Estimating China's Urban Energy Demand and CO_2 Emissions: A Bottom-up Modeling Perspective

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ABSTRACT

China is experiencing unprecedented urbanization with the urban share of population expected to grow to nearly 80% by 2050. Chinese urban residents consume nearly 1.6 times as much commercial energy as rural residents, and account for an even larger share of energy and carbon dioxide (CO_2) emissions embodied in urban infrastructure and goods. As a result, cities can play an increasingly important role in helping China meet its future energy and CO_2 intensity reduction targets. While some individual cities have conducted energy and greenhouse gas emission inventories, China lacks estimates of aggregate urban energy consumption and CO_2 emissions that take into consideration detailed sectoral drivers, fuel mixes, and end-uses specific to urban areas.

This paper describes the results of a bottom-up, energy end-use modeling methodology for estimating China's urban energy demand and CO_2 emissions for four key demand sectors. We present a detailed modeling framework that characterizes residential and commercial building end-uses in Chinese cities, differentiates between intra-city and inter-city transport attributable to urban residents, and evaluates the urban share of industrial production activity. Scenario analysis is also used to quantify the urban energy and CO_2 emissions reduction potential within each sector. We find that the Chinese industrial sector alone accounts for 56% of urban primary energy demand and 62% of urban CO_2 emissions in 2010 and holds the greatest mitigation potential – a characteristic unique to Chinese cities. Maximum deployment of commercially-available, cost-effective technologies across all four sectors can also help Chinese urban CO_2 emissions peak earlier.

Introduction

Along with rapid economic growth and industrialization, China is experiencing unprecedented urbanization with mass migration from rural areas to cities and the emergence of cities of various sizes. In 2011, the share of China's 1.3 billion population living in cities surpassed the rural share for the first time and the urban share of population has since risen to 56% in 2015. By 2020, the urban share is expected to increase to 60% under China's *New Urbanization Plan* of 2014 and international projections expect it to reach nearly 80% by 2050 (PRC Government 2014; United Nations 2015). This rise in urban population is significant for China and its energy and climate change goals because of the direct and indirect energy impact of these urban residents. All of China's new urban residents will need accommodation, schooling, health care, appliances, energy supply, transportation, food, clothing, water, sewerage, and other services, and the potential energy impact is enormous. The rising income levels and demand for greater energy services and amenities of urban dwellers result in 1.6 times higher consumption of commercial (non-biomass) energy than rural residents[1]. Urban households have much higher ownership rates for major household appliances including clothes washers, refrigerators, televisions, air conditioners, computers and microwaves than rural residents (NBS 2015). At the same time, China's growing urban population also accounts for an even larger share of energy and CO_2 emissions embodied in urban infrastructure and goods. Chinese cities have experienced a construction boom over the past decade, driven by the migration of rural residents to cities, with an estimated 40 billion square meters of additional floorspace expected to be constructed between 2005 to 2025 (Woetzel et al. 2009). A previous study of the Chinese city of Suzhou found that the energy embodied in city infrastructure and the residents' goods and services consumption exceeded operational energy by a factor of three, suggesting that the indirect energy impact of urbanization is significant (Fridley et al. 2012). Similarly, a multi-regional input-output modeling study of China's four municipalities found that energy use embodied in urban household consumption are much larger than those in rural households consumption for all municipalities, with each municipality's embodied energy use ranging from 50 to 137 million metric tons of coal equivalent (Mtce[2]) in 2007 (Zhang et al. 2015). Wang et al. 2016 also found that urbanization increases energy consumption and CO_2 emissions in all 30 Chinese provinces, but its specific impact varies depending on the province's geographical location and economic structure. As a result, cities can play an increasingly important role in helping China meet its future energy and CO_2 intensity reduction targets.

While some individual cities have conducted energy and greenhouse gas (GHG) emission inventories, China lacks estimates of aggregate urban energy consumption and CO_2 emissions that take into consideration detailed sectoral drivers, fuel mixes, and end-uses specific to urban areas. National statistics do not attempt to disaggregate between urban versus rural energy consumption but do provide basic information on urban and rural household conditions and city infrastructure. Understanding the relative contribution of cities and its dwellers to China's national energy consumption and CO_2 emissions as well as their fuel- and technology-specific trends are crucial to identifying opportunities for reducing energy use and CO_2 emissions. An aggregate estimate of China's urban CO_2 emissions is also useful because while the national government has directed Chinese provinces and cities to begin developing greenhouse gas emissions inventories, there is not yet a systematic gathering or publishing of city-level GHG data in China.

This paper describes the results of a bottom-up, energy end-use modeling methodology for estimating China's urban[3] energy demand and CO_2 emissions for four key demand sectors. The next section of the paper presents a detailed modeling framework that characterizes residential and commercial building end-uses in Chinese cities, differentiates between intra-city and inter-city transport attributable to urban residents, and evaluates the urban share of industrial production activity. It is followed by a description of China's current urban vs. rural energy and CO_2 trends, and scenario analysis that helps quantify the urban energy and CO_2 emissions reduction potential within each sector. Lastly, we discuss the key policy implications of our analysis.

[1] Based on 2010 data. When use of biomass is included, rural energy per capita is higher than urban. But rural CO_2 per capita is still lower, since biomass is treated as carbon neutral.
[2] Mtce is the standard unit for energy in China. 1 Mtce = 29.27 million GJ.
[3] We consider activity by the urban population in our analysis, which refers to all urban residents (including migrant workers currently residing in urban areas) rather than the officially registered urban residents.

Bottom-up Modeling of Urban China

For this study, we use a detailed, bottom-up energy end-use model developed through a three-year collaboration with China's Energy Research Institute and the U.S. Rocky Mountain Institute (ERI, RMI and LBNL, forthcoming) as the basic modeling framework. This model provides an accounting framework of China's energy and economic structure using the LEAP (Long-Range Energy Alternatives Planning) software platform developed by Stockholm Environmental Institute. This national model of China's economy from 2010 to 2050 includes residential and commercial buildings, industry, and transport modules on the demand-side, and power generation and other energy transformation modules on the supply side. A detailed description of the Reinventing Fire: China modeling methodology can be found in ERI, RMI and LBNL, forthcoming. For residential and commercial buildings and passenger transport subsectors, urban activity is differentiated from rural activity and the urban versus rural shares of energy consumption are reported directly by the model. For the industrial sector – the largest energy-consuming sector in China – and the freight transport subsector, we conducted additional analyses to differentiate the urban share of total activity and energy consumption from the rural share. The detailed methodology for estimating urban energy demand and CO_2 emissions in each of the four key demand sectors is described below.

Residential Buildings

Residential energy demand supports various household services and is shaped by a variety of factors, including location and climate. For China's residential building sector, urbanization and growth in household incomes drive energy consumption as urban households generally consume more commercial (non-biomass) energy than rural households and rising household incomes correspond to increases in the size of housing units (and thus heating, cooling, and lighting loads) and appliance and other equipment ownership. The residential demand module divides households into China's three major climate zones (North, Transition[4], South) and within each climate zone, households are divided into urban and rural locales based on the relative proportion of urban vs. rural population within each climate zone's geographic boundary. Urban households are assumed to live in the predominant form of multi-story high-rise apartment buildings while rural households are assumed to live in smaller single-family homes. Within the urban and rural subsectors, end-uses are broken out into space heating, air conditioning, appliances, cooking, water heating, and lighting. For all end-uses, appropriate devices and fuels are assigned, with saturation (rates of penetration) and energy efficiencies based on historical statistical and survey data up to the base year and future values based on analysis of government plans, trends, and comparisons to other countries. Changes in energy demand in the model are in part a function of driver variables, e.g., GDP, population, household size, and urbanization rate, which were determined exogenously and included in the model. Since the model already distinguishes between urban and rural buildings for all residential buildings, the primary energy consumption results for urban residential and rural residential buildings in the three climate zones were directly used to calculate urban and rural CO_2 emissions.

[4] The transition zone is defined as the central part of China corresponding to the Hot Summer, Cold Winter climate zone where both space heating and cooling are used for thermal comfort.

Commercial Buildings

All primary energy consumption and energy-related CO_2 emissions from commercial buildings are attributed to urban areas, as the commercial building data in the model were based on urban commercial buildings and rural commercial buildings were not considered due to absence of any historical data for calibration. Urban commercial building energy consumption is driven by two key factors: building area (floor space) and end-use intensities such as heating, cooling, and lighting (MJ per m^2). In the model, commercial floor space is determined by the total number of service sector employees and the amount of built space per employee as commercial building construction in China is expected to be driven by the expansion of the services sector, as was the case for today's developed economies (McNeil et al. 2012, Hong et al. 2016). Commercial building energy consumption varies by building type and its main functions, so the commercial building sector is broken out into the major building types of retail, office, school, hospital, hotel, and other buildings. The key end-uses for each commercial subsector include space heating, space conditioning or cooling, water heating, lighting, and equipment. As with the residential sector, appropriate technologies and fuels are assigned for all end-uses with historical and projected saturation and energy efficiency improvements.

Transport

Transport sector activity is driven by demand for freight transport and for passenger transport. The bottom-up national model calculates transportation energy in three key subsectors: intra-city passenger transport, intercity passenger transport, and freight transport. Passenger transport is based on average vehicle-kilometers traveled (VKT) by mode (e.g., bus, train, car) of moving people. For passenger transport, growing vehicle-kilometers traveled in different modes is driven by population growth and growing demand for personal transport with rising income levels. The largest mode of passenger transport is in road transport, which is driven primarily by the burgeoning ownership of private cars that follows rising per capita income. Because intra-city passenger transport occurs solely within a city, all of its energy consumption and related CO_2 emissions are attributed to urban areas. For intercity passenger transport, there was no readily available literature on the urban/rural split in passenger transport or easily comparable indicators of mobility demand (e.g., VKT or trips per urban/rural resident) between urban and rural residents in China. In the absence of any data, we made a simplifying assumption to allocate the urban versus rural shares of intercity passenger transport based on the ratio between urban household and rural household per capita annual cash consumption expenditure on transport and telecommunications activity reported by China's National Bureau of Statistics. From 2010 through 2013, urban per capita annual cash consumption expenditure on transport was, on average, four times greater than rural per capita expenditure on transport. Using this ratio weighted by the urban vs. rural population from 2010 through 2013, we calculated an average split of 80%/20% for urban/rural residents' share of transport expenditure. Thus, we attribute a constant 80% share of intercity passenger transport's energy consumption and CO_2 emissions to urban areas from 2010 through 2050.

In the model, freight transport demand is driven by faster economic growth in the earlier years as GDP is expected to continue its recent rapid growth with international trade continuing to play an important role in coming years. Because freight passenger transport does not distinguish between urban versus rural demand in the national model, we also made the simplifying assumption to allocate urban vs. rural shares based on the ratio between urban and rural household per capita total annual cash consumption expenditure because food, clothing, and household facilities and articles – commodities that are moved via freight transport - account for over half of household consumption. From 2010 through 2013, urban per capita annual cash consumption expenditure was, on average, three times greater than rural per capita expenditure on transport. Using this ratio weighted by the urban vs. rural population from 2010 through 2013, we derived an average split of 75%/25% for urban/rural residents' share of total household expenditure. Thus, we attribute a constant 75% share of the energy and energy-related CO_2 emissions from freight transport to urban areas from 2010 through 2050.

Industry

In the model, the industry sector is divided into 12 specific energy-intensive industrial sub-sectors including the major industries of cement, iron and steel, aluminum, glass, ammonia and ethylene that are driven by physical drivers. For cement, steel, and aluminum production, the main drivers of production are based on the requirements of the built environment that reflect China's growing urban population, with floor space construction area, highway and paved road area, railway length combined with material intensity values and ratios between cement, steel, and aluminum used to determine the resulting demand. Glass production is also largely driven by demand for new urban residential and commercial buildings, which tend to have more windows, and motor vehicles. Ammonia production, in contrast, was modeled as a function of sown area and fertilizer intensity while ethylene production was based on population and per capita demand for plastics. Exports of these major energy-intensive industrial products are held constant at the last reported annual level to reflect the policy emphasis on shifting away from energy-intensive industrial production to higher value-added production. Physical energy intensities in terms of energy use per ton (or other unit) of industrial product produced for each industrial sector are used. Physical production values are multiplied by industry average physical intensities and then summed to derive energy consumption values for the energy-intensive industries. The industrial demand module also includes 16 other industrial subsectors that are driven by economic activity, namely manufacturer value-added activity, instead of physical drivers. Economic energy intensities in terms of energy use per unit of activity (e.g., 10,000 RMB of value-added) are derived through calibration to historical data and projected to decline using international levels as future targets.

Because each of the industrial subsectors does not distinguish between industrial production in urban versus rural areas, we adopted a simplified approach of dividing the locale of industrial activity using the township and village enterprise (TVE[5]) share of total industrial value-added GDP. TVEs experienced significant growth and expansion during the initial reform period of China's economy in the 1980s and early 1990s, but their role has since declined due to privatization and increased competition that has limited TVEs' revenues and employment (Kung and Lin 2007). In 2007, TVEs are reported to have contributed to 46.5% share of total industrial value-added GDP (MOA 2008). We assume that as the rural share of total population decreases from 2007 to 2010, the TVE share of industrial value-added GDP will also decrease to 45%. We assume that as the rural population continues to decrease to 22% of total population by 2050, the TVE share of industrial value-added GDP will also decrease linearly to 15% by 2050. From 2010 to 2050, the rural share of industrial energy consumption and CO_2 emissions are thus assumed to

[5] TVE are enterprises ventured and run by farmers at township, village, cooperative and private levels and generally considered part of rural industry (Zuo 2009).

decrease linearly from 45% in 2010 to 15% in 2050. The urban share of industrial energy consumption is calculated as the remainder of total minus rural energy consumption.

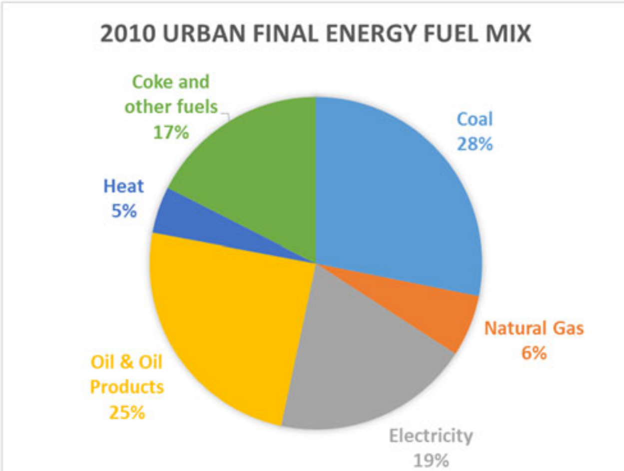
CO_2 Emissions Calculations and Scenario Analysis

The primary energy demand results by fuel type reported at the sectoral level are used to calculate the energy-related CO_2 emissions for China's urban areas. For coal, oil and oil products, and natural gas, the Intergovernmental Panel on Climate Change's default CO_2 emissions factors (in CO_2 per unit of energy) for each fuel type and China's specific energy content for each fuel type are used to calculate energy-related CO_2 emissions (IPCC 2006, NBS 2015).

To evaluate the CO_2 mitigation potential in China's urban areas, we developed two distinct scenarios to represent two possible pathways for China's energy and CO_2 development. A Reference Scenario is developed to serve as a counterfactual baseline and represents only current policies that are in place as of 2010 and expected to continue to have impact on future energy use and emissions, with no additional policies after 2010. In addition, incremental autonomous technological improvements that reflect processes of technology learning are expected to occur through 2050 since it is unrealistic to assume that the efficiencies of different technologies will stay frozen over the next 34 years. This assumption is also consistent with other long-term modeling baseline scenario storylines such as *World Energy Outlook's* Current and New Policies Scenarios (IEA 2016). An alternative Low Carbon scenario represents a pathway in which commercially-available cost-effective efficiency and renewable energy technologies are fully deployed. The difference between the two scenarios represents the CO_2 mitigation potential of China following a high-efficiency, low-carbon pathway of development through more aggressive policies and market transformation.

Profiles of 2010 Chinese Urban Energy Demand and CO_2 Emissions

China's cities are heavily reliant on fossil fuels to power and heat buildings, fuel transport systems, and run urban manufacturing facilities. In 2010, our analysis shows that China's urban areas consumed 1200 Mtce of final energy and 1740 Mtce of primary energy, or approximately 51% of the national total primary energy consumption. Figure 1 shows that coal and coke accounted for 45% of total urban final energy consumption, followed by 25% oil consumption and 6% natural gas use in 2010. Most of the coal and coke consumed by China's cities is used by the industry sector, which is responsible for consuming 56% of urban primary energy. Electricity, which provided roughly 20% of urban final energy, is mostly produced by fossil fuels as of 2010, with 75% produced by coal and 1% by natural gas. Non-fossil sources of urban electricity are 20% hydropower, 2% nuclear, and 2% other renewables like solar and wind. From a demand perspective, industry is by far the dominant user of energy with 59% share of total urban final energy consumption in 2010, followed by urban residential and commercial buildings and transport. The continued dominance of industry in the energy demand of Chinese cities is relatively unique to China and its current stage of development, compared to cities in developed countries where industry represent much smaller shares of energy demand behind buildings and transport. The larger share of industrial energy use in Chinese cities is also reflective of the significant amount of manufacturing that is still taking place within city boundaries.



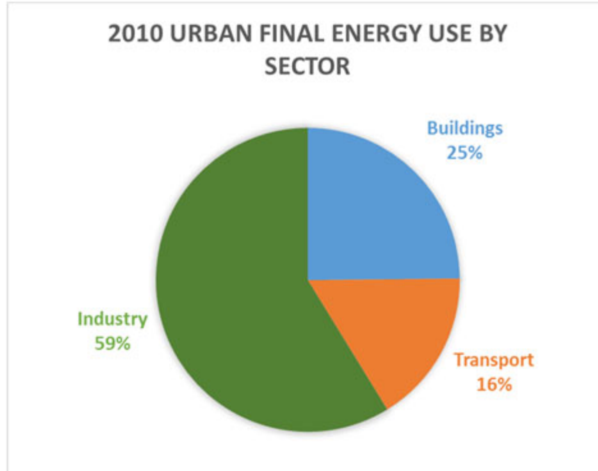


Figure 1. China's 2010 Urban Final Energy Consumption by Fuel and by Sector

Note: Total urban final energy consumption in 2010 was 1200 Mtce.

Figure 2 shows the relative shares of urban and rural energy-related CO_2 emissions in China, by sector. In 2010, the urban and rural populations were nearly equal, but the urban share of the estimated national energy-related CO_2 emissions of 8130 million metric tons (Mt) CO_2 was higher, at 58%, as seen in Figure 2. Transportation and commercial buildings have greater activity in urban areas than rural areas, contributing a larger share of total emissions, with 7% share each. Rural residential buildings are responsible for more CO_2 emissions per capita than their urban counterparts, due to larger floor space per person (34 square meters in rural households versus 27 in urban households) and greater use of coal for heating and cooking. As expected, rural transport contributes much less to CO_2 emissions than urban transport.

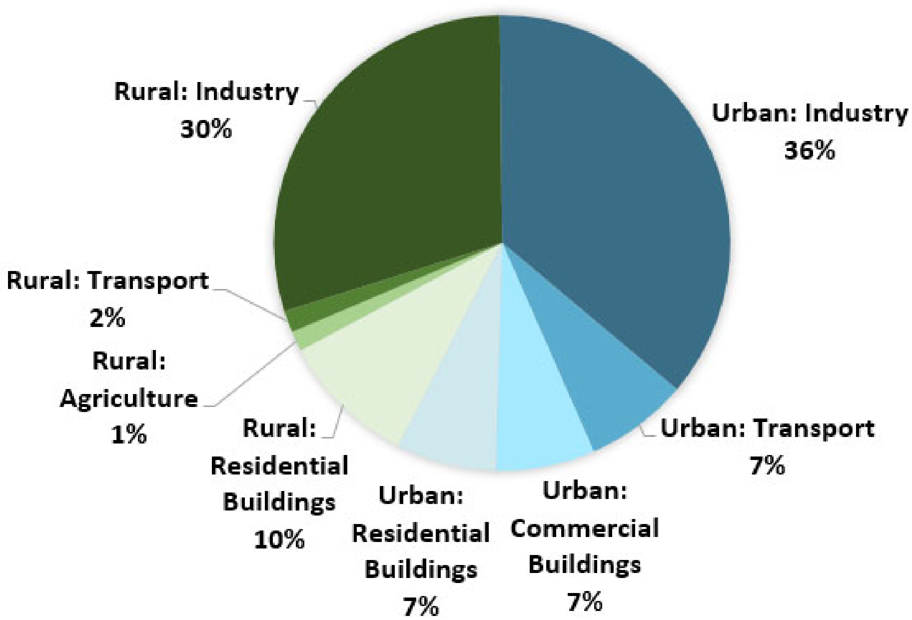


Figure 2. China Urban and Rural CO_2 Emissions by Sector, 2010

Note: China's estimated energy-related total CO_2 emissions in 2010 were 8130 Mt CO_2.

The larger share of urban industry increases the footprint of Chinese cities because coal and coke comprise of over 60% of urban industrial final energy use, versus only 30% of urban building final energy use. As a result, urban industry accounted for 36% of national CO_2 emissions, while rural industry accounted for 30%. In total, industry had a 66% share of China's national energy-related CO_2 emissions in 2010. Within Chinese cities, on average, industry had a 62% share of CO_2 emissions.

China's Urban Greenhouse Gas Emissions Outlook and Abatement Potential

Figure 3 shows the estimated urban CO_2 emissions by sector for China under the Reference and Low Carbon scenarios. If China's cities follow the Reference Scenario pathway, then urban CO_2 emissions will more than triple by 2042, when they begin to decline as population growth peaks in China and urbanization slows. By 2050, urban CO_2 emissions could remain over 13 gigatons (Gt) of CO_2, or nearly triple the 2010 level. Alternatively, if China's cities aggressively pursue low-carbon options – improving the energy efficiency of manufacturing facilities, commercial and residential buildings, and transportation in cities as well as pursuing options to reduce overall demand, move away from energy-intensive manufacturing, and switch to lower carbon fuels – urban CO_2 emissions could peak in 2030 at 8.2 $GtCO_2$, or not even double the level of 2010 emissions, then decline to levels below those of 2010 CO_2 emissions by 2050. Per capita urban CO_2 emissions will rise from 7 metric tons of CO_2/person in 2010 to nearly 13 metric tons of CO_2/person, but decline to only 4 metric tons of CO_2/person under the Low Carbon scenario – a level comparable to Tokyo, Seoul, and Barcelona in 2006 (World Bank 2011).

In 2010, China's urban energy-related CO_2 emissions were dominated by industrial emissions with 62% share coming from manufacturing facilities, industrial parks, and even heavy industries such as cement and steel plants located near cities. Buildings represent about a quarter of urban CO_2 emissions, divided relatively evenly between residential and commercial/public buildings, while about 13% of emissions were from transportation energy use. Over time, changes in the sectoral composition of Chinese cities' CO_2 emissions will reflect two national forces for reducing CO_2 emissions: economic transition and restructuring and decarbonization of China's energy supply. On one hand, the industrial share of total urban CO_2 emissions will decline over time as industry shifts from energy-intensive heavy industry to less energy-intensive, higher value-added light industry. Under both scenarios, the industrial share of urban CO_2 emissions will decline from 62% in 2010 to 50% in 2050. At the same time, transport's share of urban CO_2 emissions will increase significantly from 13% in 2010 to over 20% in 2050, as oil and oil products will still provide the vast majority of energy needed to move people and goods within and between cities. Buildings' share of urban CO_2 emissions remains relatively flat despite a doubling in the buildings' share of final energy consumption. This is due largely to the combined effects of increasing electrification and national transition to cleaner fuel mix for power generation.

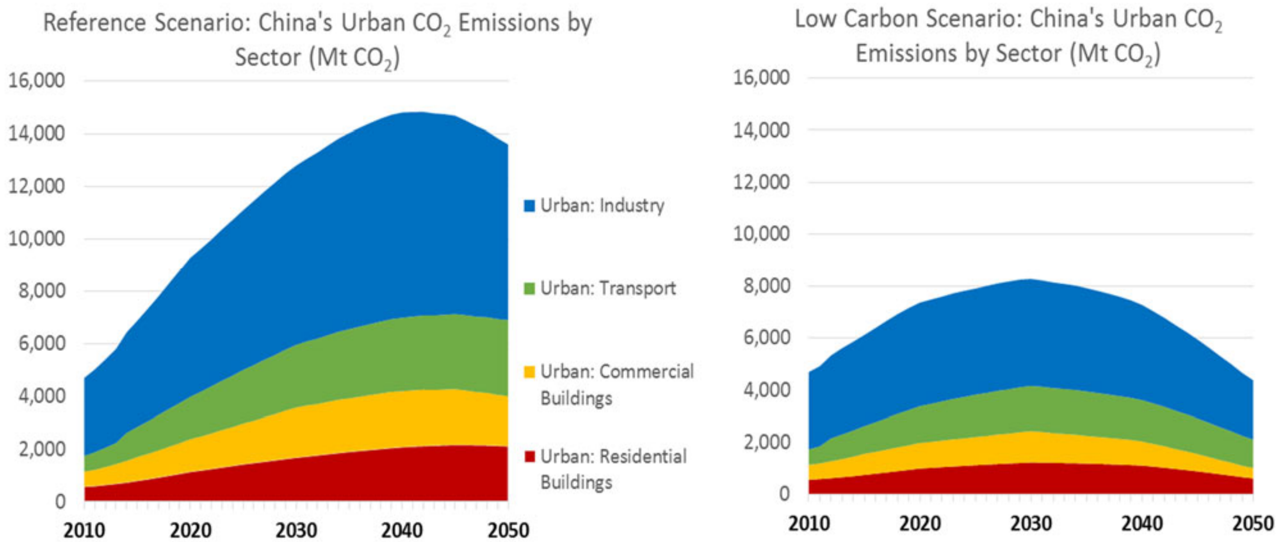


Figure 3. China's Urban CO_2 Emissions by Sector for Reference and Low Carbon Scenario

Both scenarios are dominated by industrial energy-related CO_2 emissions, which is a unique characteristic of Chinese cities. As such, much of the mitigation potential for Chinese cities is found in the industrial sector, followed by commercial buildings, residential buildings, passenger transport, and freight transport, respectively. Figure 4 shows the annual total mitigation potential by end-use sector in China's cities under the Low Carbon scenario when compared to the Reference scenario. The annual total CO_2 reduction potential grows from 1.9 $GtCO_2$ in 2020 to 4.5 $GtCO_2$ in 2030 and 9.2 $GtCO_2$ in 2050. Of this total reduction potential, the industrial sector's contribution remains the biggest, with its share ranging from 70% of the urban total potential before 2020 to 50% by late 2040s. In absolute terms, the CO_2 mitigation potential of the urban industrial sector grows from 0.1 $GtCO_2$ to 4.4 $GtCO_2$ from 2011 to 2050. Residential and commercial buildings are two other sectors with large CO_2 mitigation potential in China's cities, accounting for 10% and 15% shares, respectively, in 2030 and 16% shares each in 2050. Passenger and freight transport account for the remaining urban CO_2 mitigation potential, with shares of 11% and 8%, respectively, by 2050.

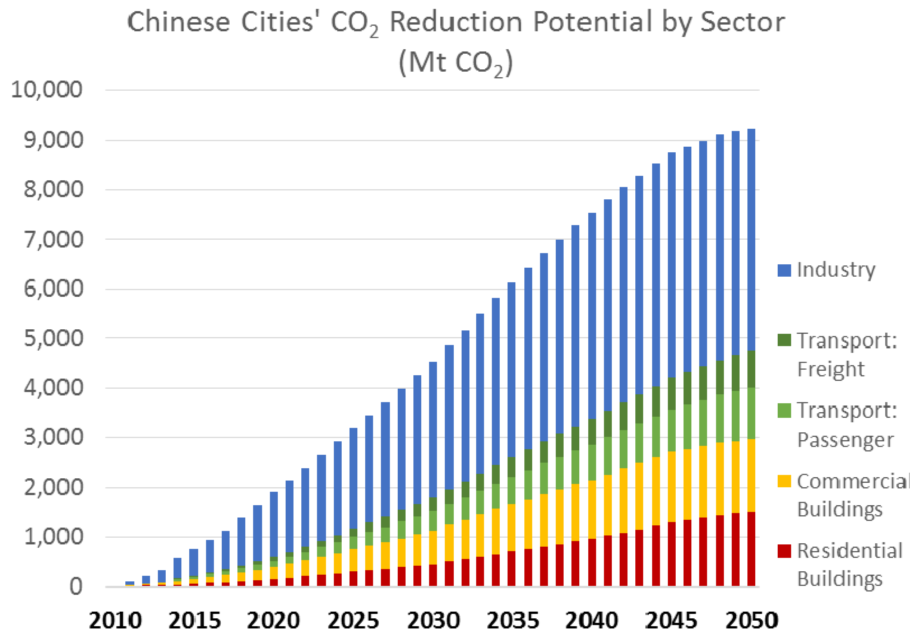


Figure 4. China's Urban CO_2 Emissions Reduction Potential by Sector

Conclusions and Policy Implications

Our bottom-up analysis of the aggregate energy consumption and energy-related CO_2 emissions for China's cities from now through 2050 highlights the dominant role industry plays in urban China. Unlike cities in developed countries, the energy consumption of Chinese cities is still largely driven by the industrial sector, which was responsible for 56% of urban primary energy use and 62% of urban CO_2 emissions in 2010. Although the industrial share of both urban energy and CO_2 emissions will decline over time as industrial activity becomes less energy intensive with higher value-added output, under the Low Carbon scenario industry nevertheless still accounts for 50% of urban CO_2 emissions by 2050.

Scenario analysis illustrates that there is significant mitigation potential within Chinese cities and across all sectors. An alternative low carbon pathway of development with full deployment of current cost-effective efficiency and renewable technologies could result in urban CO_2 emissions peaking 12 years earlier and at a much lower level than under a business-as-usual scenario with no new policies. Under this low carbon pathway, per capita urban CO_2 emissions could decline to 4 metric tons per person by 2050, versus a doubling of the 2010 per capita CO_2 emissions to 13 metric tons per person by 2050 under the Reference scenario.

In order for Chinese cities to successfully shift towards the low carbon pathway of development, urban CO_2 abatement strategies need to be designed to address the relative importance of different sectors along with the city's ability to enact, manage, and enforce specific policies and programs. For the industrial sector, Chinese cities are already responsible for implementing national and provincial industrial requirements for reducing energy and carbon intensities. However, further reductions in industrial energy consumption and CO_2 emissions can be achieved through establishing industrial stretch efficiency targets or recognition awards, adopting energy management standards for industries, conducting energy audits and assessments to benchmark enterprises, and providing rebates for industrial efficiency improvements. Cities throughout China have already started to adopt some of these strategies, including local energy conservation centers in Sichuan, Jiangsu, Henan, Shandong provinces and the cities of Shanghai and Suzhou.

In the building sector, some Chinese cities such as Tianjin, Beijing, and Shanghai have started to adopt more stringent local building energy codes to improve building efficiency with modest or no increases in up-front costs. Other possible strategies that Chinese cities could adopt to tap into building sector's mitigation potential include establishing a municipal building energy efficiency task force, city-specific green building targets, certification programs or incentives such as expedited permitting for certified green buildings.

For the transport sector, promoting mode shift from private motorized transport to public and/or non-motorized transport can help reduce more energy consumption and CO_2 emissions beyond traditional efficiency improvements and vehicle electrification. Changing urban form to promote mixed-zone neighborhoods and pedestrian and bicyclist-friendly streets as well as integrated transit development are examples of key strategies that can help enable this modal shift. Some cities in China, such as Guangzhou, Beijing and Hangzhou, have started to adopt some of these transport strategies but there is still significant potential for reducing CO_2 emission from China's growing urban transport activity.

This study represents one of the first attempts to quantify the aggregate energy consumption and CO_2 emissions attributable to China's urban areas using a bottom-up energy end-use approach. As such, it has highlighted many existing data challenges that make it difficult to do more detailed analysis of energy consumption and CO_2 emissions at a more disaggregated level. These include very limited data on industrial activity within city boundaries and outside of city boundaries and the lack of disaggregated freight transport data. Additional research into these areas as well as the establishment of more greenhouse gas inventories at the city-level can provide better data to refine our estimates, as well as shed light on differences in energy and CO_2 profiles between cities in different geographic regions and in different developmental stages.

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