbon intensity indictor, or CO_2 emissions/unit of GDP, is comprised of: (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). The multiplication of these two elements produces a country's carbon intensity, defined as the amount of CO_2 emitted per unit of economic activity.

With regard to energy intensity, 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. 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. [2]

Table 1 compares China's four large municipalities - Beijing, Shanghai, Tianjin, and Chongqing - using three macro-level economic indicators: primary energy/GDP, final energy/GDP, and end-use CO_2 emissions/GDP. Using this indicator, Beijing is the lowest-carbon city while Chongqing is the highest-carbon city, with Shanghai and Tianjin falling between these two cities. Table 2 compares these four large cities in China with other large cities around the world[3] showing that all four Chinese municipalities, including the two that appeared to be "low-

[2] 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).

[3] 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).

carbon", have significantly higher final energy and CO_2 intensities than other selected cities from around the world.

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

Region	Primary Energy Use	Region	Final Energy Use	Region	Consumption-based
	Primary Energy Consumption /GDP		Final Energy Consumption /GDP		End-use CO2/GDP
	kgce/RMB		kgce/RMB		kgCO2/RMB
Beijing	0.066	Beijing	0.045	Beijing	0.160
Shanghai	0.082	Shanghai	0.057	Shanghai	0.193
Tianjin	0.090	Tianjin	0.065	Tianjin	0.228
Chongqing	0.108	Chongqing	0.082	Chongqing	0.253

Sources: NBS 2009; NBS 2010; IPCC 1996.
Primary energy: total end-use energy consumption with electricity converted at 0.404 kgce/kWh.
Final energy: total end-use energy consumption 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).
RMB = Renminbi, the official currency of China. 1 US$ = 6.3 RMB (May 8, 2012)

Similar to the economic-based macro-level indicators, indicators using population as the denominator instead of GDP can also be used to compare cities. Table 3 shows the comparison using primary energy use/capita, final energy use/capita, and end-use CO_2 emissions/capita for the four large municipalities in China in 2008. 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 have significantly higher per capita values. 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.[4] 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.[5]

[4] Note that 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 that have significant migrant populations, such as Beijing and Shanghai, and possible under-accounting of energy use per capita in other areas.
[5] 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.

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/

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

Region	Primary Energy Use: Primary Energy Consumption /capita (tce/person)	Region	Final Energy Use: Final Energy Consumption /capita (tce/person)	Region	Consumption-based: End-use CO2/capita (tCO2/person)
Chongqing	1.83	Chongqing	1.39	Chongqing	4.28
Beijing	3.57	Beijing	2.48	Beijing	8.69
Tianjin	4.28	Tianjin	3.09	Tianjin	10.82
Shanghai	5.08	Shanghai	3.50	Inner Mongolia	12.06
avg -unweighted	3.69		2.62		8.96

Sources: NBS 2009; NBS 2010; IPCC 1996.
Primary energy: total end-use energy consumption with electricity converted at 0.404 kgce/kWh.
Final energy: total end-use energy consumption 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).

Issues with Macro-Level Indicators

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 each city's situation. Comparisons with cities outside China 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. In addition, cities are varied in their economic structure; a more fair comparison would account for these structural differences. Income levels vary by location, with generally higher incomes in the cities 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 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 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, 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 as low carbon when it is not (or vice versa) such as inappropriate use of funds for development, misguided efforts to influence development 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.

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 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 that it is: 1) based on data availability in China and applicability to the Chinese situation, 2) constructed using the underlying contributors to the overall level of energy use or CO_2 emissions of a city - the energy and emissions of the main energy-consuming end-use sectors: residential, commercial, industry, transportation,[6] 3) accounts for the carbon intensity of fuels used and power produced, and 4) 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.

[6] 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.

Methodology

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. The second step 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.

For China, the end-use low carbon indicator for the **residential buildings** sector is defined as weather-corrected residential buildings final energy[7]/capita. This indicator is 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. Weather variation can be accounted for by calculating cooling degree-days (CDD) and heating degree-days (HDD).[8]

The end-use low carbon indicator for China's **commercial buildings** sector is defined as commercial buildings final energy/tertiary sector employees.[9] 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. 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.

The end-use low carbon indicator for the **industry** sector in China is defined as industrial final energy per industrial share of city 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 city GDP. It would be ideal to have industrial value added data instead of the industrial share of city 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.

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.

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[7] 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 cannot influence the efficiency of the generation, transmission, and distribution of the electricity they consume.

[8] 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).

[9] 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.

The end-use low carbon indicator for the **electric power** sector is defined as CO_2 per unit of power produced.[10] 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.

The low carbon indicator for **fuel consumption** is defined as CO_2 per unit of fuel consumed. This indicator provides information on the relative carbon intensity of the fuels used in each city, indicating whether the city is making a transition to lower carbon fuels, such as natural gas.

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 city. For China, the data for the development of the indicators was collected from published data provided by Chinese government statistical offices. 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.[11] 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 Statistics (NBS) (NBS 2009).[12, 13] 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). Table 4 provides the end-use indicator values for each of the four cities as well as for China overall.

[10] Ideally this indicator would be based on electricity consumed; however, such data are not available.

[11] 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.

[12] Depending upon the quality and comparability of the data, some adjustments to the data may be needed. For example, in China residential energy use in industrial units is often accounted for within the industrial energy use category. Similarly, 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. A methodology for making such adjustments is provided in Zhou et al. (2007).

[13] 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. See Price et al., 2011 for additional details of this calculation.

Table 4. End-Use Indicator Values for China's Four Large Municipalities, 2008

Region	Electric Power	Fuel	Residential	Commercial	Industrial	Transportation
	CO2 per Power Produced	CO2 Intensity of Fuel Use	Residential final energy/capita (weather corrected)	Commercial final energy/tertiary sector employees	Industrial final energy/Industry GDP	Transportation final energy/capita
	kgCO2/kWh	tCO2/tce	tce/cap	tce/cap	tce/10,000 RMB (2005 yuan)	tce/cap
Chongqing	0.797	2.415	0.147	0.249	1.584	0.173
Tianjin	0.899	2.420	0.318	1.396	0.828	0.390
Shanghai	0.829	2.277	0.280	1.572	0.796	0.728
Beijing	0.664	2.168	0.385	0.978	0.908	0.584
China	0.778	2.485	0.211	0.588	1.449	0.235

While the information provided in Table 4 is interesting, it is still not possible to determine if a city qualifies as low-carbon based on these disparate indicators. In order to be able to aggregate these indicators, the next step is to index each end-use sector low carbon indicator to China's average value for that indicator. These indexed values are then multiplied by a weighting factor. 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's overall energy use. The weighting factor for power generation is the share of electricity in the total city energy use. Table 5 provides the index values and weighting factors.

Table 5. End-Use Indicator Index and Weighting Values for China's Four Large Municipalities, 2008

City	Electricity		Fuel		Residential		Commercial		Industrial		Transport	
	Index	Weight	Index	Weight	Index	Weight	Index	Weight	Index	Weight	Index	Weight
Chongqing	108	14%	97	86%	69	10%	42	4%	109	72%	74	13%
Tianjin	126	17%	97	83%	151	10%	237	9%	57	69%	166	13%
Shanghai	110	20%	92	80%	132	8%	267	12%	55	59%	310	21%
Beijing	126	19%	87	81%	182	15%	166	20%	63	41%	249	24%
China	100	19%	100	81%	100	10%	100	6%	100	71%	100	13%

End-Use Low-Carbon Indicator Calculation Results

Once the electricity, fuel, and end-use sector indexes and weights have been calculated, the next step is to multiply them to obtain values for electricity, fuels, and one combined value for the end-use sectors. These values added together comprise the Low Carbon Index for the city. Table 6 shows these values for China's four large municipalities. The lower end-use carbon indicator value denotes a more "low carbon" ranking. Using this indicator, Chongqing and Tianjin are clearly more "low carbon" than Beijing and Shanghai.

Table 6. End-Use Low Carbon Indicator for China's Large Municipalities, 2008

City	Electricity Index * Weight	Fuels Index * Weight	Sectors Index * Weight	Low Carbon Index
Chongqing	16	83	98	196
Tianjin	21	81	96	198
Shanghai	22	74	140	235
Beijing	24	71	146	241
China	19	81	100	200

Chongqing has a much larger population and less developed economy than the other three cities. Thus, when using the macro-level economic indicators, Chongqing ranked the highest among the four cities, indicating it is more energy-intensive per unit of GDP. Using the per capita indicators, Chongqing ranked the lowest, indicating that it consumed the least energy per person. When applying the end-use indicators, Chongqing scored much lower in all end-use sectors except industry, as its final energy use per capita in residential, commercial, and transport sectors are much lower than the national average as well as than the other three cities. In terms of the aggregate low-carbon indicator, Chongqing scored the lowest – and is thus the most "low carbon" – among the four cities.

Tianjin is the smallest city among the four cities in terms of population, tertiary sector employees, and total residential floor space. Tianjin ranked third in both the macro-level economic and per capita indicators. The low carbon indicators showed that Tianjin is relatively high energy-consuming in the residential, commercial, and transportation sectors when compared to China's average values. But industry in Tianjin is much less energy-intensive and represents nearly 70% of Tianjin's total energy use. Tianjin ranked the second among the four cities in the overall low carbon indicator score.

Shanghai ranks well in terms of low carbon when the indicator is based on GDP. This densely populated urban area, however, does not rank well in terms of energy consumption and CO_2 emissions per capita. Shanghai's development into China's top transshipment hub has driven up its ever-increasing energy consumption in transportation. 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. Shanghai's overall low carbon indicator value was 2^{nd} highest among the four cities, making it one of the least low-carbon cities in China.

Of the four large municipalities, ***Beijing,*** the nation's capital, with a highly-developed, economically-productive commercial sector, ranks very high in terms of being "low carbon" using metrics that are based on GDP. Alternatively, Beijing does not appear to be "low carbon" when indicators based on population are used.[14] Beijing compares well with the industrial GDP-based indicator and ranks relatively well in CO_2 emissions per kWh of electricity produced. Overall, Beijing ranks the highest in terms of the low carbon indicator – indicating that it is the least "low carbon" among the four cities -- 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.

[14] 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.

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

Although the sector-level end-use low carbon indicator 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. For commercial buildings, 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. In addition, more detailed indicators based on commercial building types would be helpful in understanding commercial building energy use and tracking progress. This information, however, is also not available at the city level for China. For industry, the industrial share of regional GDP was used as the denominator, but a better value would be city industrial sector value added. However, 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 total person-trip-kilometers for all private travel in cars and taxis, as well as 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 city level. 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 which emit insignificant CO_2 compared with coal-based power-generating areas. A preferred approach would be to base this indicator on grid-based power consumption for each city. Even if this information was available, the published grid emission factors are based on thermal generation only, so they do not reflect the contribution of non-fossil generation.

Conclusion and Recommendations

The results 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. Such macro-level indicators can lead to inaccurate or confusing comparisons and conclusions about whether certain cities are low carbon which could in turn lead to 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 making a specific location low carbon.

The sectoral end-use low carbon indicator developed in this paper has been constructed using the underlying contributors to the overall level of energy use or CO_2 emissions of a city - the energy and emissions of the main energy-consuming end-use sectors: residential buildings, commercial buildings, industry, transportation, as well as the fuel and power sectors. 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 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. There are many resources available for government officials, urban planners, and researchers to help in the development of low carbon cities. 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 to create low carbon plan or climate action plans.

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