# Urban form as a "first fuel" for low-carbon mobility in Chinese cities: strategies for energy and carbon saving in the transport sector


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## Abstract

From a systems perspective, the energy needed for urban mobility is fundamentally influenced by the design of a city, its urban form – the spatial layout, transport infrastructure, and social functions of a city. Thus urban form becomes a "first fuel" for mobility. This research examines the characteristics of urban form and other factors that encourage energy efficient and low-carbon mobility in Chinese cities. The analysis utilizes indicator systems and benchmarking in three tools (BEST Cities, ELITE Cities, and Urban RAM) to characterize and compare urban form and mobility across Chinese and international cities. The tools BEST and ELITE characterize operational energy and carbon, while Urban RAM takes a life-cycle perspective, giving attention to embodied energy in transport and other urban sectors. We highlight policies and infrastructure choices that are yielding results around the world and examine their applicability in Chinese cities, from integrated land-use and transportation planning and urban villages, to public transit investments and vehicle license restrictions. Throughout the paper, we use the city of Jinan in Shandong province, P.R. China, as a case study.


## Introduction

Transport sector energy and carbon ride high in European and American cities – ranging from 20 % of city greenhouse gas (GHG) emissions in Amsterdam (City of Amsterdam 2014) to 36 % in Austin (City of Austin 2014). In contrast, in Chinese cities, transport energy accounts for roughly 10 % to 20 % of a city's total, surpassed by industry at 40 to 70 % (Price et al. 2012). Yet mobility is on the rise with rapid urbanization. Transport energy in Chinese cites rose as much as 11 % annually from 1993 to 2002, shifting to roughly 5 % annually from 2002 to 2006 (Darido et al. 2009), driven by a rapid increase in automobiles. Within just 10 years (1997 to 2007), Beijing went from 1 million vehicles to 3 million (Darido et al. 2009). The surge of automobiles also has an immediate impact on air quality and human health: 31 % of the Beijing's PM2.5 emissions are attributed to automobiles (GIZ and Beijing Municipal EPB 2014).

Not only are Chinese urban populations growing and acquiring more vehicles; they are travelling greater distances across sprawling cities. Even with advances in vehicle fuel efficiency and low carbon fuels, a growing population with increasing travel distance will overwhelm attempts to reduce transport emission. Even with greater use of public transit, which is at least 3 times more efficient on a per-passenger basis than a typical car (Schipper et al. 2011), a growing population travelling longer distances will only continue the trend of rising transport emissions. From a systems perspective, we must look further upstream, at the drivers of urban transport energy and carbon. Ultimately, it is the shape and function of our cities – urban form – that is the underlying driver of travel distance and mode of mobility. Thus urban form is a "first fuel" for sustainable mobility, and development patterns and infrastructure choices are essential strategies for low-carbon urban form in our cities.

In the past 20 years, Chinese cities have been undergoing dramatic changes in urban form, from the traditional urban village hutong,[1] to large housing units and communal facilities nearby work units under the danwei[2] system, to gated residential skyscraper superblocks disassociated from work and other urban destinations. The rapid influx of urban residents, and the swift rise in vehicle ownership buoyed by the rapid growth of the automobile industry, coupled with changes in urban form, are having a profound influence on transport energy and carbon. These trends are also strongly impacting air quality and the social fabric of Chinese cities. In response, several pilot projects have been launched on eco-cities and low-carbon cities. China's National Development Reform Commission (NDRC) initiated eight low carbon pilot cities: Tianjin, Baoding, Hangzhou, Chongqing, Nanchang, Guiyang, Xiamen and Shenzhen; as well as five low carbon pilot provinces: Yunnan, Guangdong, Hubei, Shaanxi, and Liaoning provinces (Khanna et al. 2014; NDRC, 2010). Several cities and provinces are pursing pilot projects in collaboration with bilateral partners and non-governmental organizations. Urban form and transport infrastructure figure prominently in these efforts, such as the German GIZ and Beijing EPB collaboration on transport demand management and air quality,[3] and collaboration of Jinan, China Sustainable Transportation Center, and Energy Foundation on Bus Rapid Transit (BRT).[4]

This paper investigates two main questions: (1) What are the key characteristics of urban form that influence transport sector energy and carbon in Chinese cities? (2) What policy and infrastructure investment strategies are being successfully utilized to save energy and carbon in urban transport, and what are the implications for Chinese cities?

To answer these questions, we highlight the connections between urban form and transportation-related energy and carbon, giving special attention to characteristics of Chinese cities. We then introduce the city of Jinan as an illustrative case study. Next we utilize three tools to analyze urban transport energy and carbon in the city Jinan: BEST Low Carbon Cities, ELITE Cities, and Urban RAM. The tools provide benchmarking with other Chinese and international cities, and prioritized policy recommendations to save energy and carbon, as well as estimates of embodied energy and carbon in the city's transportation system. The rest of the paper is devoted to policy strategies and infrastructure choices that are yielding results and can contribute to low carbon urban form and mobility in Chinese cities.

## Characteristics of Urban Form Influencing Energy and Carbon for Mobility

In brief, three key variables influence transport energy and carbon in cities: (1) vehicle kilometres travelled (VKT), (2) mode share, and (3) the energy and carbon intensity of each transport mode. Those transport variables are in turn influenced by multiple metrics of urban form and transport infrastructure, including (cf. Suzuki et al. 2013; Cervero 1998; Calthorpe 2011; Yang 2010; World Bank 2012):

- Population density and density distribution.
- Access to pathways for non-motorized transport (walking and biking).
- Access to public transit.
- Distance from destinations (proximity, isolation).
- Land-use mix (mixed-use zoning).
- Connectivity of transport modes (street and intersection density).
- Quality of access and pathways to public transit (trees, greenery, safety, covered entranceways and bus stops, nearby amenities).
- Ease of use for each transport mode (fare or parking payment, speed, frequency).
- Extent of each transport mode .

Analysis of the connections between urban form and transport energy and carbon has included bottom-up fine-grained surveys of individual cities, such as Jinan (e.g., Yang 2010); analysis of more aggregated statistics, such as in Beijing or in the Bay Area region of California (e.g., Wang et al.2014; Calthorpe 2011); and comparative analysis across multiple cities and regions (e.g., Suzuki et al. 2013). Each type of analysis offers different insights for policy and infrastructure. For example, Darido et al. (2009) found that behavioural variables had larger influence on transport energy and carbon in Chinese cites than technological variables. The exponentially increasing number of vehicles, plus increasing travel distances (vehicle kilometres travelled (VKT) per trip), increases in trip rates (trips/person/day), and decreases in vehicle occupancy (persons/vehicle), overwhelmed improvements in vehicle fuel economy (vehicle fuel efficiency, energy/VKT) and vehicle emission intensity ($CO_2$/VKT). Neighborhoods with mixed-use urban form in Californian cities were found to save 40 % of vehicle miles travelled (VMT) and $CO_2e$ compared to less-dense urban areas (6 $tCO_2e$/household compared to 10 $tCO_2e$/household) (Calthorpe 2011). Dramatic savings of 70 % are possible by avoiding long-distance commutes from low-density, residential-only, sprawl developments. For existing urban neighborhoods that shift to mixed-use zoning and complete streets, cities may achieve 30 % savings in VMT and $CO_2e$ within 10 to 20 years (Portland Climate Action Plan 2009).

Notably, the analyses show that urban form is a necessary, but not sufficient, influence on a city's transport energy and carbon. The studies on Chinese cities highlight the dynamic nature of Chinese cities under rapid urbanization and the need to carefully consider the timing and time-frame in drawing conclusion. Though transport infrastructure investments and land development choices are occurring at rapid speed, there is still a lag time to observe the effects of those developments on mode choice and VKT, and ultimately on transport energy and carbon.

1. A *hutong* is a style of courtyard housing built along a narrow lane, prominent in Beijing and a rich part of Chinese culture. The hutong fostered community, singing folk and opera songs, taijiquan exercises, and street food cuisine.

2. The *danwei* system of housing associated with one's work unit was typically located near to the workplace, with schools and medical facilities incorporated or nearby. Residents shared most facilities.

3. For more info on German GIZ collaboration with Beijing, Chengdu and other Chinese cities, see: http://sustainabletransport.org/.

4. For more info on Jinan BRT, see: http://www.chinastc.org/en/project/48/403.

## Case Study: Urban Form and Mobility in Jinan

Jinan is a typical mid-sized (Tier 2) Chinese city, with a 2012 population of 6.1 million for the entire municipality.[5] Jinan is situated along the Yellow River in Eastern China (see Figure 1), and is the capitol of Shandong province, the highest energy-consuming province in China. The city has a heavy industrial base and relies predominantly on coal for direct use and electricity production. Jinan has a low population density, relative to China's largest (Tier 1) cities such as Beijing, Shanghai, and Guangzhou. Compared to Tier 2 cities in China, Jinan's population density is mid-range (Yang 2010).

*Urban Form in Jinan*. Jinan's urban form has evolved a great deal over its more than 4,000-year history. Yang (2010) and collaborators have characterized four main types of urban form in the city in recent time: traditional, grid (1920s), enclave (1980s–1990s), and superblock (2000s–present). The Traditional form has many of the qualities now advocated for low-carbon cities: residences clustered around courtyards and narrow alleys branching off a main shopping street. Transport in Traditional (urban village) form is mostly non-motorized, since residents can walk or bike to shops and work, and cars cannot fit in the alleys. The Grid form has a block structure with a mix of building types and retail on connecting streets. Access is easy by foot, bicycle, or car, and tree-lined retail streets provide a walk-able environment. The Grid form is prominent in the northern commercial district of Jinan (Yang 2010). The Enclave form is characterized by mid-size row housing with integrated communal facilities. Some streets have separated walking paths, and there is plenty of space for bicycle parking. Housing developments in the Enclave form were promoted by the municipal government (rather than a particular work unit); as a result, residents may be commuting to other areas of the city for work. The Superblock form is the most recent and is characterized by very large block sizes and high-rise housing that is gated and isolated from retail or offices. Internal roads are geared toward automobiles. The Superblock form of development is unfriendly to pedestrians and cyclists, creates longer travel distances for daily activities, and lacks the urban vitality of mixed-use districts. Analysis of urban form and transportation in Jinan by Yang (2010) shows that superblock urban form has resulted in three to four times the amount of automobile energy use than that in districts with traditional (village) urban form, grid development, or mixed-use enclave urban form.

*Transport networks in Jinan*. The rate of increase in automobile ownership in Jinan has outpaced the city's ability to add more roadways, causing worsening road congestion. Though not as severe as in China's largest cities, road congestion in Jinan has significantly lowered travel speeds and caused poor air quality (Yang 2010). In terms of public transit, Jinan has been relying on buses. To improve the efficiency and capacity of bus travel, Jinan opened its first two Bus Rapid Transit (BRT) lines in 2008. Three more lines were opened in 2009, and another line went into operation in 2014 (ITDP 2014). With 56 stations, distinctive BRT buses, segregated bus lanes, and pre-boarding fare collection, BRT is a useful addition to Jinan public transit (See Figure 2).


*Figure 1. Location of Jinan in China. Source: torontogirlwest.com.*


*Figure 2. Bus Rapid Transit Map of Jinan.*
*Source: http://www.chinastc.org/en/project/48/403.*

With a growing population and rising demand for passenger transport, Jinan began planning for a metro transit system in the early 2000s. Construction began in 2013. The first phase of construction includes 3 lines with 37 stations, 95.6 km length (see Figure 3). The first line is expected to be completed by end of 2018. Plans include a total of 8 lines with 262 km length and 154 stations. Details of how the metro will be integrated with other transport modes are unknown at this time. Integration of metro stations with pedestrian pathways, bicycle routes and parking, and bus and BRT routes will be crucial for the effectiveness of the new metro system.

## Benchmarking Low-Carbon Urban Form and Mobility

With the rapid pace of urbanization in China, and the need to characterize and assess associated changes in city energy consumption and carbon (greenhouse gas) emissions, Lawrence Berkeley National Laboratory (LBNL) has developed three tools to assist local governments, central government agencies, and associated researchers: BEST Cities, ELITE Cities, and Urban RAM.[6] In this paper, we utilize the indicator systems and benchmarking in the three tools to characterize and compare urban form and mobility across Chinese and

5. There is no official definition of city Tier levels in Chinese statistics. Rather, businesses have used criteria including population, income, and infrastructure and services to define Tier 1 cities as the most developed and affluent, e.g., Shanghai and Guangzhou. Tier 2 cities such as Jinan have a population of 3 million or greater and relatively high income levels.

6. The tools are available in English and Chinese. Though tailored for Chinese cities, they could be utilized elsewhere.


*Figure 3. Proposed Metro Routes in Jinan (2015–2019). Source: Jinan Urban Transport Planning 2015–2019 (in Chinese).*

international cities, relative to the case study city of Jinan. The tools BEST and ELITE characterize operational energy and carbon, while Urban RAM takes a life-cycle perspective, giving attention to embodied energy in transport and other urban sectors. The BEST Cities tool requires more detailed energy data by sector, therefore data collection involved more coordination and effort. The Institute of Science and Technology for Development of Shandong helped coordinate local data collection across multiple government branches, including the Jinan Office of Energy Savings and the Policy Research Office of the Jinan Municipal Government. The best available year of data for the BEST Cities tool is 2008. The data for ELITE Cities tool were collected mainly from the Jinan Statistical Yearbook, the latest of which reports data from 2012 (Jinan Statistical Bureau 2013). We also utilized 2012 data in the Urban RAM tool.

### BEST LOW CARBON CITIES

The Benchmarking and Energy-Saving Tool for Low-Carbon Cities (BEST-Cities) is a decision-making tool developed and tested to provide local governments in China with policies and measures they can implement in support of low-carbon urban development. BEST Cities has three main functions: (1) Inventory and Benchmarking, (2) Sector Prioritization, and (3) Policy Analysis. The tool assesses local energy use and carbon (greenhouse gas) emissions in nine urban sectors: industry, public and commercial buildings, residential buildings, transportation, power and heat, street lighting, water and wastewater, solid waste, and urban green space. BEST-Cities then benchmarks city energy and emissions performance to other cities inside and outside China, identifies those sectors with the greatest energy saving and emissions reduction potential, and assists Chinese city authorities in evaluating the applicability of more than 70 different strategies to reduce their city's energy use and emissions. For a more detailed description of the BEST Cities tool, see Price et al. (2014).

*Urban form and mobility indicators in BEST Cities*. In this paper, we focus on transportation sector indicators and policies in BEST Cities, along with urban green space and city-wide indicators relevant to urban form and mobility. The relevant indicators in BEST Cities are:

- Transportation Energy per capita [tonnes coal equivalent (tce)/person].
- Extent of Public Transit [km/km$^2$], length of bus and rail service divided by urban area.
- Mode Share of Non-motorized Transport [%], share of trips by walking and bicycling.
- Mode Share of Public Transit [%], share of trips by bus and rail.
- Urban Green Space per capita [m$^2$/person].
- Population Density [persons/m$^2$].

These are aggregate indicators, annual average numbers for the city or sector, for the purpose of benchmarking across cities, or for tracking a city's overall progress. Previous studies have noted that these aggregate indicators show correlations among urban form, mobility patterns, and the resulting energy and carbon (Newman and Kenworthy 1989; World Bank 2012). More detailed analyses, spatially and temporally across the population, highlight that the *distribution* of population density in relation to mobility infrastructure, and *accessibility* to destinations, have even greater influence on transport energy and carbon (Suzuki et al. 2013; Liu and Shen 2011).

Figure 4 benchmarks transportation energy per capita for four large Chinese cities, for a single year: Beijing, Jinan (our case study city), Tianjin, and Chongqing. Beijing has the highest energy intensity for its transportation sector, with Jinan the next highest. In contrast with Chongqing, Jinan has a lower population density and more extensive roadways, and it lacks a metro system. The mountainous terrain of Chongqing has clustered development and made roadway expansion more challenging, while transport via metro, light rail, and river is well utilized. Both cities have a strong bus network. The differences in VKT and modal share strongly influence the higher transport energy (and carbon) intensity in Jinan's transport sector.

Figure 5 compares the extent of public transit in Jinan with selected international cities, as a snapshot in time, showing Jinan in last place for public transit. Dehli has the highest population among the group with nearly 25 million in 2013, followed by New York City at 8.4, and Jinan at 6.1 million, while the rest

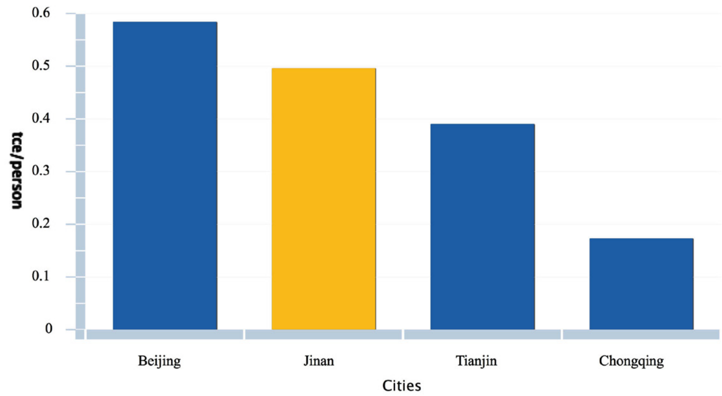


*Figure 4. Transportation Energy per capita (tce/person) in Selected Chinese Cities.*

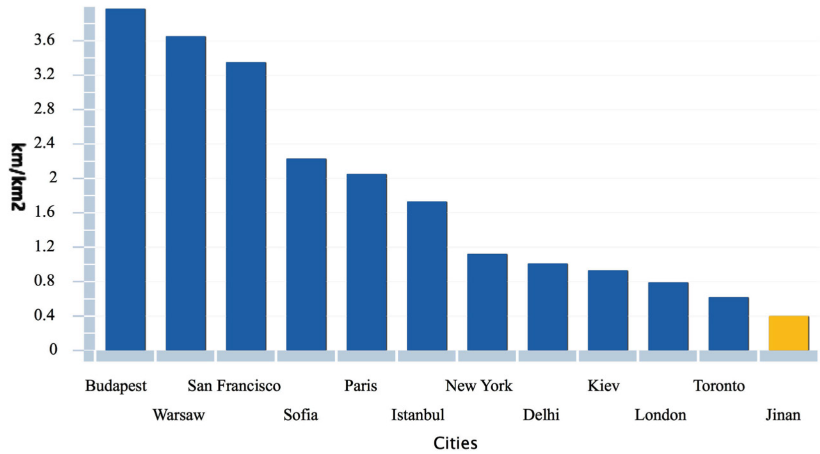


*Figure 5. Extent of Public Transit in Jinan and Selected International Cities. Note: Extent of public transit is total length of bus and rail service (km) divided by total urban area (km2). Comparator cities selected based on population >0.5 million and availability of public transit data.*

of the cities have a smaller urban population.[7] Population densities vary across the cities, as does urban form. Yet Jinan has the lowest extent of public transit lines, highlighting the need for further development of its public transit infrastructure. The situation is changing rapidly, however, in cities such as Jinan and Dehli. With the development of the Jinan BRT system, the relative ranking may change.

### ELITE CITIES

The Eco and Low-carbon Indicator Tool for Evaluating Cities (ELITE Cities) was developed to evaluate a city's progress toward high performance benchmarks and to rank it in comparison with other cities in China. ELITE Cities measures progress on 33 eco-city and low-carbon city indicators selected to represent key characteristics of eight city sectors. The Excel-based ELITE tool was developed to package the key indicators, indicator benchmarks, explanation of indicators, calculation functions, and data entry instructions. ELITE Cities could be a useful and effective tool for local city governments to define broad goals for a low-carbon eco-city and assess the progress of a city's efforts towards these goals. ELITE Cities can also be used by higher-level governments to assess city performance and discern best practices (He et al. 2013).

Table 1 summarizes the urban form and mobility indicators in ELITE Cities, as well as air quality indicators, along with the high performance benchmarks designated in the tool, and the indicator results for the city of Jinan. The indicator values are then indexed by the high performance benchmarks, weighted, and compiled to determine a score for each sector (maximum = 100). A few of the indicators are the same in both tools: Extent of Public Transit, Mode share of public transit, and Green Space per capita. Population density (people/$m^2$) in BEST and Land-use intensity ($m^2$/person) in ELITE are inverse indicators. ELITE includes two indicators directly connected to urban form and mobility: Access to public transportation (% of built area within 500 m of public transit) and share of Mixed use zoning f area). Air quality indicators are included to highlight the connection of worsening smog and Particulate

7. UN population data. If surrounding metropolitan areas are included, population figures differ. See: http://www.un.org/en/development/desa/news/population/world-urbanization-prospects-2014.html.

**Table 1. Land Use, Mobility, Air Quality Indicators for Chinese Cities: ELITE Cities Tool.**

| Indicator | Unit | High Performance Benchmark | Example City: Jinan |
|---|---|---|---|
| *Land Use* | *Score* | *100* | *70* |
| Land Use Intensity | $m^2$/capita | 100 | 100 |
| Green Space Intensity | $m^2$ of green space/capita | 50 | 10 |
| Mixed Use Zoning | % of total area | 13 % | 13 % |
| *Mobility* | *Score* | *100* | *66* |
| Public Transit Network Penetration | km/$km^2$ (total length of bus and rail service divided by total urban area) | 4 | 15 |
| Public Transit Share of Trips | % of all trips/year | 60 | 30 |
| Access to Public Transit | % of built area within 500 m of public transit | 90 % | 50 % |
| Municipal Fleet Improvement | % of energy efficient and clean fuel vehicles in municipal fleet | 100 % | 60 % |
| *Air Quality* | *Score* | *100* | *44* |
| $PM_{10}$ Concentration | μg/$m^3$ (24-hr mean) | 20 | 154 |
| $NO_x$ Concentration | μg/$m^3$ (24-hr mean) | 40 | 49 |
| $SO_2$ Concentration | μg/$m^3$ (24-hr mean) | 20 | 82 |
| Air Quality Days | % of total days per year air quality meets Chinese Level II standard ("blue sky" threshold) | 100 % | 57 % |

Matter (PM10 and PM2.5) pollution in urban areas, with the rapid increase in vehicle numbers and kilometres travelled.

In terms of sector scores, Jinan scored 70 out of 100 in Land Use, 66 out of 100 in Mobility, and a low 44 out of 100 in Air Quality. Looking at each indicator, the main area for improvement in Land Use is the expansion of green space. Expanded green space could also encourage greater use of public transit – and walking and bicycling – in the Mobility sector. China's 12th Five-Year Comprehensive Plan for Transport Systems has a target of 60 % of trips by public transit for cities up to 10 million in population; this value is used as the high performance benchmark in ELITE. Yet Jinan has only 30 % of trips by public transit. Jinan's relatively low accessibility to transit – 50 % compared to the benchmark of 90 % – indicates an urban form lacking sufficiently clustered development around transit corridors (i.e., lacking articulated densities).

### URBAN RAM

The BEST and ELITE tools, and most other tools examining city energy and carbon, focus on operational consumption and emissions, attributing energy and carbon to the operational source. However, it is a city's residents and workers for whom buildings are constructed, appliances manufactured, roads paved, and oil refined. The Urban Rapid Assessment Model (Urban RAM) was developed to characterize a city's energy and carbon footprint from the perspective of the city's inhabitants and their activities. With Urban RAM, we can gain insight into the drivers of urban growth – and opportunities for policy intervention – by attributing embodied and operational energy consumption to the functions of city residents, such as living, commuting, shopping, and working. The tool was first tested with a case study of Suzhou (Fridley et al. 2012). Here we focus on the land use and mobility components of Urban RAM for a case study of Jinan.

Based on the Urban RAM model, transportation accounts for 10 % of Jinan's operational energy (see Figure 6), and 9 % of the city's embodied energy and carbon (4 % City Infrastructure and 5 % embodied in vehicles, see Figure 7). The inhabitant-focused attribution for transport turned out to be fairly consistent with the typical energy and carbon accounting. In BEST Cities, the Jinan Transportation sector accounts for roughly 10 % of energy and carbon; Industry dominates at 60 %, followed by Buildings (Figure 7). However, other urban sectors showed a marked difference between the two accounting methods; notably, in lieu of Industrial energy, energy shifted to Buildings and consumption of food and goods by residents. In Urban RAM, industrial energy used to produce materials and goods consumed by the residents of Jinan, whether produced outside or within the city, are attributed to Jinan. Similarly, not all of the energy consumed by the Industrial sector within the boundaries of Jinan is attributed to the residents of Jinan in the Urban RAM accounting, since many of the city's industrial products are sent out of the city for consumption elsewhere. These relative proportions of energy use could change rapidly, however, with shifting patterns of urban form and increasing VKT for urban transport.

Taking a closer look at Transportation results in Urban RAM, we find that cars have the largest share of both operational and embodied energy, by far (see Figure 8). Even though a metro system is under construction in Jinan, there was not sufficient data to include this analysis. Jinan does not have light rail or high-speed rail within the city, so those items are zero.

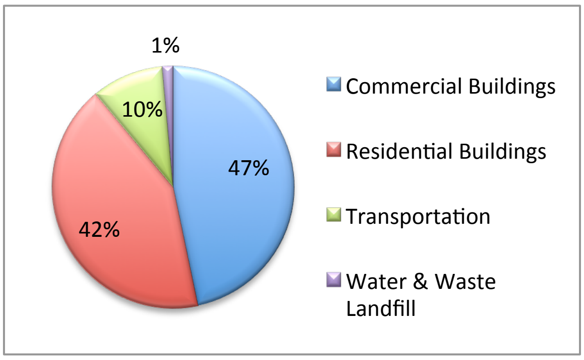


*Figure 6. Jinan City, Operational $CO_2$ Emissions.*

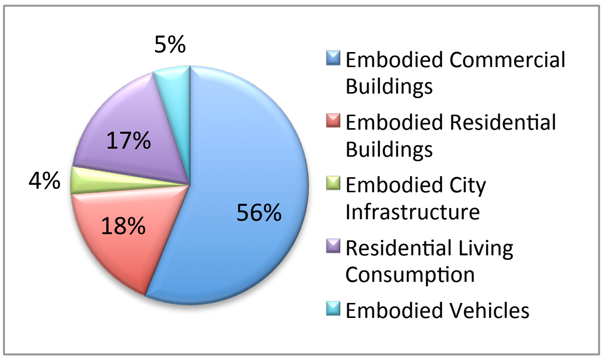


*Figure 7. Jinan City, Embodied $CO_2$ Emissions.*

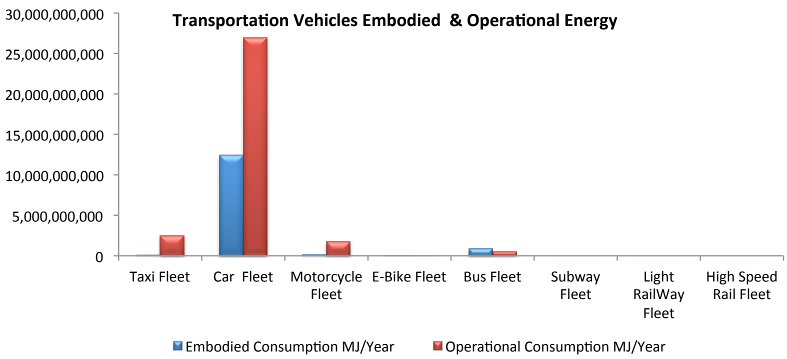


*Figure 8. Embodied and Operational Transport Energy (tce), by mode, for Jinan city (2012).*

The lower energy values for the bus fleet are due to the relative share of transport modes in the city. Kilometres travelled by cars in the city are estimated at roughly 50 × those of the bus fleet. That ratio is likely lower, and bus travel in Jinan is likely higher, based on analysis of other Chinese cities by Huo et al. (2012). The car fleet is estimated to travel nearly 10 × more distance annually than the taxi fleet in Jinan, although on a per vehicle basis, a taxi travels 10 × further than a typical private car, and likely more. The relatively higher embodied vs. operational energy for the bus fleet is due in part to the relatively larger amount of energy needed to manufacture a bus vs. its operation, compared to a car, as well as the higher per person energy efficiency of transport by bus. One implication of this analysis is that greater utilization of buses could help to lessen the city's transport footprint.

## Policy Strategies and Infrastructure Choices

Here we note the transportation policy priorities for Jinan, as evaluated by the BEST Cities model. We then highlight a few policy strategies and infrastructure choices that are yielding energy and carbon savings in Chinese and other cities. For the case study of Jinan, which has a passenger transport system dominated by automobiles and buses, the BEST Cities tool ranked vehicle efficiency and emission standards as very high priority, along with development of the public transit system (see Table 2). Several vehicle-focused policies are also high priority, encouraging shifts in timing of vehicle travel, encouraging mode shift, and promoting cleaner vehicles.

### INTEGRATED TRANSPORT PLANNING

Integrated transport planning coordinates land-use policies and transportation planning, as part of a larger vision of the shape and functioning of the city, including urban culture and the economy, as well as energy and carbon saving. This vision is necessary to prioritize development in a socially-inclusive, low carbon direction. First and foremost, integrated transport planning must prioritize people and pedestrians, as all trips begin and end by feet. With prioritized funding for low-carbon urban form and mobility, integrated planning has the goal of enhancing a community's accessibility to resources and services with:

1. urban development oriented toward walkability and public transit, e.g., Transit-Oriented Development (TOD);
2. low-VKT transport: transport options that reduce Vehicle Kilometres Travelled (VKT) per person and in total; and
3. low-carbon transport modes, beginning with non-motorized transport (walking and biking) and including efficient, clean-powered vehicles.

Integrated planning promotes development of housing and commercial properties that give priority to walking and bicycling transport modes, and integrates walkability with access to public transit (bus and rail). Incorporating tree-covered pathways and public transit connections, as well as safe crossing of roadways with motorized vehicles, are examples of how this integration is accomplished.

*Example – Chicago*. As part of Chicago's *Go To 2040* plan for "sustainable prosperity through mid-century and beyond,"

**Table 2. Transportation Policies Recommended for Jinan in the BEST Cities Tool.**

| Policy | Speed of Implementation | Carbon Savings Potential ($tCO_2e$) | First Cost to Government (RMB) |
|---|---|---|---|
| ***Very High Priority*** | | | |
| Public Transit Infrastructure: Light Rail, BRT, Buses | > 3 Years | >2.5 million | 5 million–50 million |
| Vehicle $CO_2$ Emission Standards | 1–3 Years | >2.5 million | <5 million |
| Vehicle Fuel Economy Standards | 1–3 Years | >2.5 million | 5 million–50 million |
| ***High Priority*** | | | |
| Integrated Transportation Planning | > 3 Years | 500,000–2.5 million | <5 million |
| Mixed-Use Urban Form | > 3 Years | 500,000–2.5 million | <5 million |
| Congestion Charges and Road Pricing | 1–3 Years | 500,000–2.5 million | <5 million |
| Parking Fees and Measures | 1–3 Years | 500,000–2.5 million | <5 million |
| Vehicle License Policies | < 1 Year | 500,000–2.5 million | <5 million |
| Clean Vehicle Programs | 1–3 Years | 500,000–2.5 million | 5 million–50 million |

the Chicago Metropolitan Agency for Planning (CMAP 2014) has developed a regional integrated transportation plan, in conjunction with Chicago's climate action plan and local government agencies. Key elements of the plan include: Strategic Investments (for congestion mitigation and air quality, infrastructure and maintenance); Increased Commitment to Public Transit; Bike and Pedestrian Task Force; Intelligent Transportation System (with monitoring of regional congestion performance indicators); and Regional Freight System Planning. The Transportation Improvement Program tracks local, state and federal expenditures. Chicago also uses evaluation criteria for Performance-based Funding, to be sure funding decisions are helping the metropolis meet its transportation goals.

*Example – Copenhagen*. Copenhagen has more than six decades of experience with long-range planning of rail and transit-oriented development, starting with its "Finger Plan" in 1947 (Knowles 2012). Figure 9 illustrates the corridors of urban expansion envisioned early on. Transit infrastructure built in advance of demand led land-use development in desired directions, in terms of the quality of urban life, as well as energy and carbon savings (Cervero 1998; Suzuki et al. 2013). From the late 1990s, development of the new "finger" of Orestad, connecting Copenhagen via bridge to Malmo, Sweden, highlights the challenges of balancing public-private partnerships and international economic ties with community input and local design practice. In an effort to fund the elevated metro line when economic conditions changed, the Orestad Development Corporation pulled away from its planning principles and turned to private funding of a big-box shopping mall (Olsson and Loerakker 2013). The social vitality and business appeal of the area have been adversely impacted by the shift away from human-scale development, and the full extent of low-carbon mobility in the corridor is not yet realized.

*China – National Policies*. In China, national planning regulations already require local governments to consider the impact on transport when making planning decisions. For example, China's 2007 Climate Change Plan set key goals that include supplementing existing planning policies with sustainable transport and reducing private vehicle use (NDRC 2007). This objective has also been evident in other planning policies, including regional development strategy guidelines and national port, network and airport development polices. This is also part of the implementation and policy reform process in the 2008 national planning framework, and must also be considered in climate change adaptation and mitigation guidelines. For new and emerging cities, more specific spatial planning design considerations and measures can be adopted to reduce the need for transportation. Since 2009, several Chinese cities have been undertaking low-carbon transport planning and projects under the guidance of the Ministry of Housing and Urban Rural Development (MOHURD). Transit-oriented development features prominently in these plans, including housing and commercial developments around BRT and metro systems. Public transit developments in Guangzhou (see below) are an excellent example. In many other Chinese cities, land use and transport priorities still need to be integrated and still need to shift away from vehicle-focused development (World Bank 2012; Zhou et al. 2011).

D*esign Guidance for Integrated Planning of Chinese Cities.* To concisely convey best practice in integrated planning for low-carbon cities, Calthorpe Associates et al. (2011) synthesized eight design principles: (1) Develop neighborhoods that promote walking; (2) Prioritize bicycle networks; (3) Create dense networks of streets and paths; (4) Support high-quality transit; (5) Zone for mixed-use neighborhoods; (6) Match density to transit capacity; (7) Create compact regions with short commutes; (8) Increase mobility by regulating parking and road use.

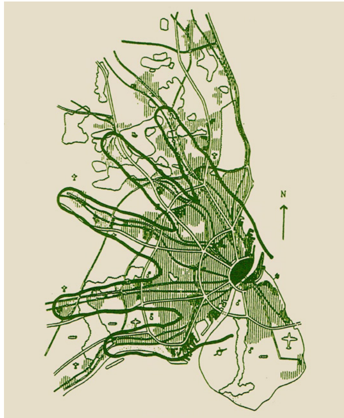

*Figure 9. Copenhagen's Finger Plan for Urban Development and Transport. Source: http://araxus.org/urban_design_studies_4.html.*

### PUBLIC TRANSIT INFRASTRUCTURE

Even with an urban form amenable to shorter distance travel, investment in public transit infrastructure is needed to give people lower-carbon alternatives to automobiles. Shifting passengers from low-occupancy vehicles to public transit results in high energy and $CO_2$ savings. Bus and rail transport can save close to 80 % of vehicle emissions per passenger kilometer. In the US, 17 transit-oriented development projects in five medium- to large-sized metropolitan areas showed a 44 % reduction in vehicle trips, compared to typical patterns of car-focused development (SFMTA, 2011; Cervero, 2009). Among public transit infrastructure choices, buses have somewhat higher emissions per passenger kilometer than rail, yet their lower capital costs make busses an affordable public transit options. Electric rail, with its higher operating efficiency, is appealing for the highest-density cities that will have sufficient fare revenue to recoup the investment. BRT offers the benefits of both: dedicated bus lanes gain improved efficiency at a lower cost than rail. The inclusion of cleaner buses with transit investment has further benefits. Hybrid buses can reduce $CO_2$ emissions by 30–40 % compared to conventional buses, along with 95 % less particulate matter and 40 % less $NO_x$ (SFMTA 2011).

*Guangzhou Integrated Public Transit*. The design details of public transit infrastructure are crucial, especially the connectivity of public transit to walking paths, cycling routes, and other transport modes. Integration of public transit with walking and biking is the key to low-carbon transportation in Guangzhou. After years of coordinated planning, in February 2010, China's third-largest city opened 22.5 kilometers of Bus Rapid Transit (BRT), the first BRT in Asia connected with the metro rail system (Hughes and Zhou 2011). The Guangzhou BRT system also includes bicycle parking in its station design and a greenway parallel to the corridor, integrating the city's bike share program of nearly 5,000 bicycles and 50 bike stations (National Geographic 2011). Within 18 months of opening the BRT, Guangzhou achieved the world's highest rate of BRT passengers – 805,000 daily boardings – carrying more passengers per hour than any mainland Chinese metro outside of Beijing, and tripling the capacity reached by other BRT in Asia (Hughes and Zhou 2011). The efficiency improvements from BRT have reduced travel time for bus riders and motorists along the route by 29 % and 20 %, respectively. The fuel savings will in turn save 86,000 t $CO_{2e}$ annually (Hughes and Zhou 2011).

*Jinan BRT*. Jinan, which has been relying on public transit by bus, opened its first two BRT lines in 2008. Three more lines were opened in 2009, and seventh line went into operation in 2014 (ITDP 2014). With 56 stations, distinctive BRT buses, segregated bus lanes, and pre-boarding fare collection, BRT is a useful addition to Jinan public transit. However, better integration with connecting modes of transport are needed. Despite the large use of bicycles in Jinan, BRT stations provide limited or no bicycle parking. Public space surrounding the stations hasn't been enhanced, especially near stations below the expressway (ITDP 2014). Analysis of Jinan by Jiang (2012) and Zegras (2013) shows notable variation in the effectiveness of BRT across types of boarding stations and access corridors. Examination of three types of BRT access – arterial edge, integrated boulevard, and below expressway – found that tree-lined integrated boulevards with everyday retail were appealing and well-utilized compared to the other types. Although arterial edge corridors to BRT had better sidewalks and pavement, and safer crossings, they lack sufficient trees or retail facilities. BRT stations below expressways, though logistically convenient from a planning standpoint, are the least appealing to users. Infrastructure and development improvements are needed to address the lack of trees, unsafe crossings, poor pavement, obstructed sidewalks, lack of bicycle parking, and limited retail near below-expressway BRT stations in Jinan (Jiang 2012, Zegras 2013, ITDP 2014).

*Financing*. To enable investment in light rail and bus systems, funding for public transit infrastructure must be prioritized over funding for private vehicle infrastructure. Funds gathered from traffic reduction measures (e.g., license fees, congestion pricing) can be ear-marked for public transit infrastructure, as well as for pedestrians and bicyclist infrastructure. Coordinating the construction of public transit infrastructure with real estate and business district development, as part of integrated transport planning and implementation, allows for "value capture" – utilizing increased land values and private revenues accompanying new infrastructure (Suzuki et al. 2013). This value capture, however, must be in the service of community interests and community-scale infrastructure, as noted above for Copenhagen. In the operational phase, transit agencies must carry out smooth operation, make easy connections and payment systems, and share information with the ridership to ensure sufficient revenue from the ridership.

#### VEHICLE LICENSE POLICIES

Vehicle license policies have been used to reduce road congestion along with its accompanying air pollution and energy consumption, and to encourage cleaner vehicles, by giving special access to those with energy-efficient or low-emission plates.[8] Policies to control the circulation of private vehicles via their license plates can contribute to carbon savings by reducing the use of this high-carbon transport mode. Vehicle license policies may control the total number of vehicles registered in a city, or they may control the operation of vehicles based on their license plate number. As early as in 1986, Shanghai municipal government began the private car license plate auction to regulate the fast growth of private vehicles at a time when there is a shortage of road construction. Shanghai's practice of auctioning license plates has controlled the total number of automobiles to 2 million and kept traffic flowing, although only the wealthy can afford the auction. The auction policy has become a practical model for other cities to emulate despite creating contentious debate and challenges. In contrast, Beijing's past policy of allowing access to certain license numbers on certain days did not sufficiently control traffic, and Beijing have continued to face road congestion from more than 5 million cars.[9] Guangzhou has learned from these two different experiences, and is implementing a combination of auction and lottery for automobile licenses. This approach will help reduce traffic, reduce $CO_2$ emissions, and enable more equitable access to licenses.

#### CLEAN VEHICLE POLICIES

Along with curbing the rapid growth of automobiles, cities from San Francisco (CARB 2012) to Stockholm (Senternovem 2009) are encouraging the adoption of cleaner vehicles for those that are in use. Clean vehicle programs are intended to encourage and accelerate low emission, zero and near zero emission, on road light-duty vehicle penetration and deployment. They can benefit a city by providing immediate air pollution emission reductions, as well as reducing greenhouse gas emissions, while stimulating development and deployment of the next generation of vehicles. Energy savings may reach 8,000–10,000 kWh/annual for each new high performance vehicle or replaced vehicle, with subsequent benefits in carbon reduction. Hybrid, all electric, or fuel cell vehicles have lower GHG emissions compared to fuel-based vehicles. The emission reduction potential depends on the size of the fleet and type of vehicles, with reported reduction of 50 % in the UK Green Cars program when compared to traditional black cabs (UK Dept for Transport 2009).

## Conclusion

The choice of urban development patterns in China's rapidly growing cities over the past 20 years has dramatically increased the energy consumed for transportation, resulting in growing greenhouse gas emissions from this sector. In terms of urban form, the residential superblock has been shown to be a high-carbon form, as noted in the analysis by Yang (2010) and Calthorpe Associates et al. (2011). Superblock development in Chinese cities has tended to be car-focused, rather than people-focused. Though the population density may be high in superblock development, the lack of mixed land-use (residential, retail, office, public and government services, and green space), creates an urban desert island with a heavy energy and carbon footprint. In contrast, clusters of urban villages, or mixed-use human-scale grid development lessens VKT and raises mode share of walking, biking, and public transit, while fostering urban vitality.

The examples discussed here highlight the importance of prioritizing people, of urban development designed first for people rather than cars, to realize low-carbon urban mobility. They also highlight the importance of large-scale action: integrated planning and long-term investments in pedestrian and bicycle pathways and public transit. Finally, the experience in Jinan and elsewhere highlights the importance of connectivity and getting the details right to enable greater use of walking, biking, and transit. Tree-lined pathways, safe road crossings, and access to sheltered transit stops with shops nearby encourage the shift to low-carbon mobility.

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