

Developing a Low-carbon Roadmap for China's Cities

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Acronyms

BAU	Business as usual
Btsce	Billion tons of standards coal equivalent
BTU	British thermal unit of energy equal to about 1.06 kilojoules
CAS	Chinese Academy of Sciences
CASS	Chinese Academy of Social Sciences
CO ₂	Carbon dioxide
CO _{2-e}	Carbon dioxide equivalent
CESE	College of Environmental Science and Engineering
CSES	Centre for Strategic Economic Studies
EIA	United States Energy Information Administration
ELCS	Enhanced low-carbon scenario
ERI	Energy Research Institute
FYP	Five Year Plan
GDP	Gross domestic product
GHG	Greenhouse gases
GW	Gigawatts
IEA	International Energy Agency
IPAC	Integrated Policy (energy and technology) Assessment Model for China
kW	Kilowatts
kWh	Kilowatt hours
LCE	Low-carbon economy
MEP	Ministry of Environmental Protection
MOHURD	Ministry of Housing, Urban and Rural Development
Mtsce	Million tons of standards coal equivalent
MW	Megawatts
NBSC	National Bureau of Statistics China
NDRC	National Development and Reform Commission
NEA	National Energy Agency
NPC	National People's Congress
OECD	Organisation for Economic Co-operation and Development
RMB	Renminbi or Chinese National Yuan
tsce	Tons of standards coal equivalent

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Executive Summary

The fundamental driver for making the transition to a low-carbon pattern of development in cities is the need to break the link between the rise in carbon emissions and economic growth. The World Bank (2012, xliii) defines low-carbon development as a pathway “that maximises low-carbon energy sources, enhances efficiency in delivering urban services, and moves to lower carbon intensity for a given unit of GDP”. Any definition of low-carbon urban development needs to acknowledge five critical considerations: first, the level of development of the city; second, the existing carbon endowment of the city; third, whether the city is a carbon consumer or producer; fourth, the institutional capacity to respond in an efficient and effective manner, and finally, the speed of development. It is also important to understand the main drivers for a city's carbon emissions. These include a city's energy mix, economic structure, level of development, population size, urban form, transport and built infrastructure, and climate, as well as its physical and resource endowments. Therefore, a low-carbon pathway needs to focus on the process of reducing emissions based upon each of these considerations. Moreover, to remain politically and socially acceptable, a low-carbon pathway needs to consider options that do not undermine economic development and liveability. Inherent in this discussion is that there is a close relationship between low-carbon development, sustainability and liveability. As noted, by the World Bank (2012, xliii) a low-carbon city is “above all, a sustainable, efficient, liveable and competitive city”.

The performance of cities is critical to China's attempt to reduce emissions and to improve the quality of life of its citizens. In 2012 there were over 700 million people, or 52.6% of the total population, living in China's cities. The Chinese Government continues to support increasing urbanisation, and before 2030 it is likely that one billion people, or about 70% of China's population, will live in cities. Around the world, emissions per capita are 3-4 times higher for those living in cities than for those living in the countryside, and about 70% of global emissions are due to cities. This continuing shift of population into high emissions urban areas in China means that the performance of these cities is critical to China's ambitions to reduce emissions and to improve the quality of life of its citizens.

The pursuit of ‘low-carbon city’ status is widespread in China. It has been reported that in 2011, 276 of the 287 cities in China with municipality status had proposed low-carbon or eco-city goals (Li Y 2010). The concept has clearly become a fashionable one, which municipal governments use to pursue a wide range of goals and activities under this general banner. This trend has been strongly reinforced by central government support. In July 2010, the National Development and Reform Commission (NDRC 2010) established low-carbon city pilot programs in eight cities (Tianjin, Chongqing, Shenzhen, Xiamen, Hangzhou, Nanchang, Guiyang and Baoding), and in December 2012 more than 20 additional cities were added to the pilot program, including Beijing. The Ministry of Environmental Protection has also been running an ‘eco-city’ program for a decade and the Ministry of Housing and Urban-Rural Development has been implementing an ‘eco-garden city’ program since 2004 (Zhou, He and Williams 2012).

As it has been developed and applied in China and elsewhere, the concept of the low-carbon city is an attempt to bring together many different elements (Chapter 2). The main elements in this report relate to energy use and emissions intensity, to the long-run sustainability of the economic and social life of the city and to the quality of life of the city's people. In principle, these and other elements might pull in different directions, and a city might achieve highly on one element while being poor on others.

The NDRC notice of December 2012 establishing the second round of pilot low-carbon city programs covered all of these elements. It noted the importance of: adjusting the industrial and energy structure and pursuing energy efficiency; incorporating the low-carbon concept into transport, land use and other urban planning; of building green environmental protection and recycling systems; emphasising the development and application of new technologies in green buildings, low-carbon transport services and emerging industries more generally; and promoting the use of low-carbon lifestyles and consumption patterns, including low-carbon housing, public transport and other low-carbon travel (NDRC 2012). The diversity of the concept of a low-carbon city raises the possibility that it might mean very different things to different people.

The low-carbon city focus in China sits within a broader and developing policy framework. The official emphasis on low-carbon cities in China sits within a complex and ongoing framework of plans, targets and initiatives. Operating within the 12th Five Year Plan (FYP) the government has provided medium-term targets for energy use and emissions, both nationally and at the provincial level, and has broken these down in the Energy Plan into more specific targets for the different forms of energy use, and for different industries. The central government has also put in place a wide range of initiatives, including the establishment of pilot emissions trading programs, to assist in meeting these ambitious targets. The low-carbon cities pilot programs being pursued by NDRC and by other agencies of the national, provincial and municipal governments must be seen as significant components of this broader policy agenda. It is also expected that the recent announcements at the Third Plenary Session of the CCP 18th Central Committee in late 2013 will result in further enhancement of the long-term reform agenda (Li and McElveen 2013).

This project 'Developing a Low Carbon Roadmap for China's Cities' has focussed on pathways for breaking the link between economic growth and rising carbon emissions, whilst improving the quality of life in cities. The project has attempted to develop a deeper understanding of innovative solutions to address the major industrial, energy planning and development challenges confronting cities in a carbon-constrained environment. These understandings and solutions are specifically designed to guide the effective implementation of low-carbon policies in China's cities to conserve energy, reduce emissions and improve living standards whilst strengthening economic, environmental and social sustainability. This final report includes several specific results pertaining to these issues.

The key contribution of this research was the development of a detailed industrial roadmap for the transition to low-carbon development by 2030 for the cities of Beijing and Tianjin (Chapter 3). The roadmap demonstrates the economic cost and benefits of emission reduction options. Both roadmaps incorporate an assessment of future carbon emissions under a variety of scenarios in order to determine the scope and scale of carbon emission reductions and actual achievable goals within a specific time frame. These assessments can assist decision makers understand the economic, employment and emission impacts of different economic and planning scenarios in the industrial sector for Tianjin and energy sector for Beijing.

The Beijing low-carbon energy roadmap suggests that Beijing could become a global low-carbon city by 2030 (Chapter 3). This study uses a version of the IPAC model to develop and analyse the roadmap, which is based on an assumed annual rate of growth of Beijing's GDP of 8.3% over 2010-20 and of 6.5% over 2020-30. The plan has a strong focus on developing Beijing's high-end manufacturing sector, especially high-tech industry, a low-carbon service sector and a low-carbon energy sector. It envisages a rise in the service sector share of real value added from 74.4% in the 12th FYP period (2010-15) to 86% by 2030. According to the roadmap, Beijing's total energy demand would peak in 2020-25, and then decline, with CO₂ emissions also peaking in 2025 and coal consumption falling rapidly. If achieved, the roadmap outlined here would set Beijing on a

path to become a global low-carbon city by 2030. While the level of emissions would remain relatively high for the stage of development, total energy use and emissions would fall before 2030 and many other aspects of the low-carbon model would be put in place. But the roadmap is an energy roadmap, and does not give detailed consideration to other aspects of sustainability and liveability.

The Tianjin low-carbon energy roadmap shows how Tianjin could achieve national energy and emissions intensity targets by 2020, but with continuing strong growth in emissions. In comparison with Beijing, Tianjin is a city strongly focused on the industrial sector, and within that on heavy industry. In 2011 the industrial sector accounted for over 50% of GDP in Tianjin, by comparison with less than 25% in Beijing, and over 80% of industrial output was in heavy industry. GDP, energy use and CO₂ emissions have all been growing more rapidly in Tianjin than in Beijing, based on strong growth in industrial output, with the industrial sector being responsible for 73% of energy demand in 2011. Over the five years 2006-2011, GDP growth was 16.1% per annum in Tianjin compared to 9.1% in Beijing, with the comparative growth rates for energy use being 11.0% and 3.5%, respectively. The Tianjin authorities plan to continue strong growth both in industrial output and in GDP, but to restructure industry towards more knowledge intensive, and less energy intensive, products. This makes the task of shifting to a low-carbon city very challenging.

Given the commitment of the Chinese Government to reduce national energy consumption per unit of GDP by 45% over 2005-2020, Tianjin is committed to reducing energy intensity by 14.6% over 2010-15 and by a further 11.8% over 2015-2020. The low-carbon energy roadmap for Tianjin (Chapter 3) uses backcasting and decomposition analysis to show how the city can achieve the targets for energy and emissions intensity with continued strong growth in GDP (12% and 15% per annum in two scenarios), but also with continued growth in emissions. The industries that dominate Tianjin's emissions are iron, steel and non-ferrous metals, followed by the chemical and petroleum industries. Reductions in energy use and emissions are achieved by both shifting the structure of industry away from these sectors, by making them more energy efficient and by reducing the emissions intensity of their energy use. But again this roadmap is an energy roadmap, with a particular focus on energy and emissions from industry, and does not give detailed consideration to other aspects of sustainability and liveability. Achieving the targets imposed by the national government for energy and emissions intensity will be far from sufficient to transform Tianjin into a low-carbon city.

While a high proportion of emissions are generated in cities, one limitation of the use of cities as a policy instrument is that targets for cities can be achieved by shifting industries, power generation processes or other activities outside city boundaries. Even sharply reducing emissions in Beijing and Tianjin will not reduce pollution in the North China plain, nor contribute much to reducing China's overall emissions, if the reduction is substantially achieved by shifting polluting activities to surrounding neighbourhoods. One response to the emissions shifting issue is to ensure that the focus for city-based measures is on the emissions embodied in the goods and services consumed in the city, rather than on the level of emissions generated within the city boundary. But this important principle is difficult to pursue in practice, because there is little data on inter-regional trade in energy sources or in emissions-intensive products.

The energy roadmap for Tianjin illustrates the well-known fact that it is easier to achieve a given energy or emissions intensity target with a high rate of growth than with a lower one, and hence with higher rather than lower emissions. If the economy is growing rapidly it is possible to add new capacity with more energy efficient and cleaner technology, thereby reducing overall intensity levels. But if the economy is growing slowly, more of the adjustment needs to occur through closing or retrofitting older plant and equipment,

which is much more difficult. But ultimately it is the absolute level of emissions that influences both local pollution and global warming.

In addition to the development of the two roadmaps, the project developed a dynamic low-carbon city index system (Chapter 4) with the aim of guiding planning and decision-making for the development of low-carbon cities. The index system offers a useful evaluative and monitoring tool to assist urban planners understand the broader impacts of incremental changes to the city's energy demand, supply and mix on GHG emissions, as well as monitor and measure progress on achieving the carbon emission reduction targets. Additional benefits of clearly identifying the key steps and priority areas of a city's emissions profile highlights areas of progress, or lack thereof, but also include, for example, the ability to better plan and integrate investments in infrastructure, such as energy supply, public transport and parks, as well as the provision of social services. There have been many attempts at developing index systems for evaluating low-carbon cities, including the Tianjin system presented here. While these provide a useful framework for monitoring and evaluating progress, further work needs to be done to develop satisfactory quantification of individual indicators appropriate to local conditions. Because of the many dimensions of low-carbon city development, these are inevitably complex considerations, which are difficult to compress into single measures.

Both the roadmaps and index system provide a helpful platform and guide for policy makers and economic decision makers in determining the efficiency of alternative development pathways for reducing emissions as measured by cost per tonne of GHG abatement in the medium and long term. This is an important consideration because of the limited time available for making efficient decisions and cost-effective use of existing technological opportunities and therefore avoiding the potential implications of carbon lock-in due to delayed action. Time sensitivity therefore remains a critical issue in making effective decisions regarding urban planning and development during the current period of rapid development. To meet the expected growth in urban demand, China will further expand the construction of new power plants, transport networks and buildings. Because such infrastructure will largely remain in place for the next 40-plus years, there is a need to ensure that such investments are carefully planned, executed and adopt global best practice. The roadmap and index system is designed to ameliorate the risks associated with such strategic planning and decision making.

This report illustrates the dangers that can arise from such a multidimensional concept as that of the low-carbon city, which can be misused in many ways. In particular cities can use it to promote their own advancement at the expense of surrounding regions, or focus on success in one aspect of it, such as low emissions intensity or liveability, at the expense of other aspects. This is exemplified by the comparison with the city of Melbourne which has achieved high recognition for its liveability and the quality of life that it offers to people living within it, but is certainly not a low-carbon city and its energy and urban development model may well not be sustainable. Indeed it is arguable that Melbourne has achieved its high level of development, wealth and quality of life through its heavy and unsustainable use of coal-based energy, land, water and other resources. The challenges this implies for Melbourne are echoed across most Australian and North American cities and are increasingly evident in many Chinese cities. For instance, a failure to appreciate the fundamental resource constraints between consumption and resources, as well as the significant emissions costs of carbon lock-in arising from poorly considered or short-term policy and infrastructure decisions. For example, most of these cities are confronting shortages of clean water and available land, yet continue to embrace ongoing urban sprawl with a general disregard for the impact upon land, water and the lock-in of future resources necessary to sustain these communities. In addition, there is very little evidence of a concerted implementation strategy to effectively reduce carbon emissions and

resource intensity despite high levels of community support, as well as innovative policy and market solutions.

As China's cities become wealthier and continue to grow, it will be increasingly important that cities make progress in achieving each of the three low-carbon city goals: reduced emissions, enhanced sustainability and better quality of life for all. This has been clearly illustrated in recent years with intensifying resource constraints and the need to reduce the serious pollution problems. While the broad concept of low-carbon development remains difficult to define, measure and implement, the evidence suggests that it should become, or remain, a central element in national and local policies for cities in China and elsewhere.

1. Introduction

A critical component of tackling the dual problems of China's rising energy use and carbon emissions is rebalancing the pattern of development in China's cities. These cities need to be at the forefront of the transition to a low-carbon economy given their central role in generating emissions but also in their capacity for addressing climate change. Currently, 700 million or over half of China's 1.35 billion people officially reside in urban areas. It is anticipated that China's urban population will reach around 1 billion by 2025-30, as a result of a further 300 million people shifting into China's rapidly growing cities. China's cities already confront serious challenges arising from rapid industrialisation, population growth, rising standards of living and demand for infrastructure and services.

In 2010, China's National Development Reform Commission (NDRC, 2010) announced a program for five low-carbon pilot provinces and eight low-carbon pilot cities, and in late 2012 the number of cities was significantly increased. According to the NDRC, the pilot program will include greenhouse gas accounting, low-carbon development planning, industrial and economic policy, government official training, communications and international cooperation. The outcome of the pilot will determine how low-carbon development can be applied to other regions and cities throughout China. These low-carbon pilots are expected to lay the groundwork for a national low-carbon assessment, planning and management system which includes guidelines on reducing energy use and carbon emissions in industry, society and the economy.

Low-carbon development in China's cities remains at the trial stage, is very diverse and is encountering a range of challenges. Many of China's low-carbon cities have concentrated on attracting investment in renewables, clean technology and energy conservation in buildings and the expansion of public transport systems. However, this approach remains limited to the consideration of short-term economic opportunities whereby cities compete with each other to promote their low-carbon "business card". Others have concentrated on new, greenfield 'model cities', while others have focused on reducing energy use and emissions from selected industries rather than a more fundamental process of city transformation. Formulating a systematic low-carbon economic development framework remains a complicated challenge for local governments, especially in the light of the broad ranging nature of the direction being provided by the central government.

The failure of city governments to adopt any systematic approach has meant that the capacity for long-term planning and structural economic change towards the implementation of a low-carbon development strategy remains weak. This has been illustrated by the difficulty encountered in negotiating carbon intensity reductions between the central government and local governments in order to achieve the national 40-45% targeted reductions by 2020. Moreover, there are no prescribed ways of meeting or implementing the carbon intensity targets at the local level, which still lack a standard form of measurement. Currently, China's municipal governments are seeking funding, market mechanisms and policy direction in order to further the transition to a low-carbon development pathway, but are constrained by limited direction about how to achieve such a challenging task.

Given this context, the purpose of the project was on developing further the knowledge base and tools to guide effective implementation in China's cities of low-carbon policies to conserve energy, reduce emissions

and improve living standards whilst strengthening economic, environmental and social sustainability. As such the project involved several key objectives:

- examine how low-carbon development is framed, understood and implemented in China's cities;
- develop a low-carbon energy and industrial development roadmap for the cities of Beijing and Tianjin including both the scope and scale of carbon emission reductions by 2020 and 2030; this involves mapping transition roadmaps to a low-carbon pattern of development under a variety of emissions peak and decline scenarios encompassing investment costs and required policy measures;
- explore what mechanisms and tools can assist policy makers and decision makers in guiding, monitoring and evaluating progress towards achieving their low-carbon targets; and
- lastly, examine what additional policy and market measures are required for China's cities to become not only low-carbon, but also sustainable and liveable.

For the Beijing study, both qualitative and quantitative methodologies were adopted. Firstly, the recent energy development of Beijing was analysed to identify the key factors driving increasing energy demand and their resultant environmental impact. Based upon research by the Energy Research Institute (ERI), the analysis uses IPAC modelling to quantitatively analyse the future energy and environmental development of Beijing, and forecast energy and emission scenario pathways, especially focusing on green, low-carbon, secure energy systems. The Beijing study also looks at the experience of other world cities, such as New York, Tokyo, London and Paris to provide a global context and reference for Beijing's energy and low-carbon development. Based upon the scenario outcomes, proposed strategies and policy recommendations for energy security development have been developed as an important reference for a technical roadmap as well as some suggestions on policy preparation and strategic planning for future energy demand and development in the city.

In contrast, the Tianjin study is based upon a combination of quantitative decomposition and backcasting analysis to map out the potential emissions reductions in each of the industrial sectors through to 2020. The required investment levels for implementing these industrial energy efficiency measures and technologies are also included. Backcasting is a common scenario analysis technique for determining future pathways when the future situation remains highly uncertain (Wilson et al. 2006). For a given figure, such as the 2020 emissions per unit of GDP target, various trajectories to 2020 were estimated or 'backcast', by making assumptions about the respective sector's emissions intensity. Two functional forms were used, the logistic function and the Gauss function, for the analysis of the sectoral emissions reductions and anticipated investment costs. The different results and trajectories for each of these functional forms are presented through the 2010-20 period. The trajectories are sensitive to the implicit relationships between several determinants, such as shifts in industrial structure, which makes the analysis more sensitive to changing economic structural relationships and parameters. The analysis also uses grey correlation analysis, which is an extension of principal component analysis to apply to data which may be non-linear and may contain irregularities or missing data points (Chen 2012). Grey correlation analysis is widely used in the Chinese literature for the analysis of such data. This analysis was primarily undertaken by the School of Environmental Science and Engineering at Nankai University.

The different methodological approaches for the Beijing and Tianjin study were chosen due to the divergent local conditions. Beijing is now considered as having a developed-status city with a medium to high income level, whereas Tianjin will attain this status by 2015. However, the two cities are starkly different with Beijing's economy and social status very similar to other advanced economies with a large services sector

and a heavy concentration of the best educational and health institutions in the country. A world city peer comparison was therefore adopted to complement the scenario analysis because the capital is leading the way in China. Furthermore, municipal leaders are seeking comparable global city models which can provide some direction and guidance for the current policy setting. In contrast, Tianjin remains an industrial city with significant investments in retaining its industrial, trade and logistics role in regional development. Because the city remains committed to an industrial future, an internal industrial analysis was deemed to be more relevant to local decision makers.

This report is structured in four parts. First, a review of the context of the low-carbon city movement in China is presented in Chapter 2. It begins with a discussion of the low-carbon concept and its implications for mitigating carbon emissions in an urban Chinese context including the role of a low-carbon economy as a catalyst for gradually shifting away from the existing approach to development. Second, a variety of low-carbon scenarios are developed for the cities of Beijing and Tianjin in Chapter 3. These pathways are based upon an analysis of industrial and energy scenarios for achieving a peak and decline in emissions for the two cities through to 2020 and 2030. Third, a comparative analysis of low-carbon city development through other global cities is provided in Chapter 4 together with an index system for assessing and monitoring progress towards low-carbon city status. The low-carbon city index system also provides a useful tool for guiding planning and decision-making towards the development of low-carbon cities. The fourth and final part reviews the key findings of the report, introduces several issues requiring further work and consideration, and includes some broader outcomes of the research project.

2. A Low-Carbon Roadmap for China's Cities: The Context

2.1 The low-carbon city development concept

The fundamental driver for making the transition to a low-carbon pattern of development in cities is the need to break the link between the rise in carbon emissions and economic growth. The World Bank (2012, xliii) defines low-carbon development as a pathway “that maximises low-carbon energy sources, enhances efficiency in delivering urban services, and moves to lower carbon intensity for a given unit of GDP”. Any definition of low-carbon urban development needs to acknowledge five critical considerations: (i) the level of development of the city; (ii) the existing carbon endowment of the city; (iii) whether the city is a carbon consumer or producer; (iv) the institutional capacity to respond in an efficient and effective manner; and (v) the speed of development. It is also important to understand the main drivers for a city's carbon emissions. These include a city's energy mix, economic structure, level of development, population size, urban form, transport and built infrastructure and climate, as well as its physical and resource endowments. Therefore, a low-carbon pathway needs to focus on the process of reducing emissions based upon each of these considerations. Moreover, to remain politically and socially acceptable, a low-carbon pathway needs to consider options that do not undermine economic development and liveability. Inherent in this discussion is that there is a close relationship between low-carbon development, sustainability and liveability. As noted, by the World Bank (2012, xliii) a low-carbon city is “above all, a sustainable, efficient, liveable and competitive city”.

The low-carbon concept has become quite popular amongst China's leadership especially at the city level. While the concept has often reinforced the same processes, actions and principles of ecological, social and economic sustainable development, Chinese scholars have adopted a locally sensitive definition which highlights for example: its structural rebalancing potential (Hu 2009, 2011, 2012); its potential for reshaping state, societal and industry ideology and behaviour (Gu and Li 2008); and, accommodation of rapid economic growth so long as resource consumption and carbon emissions are constrained (Jin 2008). Hu Angang (2009, 2011, 2012) added that the low-carbon city concept has much to offer China during the transition from a high-carbon economy to a low-carbon one, in particular for the development and utilisation of low-carbon energy, an increase in the urban greening rate, an expansion of natural gas penetration and widespread waste to resource recycling and reprocessing. Fu, Wang and Li (2008) similarly emphasised the transformative significance of the concept whereby a low-carbon city should realise technological innovation, lifestyle changes, the end of the current unsustainable socio-economic pattern of development and consumption whilst realising lower carbon emissions. Long, Bai and Liang (2007) adopted the WWF's “CIRCLE” approach to a low-carbon city. The CIRCLE principle calls for:

- a compact city that restrains urban sprawl (compact);
- individual actions promoting responsible consumption (individual);
- minimisation of the potential impacts of resource consumption (reduce);
- reducing the carbon footprint of energy consumption (carbon);
- maintaining the ecological and carbon sink function of the environment (land); and
- improving energy efficiency and the development of a circular economy (efficiency).

Xia (2008) emphasised the importance of low-carbon production and consumption in developing a low-carbon economy in the city. Whereas Gu and Li (2008) focused on the mode and direction of a low-carbon

city as requiring a blueprint for a low-carbon society and behavioural change from its residents. They also suggested that living standards should not be compromised by reducing carbon emissions, whilst Xin and Zhang (2008) emphasised the central role of low-carbon energy as a guarantee for achieving a low-carbon city. However, Zhuang (2007, 2010) noted that low-carbon planning, transport and buildings are the critical first steps for the transition to a low-carbon economy. A common argument in much of the Chinese literature is the important role of clean technology in realising a more sustainable and low-carbon pattern of development in China's cities (Feng and Yang 2010). Xu and Bai (2012) emphasised an additional four ingredients of low-carbon cities, namely: ecological, economic and social security; adaptation; strategic long-term planning; and a regional focus. The key challenge for China's cities will be keeping up with the rapid rate of economic growth and the even faster rate of urbanisation. Since 2004, the rate of urbanisation has exceeded economic growth which has exacerbated pre-existing problems in terms of the environmental, but also in terms of delivering quality cities (Chen, Liu and Tao 2013).

This brief summary of the Chinese literature on the low-carbon city concept illustrates how the concept is often viewed in China as an application of sustainability (WCED 1987) with an emphasis on the practical elements of a low-carbon economy. These elements often include economic structure, energy mix, industry, transport, buildings, technological innovation and lifestyles. While the objective of the low-carbon city concept in China is the need for a sustained reduction in carbon emissions and the development of a clean energy structure, there is an overriding consideration of sustaining urbanisation, rapid economic growth and reducing resource waste. As such, objectives such as reducing the energy intensity and carbon intensity of the economy are foremost in specific measures behind governmental objectives. A further consideration within the Chinese literature is increasing the city's involvement in clean production and realising new investment and economic opportunities. In other words, growth and industrial expansion will remain fundamental to developmental considerations. The key for low-carbon city development is ensuring that the ratio of energy consumption or carbon emissions to economic output is reduced. The second requirement of China's low-carbon city concept is resource efficiency or reducing the inputs (water, materials, land, labour, capital, etc.) whilst increasing the value of outputs. Many of these central concerns have been addressed in the earlier roadmap and indicator chapters, but they are only one step of many towards making the transition to a low-carbon economy.

2.2 Adjusting the pattern of development

Reflecting an accumulation of issues over 35 years of unprecedented economic growth, China now faces a complex set of problems – from over reliance on investment, intergovernmental fiscal imbalances, widespread corruption and the difficulty of reforming state-owned enterprises, to heavily indebted banks and local authorities and severe environmental pollution and land degradation (CSES 2010). This set of problems will sorely test the reform capabilities and authority of the new government under President Xi Jinping. The centrality of environmental issues in this mix is clear not only from the growing impact of global warming on China, but also from the extent of local pollution, as illustrated in the severe smog that blanketed Northern China in February 2013 and has recurred at times throughout the year.

The depth of the continuing environmental problems reflects the fact that China's emissions of greenhouse gases continue to increase rapidly, while emissions of particulate matter remain high. This remains so even

as the Government actively pursues policies, most recently in the current 12th FYP, to improve the quality of the economy and of economic growth through the introduction of clean technologies, to control energy use and to shift the structure of the economy towards the service sector. Given the scale and expected growth of China's energy use and emissions, the successful implementation of these policies is of immense and urgent importance to China and the world.

The November 2013 Third Plenary Meeting of the 18th Central Committee of the Chinese Communist Party ushered in a new round of 'opening up' and reform directed at this set of problems, and reiterating the need for structural change and strong measures to address the environmental issues, among others. The preparation of these new measures is reportedly led by three reformers: Mr Zhou Xiaochuan, longstanding Governor of the People's Bank of China; Mr Lou Jiwei, the new finance minister and Mr Liu He, Director of the Office of the Central Leading Group on Financial and Economic Affairs (Li and McElveen 2013).

The Chinese Government has for some time recognised the need to adjust China's development model to one that is 'socially and environmentally sustainable' and that contributes to maintaining a 'harmonious society', and in the process has set out to change China's economic structure. These goals continue to be reiterated in the 12th FYP with a commitment to slower and higher quality economic growth. The rising importance of these issues reflects in part the urgency for China to secure diverse energy supplies, reduce pollution and of the global need to reduce emissions. But another important factor is the growing recognition that China's long-run development will be definitively shaped by the low-carbon economy.

2.3 Cities in China's sustainable development

China's pattern of development remains heavily reliant upon resource intensive and low value added production and high levels of investment. This pattern of development has produced rapid growth over the past three decades, but it remains unsustainable. Rapid and unfettered growth has resulted in serious air, land and water pollution and degradation, biodiversity loss and high levels of waste across most of China and especially in the cities. Institutional and governance norms have exacerbated these negative outcomes and externalities, largely due to the presence of an 'ideology of economic growth' at the core of government. However, the deteriorating environmental quality, serious water, air and land pollution and apparent neglect of government has resulted in growing social concern and activism. In response, a string of top leaders have expressed concern about China's "unstable, unbalanced, uncoordinated and unsustainable" pattern of development (Wen Jiabao 2009) and that economic growth should not be pursued at "the expense of the environment. Such growth won't satisfy the people" (Li Keqiang quoted in Zhu 2013), as well as the need for tighter standards of environmental accountability to ensure that government officials "who make blind decisions that cause serious consequences due to negligence towards the environment must be held responsible – lifetime responsibility" (Xi Jinping 2013).

As most Chinese cities are expected to double the size of their built environments and supporting infrastructure over the next 15-20 years, there is an urgent need to avoid the risks and costs of carbon 'lock-in'. This is especially critical, argues Davis, Caldeira and Matthews (2010, 1330) because the "sources of the most threatening emissions have yet to be built". This is especially important in the energy, transport and housing sectors, which are rapidly expanding their energy use demands due to rising living standards. For example, between 2005 and 2010 Chinese cities added 33 new airports to the existing 142. A further 55 airports are to be built during the 12th FYP, bringing the total number to 230. While investments in urban infrastructure (buildings, bridges and roads) typically have 40-year lock-ins, decisions regarding urban land

planning and form typically have over 100-year lock-ins. Therefore there is an urgency linked to developing low-carbon cities in China.

It is widely argued that spatial growth patterns are related to carbon emissions. The World Bank (2012) argued that the urban “built form is highly durable, largely irreversible, and very costly to modify”. The low density urban sprawl that characterises most Australian and North American cities, results in long commutes generally reliant upon private vehicles, large and inefficient homes and poorly allocated and inefficient infrastructure. While many Chinese cities are generally high density, during the past decade much of the urban growth around cities has been driven by the financial incentives of land sales which are driving urban sprawl and starting to undermine the initial advantages of higher density cities.

Why is urbanisation related to low-carbon development? Firstly, a generally accepted mantra in China has been that urbanisation equals economic development and that a higher rate of urbanisation would generally reflect a higher level of development. It was therefore assumed that the ongoing rapid urbanisation of the past thirty years was a *fait accompli* and that it was expected to play a critical role in sustaining economic growth for the next two decades. The government had forecast the cost of accommodating a further 400 million people in its cities by 2050 would require RMB40 trillion in investment. This investment requires massive quantities of concrete, steel and bricks to build the required infrastructure of roads, buildings, railways, power stations and so on.

Local governments warmly embraced urbanisation because land transfers and property developments have been the main source of local revenues since the 1994 fiscal reforms transferred most tax receipts to the central government. Putting to one side the issue of whether ongoing urbanisation is sustainable, one critical question remains the growing levels of local debt and borrowing. The urbanisation issue cannot be resolved until the government reforms two closely interconnected issues, namely fiscal allocations and tax revenues as well as the *hukou* residential system of determining access to social services, such as health, education and pensions. This discussion is elaborated upon in Appendix 1 in a discussion of urban layout, planning and design.

2.4 The changing policy context

2.4.1 The national plans

It is necessary to frame low-carbon city development within the context of contemporary China's socio-economic development. Broadly there are four main policy objectives of the central government as expressed in the 12th FYP and other official statements: sustained economic development, structural rebalancing, building a harmonious society, and green development (see Table 2.1). These national policy objectives then need to be understood and implemented as actions by local governments, such as Beijing and Tianjin.

Table 2.1 National policy objectives

National policy objectives	Local government actions
Economic development	• A sustained rate of urbanisation is the key driver for rapid economic growth • Promote regional economic development • Avoid exceeding natural resource limits and environmental capacity
Structural rebalancing	Adjust the structure of the economy by moving towards: • Lighter and cleaner industry • Upgrading industrial and manufacturing capacity

	• Developing services as a strategic sector • Strategic and emerging new industries reliant on high technology and higher value added • New financial and technical resources to foster innovation and creativity
Harmonious society	• Increase levels of development in all regions • Build sustainable neighbourhoods • Raise household consumption • Enhance quality of life
Green development path	• Improve energy and water efficiency • Reduce the intensity of carbon emissions, major pollutants and energy consumption as a unit of GDP • Ensure sustainable urban development

The shift towards low-carbon city development is on solid institutional ground with the 12th FYP, which is committed to adjusting the development model:

- towards a more 'socially and environmentally sustainable' path;
- to contribute to maintaining a 'harmonious society';
- to promote growth driven by welfare enhancement rather than low value added industrialisation;
- to drive change in China's economic structure; and
- to achieve slower but higher quality economic growth.

One of the main drivers for the move towards a more sustainable pathway is the realisation that fixing the problem rather than remediating it is going to be a lot cheaper. Other drivers are also playing an important role in the change. Namely, that low-carbon city development can:

- sustain growth and build globally competitive cities;
- reduce resource use, pollution and emissions;
- minimise rising health costs;
- reduce resource pricing pressures;
- protect the natural resource base and ensure future resilience; and
- avoid the adverse impact of anthropogenic climate change.

2.4.2 Energy intensity targets under the Plans

To ensure implementation of national policy objectives, the national government typically sets a range of mandatory and guiding targets for local officials to meet. Several of these targets specifically relate to the development of a low-carbon city. The 11th FYP (2005-2010) "essentially met" the 20% improvement in energy intensity target (energy use per unit of GDP) with a 19.1% reduction, and the renewables share of energy use rose to 8.6% by comparison with the target of 10% .

The 12th FYP includes two 'binding' targets in the energy sector: a 16% reduction in energy intensity by 2015 and a rise in the share of non-fossil energy sources in total energy use from 8.6% to 11.4% by 2015. For the first China has announced a cap on total energy consumption for the end of the Plan period of 4 billion tonnes of standard coal equivalent (btsce). This is 23% (or 4.3% per annum) higher than the 2010 figure, and only 10.6% higher than the announced 2012 figure. The Government has also announced a cap of 6.15 trillion kilowatt hours (kWh) on total electricity consumption for 2015, which is 46% higher than the 2010 level.

For 2020 the Government has committed to a 40% improvement in energy intensity over 2010 levels and a rise in the share of non-fossil fuels in total energy use to 15%. In terms of emissions, China is committed to achieving a 40-45% reduction in CO₂ emissions per unit of GDP by 2020. The energy use and emissions targets in the 12th FYP have been broken down into detailed targets at the provincial level, and provincial leaders are increasingly being held responsible for ensuring that they are achieved.

2.4.3 Pilot programs and other initiatives: Low-carbon cities

A critical component of tackling the challenges of China's high pollution levels, rising energy use and carbon emissions is rebalancing the pattern of development in China's cities. China's cities are at the forefront of this transition to a more sustainable pattern of development given their central role in consumption, resource use and pollution, but also in their capacity for addressing climate change, as engines of innovation, wealth creation and their scale of production. In this context cities present both opportunities and challenges. An important part of this process is the development of low-carbon cities and pilots, such as Beijing's, which are leading by example.

In terms of low-carbon cities, NDRC (2010) launched a pilot low-carbon program for five provinces and eight cities, and extended this by adding more than 20 other cities in 2013. The objective of these city pilot programs is to lay the groundwork for a national low-carbon assessment, planning and management system which includes guidelines on reducing energy use and carbon emissions in industry, society and the economy. The outcome of the pilots will determine how sustainable development can be applied to other regions and cities throughout China and, perhaps, around the world. Currently, they remain at the trial stage and are encountering a range of implementation challenges. As a result it is still too early to know which, if any, of them will provide a good model of low-carbon development. In many cases the pilots are in greenfield sites (Sino-Singapore Binhai, Shanghai Dongtan, Wuxi, Tangshan), rather than attempting at this stage to transform activities in existing cities. In some others, the pattern of development remains largely unchanged, with a "business card" approach adopted as basis for inter-city competition and for grand announcements mainly focusing on attracting investment in specific areas such as renewables, clean technologies, energy conservation, environmental protection, biotechnology and the expansion of mass public transport systems.

At the city government level, there generally remains limited capacity for adopting a systematic and integrated sustainable economic development framework, especially for pursuing extensive structural change from the industrial to the service sector. There has been considerable difficulty in negotiating the local level implications of the national 40-45% carbon intensity targets for 2020, and there are no implementation pathways for these targets at the local level, and standardised forms of measurement are yet to be developed. City-based long-term energy targets remain based on business as usual in most cities, with some notable exceptions (e.g. Beijing versus Shenzhen). Arriving at local caps for total energy use, and for total coal use, is also likely to prove difficult. In general, local governments are searching for funding avenues, market mechanisms and policy direction to commence the transition to a more sustainable development pathway, but are being provided with little overall direction in how to achieve these ends.

Table 2.2 provides a summary of several cities and regions that have adopted the low-carbon concept and the actions they are implementing. The table brings out, in a limited way, the diversity of objectives being pursued and the activities being carried out, under this general rubric. Despite the uneven experience of low-carbon urban development in China (Liu 2010), these cities offer a basic reference point for other cities and regions. It is critical that the lessons, successes and failures experienced in these cities and regions in implementing low-carbon strategies, policies and regulatory measures are shared, and the lessons learned.

Table 2.2 Overview of domestic low-carbon urban construction

City	Development mode	Planning strategy
Shanghai	Emphasis on comprehensive low-carbon urban construction, planning and construction of Chongming Island Dongtan Eco City and Nanhui New City.	Focus on the development of new energy, energy grid, green buildings, fuel-cell buses, Chongming Island Dongtan Eco-city (currently on hold) and Nanhui New City.
Baoding	Construct a low-carbon city based on clean industry expansion.	Under the slogans "China Power Valley" and "Solar City", support has been available to local industries manufacturing wind turbines, energy efficiency appliances, PV cells, battery storage, transmission and electric power automation systems. Low-carbon city construction commenced with ecological construction and then the establishment of a low-carbon city traffic system.
Beijing	Both city-wide plans and pilot programs such as the Changxindian low-carbon community.	For details of the overall low-carbon city plans see Chapter 3. The Changxindian low-carbon community is a greenfield development for a population of 70,000 on a 500 hectare site.
Tianjin	New low-carbon eco-city construction with pilot Sino-Singapore Tianjin Eco-City.	Build new circular low-carbon industrial system, safe and healthy environment, natural and beautiful urban landscape, convenient green transportation system, circulation and efficient utilisation of resources and energy system, and liveable eco-community model.
Tangshan	Low-carbon eco-city construction in Caofeidian Eco-city New Area.	With the cooperation of Chinese and Western experts, the new solutions of city form by combining different ideas and knowledge: guided by the index system of comprehensive integration planning, focused on exploring recycling economy, energy, water.
Shenzhen	Emphasis on comprehensive low-carbon urban construction. Guangming New Area as pilot.	Guangming New District's low-carbon construction includes optimising the structure of urban space, perfecting green municipal planning, guiding low-carbon industrial development, establishing a green transport system and developing green building.
Nanchang	Construct a low-carbon city prioritising industry.	Build a low-carbon eco-industrial system in LED lighting, solar PV and service outsourcing industry. Aim to build Nanchang as a world-class solar PV industry base.
Wuhan	Emphasise comprehensive low-carbon urban construction.	Explore low-carbon energy, low-carbon transport, low-carbon industrial development model with World Bank and to establish and promote resource conservation and a low-carbon economic development policy system.
Changsha	Construct a low-carbon industrial city.	Develop a model low-carbon economy city focusing on new energy vehicles, solar energy utilisation, renewable energy, energy-efficient buildings and LED green industry development.
Dezhou	Construct a low-carbon industrial city.	Focus development on solar energy equipment manufacturing and build a "Sun Valley".
Shenyang	Emphasise demonstration-type low-carbon urban construction.	Develop the Shenyang Economic and Technological Development Zone and Shenyang High-tech Park with UNEP.
Zhuhai	Low-carbon urban construction is based on low-carbon buildings and low-carbon communities.	Promote the construction of "green community", to popularise the concept of low-carbon lifestyle and attract carbon sequestration technology manufacturers.
Jilin	Focus on industrial restructuring.	"Jilin City low-carbon roadmap" was developed by the Chinese Academy of Social Sciences to explore structural change in heavy industry.
Xiamen	Emphasise comprehensive low-carbon urban construction.	Explore low-carbon development model from the three areas of transportation, construction and production, whilst developing LED lighting and solar architecture sector.
Hangzhou	Emphasise comprehensive low-carbon urban construction.	Proposed 50 "Low-carbon Deal" for the city to create so-called "Six in One" low-carbon economy, buildings, transport, lifestyle, environment and society.
Guiyang	Emphasise comprehensive low-carbon urban construction.	Building low-carbon urban transport systems and green building system. Use financial subsidies to promote LEDs in residential buildings. Guide the public to accept a low-carbon lifestyle and consumption patterns.
Wuxi	Emphasise comprehensive low-carbon urban construction.	Planning to establish six low-carbon systems, namely a low-carbon: regulatory system, industrial system, urban construction system, transport and logistics system, lifestyle and cultural systems, carbon sinks and utilisation system.
Chongqing	Focus on industrial restructuring.	Reduce the proportion of energy-intensive industries and build a modern service industry and advanced manufacturing industrial structure and gradually form a low-carbon industrial group.

2.4.4 Emissions cap and trade programs

The 12th FYP foreshadowed China's intention to gradually develop carbon markets, and as a result eight pilot carbon trading schemes have been announced, in the cities of Beijing and Tianjin, as well as Shanghai, Shenzhen and Chongqing, and in two provinces Hubei and Guangdong. The Guangdong Province scheme commenced in December 2013 and provides for a cap on emissions and trading rights for large polluters. These pilot schemes are clearly experimental, with for example quite different coverage and rules of operation, but are seen as steps towards a national emissions trading scheme in China in the medium term. The Shenzhen market began operating in June 2013, followed in November 2013 by Shanghai and Beijing's markets, and the eight markets are expected to come on stream progressively through to 2015. Jotzo et al. (2013) surveyed 86 China-based experts on carbon markets and carbon pricing, and found an expected average prices of RMB32/t (A\$ 5.5/t) in 2014, RMB41/t (\$A7/t) in 2015 and RMB53/t (A\$9/t) in 2015. While the future development of these markets remain uncertain, these seem likely to build upon and complement the establishment of low-carbon cities in Beijing, Tianjin and elsewhere.

2.4.5 Transport

China's different levels of government continue to take a wide range of initiatives in relation to both public and private modes of transport, and these will be critical to implementation of low-carbon programs. In addition to building up public transport, several city governments have resorted to capping the number of annual vehicle registrations, to curtail the rising popularity of passenger vehicles. Beijing, Shanghai and Guangzhou as well as other cities have introduced caps combined with lotteries or auction systems to restrain the allocation of new vehicle registrations. The adoption of the registration cap was a significant U-turn from an earlier policy of promoting the local motor vehicle industry and the local sales of passenger vehicles. The worsening congestion, urban grid lock, air pollution and road construction costs forced the municipal governments to change position.

Continuing attention is being given to new motor vehicle technologies, especially electric vehicles (EVs). Despite the initial obstacles confronting the electric vehicle sector, the Beijing government has continued to introduce supportive policies and programs. The city has set a target of 50,000 EVs in the city by 2015. This figure includes 30,000 private vehicles, 8,000 hybrid or electric buses and 10,000 EV taxis or government fleet vehicles. A subsidy scheme for buyers of new energy vehicles, including EVs, was introduced in 2010 with rebates of RMB60,000 per vehicle on top of the central government's RMB60,000 subsidy. This subsidy scheme is expected to be gradually phased out and replaced by government funding of research and development into new EVs through to 2020. Other support for new EVs includes exemptions from the cap on registrations and licence plate restrictions. Despite ambitious EV targets, China is unlikely to meet the national and city targets due to structural weaknesses in the auto sector (Sweeny et al. 2011).

2.5 New urgency to an old imperative: Clean air

In early 2013, China's leadership was confronted with the most visible environmental cost of increasing industrialisation and its heavy reliance upon coal for energy. For more than a week, the national capital was immersed in severe smog with local commentators describing the situation as an "airpocalypse". Air quality readings literally went off the charts (government air quality stations only measure 0-500) with PM2.5 recorded over 775 ppm. It came as no surprise then when the World Health Organisation (WHO 2013) ranked Beijing 1,054th, out of 1,100 international cities, in air quality. In a separate study (Lim *et al* 2013), the WHO claimed that poor air quality caused 1.2 million deaths in 2010 in China. In 2012, an estimated

8,572 premature deaths occurred in Beijing, Shanghai, Guangzhou, and Xi'an – four major Chinese cities – due to high levels of PM2.5 pollution, and caused US\$1.08 billion in economic losses, according to research by Greenpeace and Peking University's School of Public Health (2012).

It is estimated that local industry and power plants are responsible for around half of the city's pollution, transport around a quarter and regional pollution from neighbouring provinces for a further quarter. However, these figures vary considerably depending upon the weather.

Beijing has decided to implement control measures on air pollution aiming for a specific target of PM2.5, which requires strict controls on coal-based and energy-intensive activities and large energy consumers in Beijing. To this end, the energy system of Beijing has an important role to fulfil and is explored in Chapter 3.

While the air pollution problem and the government's responses were not new, the severity of the problem forced the government to tighten regulations, better monitor implementation and speed up air quality targets and standards. For example, by 2017 emissions of key air pollutants are to be reduced by 30% per unit of GDP in a number of polluting industries. However, there were no details for the baseline figures so it is assumed the program is still under negotiation. PM2.5 will be targeted at the regional level in and around the three pilot areas of Beijing, Tianjin and Hebei area, the Yangzi River delta and Pearl River delta. In October 2012, China introduced a FYP for air pollution control. In addition, under the 12th FYP China has implemented obligatory sulphur dioxide emissions and nitrogen oxide emissions targets of 8% and 10% reductions, respectively. However, it will be the cap in coal use that will probably play the biggest role in improving air quality. The region is considering introducing restrictions on industrial capacity and a major reduction in coal use of around 100 mt by 2015. The three jurisdictions of Beijing, Tianjin and Hebei consumed around 375 mt of coal in 2012, but it is Hebei province, which is China's main steel producer, which is critical because it consumed about 300 million tonnes of coal in 2012 (Stanway 2013). According to the president of the World Bank, Kim Jim Young (Mufson 2013), Premier Li Keqiang has requested assistance from the bank to develop “a plan to come up with clean, liveable cities. The Chinese want to do it. This is a huge issue with them.”

The implementation of stricter air quality controls ensures three things. First, a reduction in absolute emissions. Second, polluting companies need to internalise the environmental externalities of their emissions. Third, energy produced by polluting and carbon-intensive coal power plants will be more expensive. Finally, it should limit the expansion of energy-intensive polluting industrial facilities.

3. Low-Carbon Roadmaps for Beijing and Tianjin

3.1 Background

The global environment and climate change have become critical issues in recent years with greater international significance, particularly in terms of future economic and sustainable development. The international community, including developing countries, has begun to invest in addressing this problem, with climate change discussion becoming very heated in setting and implementing mitigation targets. As noted in Chapter 2, China has introduced a comprehensive range of policy measures aimed at addressing these issues, including the adoption of energy efficiency standards and targets, carbon intensity targets, caps on coal consumption, pilot emissions trading schemes and even a trial carbon tax in Guangdong Province.

Recently the national emphasis on low-carbon and green growth offers a supportive background for the two cities of Beijing and Tianjin to attain a green, low-carbon and secure energy system. As such, the first part of this chapter provides some background on the socio-economic, industrial and energy structure for Beijing and Tianjin. This is followed by an analysis of each city's low-carbon industrial and energy pathways. For the city of Beijing this involves a feasibility study of capping total energy use and peaking carbon emissions at the earliest opportunity. The resultant Beijing energy security and low-carbon development pathway study is based upon targets for sustainable development addressing climate change, reducing air pollution and becoming a world city. The Tianjin study maps out a low-carbon pathway for the city's industrial sector using quantitative decomposition and backcasting analysis to determine the required emissions reductions and investment levels for implementing these industrial energy efficiency measures and technologies. Both studies underscore the argument that such low-carbon pathways are not only necessary, but attainable from an economic, technological and policy perspective.

3.2 A tale of two cities

This section introduces the economic structure, industrial development, energy mix and carbon emissions of Beijing and Tianjin. The two cities are located 140 km apart in northern China and share an inter-connected history that has steadily grown during the past century of increasing global trade. Today the outer suburbs of each city are already touching with a regular 30-minute rapid train service ensuring their increasing inter-dependency.

3.2.1 Socio-economic background

Beijing is the capital of the People's Republic of China and the nation's political, cultural and educational centre. The metropolis is governed as one of the four directly-controlled municipalities under the central government (the others being Tianjin, Shanghai and Chongqing). Beijing is one of the most populous cities in the world and the second largest Chinese city by urban population after Shanghai. Beijing is not only a national capital, but an emerging global city and aspiring liveable city.

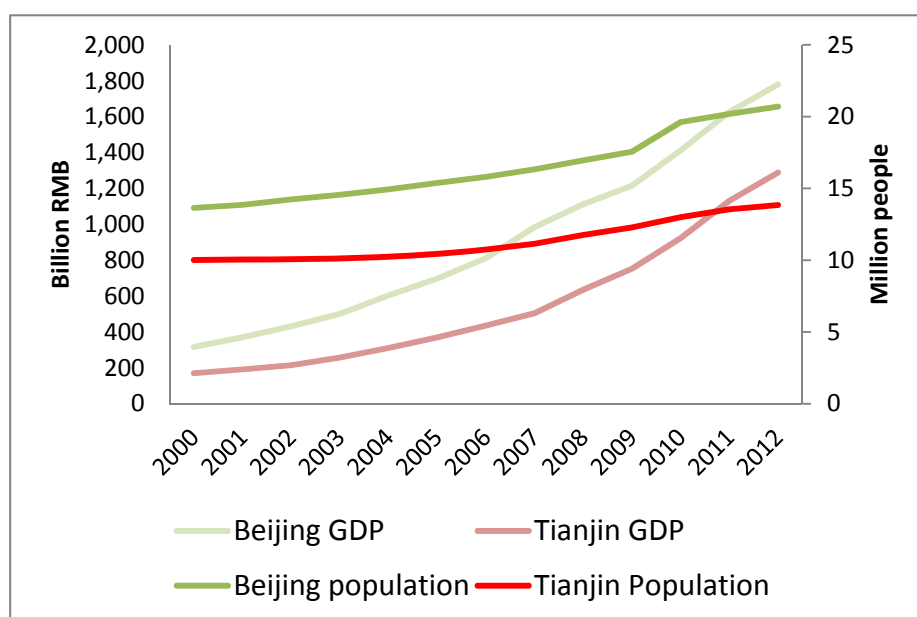
Tianjin is the largest coastal city in northern China. It is an established major industrial city and an important industrial base on China's northern plains. It is governed as a directly-controlled municipality under the direct administration of the central government. In terms of urban population, Tianjin is the fourth largest city in China (after Shanghai and Beijing and Guangzhou). Since the mid 19th Century, Tianjin has been a major seaport and trading gateway for Beijing. Tianjin aims to retain its status as a key international port and build upon its role as the centre of economic in the north whilst becoming an eco-city.

The projections for socio-economic development in the following sections is partly sourced from each city's respective 12th FYPs.

By 2012, Beijing's annual growth grew at around 9.5% with GDP exceeding RMB1,780 billion with per capita GDP of RMB87,091 (US\$14,000). In 2013, the city set itself a GDP growth target of 8%. In the same year, Tianjin's GDP exceeding RMB1,289 billion with per capital GDP of RMB93,113 (US\$14,970) (see Figure 3.1).

In the period of the 11th FYP, urban resident per capita disposable income in Beijing increased by 9.2% in real terms, 2.4 percentage points lower than the average increasing ratio of the 10th FYP. Rural resident per capita income in real terms grew by 9%, 0.9 percentage points lower than the average increasing ratio in the 10th FYP.

Figure 3.1 GDP and population for Beijing and Tianjin, 2000-2012



The key driver for GDP growth in Beijing between 2000 and 2012 has been the services sector (tertiary industry) as clearly illustrated in Figure 3.2. In 2012, tertiary industry increased to RMB1,359.2 billion and contributed to 76% of economic activity in the city. While secondary industry has grown steadily through this period from RMB103.3 billion in 2000 to RMB405.8 billion in 2012, its share of GDP has been steadily declining vis-à-vis growth in services. Prior to hosting the Olympics in 2008, Beijing has closed down and moved heavy, energy-intensive and polluting industries outside the city's jurisdiction, whilst retaining and attracting higher value added industries. During the past decade the share of Beijing's primary industry (0.8%) to GDP has continued to gradually decline to be RMB15 billion in 2012.

In 2011, Tianjin's industrial output exceeded RMB1 trillion (see Figure 3.2). Industrial expansion was the key driver for the city's GDP during the 11th FYP with total industrial output experiencing an average annual increase of 21.5%.

Tianjin's industrial policy was to build a high-quality and high-technology industrial structure. Tianjin focussed on eight industrial sectors including aerospace, petrochemical, equipment manufacturing, electronic information, biological medicine, new energy and new materials, light industry and textile,

defence-related science and technology and defence. As a result, by 2010, above-scale industrial production value reached RMB1.5 trillion, accounting for 91.6% proportion of the city's industrial value. The high-tech industries accounted for 30.6%, and became one of the six comprehensive national high-tech industry bases in China.

Figure 3.2 GDP structure for Beijing, 2000-2012

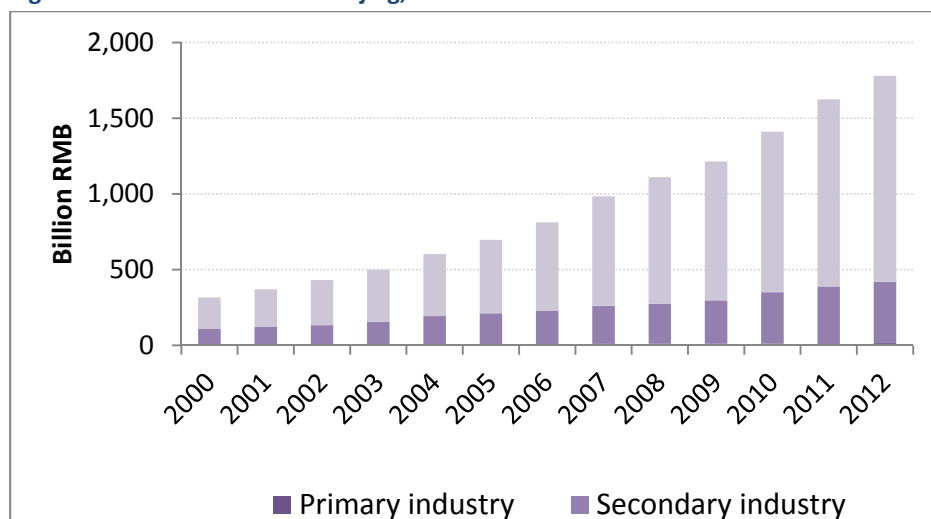


Figure 3.3 GDP structure for Tianjin, 2000-2012

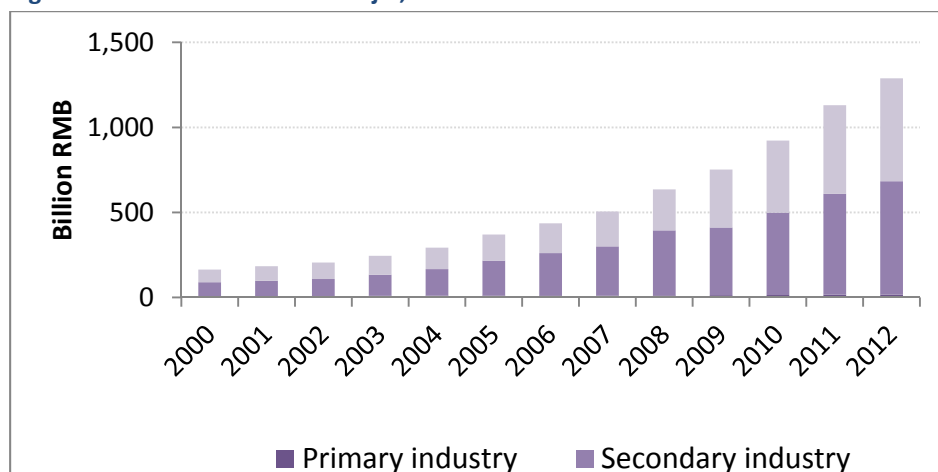


Table 3.3 shows the comparison energy consumption between Beijing and Tianjin from 2009 to 2011. The picture emerging from this data reveals a tale of two very different cities. In Tianjin, energy consumption has grown at a rapid pace with over 16% year on year growth in 2010 and then nearly 12% growth in 2011. Most of this growth has been driven by the rapid expansion of the industrial sector, especially heavy industry which makes up over 75% of value added. In contrast, Beijing's energy consumption growth has slowed considerably and while industry still consumes a significant proportion of energy, the services sectors growth has resulted in strongly improving energy intensity figures which have dropped from 0.54 in 2009 to 0.43 in 2011. The growth in energy consumption by Beijing residents is concomitant with rising incomes.

The number of permanent residents in Beijing reached 19.62 million in 2010, including a permanent floating population of 7.05 million. The urban population was 16.86 million, 86% of the permanent residents, with a

rural population 2.76 million. The registered “local” population of the city was 12.58 million with 4.96 million households. The annual increasing ratio of the permanent population came to 11.8% in 2010.

Table 2.3 Energy situation in Beijing and Tianjin, 2009 to 2011

Year	2009	Tianjin 2010	2011	2009	Beijing 2010	2011
Final consumption of energy (1,000 tce)	5652.62	6574.87	7346.13	6570.3	6954.1	6995.4
Energy consumption elasticity	0.58	0.93	0.7	0.38	0.57	0.07
RMB10,000 GDP energy consumption (tce)	0.84	0.74	0.71	0.54	0.49	0.43
Energy structure %						
Primary industry	1.4	1.4	1.4	1.5	1.4	1.4
Secondary industry	69.1	71.5	73.1	38.7	39.2	35.6
Tertiary industry	16.9	16.1	15.3	42	41.7	44.3
Households	12.5	11	10.3	17.8	17.7	18.7

The industrial added value of Beijing was RMB270.16 billion in 2010, in which value added of industrial enterprises above designated scale increased by 15%. Among the industrial enterprises above designated scale, the value added from high-tech and modern enterprises increased 15.1% and 16.3%, respectively. In the 11th FYP, city-wide industrial added value increased on average by 9.1% annually. The yearly index of chemical and plastics industrial economic benefits was 233.96%. Transportation industry enterprises realised a profit of 16.95 billion, an increase of 61.2%. Industry power generation, generation and supplying of thermal power realised a profit 22.07 billion, an increase of 43.4%. The medical products industry realised a profit of 5.6 billion, an increase of 17.9%. The industry of telecom equipment, computer and other electric equipment manufacture realised a profit of 7.6 billion, an increase of 11.8%.

In 2010, the traffic mileage of Beijing was 21,201 km, among which highway mileage was 903 km, and urban road mileage 6380 km. At the end of 2010, city-wide buses operated 713 lines with 18,743 km in total and ran 22,000 buses for 5.04 billion passengers. Mass transit operated 14 lines with 336 km in total and ran 2463 trains for 1.84 billion passengers. The annual freight turnover of Beijing was 51.18 billion ton km and passenger turnover was 132.69 billion person km. By the end of 2010, city-wide motor vehicle ownership totalled 4.809 million cars. From a traffic energy efficiency and emission perspective, Beijing's per capita motor vehicle emission in 2010 was at a similar level to western countries. However, the number of motor vehicles per thousand persons in western countries was 600-800 cars, while Beijing's was 220 cars. This indicates that the emissions per car in Beijing were far higher than in western countries.

3.2.2 Urban form

Beijing

Beijing has grown with a combination of new residential satellite cities as well as the establishment of six cutting-edge industry functional areas and the Zhongguancun National Innovation Demonstration Zone. Together with the expansion of expressways and the metro subway system into suburban areas, growth corridors have formed along nearly all compass points to the west, north-west, east, south-east and south of the city.

By the end of 2010, the urban civil building architecture general area was 644.99 million m². This included: a household area of 393.44 million m² or 61.6% of the urban civil building architecture general area; a public

building area of 247.68 million m² or 38.4% of the urban civil building architecture general area (of this, big scale public building was 82.10 million m² or 35.3% of the urban civil building architecture general area); and a rural civil building architecture general area of 0.28 billion m² of which household area was 0.22 billion m² or 80% of the rural civil building architecture general area. In 2010, the city-wide energy consumption of urban civil building was 20.42 million standard tons of coal; 29.6% of the general energy consumption was 69.54 million standard tons of coal for the whole city. In 11th FYP, the construction industry annual value added increased by 11.3% on average, 3.2 per cent lower than in the 10th FYP.

In 2010, the service industry value added was RMB988.9 billion (excluding the traffic industry). In the 11th FYP, the accumulated social consumption retail was RMB2,331.52 billion. By the end of 2010, 1592 enterprise had opened in the Beijing Economy Technology Development Zone, generating a general income of 350.0 billion. The number of employees working in research and development activities was 0.26 million, expenditure on R&D was 75.8 billion, equal to 5.8% of GDP (2012); and the number of yearly inbound tourists was 4.901 million, 18.8% more than the previous year.

An important shift in restructuring Beijing's economy has seen investments in the service sector and consumer spending become the driving force behind local economic growth.

Tianjin

As a large established industrial city with a shortage of natural resources, Tianjin began to develop a circular economy relatively early. In the mid 1980s, Tianjin implemented a strategy of "industrial eastward shift" in an attempt to optimise the city's industrial layout. In 2007, the city established a special fund to support the development of a circular economy in 2007, which included 41 specific economic and technological development projects across the city.

At the same time, the municipal government committed itself to developing a circular economy by funding six national and 39 municipal recycling economy pilots and a number of circular economy industrial chains. These zones and industrial projects not only contributed to the industrial transformation of the city and attracted additional investment in the sector, but also laid the foundation for low-carbon development of the city.

3.2.3 Energy use and emissions

According to the IPCC's Fourth Assessment Report (2007), the burning of fossil fuels is the main source of increasing greenhouse gases (GHG). In 2004, carbon dioxide emissions resulting from fossil fuel combustion accounted for nearly 95.3% of total emissions globally. China, like most nations, continues to rely heavily upon the combustion of fossil fuel for energy. Energy consumption therefore acts as a proxy for carbon dioxide emissions. In 2010, Tianjin's emissions per unit of GDP were double those of Beijing.

According to a World Bank report, in 2010, Beijing and Tianjin's carbon intensity was 1063 and 2316 tons/million U.S. dollars, respectively. In the same year, Beijing's and Tianjin's carbon emissions intensity ratio was also about 2. Therefore, the energy consumption can indirectly represent urban carbon emissions.

From 2009 to 2011, the energy consumption per 10 thousand GDP in Tianjin (tce) was 0.84, 0.74, 0.71, respectively; the energy consumption per 10 thousand GDP in Beijing (tce) was 0.54, 0.49, and 0.43,

respectively. In general, the energy consumption per 10 thousand GDP in Tianjin is approximately 2 times of Beijing's, which indicates that carbon emissions intensity is much greater than Beijing's.

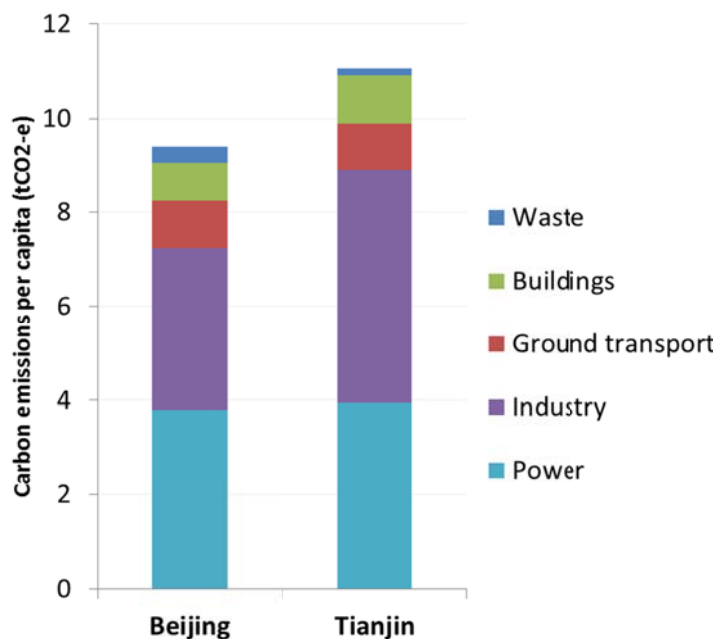
Through the analysis of the table above, we can see that Beijing has the tertiary industry as the leading industry, accounting for more than 70% of the city's GDP. Secondary industry accounted for only about 23% of the city's GDP, in which industry accounted for about 20%. Tianjin has the secondary industry as the leading industry, accounting for more than 52% of the city's GDP, in which industry accounted for about 48%. Tertiary industry is only about 45% of the city's GDP; the value is almost half of Beijing tertiary industry's GDP. And in Tianjin, the industrial output structure, the proportion of heavy industry is as high as 80% or more. The higher the proportion of heavy industry, the greater the energy consumption, and the more carbon emissions. This is different from Beijing who is dominated by tertiary industry, whereas Tianjin is dominated by secondary industry creating higher carbon emissions than Beijing.

In addition, studies have shown that population factors affect carbon emissions. Take 2010 as an example. When Beijing's resident population was 1961.9 million, the resident population density was 1195 people/sq km. In the same year, Tianjin's resident population was 1299.29 million and the resident population density was 837 persons/sq km. Although the resident population and population density in Beijing is slightly larger than Tianjin's, Beijing's carbon emissions intensity in 2010 was far less than the carbon emissions intensity of Tianjin. This indicates that for Beijing and Tianjin, population is not the key factor contributing to carbon emissions, at least not the main one.

It is believed that the most important factor that affects the quantity of the carbon emissions in Beijing and Tianjin is the industrial structure of the two cities. Therefore in the development of a low-carbon city evaluation index system in these cities, we need to take into account the economic and social status and characteristics of their industrial structure, and set up appropriate evaluation indicators.

According to World Bank (2012) figures, by 2006 the per capita CO₂ emissions (tsce) in Beijing (9.7) and Tianjin (11.1) had already surpassed those in other global cities such as New York (7.9), London (6.2), Paris (5.2) and Tokyo (4.9) (Figure 3.4). The carbon intensity of Beijing and Tianjin's respective economies were 1,063 tsce/\$US1 million and 2,316 tsce/\$US1 million, or more than six times levels in New York, London and Tokyo. The explanation for this discrepancy is mainly due to the different economic structures, levels of industrial development, technological innovation and energy mix found in these cities (Xu, 2002; York, Rosa and Dietz 2003; Zhu et al. 2009; Liu et al. 2009; Liu and Liu 2010; Xiao 2012).

Beijing, as an energy consuming Global City and due to limited energy resources (so far no mineable workable reserves of oil and natural gas), has an energy supply that is highly dependent on imports from outside. Therefore, it needs to import its energy supplies from other provinces for an energy demand of 94% coal, 67% electric power, 100% natural gas and 100% raw oil. For the electric power, besides local generation, there is still a large amount imported from the North China Grid; natural gas comes from the Shangganning gas field and Huabei oil field, raw oil is also fully dependent upon importation from other provinces; and raw coal mainly comes from the provinces of Shanxi and Inner Mongolia. While Beijing is heavily reliant upon energy imports, energy manufacturing and industrial value adding continue to operate in the city. For example, thermal power generation, heat supplies and oil refining. In addition, the city exports some oil and petroleum products.

Figure 3.4 Carbon emissions per capita (tCO₂e) in Beijing and Tianjin, 2012

Source: World Bank 2012, xlv.

In recent years, the yield of raw coal and coke of Beijing has declined (with the annual average yield falling by 9% and 14% respectively). Driven by traffic demand in Beijing, the demand for petrol oil obviously keeps increasing (with annual average yield rising by 7%) and power generation is also increasing relatively slowly (with annual average yield rising by 4.6%). Looking at the production sale ratio of main energy in Beijing, the supply of coal, coke, petrol oil and power is still far behind the consumption demand, especially in primary energy such as raw coal, raw oil, natural gas and power generation.

While keeping the economic development speed in Beijing at a certain level, in 2010 the energy consumption general amount was up to 69.541 million standard tons of coal, which comprised coal consumption 26.346 tons (general amount), natural gas 7.48 billion m³, imported electric power 56.56 billion KWh and product oil 10.016 million tons. GDP energy consumption per thousand RMB was 0.582 standard tons coal (calculated at 2005 prices), and energy efficiency was the highest in China. With regards to changes in the energy consumption structure of Beijing, compared with 2010 and 2005, the percentage of coal decreased from 34% to 26%, the percentage of petrol oil increased from 2% to 2.5%, the percentage of kerosene increased from 4.8 to 6%, the percentage of natural gas percentage increased from 7.7% to 15%, the percentage of electric power (including imported electric power) increased from 19% to 24%. One observation is that the energy consumption proportion excluding coal increased from 66% in 2005 to 74% in 2010, which indicates that the energy consumption structure of the industries in Beijing has effectively shifted towards a cleaner direction.

As mentioned earlier in this report, the environmental costs of China's rapid growth have been significant. Neither Beijing nor Tianjin have escaped the environmental externalities of their industrialisation and demand for private motor vehicles and new housing. Moreover, it is increasingly evident that neither city can improve the lifestyle and quality of life of the populace without serious tackling deteriorating environmental quality locally and regionally. This last point has been highlighted by the air pollution problem, but is equally important for water quality, food safety and energy security.

In the years leading up to the 2008 Olympic games, Beijing allocated enormous resources to cleaning up the city's environment by adjusting its industrial structure, treating the point sources of pollution, optimising the energy structure, tightening the emission criteria for motor vehicles and improving air quality.

However, the growing appetite for energy and motor vehicle ownership in Beijing combined with a makeshift approach of closing polluting industries resulted in an air quality crisis in early 2013. This latest "crisis" revealed how intransigent and intractable environmental problems can be, but also alerted the Beijing authorities to the reality that environmental problems are typically transboundary in nature.

Beijing has recently introduced strict control measures on air pollution with specific targets for PM2.5.¹ For example, in 2013, Beijing city has to reduce major pollutants by 2%. In addition, under a national air quality plan, heavy polluters are required to reduce the intensity of emissions by 17% by 2030. Given ongoing rapid rates of economic and industrial growth, emissions are unlikely to be reduced for at least another decade. In Beijing, many of the most polluting industries have already been closed down and moved beyond the city's boundaries. Coal power plants have been identified as the main source of the three key pollutants linked to PM2.5: sulphur oxide, nitrogen oxide and particulate matter (Zhao 2009). Therefore, to reach the targeted emission reductions, the city will be required to implement significant controls on energy consuming activities.

3.3 Development of a social economy and secure energy environment for Beijing

3.3.1 Social economic development

In 2012, Beijing's GDP was RMB1,377.79 billion, an increase of 10.2% from 2009. During the same period, primary industry decreased to 12.43 billion (1.6%), secondary industry increased to 332.31 billion (13.6%), tertiary industry increased to 1033.05 billion (9.1%). In the period of the 11th FYP, urban resident per capita disposable income increased by 9.2% in real terms, 2.4 percentage points lower than the average increasing ratio of the 10th FYP. Rural resident per capita income in increased by 9% in real terms, 0.9 percentage points lower than the average increasing ratio in the 10th FYP.

The number of permanent residents in Beijing reached 19.62 million in 2010, including a permanent floating population of 7.05 million. The urban population was 19.86 million, 86% of the permanent residents, with a rural population 2.76 million. Beijing's census registered population was 12.58 million and census registered families 4.96 million. The annual increasing ratio of the permanent population came to 11.8% in 2010.

The industrial added value of Beijing was RMB270.16 billion in 2010, in which the added value of industrial enterprises above the designated scale increased by 15%. Among the industrial enterprises above the designated scale, the added value from high-tech and modern enterprises increased 15.1% and 16.3%, respectively. In the 11th FYP, city-wide industrial added value increased on average by 9.1% annually. Transportation industry enterprises realised a profit of 16.95 billion, an increase of 61.2%. Industry power generation, generation and supplying of thermal power realised a profit of 22.07 billion, an increase of 43.4%. The medical products industry realised a profit of 5.6 billion, an increase of 17.9%. The telecom

¹ In June 2013, the State Council adopted ten measures for improving air quality in China's cities. Most of these measures had already been adopted by cities such as Beijing with the exception of one new measure which requires the biggest polluters, namely coal-fired power plants and metal smelters, to release detailed environmental information to the general public. The penalties for polluting companies were also raised.

equipment, computer and other electric equipment manufacturing industry realised a profit of 7.6 billion, an increase of 11.8%.

In 2010, the traffic mileage of Beijing was 21,201 km, among which highway mileage was 903 km, and urban road mileage 6380 km. At the end of 2010, city-wide buses operated 713 lines with 18,743 km in total and ran 22,000 buses for 5.04 billion passengers. Mass transit operated 14 lines with 336 km in total and ran 2463 trains for 1.84 billion passengers. The annual freight turnover of Beijing was 51.18 billion ton km and passenger turnover was 132.69 billion person km. By the end of 2010, city-wide motor vehicle ownership totalled 4.809 million cars. From a traffic energy efficiency and emission perspective, Beijing's per capita motor vehicle emission in 2010 was at a similar level to western countries. However, the number of motor vehicle per thousand persons in western countries was 600-800 cars, while Beijing's was 220 cars. This indicates that the emissions per car in Beijing were far higher than in western countries.

By the end of 2010, the urban civil building architecture general area was 644.99 million m². This included: a household area of 393.44 million m² or 61.6% of the urban civil building architecture general area; a public building area of 247.68 million m² or 38.4% of the urban civil building architecture general area (of this, big scale public building was 82.10 million m² or 35.3% of the urban civil building architecture general area); and a rural civil building architecture general area of 0.28 billion m² of which household area was 0.22 billion m² or 80% of the rural civil building architecture general area. In 2010, the city-wide energy consumption of urban civil building was 20.42 million standard tons of coal, 29.6% of the general energy consumption was 69.54 million standard tons of coal for the whole city. In the 11th FYP, the construction industry annual value added increased by 11.3% on average, 3.2 per cent lower than in the 10th FYP.

In 2010, the service industry value added was RMB988.9 billion (excluding the traffic industry). In the 11th FYP, the accumulated social consumption retail was RMB2,331.52 billion. By the end of 2010, 1592 enterprise had opened in the Beijing Economy Technology Development Zone, generating a general income of 350.0 billion. The number of employees working in research and development activities was 0.26 million, expenditure on R&D was 75.8 billion, equal to 5.5% of GDP and the number of yearly inbound tourists was 4.901 million, 18.8% more than the previous year.

3.3.2 Energy development and environment improvement

3.3.2.1 Energy development

Beijing, as an energy consuming metropolis and due to limited energy resources (so far no mineable workable reserves of oil and natural gas), has an energy supply that is highly dependent on imports from outside. Therefore, it needs to import its energy supplies from other provinces for an energy demand of 94% coal, 67% electric power, 100% natural gas and 100% raw oil. For electric power, besides local generation, there is still a large amount imported from the North China Grid; natural gas comes from the Shanganning gas field and Huabei oil field; raw oil is also fully dependant on the importation from other provinces; and raw coal mainly comes from the Shanxi province. There is a certain scale of the energy manufacturing transformation industry, mainly thermal power generation, heating supplying, and oil refining.

3.3.2.2 Improvement of the environment

Along with the continual increase in energy consumption and the drastic increase in motor vehicle ownership, air pollution shows the typical feature of combined pollution. Beijing has undertaken a lot of

effort in adjusting its industrial structure, treating the prior sources of pollution, optimising the energy structure, tightening the emission criteria for motor vehicles and improving the air quality. In the 11th FYP, Beijing shut down high energy consumption industrial enterprises such as a coking plant, eliminated and shut down small-scale thermal power generation units of about 0.856 million kwh and more than 200 small-scale coal mining enterprises. An integrated heating supplying system has been developed in the new downtown area, all the thermal power generation enterprises have implemented innovative means to remove dust, de-SO_x and de-NO_x, and the first CO₂ capture equipment in China has been constructed. In the advanced stages of energy saving and emission reduction in China, the main pollutants such as SO₂ have been controlled, attaining and surpassing the target of the 11th FYP.

3.4 Future low-carbon energy development scenario of Beijing

3.4.1 Scenario of social economic development

In the scenario analysis, a thorough review on the future of Beijing's economic development has been undertaken. Assuming average annual GDP will increase 8.3% from 2010 to 2020, growth will be faster than that planned by the government in the 12th FYP. Average annual GDP will increase by 6.5% from 2020 to 2030. Considering the currency increasing and the floating of the exchange rate, it is predicted that Beijing's GDP will come to RMB4,000 billion in 2020; and per capita GDP will increase from US\$25,000 to US\$45,000 in 2030. Beijing will become a world city from an economic point of view.

The third industry will be the emphasis of policymakers in Beijing. The 12th FYP economy planning outline of Beijing proposes a target for the proportion of the third industry value added production to be 78%. This research predicts that, in the 12th FYP the proportion of the third industry value added would be 74.4% (calculated by comparable price). Based on the increasing speed of historical value added production, estimates for 2020, 2025 and 2030, are 78%, 82% and 86%, respectively. See Figure 3.5 for the energy consumption trend along with the growth of future added value.

Table 3.1 The increasing population of Beijing

	2010	2015	2020	2025	2030
Permanent residents (million)	1962	2500	2700	2750	2800
Permanent floating population (million)	705	898	970	988	1006
Urban population (million)	1686	2150	2321	2420	2576
Rural population (million)	276	350	379	395	224
Census registered population (million)	1258	1603	1731	1763	1795
Urban population ratio (%)	0.86	0.86	0.86	0.88	0.92

According to labour demand by the future industrial development structure, and the relevant family model related to those labourers, along with the resources supplying capability and the impact on the population floating by the surrounding regions' social economic development model, this research analyses the future possible population scale of Beijing (see Table 3.1). Considering the attractiveness of Beijing in the Chinese economy, its social development, with the surrounding regions gaining wealth in the future, we assume the population of Beijing will reach 27 million in 2020 and 28 million in 2030.

3.4.2 Energy demand and CO₂ emission scenario

In Beijing, construction and traffic are the main energy consumption sectors. Future energy demand decides the energy demand pattern of Beijing in the future.

Currently, the number of urban residents in Beijing is around 6.6 million families (calculated as permanent residents); estimates to 2020 and 2030 are 10 million and 10.7 million families, respectively. Looking at the energy consumption of urban residents, if high energy saving buildings are rapidly developed (65% and 75% energy saving buildings), with mostly a central heating supply, the demand of energy from heating supply will decrease after the peak in 2020. At the same time, due to the development of advanced energy saving household electronics and its implementation to a standard similar to developed countries, the increase of household electric power consumption would be limited after 2020.

The number of families in rural areas keeps on decreasing while the population shrinks. Currently the biggest energy consumption in rural regions is heating in winter; with per family energy consumption higher than in urban regions. In the future, energy saving buildings can be promoted in rural regions, realising a heating energy saving of over 50%. Furthermore, if passive heating and ventilating designs in buildings can be promoted, heating demand would decrease further. Meanwhile, energy saving electronics could be promoted in rural regions and become popular, so energy consumption demand would generally decrease while quality of life would increase.

The energy consumption in the service industry (excluding traffic) is currently the fastest growing industry in Beijing. Energy consumption in the service industry mainly came from public building construction energy consumption. Considering the economic development of Beijing, the area of public buildings will increased sharply; from the current 0.25 billion m² to 0.43 billion m² in 2020 and 0.51 billion m² in 2030. Similarly, in the civil building area, high energy saving buildings are being developed rapidly (65% and 75% energy saving buildings), with mostly central heating supply and a CCHP cogeneration system, so energy demand for heating would start decreasing after the peak in 2020. At the same time, with the promotion of energy saving facilities in public buildings, generally, the energy demand in the service industry would start decrease after 2025.

Urban traffic, which includes all traffic except jet fuel, is an important factor in the increase in energy demand in 2010. The modelling analysis shows that, with 6 million motor vehicles in Beijing, implementing measures such as encouraging non-motor vehicle transportation, establishing a broader and more comfortable public transportation system, intensively promoting the energy saving automobile, and introducing renewable-based fuel, future energy consumption in traffic could increase unobtrusively. Supposedly, if the policy design is effective enough, energy consumption could only increase by 25% from now until 2020, and being controlled after 2025, fuel consumption could stabilise or decrease.

Figure 3.5 and 3.6 illustrate the results of the energy demand scenario of Beijing based on the IPAC modelling. Figure 3.7 shows the CO₂ emission scenario by energy consumption.

Figure 3.5 Primary energy demand of Beijing

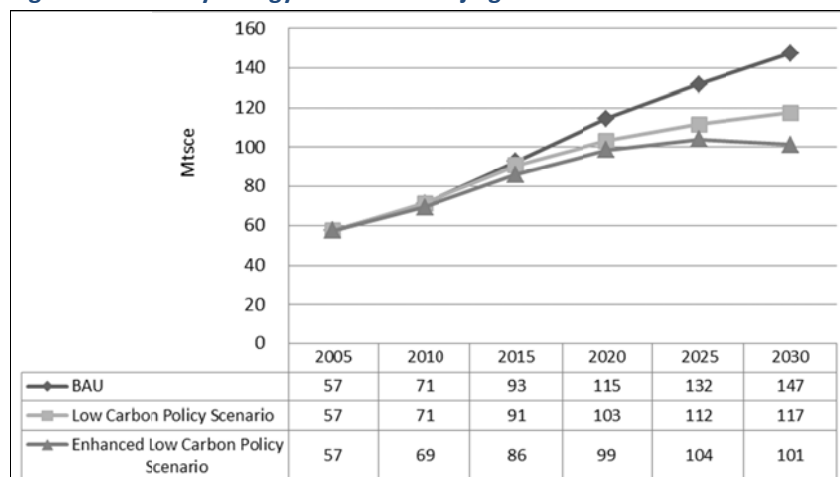


Figure 3.6 Final energy demand of Beijing

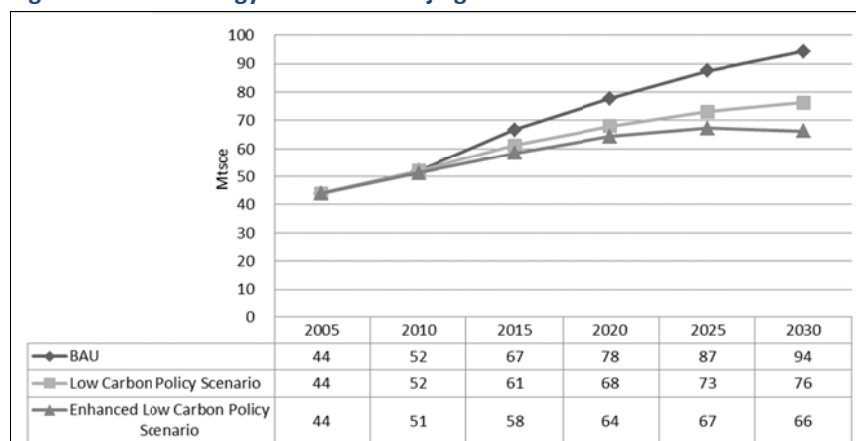
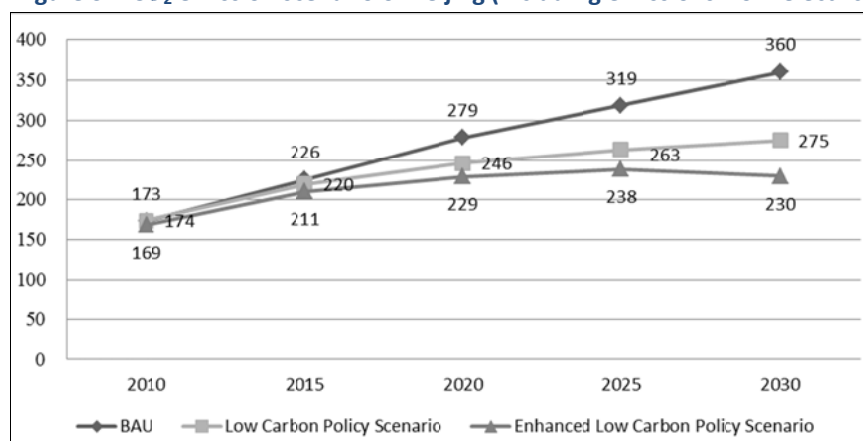


Figure 3.7 CO₂ emission scenario of Beijing (including emissions from electricity transfers), 10,000t of CO₂e



Therefore, generally speaking, the energy demand in Beijing would peak between 2020 and 2025. In this case, CO₂ emissions would peak in 2015 (with coal consumption decreased), the effect could be comparable to other international metropolis in 2030. Pollutants related to energy consumption, including PM_{2.5}, could possibly be reduced by 2020, basically accomplishing the target of local pollutant reduction, and conforming to the WHO ambient air standard.

If the future growth of economic development and the industrial structure adjustment of Beijing is designed as above, future energy demand would be decided by the industrial sector's per capita added value energy consumption. For Beijing from 2011-2015, taking the industrial sector's value added decreasing ratio in energy savings and emission reduction to address the climate change planning, considering the industrial sector's value added energy consumption decreasing ratio over the past 10 years (increase or decrease), and taking the reference of target of "Beijing 12th FYP energy saving and emission reduction to address the climate change planning" for agriculture, industry, construction, traffic and transportation and service industries, the ultimate estimate is that: the industrial sector's per capita value added energy consumption ratio would decrease by around 22–28%; scientific research, education, health, entertainment and culture, public administration, water conservancy and public facility would decrease by around 10%; and residential services, rent and business services would decrease by around 18%. Assuming that the resident daily life energy intensity decreasing ratio will be lower than the public building added value energy consumption decreasing ratio (10%), by approximately around 7%, consequently this will result in achieving the GDP energy consumption general decreasing ratio of 17% in the 12th FYP.

In 2016-2020, some of the traditional high energy consumption industries would reduce production and transformation, then added value would decrease, resulting in a drastic drop in the per capita value added decreasing ratio, requiring an adjustment of the value added energy consumption decreasing ratio for those industries (from 28% to 10%). The emerging industries, technical innovation, culture innovation and service industries need to enhance their energy saving, keep decreasing the value added energy consumption ratio, control the general amount of the sector's energy demand, and decrease the GDP energy consumption ratio by 15%.

In 2021-2030, along with the emerging industries achieving real productivity in the market, the industrial sector's value added would have an increasing trend, and energy saving technology would be popularised in the science and service industries. This would keep the service industry's value added energy consumption increasing and result in the service industry's added value energy consumption showing a decreasing trend. The value added energy consumption decreasing ratio is estimated to be 1.4%–2.5% lower than the value added energy consumption decreasing ratio in the 12th FYP.

3.5 Feasibility study on Beijing to reach total energy control and a carbon emission peak by earliest opportunity

In Beijing, construction and traffic are the main energy consumption sectors. The future energy demand will decide the energy demand pattern of Beijing.

Currently, the number of urban residents in Beijing is around 6.6 million families (calculated as permanent residents); according to current estimates this will be 10 million and 10.7 million families in 2020 and 2030, respectively. Looking at the energy consumption of urban residents, if high energy saving buildings are developed rapidly (65% and 75% energy saving building), with a broad central heating supply, the demand for energy from the heating supply will decrease after a peak in 2020. At the same time, due to the development of advanced energy saving household electronics and their use within the population reaching a similar level as in developed countries, the increase of household electric power consumption would be limited after 2020.

The number of rural families continues to decrease as the population shrinks. Currently the biggest energy consumption item in rural regions is heating demand in winter, with per family energy consumption for heating in the rural regions higher than in urban regions. In future, energy saving buildings applicable to the rural regions can be promoted, and can realise a heating energy saving of over 50%. Furthermore, if passive building heating and ventilation designs are promoted, the heating demand in energy consumption would be further decreased. Meanwhile, if energy saving electronics are also promoted in the rural regions and become widely used, the energy consumption demand will decrease while the quality of life will improve.

Energy consumption in Beijing is mostly increasing in the service industry (excluding traffic). This comes mainly from public building energy consumption. Considering the economic development of Beijing, the number of public buildings will grow rapidly. To 2020 and 2030, the general area of public building will increase from the current 0.25 billion m² to 0.43 billion m² and 0.51 billion m², respectively. A similar situation is occurring in civil building, where high energy saving buildings are being developed vigorously (65% and 75% energy saving building), with a broad central heating supply and the CCHP cogeneration system. Therefore energy demand for heating would start decreasing after the peak in 2020. At the same time, promoting energy saving facilities in public buildings would generally decrease energy demand from the service industry after 2025.

Urban traffic including all traffic means (excluding jet fuel) is an important factor in the increase of energy demand in 2010. The modelling analysis shows that with 6 million motor vehicles in Beijing, through measures such as encouraging non-motor vehicle transportation, establishing a suitable public transportation system widely, intensively promoting energy saving automobiles, and introducing renewable-based fuel, the future energy consumption of traffic can be kept to a slight increase in level. If the policy design is targeted correctly, energy consumption may only increase by 25% from now until 2020. Then continuing control after 2025 can keep fuel consumption stable or decreasing.

Summarising, energy demand in Beijing will peak in 2020 to 2025. In this case, CO₂ emissions would peak in 2015 (with coal consumption decreased), and the effect could be comparable to other international metropolis by 2030. Also, the pollution related to this energy consumption, including PM_{2.5}, would be decreased by 2020, basically accomplishing the target of local pollutants not present in the air, i.e., particularly PM_{2.5} levels, and Beijing would then conform with the WHO ambient air standard.

In general, it is possible for Beijing's total energy demand to peak between 2020 and 2025, and start to decline after 2025, with coal consumption falling by 40%-60% by 2015. Under this scenario, Beijing's CO₂ emissions could peak by 2015 (not including emissions from electricity from external sources). Other pollution related to energy consumption, including PM_{2.5}, would be improved leading to a reasonable control of local pollution emissions that will avoid air pollution. By 2030, Beijing will be at a similar environmental level to that of other international metropolis. That said, Beijing would then also conform to the WHO standard on the levels of PM_{2.5} in the atmosphere.

3.6 Development path for Beijing to become a low-carbon energy world city

Beijing has great development potential in China and internationally, as it is a dynamic city in both economic and social development. It will continue to grow rapidly in future decades, while other international metropolis are under stable development. Such background needs to be set when we do the analysis on Beijing's future energy system.

The main challenges that Beijing is facing for its future energy development are:

- rapid growth in energy consumption led by economic development and population growth;
- long-term security risk led by dependence on an external energy supply; and
- serious environmental pollution led by excessive total energy consumption, etc.

In this research, the strategic measures that could resolve Beijing's energy issues are to:

- adjust the economic structure to develop a low energy high value-added economy;
- conduct high end research on the development and manufacturing of clean energy;
- continuously strive for energy saving and emission reduction;
- control total energy consumption growth;
- ensure energy supply security;
- transform the model of external energy supply;
- promote policy innovation; and
- foster a good policy environment on energy saving and carbon emissions.

The above energy development overall strategy will allow Beijing to achieve its energy saving and emission reduction goal sustainably, by developing low-carbon transportation, low-carbon building, low-carbon industry and low-carbon energy, and finally to achieve its long-term goal of becoming a low-carbon city and world metropolis.

In order to realise Beijing's energy goal to go green and go low-carbon, policy innovation needs to be made in the following aspects (we will not mention those which already exist).

Overall development strategy for Beijing's low-carbon energy

Beijing *firstly* needs to define the total energy sector target and emission reduction goals. *Secondly*, it is important that energy saving and emission reduction measures be identified and implemented to retain growth in total energy consumption so that Beijing's is able to achieve every conservation goal to the level of world cities. *Thirdly*, it is critical for Beijing to develop a robust, highly secure, and diversified energy supply system, a collaborative and development-oriented energy input mode, as well as a high-tech low-carbon energy industry support system. *Fourthly*, the low-carbon development strategy should be integrated in the city's economic development to improve the city's competition capability as a world class metropolis. The Beijing low-carbon energy roadmap is summarised in the following sections.

3.6.1 Beijing energy sector targets and carbon emission reduction goals

Announcing ambitious greenhouse gas (GHG) emission targets is not only an important strategy to lead Beijing to a world level metropolis, but a common approach for the world's large cities to achieve low-carbon development. This study projects that under an intensified emission control policy scenario, Beijing's total energy demand will reach a peak in 2025, then begin a slow decline afterwards, with coal consumption decreasing by 40%-60% in 2015. The study also finds that in Beijing the CO₂ emission due to energy related activities (not including the export of electricity) will reach a maximum 120 million tons in 2015. If indirect carbon emissions due to electricity imports from outside grids are included, the emissions will peak at 240 million tons in 2025. Discharges of other energy-related pollutants (including PM_{2.5}) will be significantly improved by 2020. By then the local pollutant discharges will not cause apparent air pollution. It is expected

that by 2030, major environmental indicators will be as good as in other international metropolis, that is, the indicators including PM2.5 will meet the standards specified by the WHO. By 2030, Beijing's per capita CO₂ emission could stabilise at a level of 8 tons/person (currently 9 tons/person), close to the level of other world cities (6-7 tons/person).

Our findings show that the above objectives are achievable. The main strategies to achieve the above energy and environmental targets include: comprehensive and persistent implementation of the energy conservation policies, especially during 2011-2020, in a broader and more intensive scale; development of a technologically innovative energy system; and strengthened energy efficiency management with performance-based measures such that the energy efficiency in Beijing will progress to an international advanced level during 2020-2030.

3.6.2 Stringent energy saving and emission control measures to drive the total energy consumption down as early as possible

The scenario analysis results of the study show that in contrast to other international metropolis, Beijing will maintain rapid economic growth in the coming decades. Its energy strategies and visions should be developed based on the above mentioned scenarios. As a capital city with strong vitality in economic and social development, Beijing has great development potential in China and the world. Its expected annual GDP growth rate will be maintained at about 8.3% in 2012-2020, and at about 6.5% in 2020-2030. Taking into account the GDP growth rate and exchange rate factors, by 2020 and 2030, Beijing's GDP will reach about 35 and RMB67 trillion respectively, or per capita GDP US\$20,000 and US\$38,000. Economically, Beijing will become among the top world cities (if not the number one in the world).

Due to Beijing's economic and social advantages as well as its leading role in the surrounding region, is expected that by 2020-2030, Beijing will host around 27 million people and 28 million of its resident population. Ten million and 10.7 million households will live in the urban areas (it was 6.6 million in 2010).

In a strong policy scenario, by 2030, even though Beijing will continue to maintain rapid economic and population growth, supposing that its construction area will be significantly increased (by double based on 2010) and motor vehicles increased to 6.5-7.0 million, it is still possible for Beijing to drive its energy consumption down by 2025. This conclusion is based on taking the following emission control measures.

To control the growth of total energy consumption Beijing needs to take strong measures in restructuring its economic structure, as well as take effective measures in energy efficiency and emission reduction in the construction sector, transportation, services and resident end-users. These measures are critical to ensuring near-zero growth in total energy consumption by 2025.

Urban transport is an important factor in the growing energy demand in Beijing. The model analysis shows that, in the case of the number of motor vehicles in Beijing exceeding 6 million, comprehensive measures must be taken to ensure the transport energy will not grow significantly, which include: an innovative low-carbon transport service system, easy access to fast and comfortable public transport, energy efficient vehicles such as fuel saving vehicles, electric vehicles, metro transportation; the introduction of biofuels; higher fuel efficiency standards, etc. With the effective implementation of these policies, it is expected that by 2020, assuming a 60% increase in the number of vehicles, the increase in fuel consumption in Beijing can be limited to 20% and this increase will level out after 2025, so that the fuel consumption remains stable or begins to decline. The above discussion does not include aviation fuel.

The service sector and resident energy use will be a critical part of future energy consumption in Beijing. Energy use in the service sector will be dominated by public buildings. In the future economic development in Beijing, the floor area of public buildings will increase significantly, from the current 250 million m², to 430 million m² by 2020 and to 510 million m² by 2030 respectively, which will use more energy accordingly. To drive down the public building energy consumption from 2025, it is necessary to strongly promote high standards of energy-efficient buildings (i.e. 75% energy saving building code or higher standard), encourage energy efficient renovations of existing buildings, and widely implement central heating projects and thermoelectric cooling technologies.

Similarly, as resident energy use is mainly for heating, highly energy efficient residential buildings, central heating and co-generation technology, combined with measures of higher standard energy efficient electric appliances and building integrated energy saving equipment, will help drive down the resident energy demand after 2020. For rural residents, similar strategies will include promoting energy saving houses in Beijing suburban areas for 50% or more energy saving in heating. By actively promoting the use of passive solar house heating and ventilation designs, heating energy demand of rural residents will be further reduced. At the same time, popularising energy-saving household appliances of the same EE code with urban users can effectively reduce rural household energy demand along with providing improved living conditions.

3.6.3 Robust and highly secure energy supply system

Learning from the experiences of international metropolis in safeguarding the security of energy supply, Beijing needs a robust and highly secure energy supply system. This should be defined as a locally distributed supply, diversified energy sources, cooperative development-oriented energy importation, and a high-tech new and renewable energy system. To build up this innovative energy supply system, all sectors in Beijing are required to change their current energy usage scheme, from currently relying on capital advantages to a multi-source clean energy supply approach, and from currently relying solely on energy imports to a cooperative and development-oriented energy import mode, so as to finally implement the energy resource development strategy. This strategy aims to improve the competitiveness of clean energy while achieving energy supply security. Clean energy and renewable energy should share a large proportion of the required energy imports. Advanced low-carbon energy development technologies will be developed to an international advanced level through practical applications. The clean energy related emerging industries will grow fast and mature. The energy portfolio will be restructured and optimised in the end.

Achieving these goals requires the Beijing Municipal Government to consider low-carbon development issues, pursue clean energy resource development planning, and develop financial incentive policies for joint research and development for the whole city's economic circle or even greater regional economic development. The low-carbon energy strategies shall include encouraging the use of a smart grid, intelligent energy management, and information technologies, to fully use advanced intelligent technologies for a robust and secure energy supply system in Beijing. It is important to carry out in-depth collaboration with the neighbouring energy production provinces for a sustained energy resource development partnership such that the joint parties contribute 10%-20% of total energy imports. Meanwhile, Beijing should improve its energy reserves to guarantee the minimum threshold of energy reserves to be adequate for 3 month usage by 2020-2025.

3.6.4 Integrated low-carbon strategy with economic development to improve Beijing's competitiveness

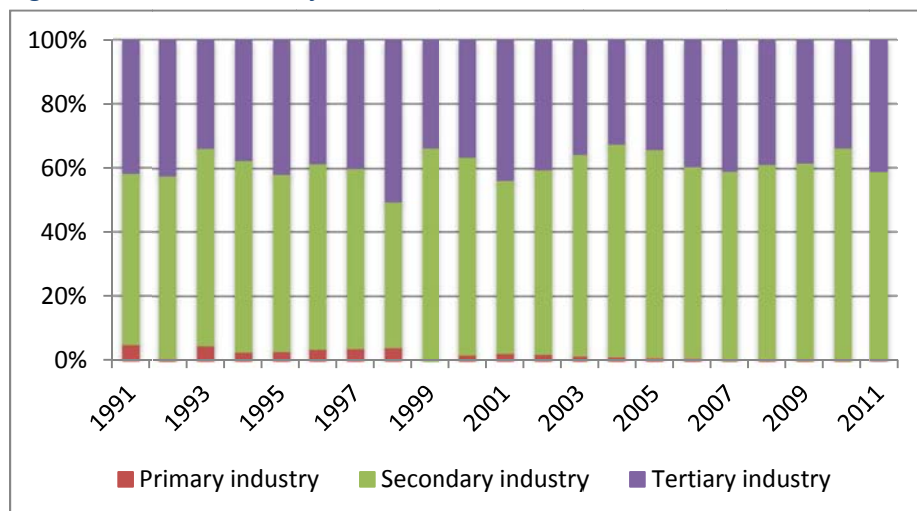
The lessons from low-carbon development strategies in the world metropolis indicate that integrating low-carbon energy use with a city's economic and social development can make low-carbon energy not only an energy strategy, but an economic strategy that will lead a metropolis or the entire country's economic growth. For example, London has an integrated energy supply and low-carbon city development process in place. This process has created economic growth. Energy supplies, low-carbon development and economic growth are closely correlated and support each other. The systems work together and strengthen the improvement of the city.

To integrate a low-carbon energy strategy and economic development, Beijing needs to develop its high-end manufacturing sector, innovative high-tech industry, low-carbon service sector and low-carbon energy sector. This can be achieved in the high-end manufacturing sector, by setting up higher standards than the national standard energy efficiency codes and comprehensively promoting energy-saving equipment in the manufacturing process to develop a highly efficient and low energy consumption manufacturing industry and highly intelligent management system. In the innovative science and technology industry, capabilities in innovative basic research, R&D, demonstration, and applications can be developed in the areas of solar power, building integrated solar energy applications, smart grid, electric vehicles, intelligent information technologies, biofuels, energy storage, distributed energy technologies, carbon capture, solid waste processing technologies, and so on. In the low-carbon services area the government of Beijing can provide incentives for low-carbon services in consulting and planning, financing, energy saving, carbon trade, and other low-carbon services to support the improvement and maturing of leading service sectors in China. In the low-carbon energy industry, Beijing can encourage, on the one hand, low-carbon fossil fuel power generation by promoting natural gas combined with cycle power generation (NGCC) and support the use of carbon capture and storage technology (CCS). On the other hand, it can fully develop the limited local wind resource potential and develop wind power projects in neighbouring provinces, including near offshore wind farms. After 10-20 years of effort, Beijing will have developed a competitive low-carbon economy with metropolitan characteristics.

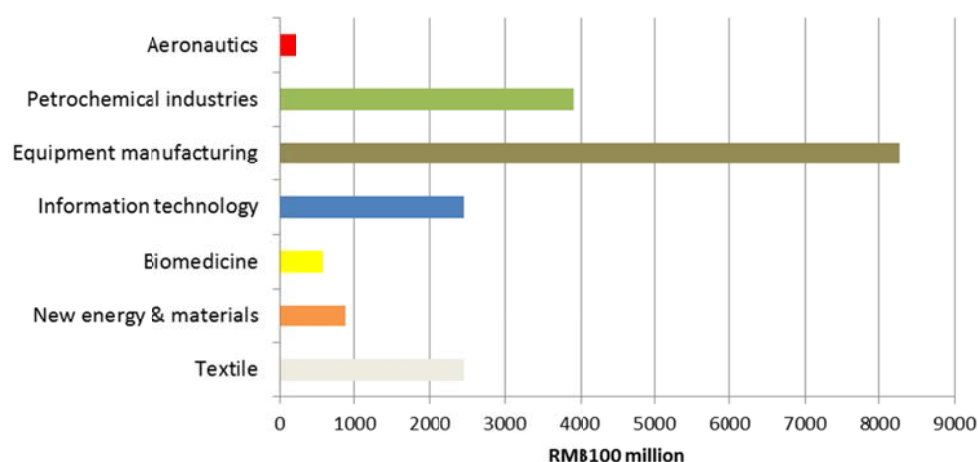
3.7 Low-carbon energy roadmap for Tianjin

As mentioned earlier, Tianjin is an established major industrial city and an important industrial base on China's northern plains. In terms of urban population, Tianjin is the fourth largest city in China and the largest coastal city in northern China. Tianjin aims to retain its status as a key international port and build upon its central economic role in the north whilst becoming an eco-city. As an established national industrial base, the structure of energy consumption combined with the optimisation and upgrading of industries in Tianjin is the starting point for industrial improvement and the implementation of a low-carbon strategy.

Between 1978 and 2011, the ratios of the three economic sectors in Tianjin (primary, secondary and tertiary) have changed from 6.1 : 69.6 : 24.3 to 1.64 : 52.4 : 46.2. During this period, primary industry's share of GDP decreased by 4.7%, secondary industry decreased by 17.2%, and tertiary industry increased by 21.9% (see Figure 3.8). The development momentum of the tertiary sector has been consistently strong since 1989, so that it was gradually closing the gap with secondary industry. However, since the commencement of the 10th FYP in 2000, secondary industry has rebounded somewhat due to Tianjin's designation as a key development region and the establishment of the Binhai New Area.

Figure 3.8 Structure of Tianjin's GDP, 1978-2011

These decisions were backed by an industrial strategy to establish the city as one of China's six high technology industrial bases (Figure 3.9) formed around pillar industries, such as petrochemicals, aeronautics, information technology, equipment manufacturing, biomedicine, new energy and new materials, light industry and textiles, national defence science and technology, and so on, becoming one of six industrial bases to integrate high technology in China.

Figure 3.9 Output of key pillar industries in Tianjin, 2011

3.7.1 Constrained energy resources

Tianjin's energy supply and demand are characterised by insufficient domestic energy production and a high dependence on imports. Coal and oil are the key energy sources for the city with oil mainly sourced from CNOOC (China National Offshore Oil Corporation) and the local Dagang oilfield, and the coal supply is entirely dependent upon transfers from other provinces. The rapid pace of industrial expansion in recent years has constrained local energy supplies due to slower investment in the construction of power and natural gas infrastructure. Instead, investment in the energy sector has focussed on upgrading and expanding existing infrastructure rather than developing new networks or supplies remains well below demand. As a result, there have been shortages in the supply of electricity and especially natural gas. The current energy situation has revealed the potential for ongoing risks in securing a reliable supply of energy in

the short to medium term. As such, implementing a low-carbon development path for the city adds a further prerogative for reducing energy demand whilst increasing energy security.

Rapid economic growth during the past decade in Tianjin has meant that energy demand has grown steadily. Between 1995 and 2011, total energy consumption grew from 25.7 million tons of standard coal equivalent to 75.985 mtsce in 2011, growing at an average annual rate of growth of nearly 7%. Despite the structural economic shift towards the tertiary sector during this period, the proportion of total energy demand by the industrial sector has exceeded its economic contribution. Between 1995 and 2011, the proportion of energy demand for the primary, secondary and tertiary sectors has shifted from 2.7%, 69.8% and 18.8% to 1.4%, 73.1% and 15.3%, respectively (Figure 3.10). Figure 3.11 shows that the proportion of total energy consumption by the industrial sector has been steadily increasing since China entered the WTO in 2001. The growing industrial demand for energy has not reflected the sector's fluctuating contribution to local GDP. Despite the year on year changes, the industrial sector's value added share of GDP has only grown from 53% in 1995 to around 63% in 2011. The explanation for the strong growth in the industrial sector's energy demand is due to the dominant presence of heavy industry and its rapid growth, especially compared to light industry (Figure 3.12)

Figure 3.10 Proportion of final energy consumption of Tianjin's three industries, 1995-2011



Figure 3.11 Comparative schematic diagram of the proportion of industrial energy consumption in total consumption and industrial contribution rate, 2000-2011

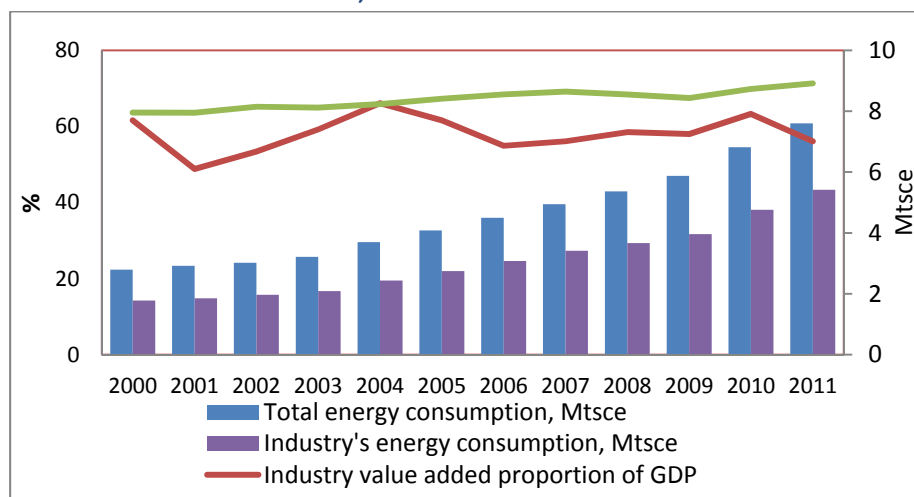
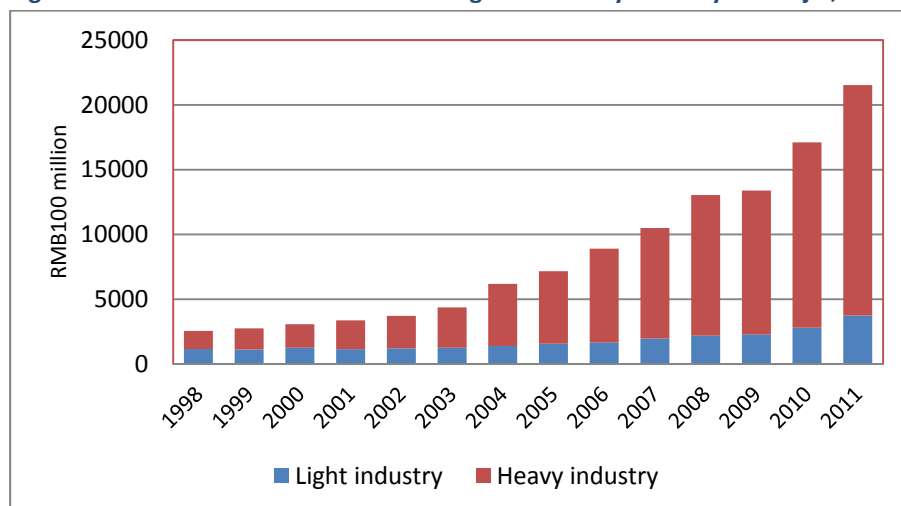


Figure 3.12 Value added contribution of light and heavy industry in Tianjin, 1998-2011

The recent trend in increasing energy demand from the industrial sector in Tianjin poses several problems for developing a low-carbon development pathway, especially in terms of reducing emissions and saving energy. First, adjustments to the city's industrial structure have been slow, while the growth of energy-intensive heavy industries has been strong, so that industrial energy consumption has been too rapid. Second, the balance between the development of old and new industries and enterprises is strained whilst advanced and backward production capacities coexist, largely because the level of technical equipment remains low, so that energy consumption per unit of production is poor. Third, the technological innovation capacity, especially energy intensive enterprises remains weak so that it will continue to remain difficult to satisfy energy demand without structural change. Fourth, there remains an over reliance upon administrative measures to curtail energy demand with weakness in the adoption of market-oriented energy-saving mechanisms. As a result, local energy intensive enterprises lack endogenous motivation for establishing and improving energy conservation. Finally, energy conservation management services remain too small, organisationally ineffective and confront many institutional barriers for effective implementation especially against the context of rapid industrial development.

Table 3.2 Key industries targeted for energy saving and emissions reduction in Tianjin

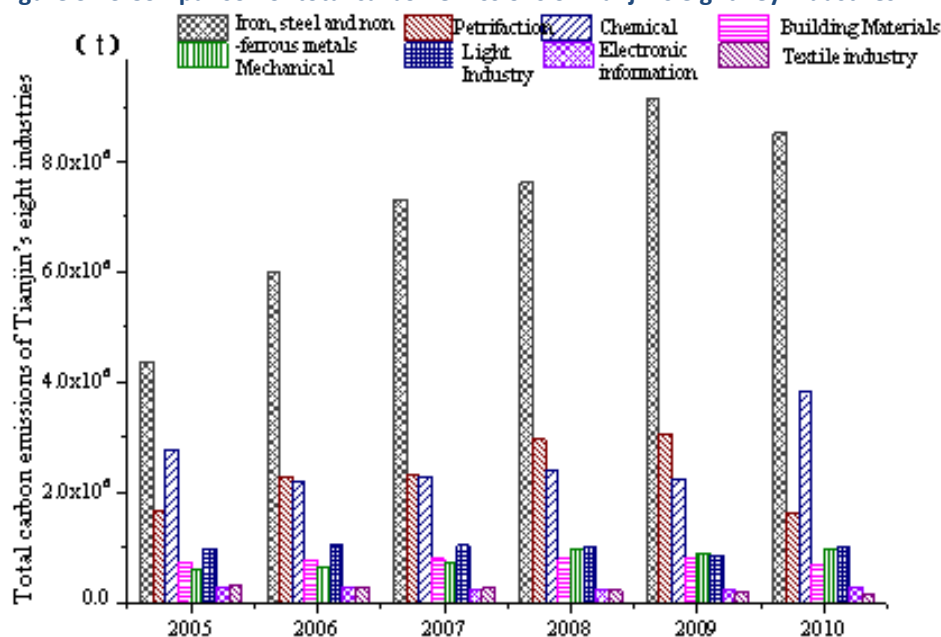
Key industries	National industry classification in Tianjin
Iron, steel and non-ferrous metals	Ferrous metal mining
	Coal mining and washing
	Ferrous metal smelting and rolling
	Non-ferrous metal smelting and rolling
	Fabricated metal products
Petroleum	Oil and gas exploration
	Petroleum coking and nuclear fuel processing
	Manufacture of chemical fibres
Chemical industry	Chemical materials and products manufacturing
	Pharmaceutical manufacturing
Building materials	Non-metallic mineral products
	Non-metallic mining
Mechanical	Instrumentation and cultural and office machinery manufacturing
	General equipment manufacturing
	Special equipment manufacturing
	Transportation equipment manufacturing
	Electrical machinery and equipment manufacturing
Light industry	Agro-food processing
	Food manufacturing
	Beverage manufacturing
	Tobacco
	Paper and paper products
	Printing and record medium reproduction
	Educational and sports goods
	Leather, fur, down products
	Rubber products
	Plastic products
	Furniture manufacturing
	Wood processing and wood, bamboo, rattan, brown, grass products
	Artwork and other manufacturing
Electronic information	Communication equipment, computers and other electronic equipment manufacturing
Textile	Spinning
	Textile, manufacturing

3.7.2 Mapping out a low-carbon industrial pathway for Tianjin's industrial sector

Specific quantitative carbon emission reduction targets were included for the first time in China's Industrial 12th FYP for the eight key industries of iron, steel and non-ferrous metals, petroleum, chemical industry, building materials, mechanical, light industry, spinning and electronic information. Table 3.2 above lists the reclassification of the city's 33 industrial sectors according to the eight national categories.

Figure 3.13 below highlights the eight largest industrial generators of carbon emissions between 2005 and 2010. The iron, steel and non-ferrous metals industries have dominated the city's industrial emissions profile, followed by the chemical and petroleum industries.

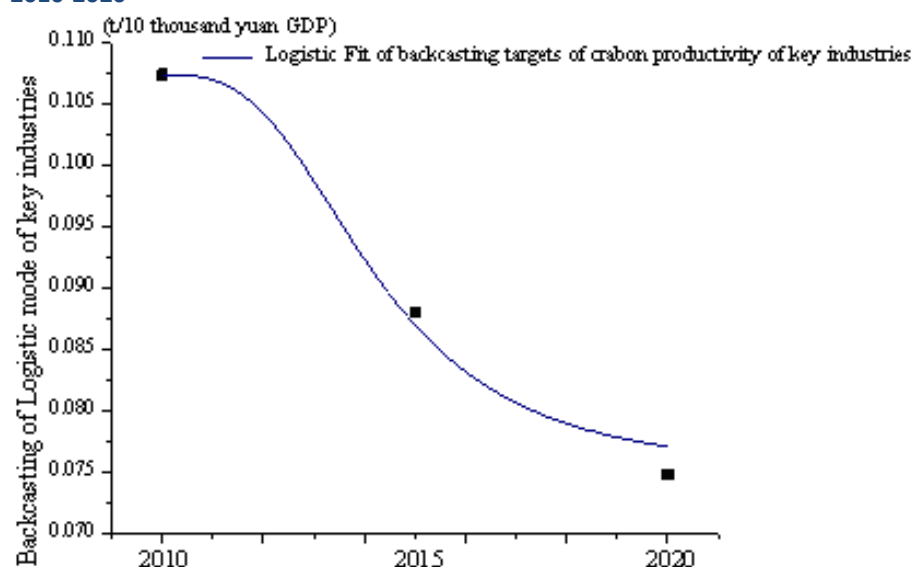
Figure 3.13 Comparison of total carbon emissions of Tianjin's eight key industries



Initially, under the “Tianjin Climate Change Program”, the city was committed to a 15% reduction in energy intensity. However, under the 45% national energy intensity reduction targets (2005-2020), Tianjin is required to reduce energy consumption per unit of GDP by 14.6% from 2010 to 2015 and then a further 11.8% between 2016 and 2020. In order to understand what is necessary to meet these targets, quantitative decomposition and backcasting analysis was undertaken of the potential emissions reductions in the industrial sector through to 2020. This is followed by an analysis of the emission scenarios for Tianjin in relation to meeting the targets and the required investment in the industrial sector through to 2020. The required investment levels for implementing these industrial energy efficiency measures and technologies were also undertaken.

Backcasting is a common method in scenario analysis, which recognises that the future path to a desired goal might be highly uncertain (Wilson, Tansey and LeRoy 2006). For a given end point (e.g. a given level of emissions per unit of GDP in 2020), various trajectories to 2020 can be estimated (or ‘backcast’), by assuming the emissions intensity series follows a given functional form. In this analysis two functional forms are used, the logistic function and the Gauss function, and these imply different trajectories through the 2010-20 period to reach a given 2020 endpoint. Figure 3.14 illustrates the required carbon intensity curve for Tianjin’s key industrial sectors from 2010 to 2020, with a logistic function, in order to meet the emissions reduction target for 2020. If the Gauss function is used for the backcasting the reduction in intensity in the earlier years is less rapid, but accelerates though the middle of the period. For a backcasting analysis through to 2020, the two functional forms might give quite different values for 2015.

Figure 3.14 Backcasting of the logistic approach for carbon intensity reductions with Tianjin's eight key industries, 2010-2020



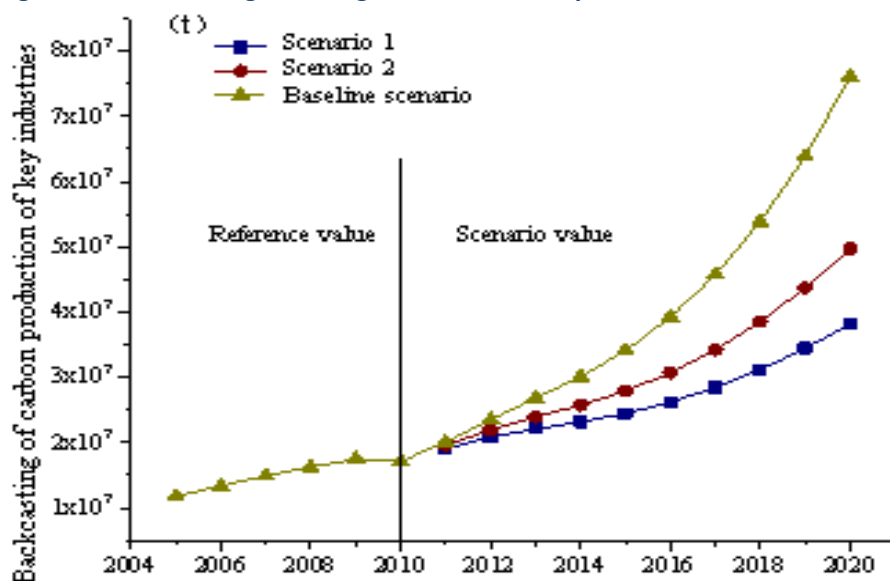
The analysis also makes use of grey correlation analysis, which is an extension of principal component analysis to apply to data which may be non-linear and may contain irregularities or missing data points (Chen 2012). Grey correlation analysis is widely used in the Chinese literature for the analysis of such data.

3.7.2.1 Tianjin emissions scenarios for industry and investment

Two GDP growth scenarios were developed to map Tianjin's forecasted emissions growth during the 12th and 13th FYPs: a low-growth strategy with average annual GDP growth of 12% (*Scenario 1*) and; a high-growth strategy with average 15% annual GDP growth (*Scenario 2*). A third business as usual or *baseline scenario* is also included as a reference point in line with the current rapid GDP growth of the key industries' set at 20% with no macroeconomic regulation and controls. Most of the focus in this analysis is on scenarios 1 and 2. Figure 3.15 shows the trajectory of emissions consistent with these GDP paths, using a logistic function.

A comparison of the emissions reduction pressures under the three scenarios reveals exponential emissions growth under the baseline scenario and the doubling of emissions under the slower growth Scenario 1. Therefore, the rate of industrial growth will impose enormous pressures on Tianjin in implementing both macro and micro mitigation policies. Ironically, a higher growth rate will make it easier for the city to meet its carbon intensity reductions, but will result in a substantial increase in overall carbon emissions. The next sections explore, through backcasting, how emission reductions can be achieved from both a micro and macro-energy policy perspective.

Figure 3.15 Backcasting of the logistic scenario of key industries, 2010-2020



3.7.3 Energy saving and emissions reduction targets under the 12th FYP and 13th FYP

The two scenarios presented in the previous section have been backcasted using a Bayesian regression model and a logistic process to determine the required emissions reduction steps through the 12th FYP (2011-2015) and the 13th FYP (2016-2020). By comparing the backcasting index of different functions, the two trends “Approach 1” and “Approach 2” are presented.

Approach 1: Using the Logistic function

In this approach, the reduction of carbon emissions per unit of GDP during the 12th FYP are initially accelerated and then decelerated. On the basis of established programs and strategies, policymakers carry out technological reduction first and then focus on structural reduction in line with macroeconomic strategies articulated in the 13th FYP.

Approach 2: Using the Gauss function

The reduction of carbon emissions per unit of GDP during the 12th FYP in this approach is very different from Approach 1. Under the guidance of policy planning for the economy, society and environment, policymakers can fine tune the indexes first and then accelerate the reduction of emissions after the mid period of the 12th FYP, commencing around 2013. Under this scenario, the reduction of carbon emissions is initially gradual and then accelerates from 2013. As a result, emissions per unit of GDP are quite different in 2015 for a given GDP scenario, for the two functions, in spite of targeting a common outcome in 2020.

3.7.4 Backcasting of energy saving of industrial projects during the 12th FYP

China's National 12th FYP for Industrial Energy Conservation identified a range of generic measures that industrial enterprises should adopt such as enhancing energy efficiency, improving energy-saving technologies and increasing the level of energy-saving management, as well as the following technologies and structural changes:

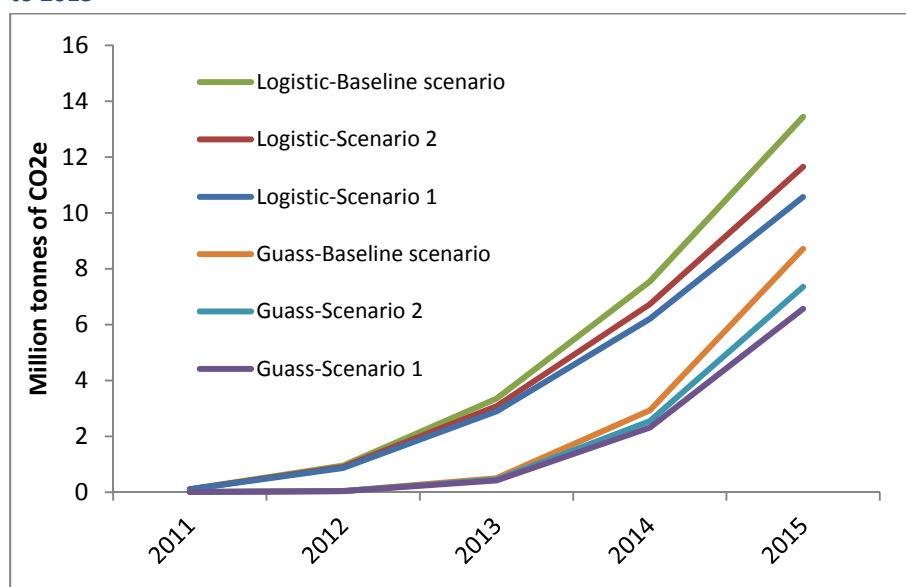
- energy efficient internal combustion engine systems;
- transformation of motor systems;

- cogeneration;
- transformation of industrial boilers and furnaces;
- recycling of industrial by-product gas;
- recycling of residual heat and pressure;
- construction of energy control centres in enterprises;
- the merger of petrochemical and chemical industries; and
- expansion of energy-saving companies (ESCOs).

Figure 3.15 shows the status of energy saving and backcasting of tasks of industrial projects settled during the 12th FYP in Tianjin. The results include the investment budget and the expected aggregate emissions reductions from successful implementation of all of the energy efficiency measures and policies.

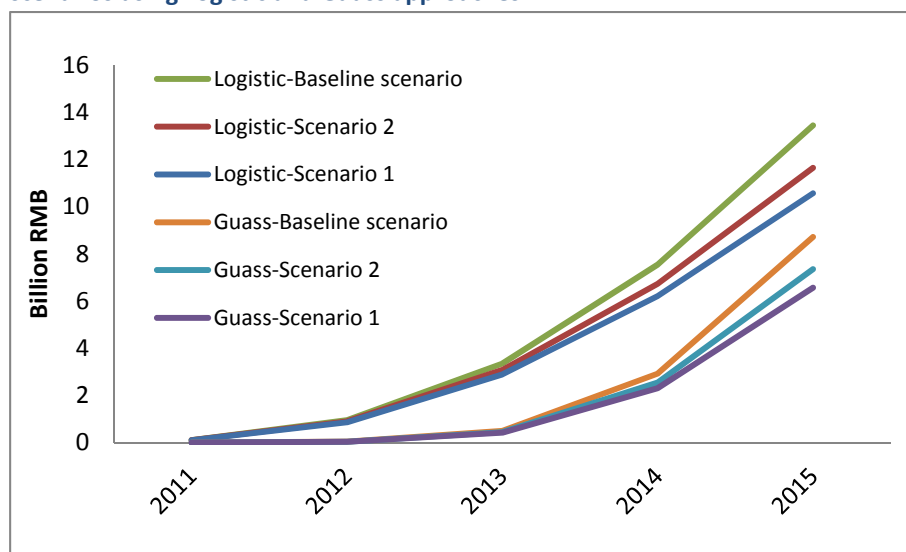
A comparison of the two approaches reveals that the logistic mode provides higher emission reductions at a higher investment cost in the period to 2015, while the Gauss mode offers higher emissions abatement at a lower cost. It is important to recall the underlying assumptions of the scenarios whereby actual emissions will be much higher under each of the baseline scenarios due to the higher rate of growth (Figure 3.16). The main difference between the two approaches occurs in the initial phase where the emissions reduction speed with the Gauss approach is slower, and hence the emissions reduction targets are easier to achieve, and the investment cost is lower.

Figure 3.16 Tianjin's estimated carbon emissions mitigation under three scenarios using Logistic and Gauss approach to 2015



As shown in Figure 3.17, the initial rapid emissions reduction under the logistic approach requires higher investment, therefore the risk of investment is significant. But if it succeeds, this approach remains relatively cost-effective over the longer term. From the above analysis, we can see that the implementation of energy conservation measures and technologies to realise critical emissions reduction in Tianjin's key industries requires both significant time and investment costs. However, regardless of which approach is adopted both options require strategic planning and careful implementation to ensure an effective and efficient outcome is achieved. Generally, considering the fact that realising significant energy conservation across all the key industries requires a long time, the Gauss approach is probably more suitable.

Figure 3.17 Estimated investment costs for projects under the 12th FYP for Industrial Energy Conservation under three scenarios using Logistic and Gauss approaches



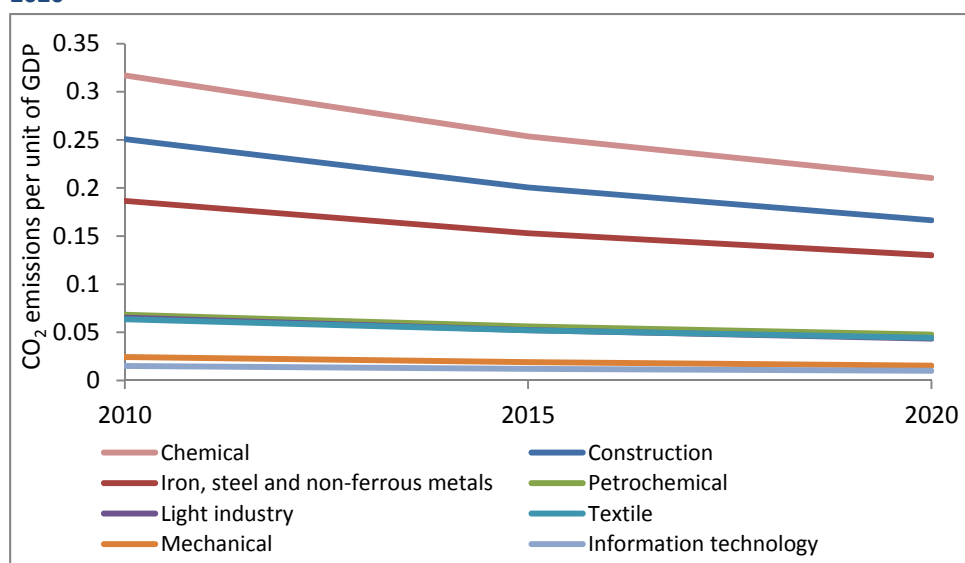
3.7.5 Summary

In this section, the decomposition of the strategic approach, scenarios and the backcasting of emission reduction targets of key industries were presented, and the backcasting of carbon emissions targets per unit of GDP were also formulated according to the 12th and 13th FYPs. Moreover, in order to backcast the targets of carbon emissions per unit of GDP and the total carbon emissions, three different scenarios were built by using a Logistic function and a Gauss function. On the basis, the report also undertook backcasting to determine the investment costs of implementing the energy efficiency projects under three different scenarios. The results of the backcasting revealed that the Gauss approach of implementation is easier to achieve and the investment cost is lower than using the Logistic approach. However, on the other hand, the total amount of emission reductions of the Logistic approach is greater than the Gauss approach, although it requires higher investment. Therefore, policymakers need to consider investment budgets and the demand for emissions reduction in Tianjin when making a decision.

3.8 Developing a 2020 low-carbon industrial roadmap for Tianjin: Individual industries

This section provides a detailed breakdown of the economic contribution and carbon emissions for Tianjin's eight key industrial sectors, including the emissions growth in recent years as well as estimated reductions in carbon intensity and economic output for each sector through to 2020. Figure 3.18 illustrates the ambitious carbon intensity targets for each of these eight industrial sectors. It highlights the dominant role played by the three most carbon intensive sectors: chemical, construction and iron, steel and non-ferrous metals. According to the city's energy saving and carbon emission programs, these three sectors are expected to realise the greatest efficiency dividends by 2020 in terms of carbon intensity reductions (Figure 3.18). While all eight sectors should be able to realise improvements in their respective carbon intensity, the reductions will be most significant to the overall carbon emissions target for Tianjin in the three most carbon intensive sectors due to their dominant role in the economy.

Figure 3.18 Carbon intensity figure and reduction targets for Tianjin's eight key industrial sectors, 2010, 2015 and 2020



3.8.1 Petrochemical industry

By analysing the total amount of carbon emissions and carbon emissions per unit of GDP from 2005 to 2010, we find in the petrochemical industry the implementation effect of energy saving and emissions reduction was significant (Figure 3.19). The total amount of carbon emissions changed noticeably, the total amount of carbon emissions increased by 0.8% and 3.4% in 2006-2007 and 2008-2009, respectively, and decreased by 46.9% in 2009-2010. Compared with 2005, the total amount in 2010 decreased by 2.5%.

During the 11th FYP, the implementation effect of carbon reduction in the petrochemical industry was significant, carbon emissions per unit of GDP reduced by 69.179% in 2009-2010, and the rate of decline in 2005-2010 was 64.967% (Figure 3.20).

Figure 3.19 Total carbon emissions from Tianjin's petrochemical industry, 2005-2010

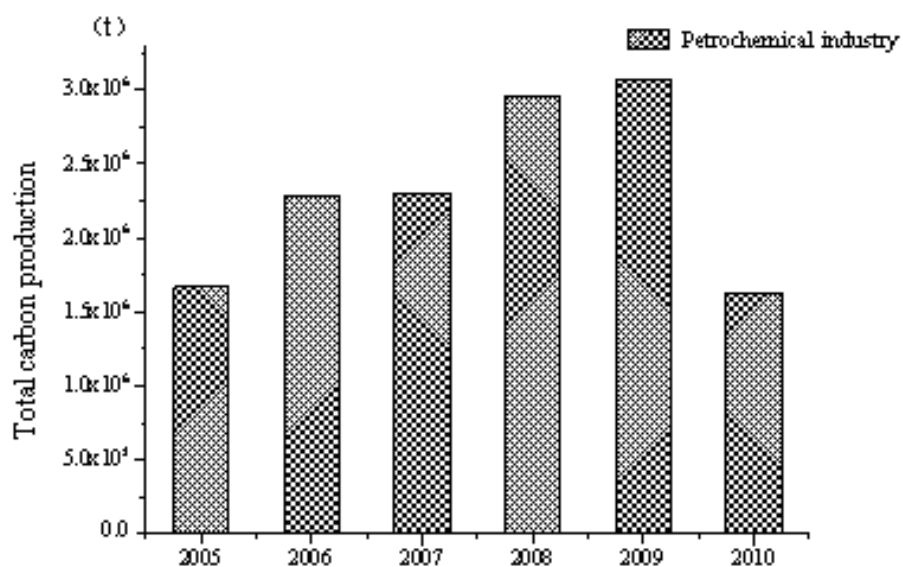
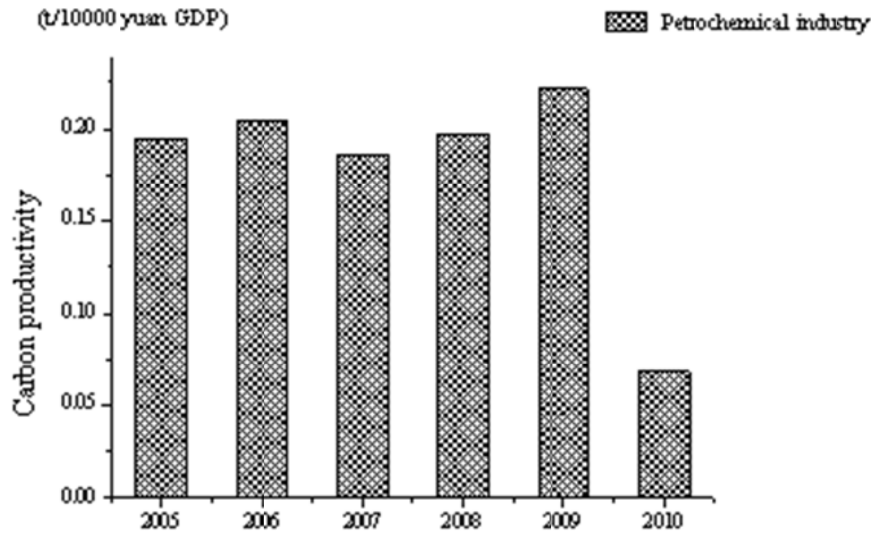


Figure 3.20 Carbon emissions per unit of GDP in Tianjin's petrochemical industry, 2005-2010

3.8.1.1 Backcasting the carbon intensity impact of industrial efficiency policies during the 11th FYP

The petrochemical industry in Tianjin can be divided into three smaller industries, oil and gas exploration industry, petroleum processing and coking and nuclear fuel processing industry, and chemical fibre manufacturing industry. The carbon intensity (productivity) and total carbon emissions of these three sectors for the period 2005 to 2010 are illustrated in Figures 3.21 and 3.22.

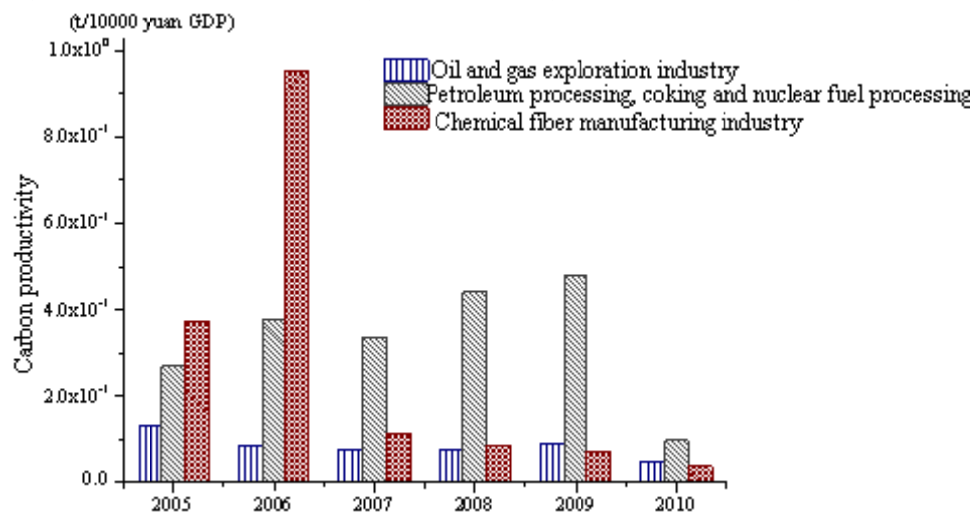
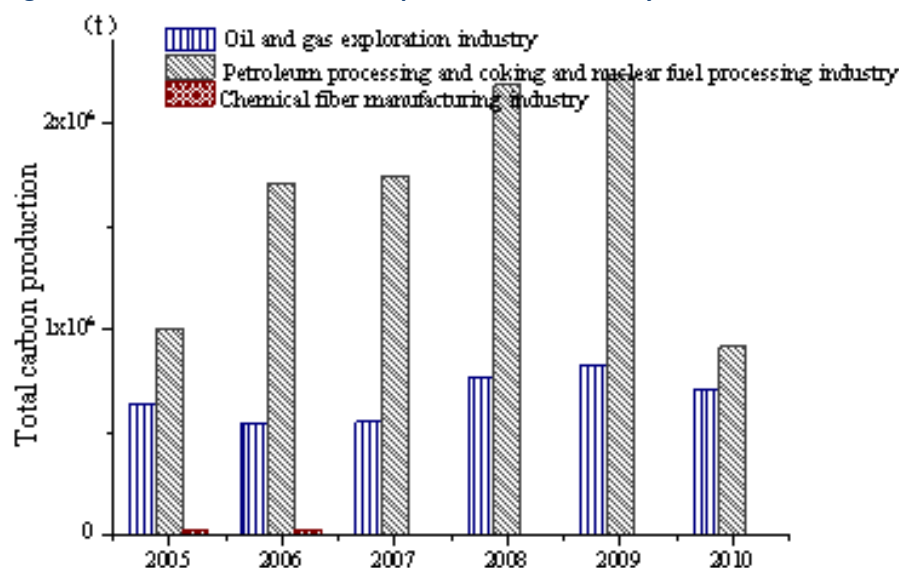
Figure 3.21 Carbon emissions of per unit of GDP, petrochemical industry sectors, 2005-2010

Figure 3.22 Total carbon emissions, petrochemical industry sectors, 2005-2010

Comparison of the total amount of carbon emissions and rate of carbon emissions for these three industries show that:

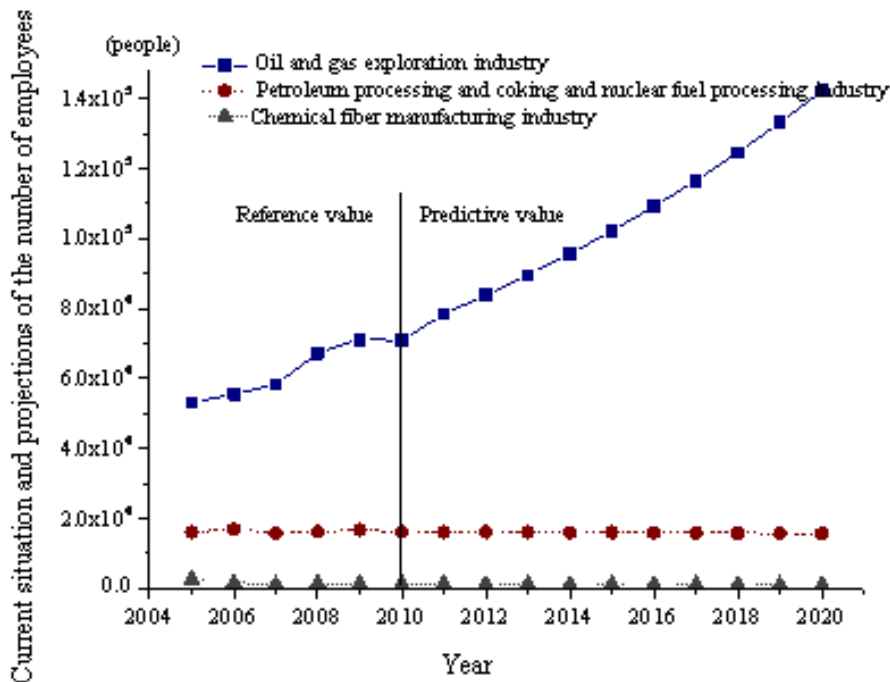
petroleum processing and coking and nuclear fuel processing industry > oil and gas exploration industry > chemical fibre manufacturing industry.

The total amount of carbon emissions of the chemical fibre manufacturing industry was not large, but the amount of carbon emissions per unit of GDP was great. The trends of total carbon emissions and carbon emissions per unit of GDP of the oil and gas exploration industry and the petroleum processing and coking and nuclear fuel processing industry were similar, both increased first and then decreased.

- (1) By analysing the degree of correlation between GDP and its trend, number of employees and its trend, and carbon emissions per unit of GDP, we find that: for the chemical fibre manufacturing industry the effects of GDP, number of employees and scale on carbon emissions was relatively significant; and for the petroleum processing and coking and nuclear fuel processing industry, the correlation degree between carbon emissions of per unit of GDP and GDP was high, and the correlation degree of the number of employees was low, the effect of these two factors was not great for the mining industry. Therefore, for this industry, we should focus on both macro-financial guidelines and micro-scale guidelines for the attainment of energy saving and emissions reduction.

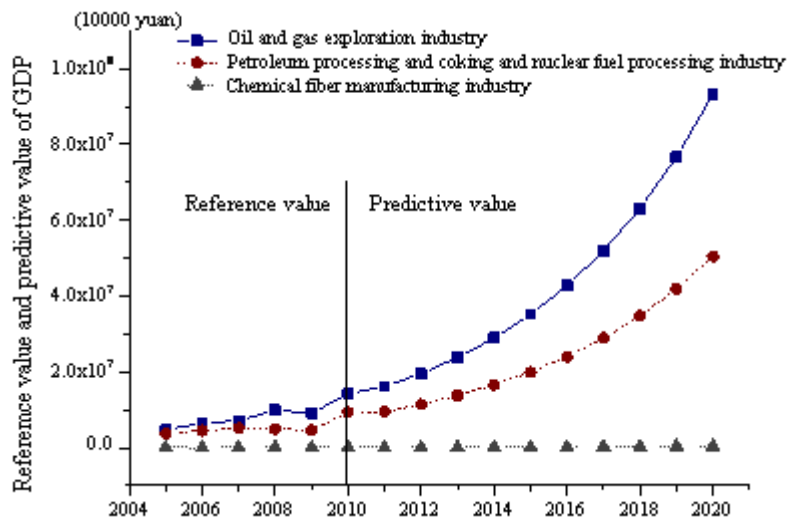
By analysing the current situation and projections of the number of employees, we can see that the oil and gas exploration industry was in a period of expansion, and the trends of the other two industries were stable (Figure 3.23). During the 12th FYP and 13th FYP, the scale of the petroleum processing and coking and nuclear fuel processing industry and the chemical fibre manufacturing industry is expected to expand alongside improvements in the training of professionals. The expansion of the scale of the oil and gas exploration industry has already commenced. For this industry, the focus should be on improving professional and technical standards to ensure the sector reaches the levels illustrated in Figure 3.24.

Figure 3.23 Current situation and projections of the number of employees of petrochemical industry



- (2) By analysing GDP and its trend, we can find that the carbon emissions per unit of GDP in the chemical fibre manufacturing industry and the oil and gas exploration industry were affected significantly by GDP. Therefore, we can strengthen macro-financial guidelines and increase financial requirements for these two industries to reduce the internal differences of the petrochemical industry.

Figure 3.24 GDP and its predictive value in ten years, petrochemical industry



3.8.1.2 Backcasting of guidelines energy policies

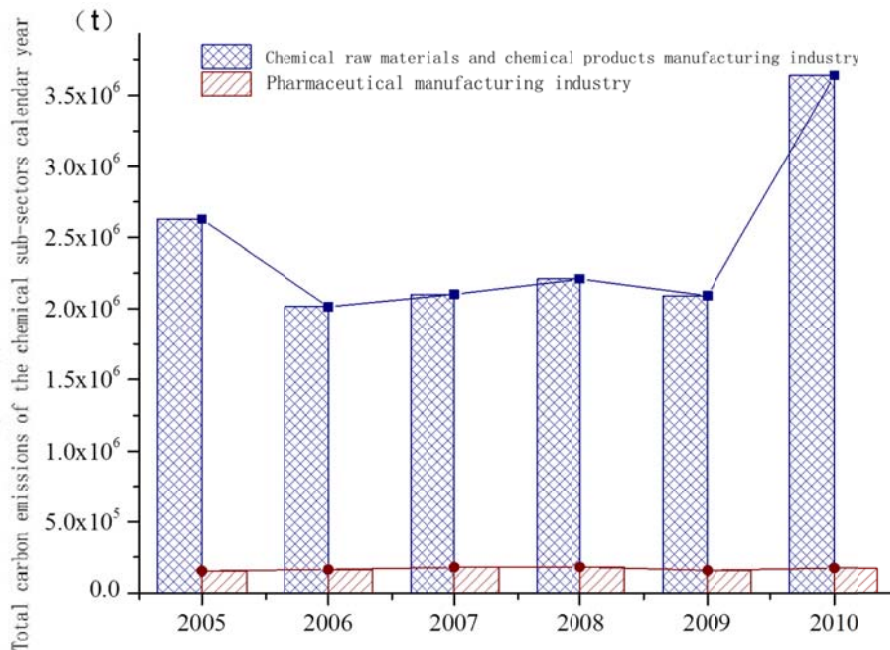
By comparing the grey correlation degree between the proportion of energy (coal, petroleum, electric heating and natural gas) in the petrochemical industry with carbon emissions per unit of GDP, this report has made a policy backcasting and performance evaluation. One conclusion is that the petroleum processing and coking and nuclear fuel processing industry should be the key industry that needs to adjust its energy structure.

- (1) Tianjin's oil and gas exploration industry is in a growing phase, both the finances and scale can expand substantially. Additionally, the upgrading of overall technology and internal structure is predictable. The use of coal-based energy decreased from 13.48% in 2005 to 1.16% in 2010, the proportion of petroleum-based energy increased from 53.5% in 2005 to 66.3% in 2010, and the use of natural gas was steady. The increase of the use of natural gas mainly depends on the improvement of technology and energy efficiency.
- (2) The petroleum processing and coking and nuclear fuel processing industry is an industry whose energy structure needs to be adjusted. The use of electric heating and natural gas determines the carbon emissions per unit of GDP, and the use of natural gas influenced the carbon emissions per unit of GDP to a very large extent. As a re-processing industry of petroleum-based energy, the correlation between carbon emissions per unit of GDP with the number of employees, and the share of petroleum-based energy was weak. This report finds that although the carbon emissions per unit of GDP was high, the value added of the raw material processing industry is high, therefore we should strengthen the development of this industry, expand the industry chain, and unearth its value-added potential.
- (3) The development of Tianjin's chemical fibre manufacturing industry has been relatively stable, natural gas and other renewable energy have not been used in this industry. The emphasis was coal-based energy, petroleum-based energy and electric heating through 2005 to 2010, where the proportion of petroleum-based energy declined, having a great effect on carbon emissions of per unit of GDP. The proportion of usage of coal-based energy changed from 72.3% in 2005 to 15.4% in 2010. The use of petroleum-based energy was 1.6% in 2005, and 0% in 2010. On the other hand, the proportion of usage in electric heating changed from 26.1% in 2005 to 84.6% in 2010, the correlation with carbon emissions per unit of GDP was strong.

3.8.2 Chemical industry

According to emissions from the two sub-industries of the chemical industry over the years, it is not difficult to see that chemical raw materials and chemical products manufacturing are the dominant developed industry in Tianjin in recent years (figures 3.25 and 3.26). Although the amount of carbon emissions per unit of GDP continuously decreased each year from 2005 to 2009, the total amount of carbon emissions was still showing a slight shock mode compared with productivity. In the period of 2009 to 2010, annual carbon emissions increased by 73.8%, while carbon emissions per unit of GDP increased by only 8.7%. In the period of the 11th FYP, the effective energy saving mode of the chemical industry in Tianjin has been quite outstanding.

In recent years, the economic index of the pharmaceutical manufacturing industry has been growing slowly, and it has formed a circular economy industrial chain which is represented by bio-pharmaceutical industry representatives.

Figure 3.25 Total carbon emissions, chemical sub-industries, 2005-2010

- (1) Based upon the increasing growth of the industrial sector, the chemical materials and chemical products manufacturing industry is likely to expand at a much faster rate over the coming decade compared to the pharmaceutical manufacturing industry (Figure 3.27). As a traditionally strong industry in Tianjin, chemical materials and chemical products manufacturing industries have a firm foundation, a large growth potential and an obvious advantage in industry expansion based on the current level. The pharmaceutical manufacturing industry, one of the eight pillar industries in Tianjin, which is represented by the biomedical manufacturing industry, is developing steadily. But the effectiveness of technical and professional construction is growing too slowly and the output and safety of the pharmaceutical industry appraisal need a long time. These two key factors affect the overall industrial output efficiency.

Figure 3.26 Carbon emissions per unit of GDP, chemical sub-industries, 2005-2010

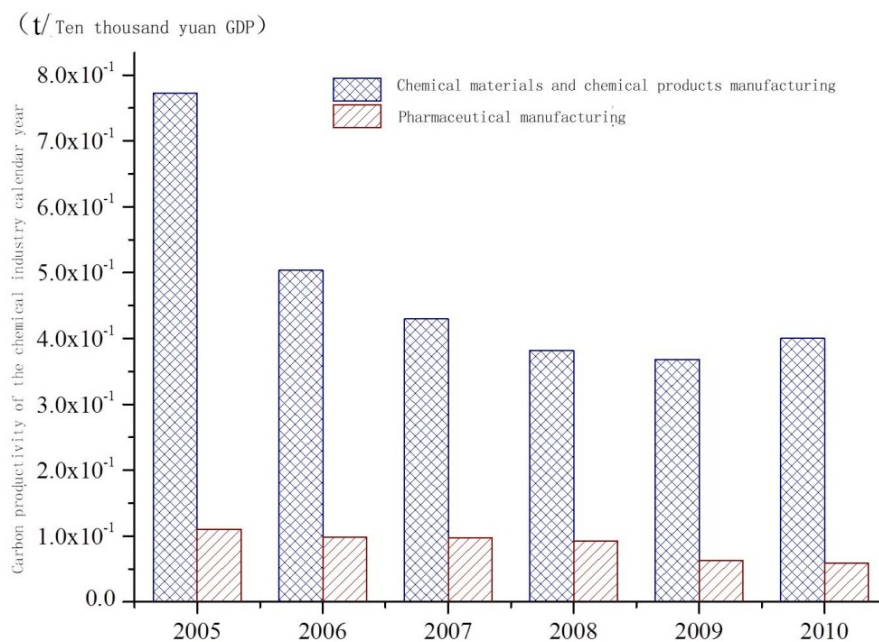
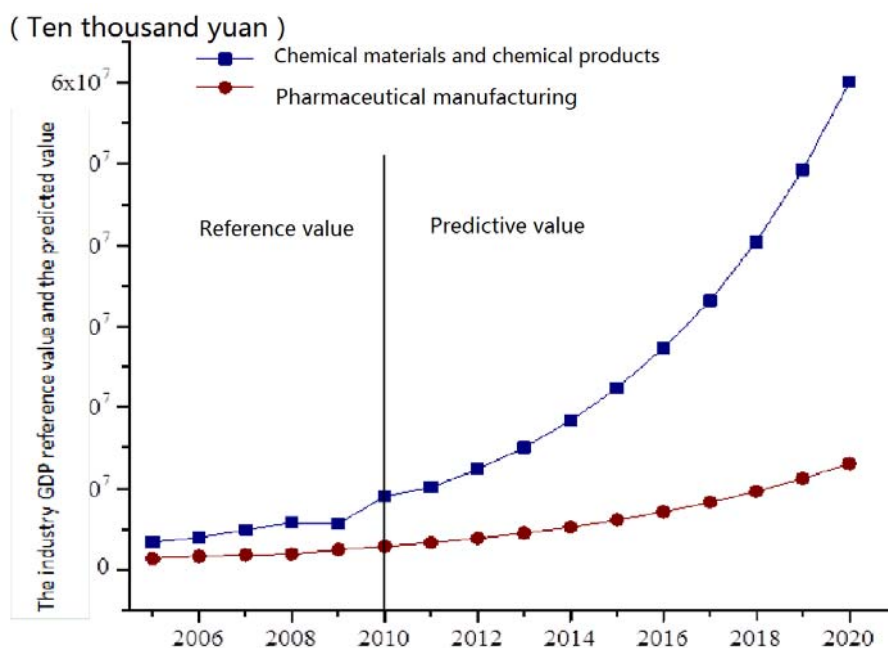
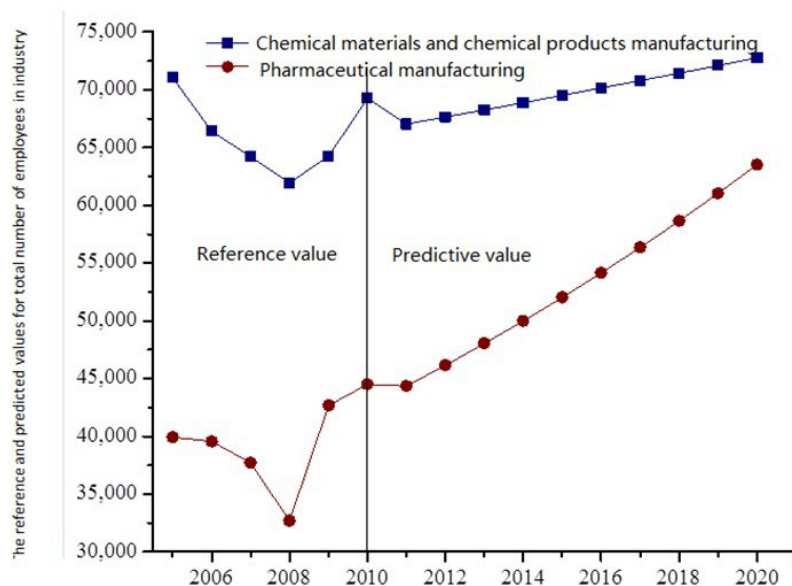


Figure 3.27 Chemical sub-industries GDP and 10 years predicted values



- (2) If we regard the two major chemical manufacturing industries as the focus of local industrial development, which combine the professional research advantage of leading universities, such as Tianjin and Nankai universities, then it is recommended that policymakers develop a combination of industrial and academic research and technology incubators, and continue to strengthen the construction of an industry technology chain.

Figure 3.28 Number of employees and 10-year projection value of the chemical sub-industries, persons



- (3) The maturity and size of industry determines the overall trend of the development of its scale. From this point of view, pharmaceutical manufacturing industry size and growth expectations are much larger than that of the chemical raw materials and chemical products manufacturing. In addition, the characteristics of the industry and its late start determine the high demand for pharmaceutical industry professionals and high-end talent and professional training. Also technical practices are in dire need of improvement.
- (4) There is grey relational degrees between carbon emissions per unit GDP and GDP, industry employees of two sub-industries of the chemical show there is a general correlation between carbon emissions per unit of GDP of the chemical materials and chemical products manufacturing and GDP, with $0.5 < \zeta_i(k) < 0.6$. To regulate the industry carbon emissions per unit of GDP, we should guide macro-financial policy and ignore the correlation between the number of employees. In contrast, pharmaceutical manufacturing industry carbon emissions per unit of GDP and the two above are highly related, so we should strengthen the adjustment of macro and micro control. At present, the factors which impact the carbon emissions per unit of GDP in the chemical raw materials and chemical products manufacturing industry are energy policy, technology, efficiency, etc.

Comparing the degree of grey correlation between the proportion of coal-based energy, petroleum-based energy, electricity, heat, natural gas energy and carbon emissions per unit of GDP of two chemical sub-industries, we apply a policy backward derivation and performance assessment in the aspect of energy guidance.

- (1) As a new industry, final energy consumption of the pharmaceutical manufacturing industry in Tianjin is mainly coal-based energy and electric heating, whose proportion of the total is nearly 95% in the years 2005 to 2010. The share of coal-based energy decreased by 12.9%, while the share of electric heating increased by 13.4 points. The rest is petroleum-based energy and gas, the reduction in the proportion of petroleum-based energy sources was almost replaced by an increase in the proportion of natural gas.

- (2) In the chemical industry, the chemical materials and chemical products industry have older capital, and have produced more derivative products in recent years. In the period of 2005 to 2010, the proportion of petroleum-based energy nearly doubled, dropping to 8.9% from 21.4% in 2005 and rising to 45.0% in 2010. The use of coal-based energy declined by nearly double, increasing first from 22.4% in 2005 to 29.7% in 2006 and then falling to 11.5% in 2010. In addition, the decline of the proportion of electric heating and an increase in the proportion of natural gas proportion reflect the gradual upgrade of the energy structure.
- (3) The proportion of energy which impacts on carbon emissions per unit of GDP in the chemical raw materials and chemical products manufacturing industry sequentially arranged are:

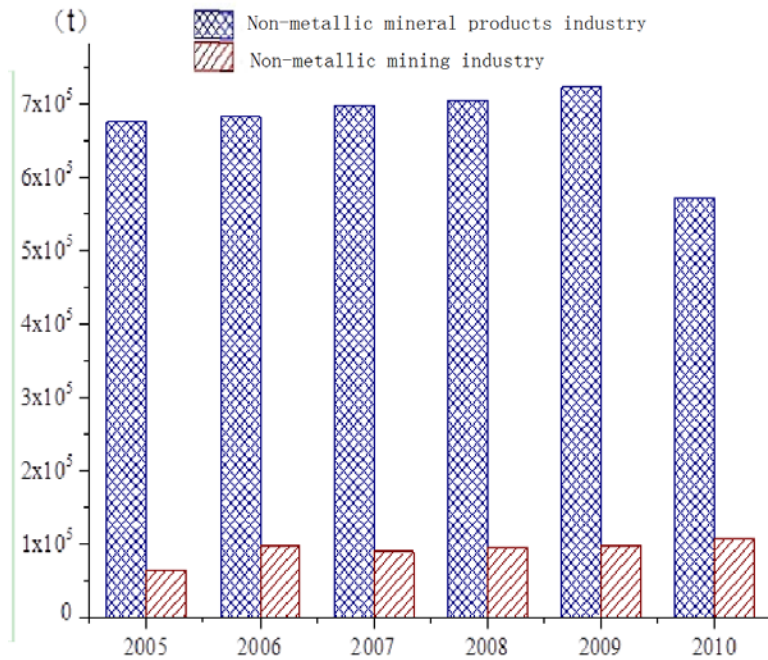
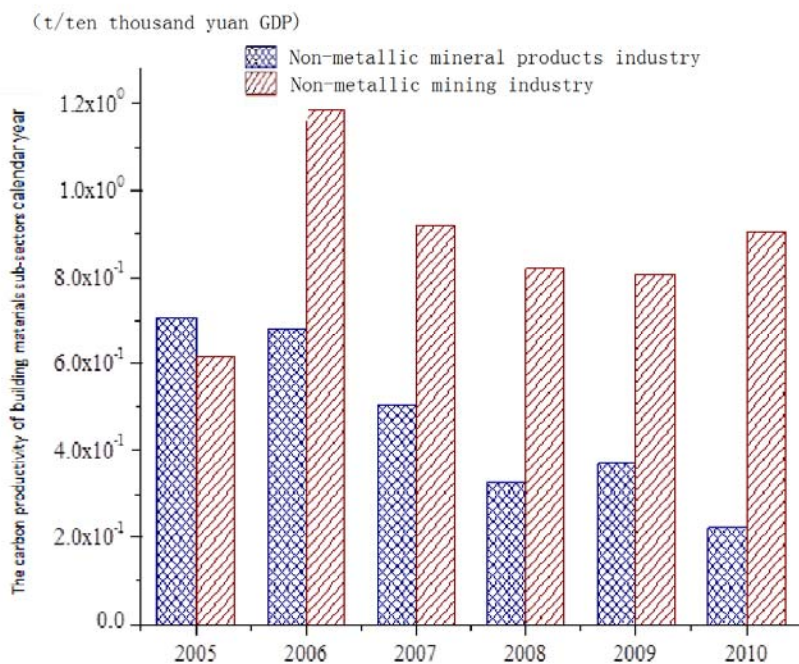
petroleum-based energy > electrical thermal > coal-based energy > gas,

and the associated degree shows that petroleum-based energy is $0.8 > \zeta_i(k) > 0.7$. The proportion of the use of petroleum-based energy industry carbon emissions per unit of GDP is very high. Therefore, besides appropriate macro-financial guidelines with the premise of meeting industry production and expanding premises, the efficiency of petroleum-based energy use should be enhanced primarily in the aspect of energy structure, by increasing the energy efficiency and conversion rate of gas. This can indirectly increase the proportion of coal-based energy and electric heat, and lead to a further decline in carbon emissions.

- (4) The pharmaceutical manufacturing industry, whose carbon emissions per unit of GDP is influenced by macro-financial and micro-scale industries, is relevant because the usage proportion of the four industries and the level of carbon emissions per unit of GDP energy shows the rising proportion of gas heavily impacting the industry's carbon emissions per unit of GDP. The second reason is the impact of the rising proportion of coal-based energy rising. For the industry's energy structure adjustment, this should proceed simultaneously and steadily in the case of different energy usage.

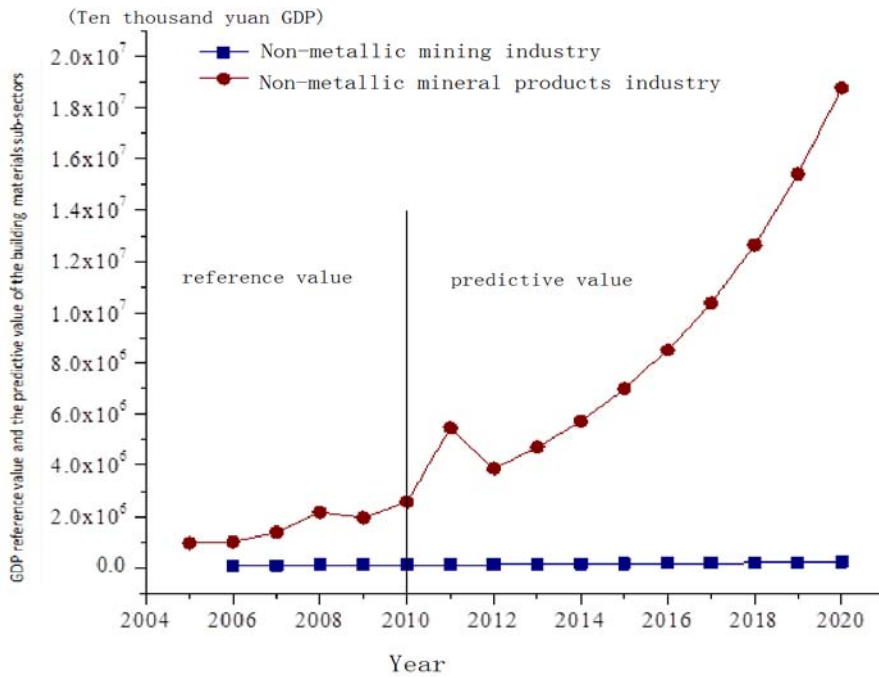
3.8.3 Construction industry

For the total carbon emissions, the six-year average of the non-metallic mineral products and non-metallic mining industry is 675,253 tons and 91,241 tons; the former is about 5.4 times the latter (Figure 3.29). In 2005-2010, the average annual decrease of the non-metallic mineral products industry was 3.3%, and the average annual increase of the non-metallic mining industry was 10.6%. In 2005-2009, the products industry's carbon emissions were slightly increased. For 2010 alone, compared with the previous year, the products industry's carbon emissions represented a decrease of 20.8%. In 2005-2010, the carbon emissions of the mining industry and GDP growth trends reversed and increased by 50.5% in 2005-2006, and showed an overall upward trend with a short-term decline.

Figure 3.29 Total carbon emissions of metallic and non-metallic materials industries, 2005-2010**Figure 3.30 Carbon emissions per unit of GDP of building materials sub-industries, 2005-2010**

The carbon emissions per unit of GDP average of the products industry and the mining industry for the years 2005 and 2010 are respectively 0.468t/million GDP and 0.0794t/million GDP, and the former is only 53.4% of the latter (Figure 3.30). This shows that the energy efficiency of the non-metallic mineral products industry in Tianjin is much higher than that of the mining industry, and its overall utilisation of energy efficiency needs to be increased dramatically.

Figure 3.31 GDP reference value of the building materials sub-industries with the 10-year forecast value

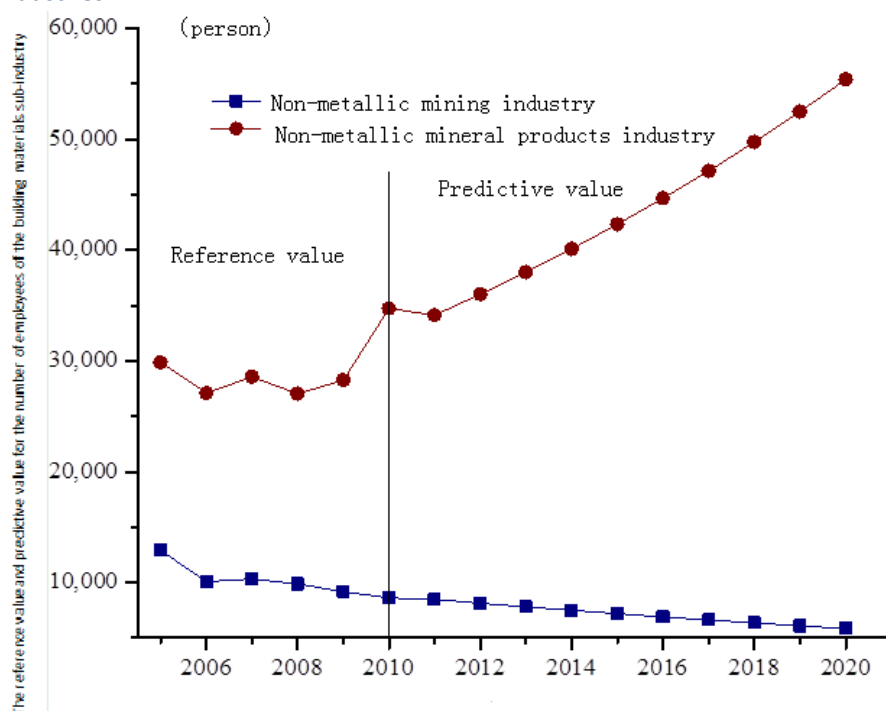


For the reference value and the predicted value of the industry GDP, among the building materials sub-industries of the industry, the products industry is the key object of development and economic enhancement (Figure 3.31). In accordance with the existing situation, GDP will increase dramatically in the next 10 years. In contrast, the mining industry has no economic development advantage. In accordance with the situation from 2005 to 2010, the lower mining industry GDP is, the higher the total carbon emissions are, which demonstrates that the mining industry in Tianjin has an absolute disadvantage. If enhancement development within the industry cannot be achieved, this would not be in line with the strategic decision-making in accordance with the status. We can increase the foreign trade of the area and expand the industrial chain, apply a mining industry outsourcing policy, which can enhance the utilisation of the overall energy consumption in Tianjin.

From the point of view of industry employees in the building materials industry sub-industries, there is an overall downward trend in the mining industry, while the manufacturing sector has gradually increased (Figure 3.32). Therefore, if an overall reform of the mining industry in the city is implemented, the introduction of investors and human resources enhancement driven by the industry as a whole should be considered.

Two associations appear: the association of carbon emissions per unit of GDP and GDP of the building materials industry in the mining industry. Industry employees is at a general level, which further confirms that the introduction of investment funds can be considered for the construction industry, which promotes and drives the industry as a whole. In addition, the association between products and the two factors is high, integrated micro-macro decision-making and overall enhancement, which should be implemented.

Figure 3.32 Industry employees' reference value and 10 years predictive value of the building materials sub-industries



Comparing the grey correlation between the proportion of the two sub-industries of the building materials industry of coal-based, petroleum-based, electric heat, natural gas and carbon emissions per unit of GDP, we apply a policy backward derivation and performance assessment in the aspect of energy guidelines.

With regards to energy structure, the non-metallic mineral products industry is far beyond the non-metallic mining industry. In the six years from 2005 to 2010, the ratio of natural gas use in the products industry has been enhanced 9.6 times, the proportion of coal-based energy has been reduced by 18.4%, the proportion of petroleum-based energy has been reduced by 3.6%, and the electric heating ratio has nearly doubled.

Between 2005 and 2010, the proportion of coal-based energy usage of the non-metallic mining industry decreased by 50.3% (from 21.6% to 10.7%), and the electric heating proportion increased from 73.1% to 87.7%.

For the grey correlation, the impact of electric heating on carbon emissions per unit of GDP of the mining industry is greater, with the proportion of coal-based energy and petroleum-based energy only having a minor effect.

The impact of electric heat on the manufacturing industry is the largest, followed by petroleum-based energy, then natural gas and coal-based energy. Manufacturing occupies a high position in the equipment manufacturing industry in the city, and has a great benefit. The adjustment of the energy structure and construction of the industry should be increased and the products industry of clean energy needs to occupy a dominant position.

3.8.4 Iron, steel and non-ferrous metals industries

Tianjin's iron, steel and non-ferrous metals industries include ferrous metal mining, coal mining and washing, ferrous metal smelting and rolling processing, non-ferrous metal smelting and rolling processing, and

fabricated metal products. Carbon emissions in this sector have doubled from 2005 to 2010 driven by rapid growth in the manufacture of ferrous metals, particularly steel (Figure 3.33).

Figure 3.33 Carbon emissions from Tianjin's iron, steel and non-ferrous metals industries, 2005-2010

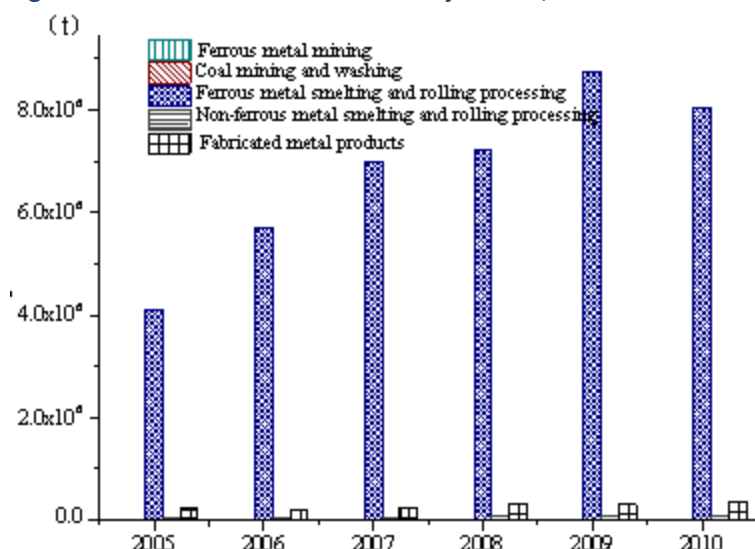
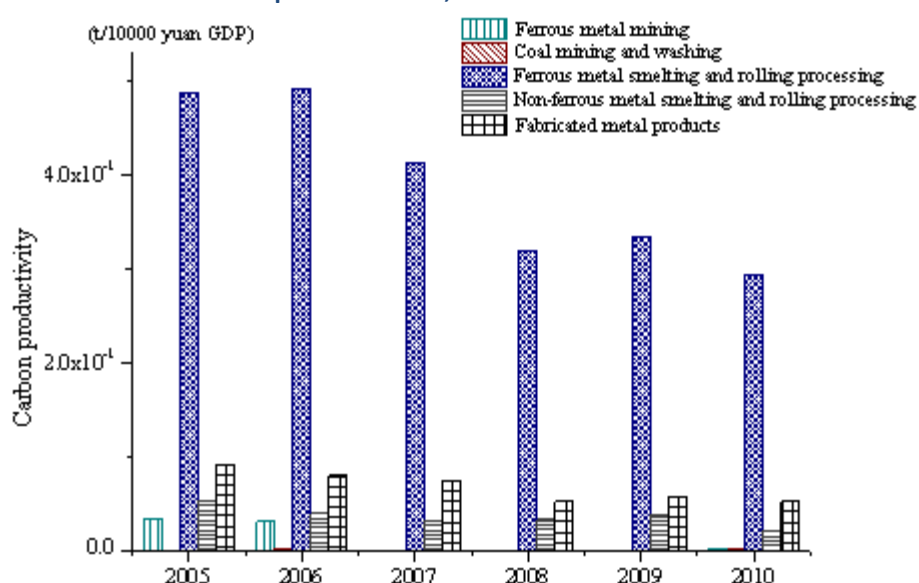


Figure 3.34 Carbon emissions per unit of GDP, iron and steel and non-ferrous metal industry



While the emissions profile of the iron, steel and non-ferrous metals industries have grown steadily, an analysis of the sector's carbon intensity or carbon emissions per unit of GDP (Figure 3.34) reveals that Tianjin's energy saving and emission reduction programs have achieved some recent improvements despite the increasing investment and growth in production and capacity. Important recent shifts in the iron, steel and non-ferrous metals sector include:

1. A steady decline in the growth of carbon emissions per unit of GDP in the period 2006 to 2010 with annual reductions in carbon of 11% (2006-2007), 29% (2007-2008) and 25% (2009-2010).
2. The annual growth rate of total carbon emissions decreased from 37% between 2005 and 2006, to

7% for the years 2009 to 2010.²

3. During 2009, the government announced plans for the introduction of a range of new emission reduction programs commencing from 2010. As a result, there was a large upsurge in investment in the iron, steel and non-ferrous metals industries to avoid sanctions in 2009. As a result, the slowdowns in total emissions growth and improved carbon intensity figures were reversed, resulting in carbon emissions spiking in 2009 only to decline during 2010 by 7%.³
4. The increased use of natural gas, the promotion of energy efficiency in the use of traditional energy intensive sectors and the closure of three large industrial enterprises have realised overall energy savings and improvements in carbon intensity across the sector.

The expected growth areas through to 2020 within the iron, steel and non-ferrous metal industries can be estimated based upon an analysis of industrial, productivity and GDP backcasting, and an examination of guiding policies under the 12th and 13th FYP (Figure 3.35).

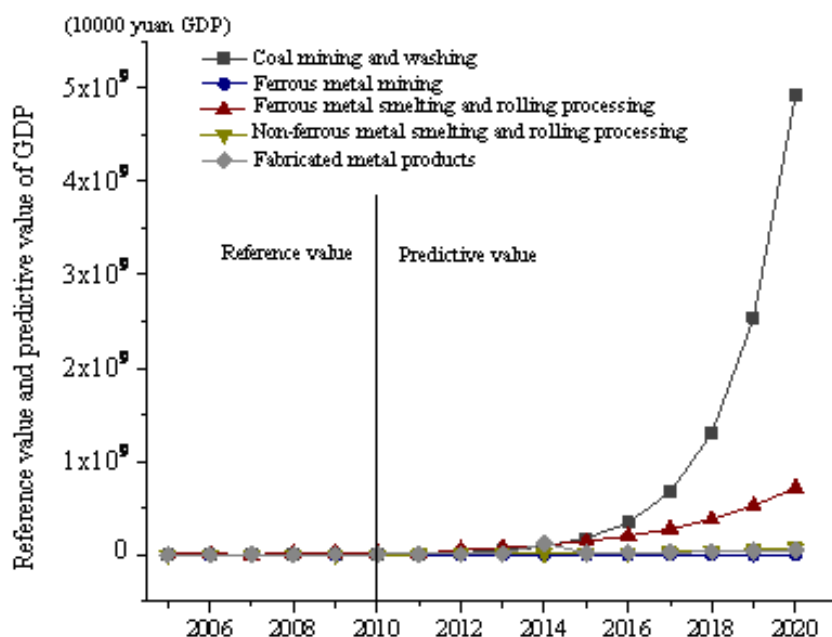
1. The grey correlation degree of the coal mining and washing industry was the greatest of the 25 industries, it was related with the property of Tianjin (city's energy supply depends on input). Basic reserves of coal in Tianjin are 297 million tons, and have not been mined since 2008. The coal mining and washing industry in Tianjin has developed slowly, with the number of employees in 2010 increasing significantly, and carbon emissions of per unit of GDP increasing by 4.8-fold. However, the scale, energy consumption, and carbon emissions quota of industry is small, leading to negligible amount of carbon emissions. Therefore, the coal mining and washing industry can occupy a place in the field of energy saving and emission reduction in the future. From these trends we can conclude that the coal mining and washing industry can develop strongly in the future.
2. In the ferrous metal mining industry, because of suspending the business for rectification for two years, the number of employees plummeted, and the GDP of those years has not been included in statistics, the trends of two variables were unsystematic. The total amount of carbon emissions and carbon emissions per unit of GDP of the ferrous metal mining industry were relatively small, the scale had a great effect on carbon emissions per unit of GDP. Because the finance and macro-financial guidelines on the scale of ferrous metal mining industry were not emphasised in Tianjin, relevant departments should strongly pursue the construction of a database if they want to standardise this industry.
3. The non-ferrous metals, ferrous metal smelting and rolling processing industry is one of the energy saving and emission reduction key industries and "three high" industries. GDP and employment levels have a great effect on carbon emissions per unit of GDP. The emissions reduction effect in the 11th FYP was significant. In future, Tianjin can strengthen the policy guidance on the macro-finance and microscopic scale of the industry.
4. The fabricated metal products industry was similar to the ferrous metal smelting and rolling processing industry, the only difference was that the technical room for improvement of fabricated metal products was bigger, and the ability to extend the industrial chain was greater and wider.

² The central government's strict implementation of the energy intensity targets in late 2010 are likely responsible for the absolute decline in emissions during 2010, rather than a shifting downward trend. New data is more likely to reveal that overall emissions have strongly rebound in the period 2011 to 2013 due to high levels of rapid economic growth driven by high levels of investment in these energy and carbon intensive sectors.

³ It is important to consider overall trends rather than year on year variations, which are vulnerable to policy shifts and the strict implementation of short-term administrative targets.

Therefore, for this industry, relevant departments should pay attention to the improvement of value added and the quality of production, and the structure of energy.

Figure 3.35 Predictive value in the iron, steel and non-ferrous metal industries through to 2020



By comparing the grey correlation degree between the proportion of energy (coal, petroleum, electric heating and natural gas) in iron, steel and non-ferrous metals industries with carbon emissions per unit of GDP, this report presents a policy backcasting and performance evaluation below.

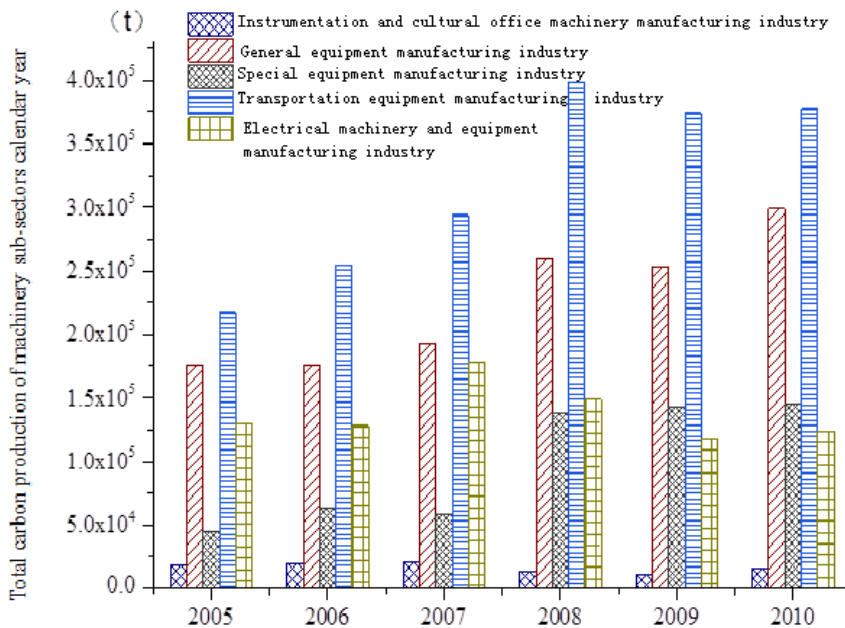
- (1) The change of the structure of energy use in the coal mining and washing industry was relatively obvious, this industry only used petroleum-based energy and electric heating, the proportion of petroleum-based energy changed from 100% to 3.176% from 2005 to 2010, and the proportion of electric heating changed from 0 to 96.824%. The grey correlation degree was relatively high ($0.6 < \zeta_i(k) < 0.7$). The use of electric heating indicated that the upgrading of energy usage and the requirements for clean energy has changed from mining of primary energy to clean production of secondary energy.
- (2) The effect of electric heating on the ferrous metal smelting and rolling processing industry was greatest, and so were the effects of natural gas and coal-based energy. In the ferrous metal smelting and rolling processing industry, coal was used widely, so the use and short-term adjustment of natural gas and electric heating would have a significant effect on the total amount of carbon emissions and carbon emissions per unit of GDP. On the other hand, for the non-ferrous metal smelting and rolling processing industry, the effects of coal-based energy and electric heating were great. The usage proportions of coal-based energy, petroleum-based energy and electric heating were relatively stable, and trends were downward from the overall point. The use of natural gas changed from 5.2% in 2005 to 17.7% in 2010, indicating the energy efficiency of natural gas should be improved.
- (3) The development and energy usage in the fabricated metal products industry were mainly dependent on the use of coal-based energy, so clean coal energy must be used in this industry. The use of natural gas has risen and become the secondary energy here. The use of petroleum-based

energy and electric heating also had effect on carbon emissions of per unit of GDP. The elimination of backward production capacity should be carried out gradually.

3.8.5 Equipment manufacturing industry

The mechanical industry sub-industries were the instruments and cultural office machinery manufacturing industry, general equipment manufacturing industry, special equipment manufacturing industry, transportation equipment manufacturing, and the electrical machinery and equipment manufacturing industry. From 2005 to 2010, the average annual industry carbon emissions increased or decreased in the above sub-industries respectively as follows: -2.6%, 11.2%, 26.4%, 11.7% and -1.0% (Figure 3.36). From 2005 to 2010, the average annual increase or decrease of the above sub-industries' carbon emissions per unit of GDP were respectively: -21.5%, -11.7%, -4.9%, -12.0% and -13.7%. This demonstrates that the five machinery manufacturing sub-industries are also important and energy saving industries in Tianjin, and important elements of the energy structure and industrial planning, which have achieved initial results in reducing carbon emissions.

Figure 3.36 Carbon emissions, machinery sub-industries, 2005-2010



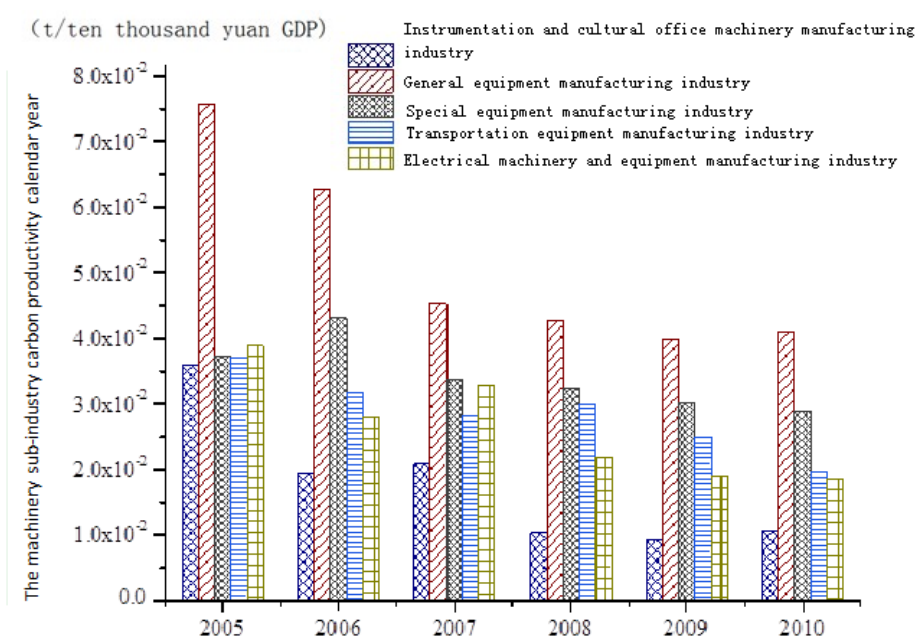
For the total carbon emissions of the industry, the total carbon emissions of the transportation equipment manufacturing industry and general equipment manufacturing industry are the highest, but in the electrical machinery and equipment manufacturing industry they have decreased significantly. Catching up with the electrical machinery and equipment manufacturing industry in 2009-2010, the special equipment manufacturing industry produced a third of the industry total carbon emissions. The decline in the instrumentation and cultural office machinery industry is not very significant.

Carbon emissions per unit of GDP of the machinery sub-industries from 2005 to 2010 are in descending order: general, special, transportation, electrical and instrumentation; and the equipment manufacturing industry is the first one to have an average annual decrease, with a reduction rate up to 21.5% (Figure 3.37). The average annual reduction rate of the electrical manufacturing industry comes in second with 13.7%. The

third two are the transportation and general manufacturing sectors, which are 12.0% and 11.7%, respectively. The carbon emissions per unit of GDP in the special equipment manufacturing industry has the lowest average annual decrease of 4.9%.

Overall, of two energy-carbon emissions targets, the general, special and transport machinery manufacturing industries are the key sectors practicing energy conservation and emissions reduction. The carbon emissions and carbon emissions per unit GDP of the electrical machinery and equipment manufacturing industry energy usage increased gradually, meeting requirements for the gradual electrification of the major industries and the demand for Tianjin's development of key equipment manufacturing. In addition, the energy saving operation mechanism of the instrument manufacturing industry is gradually being perfected.

Figure 3.37 Carbon emissions per unit of GDP, machinery sub-industries, 2005-2010



The GDP reference value and the predictive value of the machinery sub-industries shows that the transportation equipment manufacturing industry has become the largest increasing industry in Tianjin (Figure 3.38). The machinery industry is next, followed by the electrical and instrument industry for completing their energy-saving emissions reduction targets well. It is feasible that enhancing these industries with appropriate financial guidelines will reduce the industry output value differences of the industry internally.

Figure 3.38 Machinery sub-industries GDP reference value and predictive value in 10 years

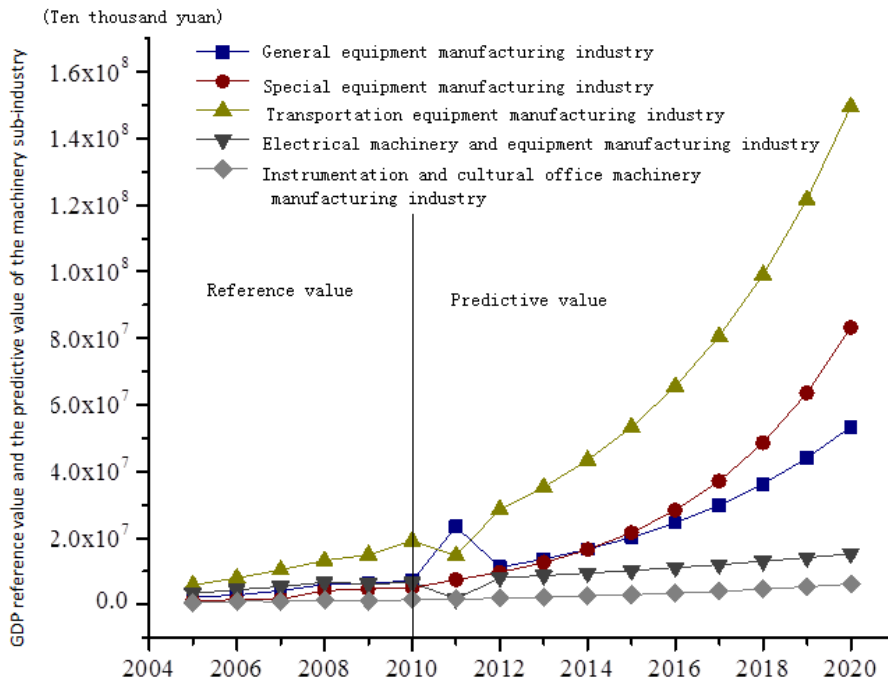
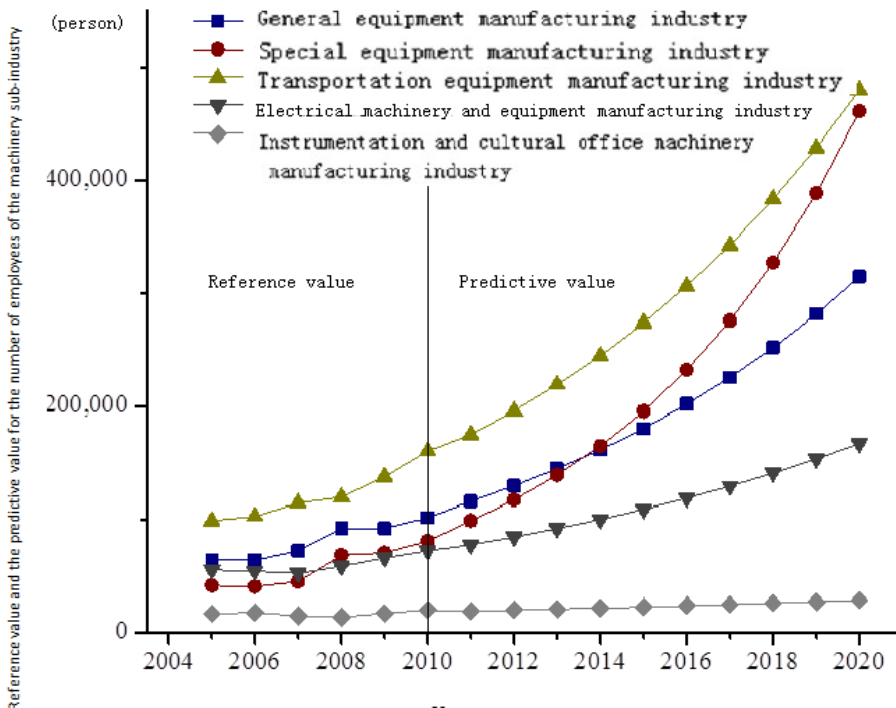


Figure 3.39 Industry employees reference value and predictive value of machinery sub-industries



The reference value and predictive value of industry employees show that in next 10 years, traffic, special equipment and general equipment manufacturing are the industries most likely to develop and grow. The size of the electrical industry growth was lower, and the instruments and other office manufacturing's number of industry employees and overall size will not change greatly over the next 10 years.

The grey correlation between the industry employees' reference value and predictive value and carbon emissions per unit of GDP shows that the carbon emissions per unit of GDP of special equipment and transportation manufacturing are associated with these two influencing factors, $\zeta_i(k)$ and are close to 0.5 (Figure 3.39 above). For electrical manufacturing, the carbon emissions per unit of GDP is closely associated with a larger level of and number of employees and the influence between the two other manufacturing industries are limited by two factors, $0.5 < \zeta_i(k) < 0.6$. Therefore an adjustment for promoting macro and micro economic industry size is needed and we should focus on guidelines for the energy structure, energy efficiency and technical level of these equipment manufacturing industries.

Comparing the grey correlation between the proportion of the five sub-industries of the mechanical industry, which are coal-based, petroleum-based, electric heating, natural gas energy and carbon emissions per unit of GDP, we apply a policy backward derivation and performance assessment in the aspect of energy structure guidance.

Between 2005 and 2010, the proportion of coal-based energy of the various sub-industries of the mechanical industry reduced significantly: general, special, transportation, those of electrical and instrumentation industries decreased by 26.5%, 15.0%, 28.0%, 20.4% and 29.1%, respectively. The proportions of electric force and gas have increased in different levels with the equipment manufacturing industry being the most significant. The change in the petroleum-based energy proportion of the special equipment manufacturing industry is slightly larger with an increase of nearly 50% in 2010 compared to 2005.

The various grey correlation degrees between carbon emissions per unit of GDP and these factors in the aspect of energy structure are as follows:

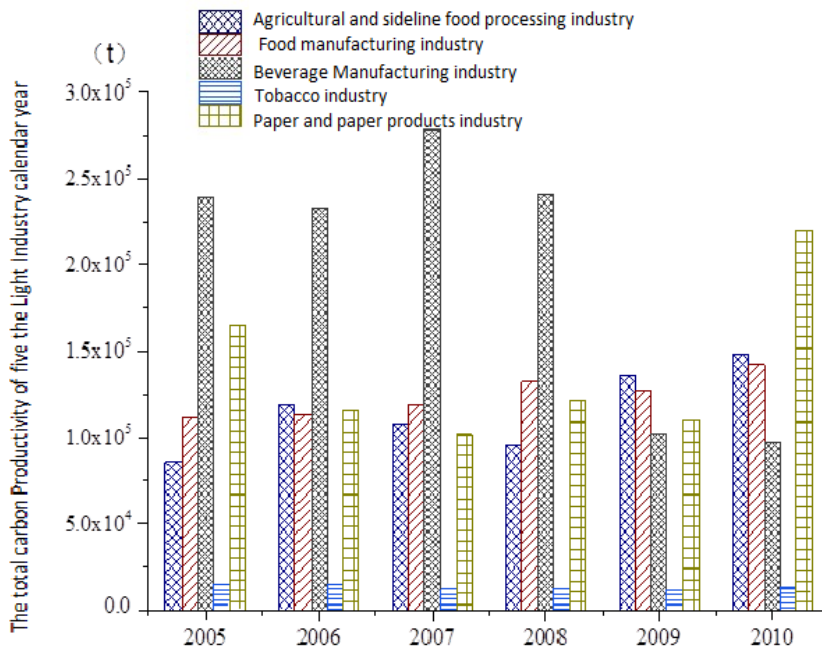
- (1) In terms of the four general manufacturing equipment industries in energy construction, $\zeta_i(k) > 0.7$ for coal-based energy and natural gas, whose association degree is large and $0.6 < \zeta_i(k) < 0.7$ for petroleum-based energy, whose association degree is large too. For electric heating this is $0.5 < \zeta_i(k) < 0.6$. For the general industry, the energy structure adjustment should be increased and the proportion of petroleum-based energy usage and coal-based energy usage should be reduced. In addition, increasing the heating energy consumption proportion of gas and electricity can reduce the overall impact of carbon emissions per unit of GDP of these two energy industries.
- (2) In terms of the four construction of special equipment manufacturing industries, $\zeta_i(k) > 0.7$ for petroleum-based energy for its great degree of association, and the other three are $0.6 < \zeta_i(k) < 0.7$. For private industry's petroleum-based energy use, over the years GDP has had great relevance with the growth of the industry scale. For private industries whose significant has increased, improving energy efficiency of petroleum-based energy and coal-based energy and raising the proportion of natural gas and electric heat are required.
- (3) Transportation equipment manufacturing is greatly supported in Tianjin. And the relevance of four sectors within energy construction and carbon emissions per unit of GDP is not of great significance.
- (4) The electrical machinery and equipment manufacturing industries have developed rapidly in Tianjin. The grey correlation shows petroleum-based energy has great impact. The use of natural gas in the cultural and office machinery manufacturing and instrumentation industry has no influence on the change of carbon emissions per unit of GDP. Compared with the large-scale equipment

manufacturing industry, the minor equipment manufacturing's system energy reform restructuring was relatively quick. This can speed up the process of development and play a role in the overall promotion of reducing carbon emissions.

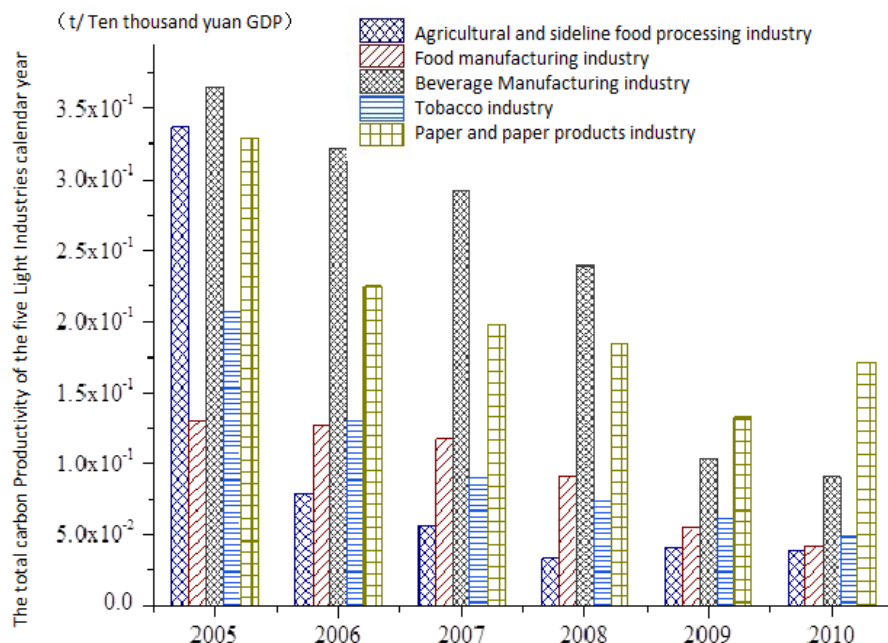
3.8.6 Light industry

For the five light industries recorded in the "China Industrial Economy Statistical Yearbook", the total carbon emissions indicators of the beverage products industry has reduced very significantly. In 2005 and 2008, the reduction of total carbon emissions of the beverage manufacturing industry was the greatest. It took only two years for the total carbon emissions to drop from fifth to second place with an average annual reduction of 16.4%, which is the most significant industry reduction in the five light industries. The tobacco industry's total carbon emissions is less than 3% of the five light industries' total carbon emissions, with an average decrease from 2005 to 2010 of 2.9% (Figure 3.40). In addition, the total carbon emissions of the agro-food processing industry, food manufacturing and paper and paper products industries showed a rising trend.

Figure 3.40 Total carbon emissions, five light industries, 2005-2010



The five light industrial energy saving measures performed extremely well in the 11th FYP. In terms of carbon emissions per unit of GDP, the annual average reduction is as follows from high to low: agro-food processing industry 35.1%, tobacco industry 26.0%, beverage manufacturing 24.3%, food manufacturing industry 20.1%, and paper and paper products industry 12.2% (Figure 3.41 below). In Tianjin, the paper and paper products industry emissions reduction is still a key objective in the light industries.

Figure 3.41 Carbon emissions per unit of GDP, five light industries, 2005-2010

In accordance with the energy saving measures and plans for key areas of the paper-making industry among light industries in the 12th FYP, the chemical pulping process optimisation is mainly low energy cooking, and the chemical pulping process optimisation for closed and concentrated filter technology and equipment. The application for vapor recovery technology and equipment in the production of mechanical pulp should be strengthened and accelerated; and the waste paper pulping process and technology enhancement should be by means of dry screening, using efficient pulping technology and equipment. The industry should also use a new type of dehydration components, efficient washing nets devices for paper machine wire sections, a closed the dryer hood, bag ventilation and waste heat for recovery drying section. This industry should demonstrate and promote the press section strengthen nip, and composite, shoe press technologies. Besides, the papermaking fibre raw materials industry structure should be adjusted with the proportion of waste paper pulp being used reaching 65% of total input in 2015.

According to the analysis of the GDP reference value and the predicted values for the five light industry sectors, the development momentum of the food industry in Tianjin will be important in the next 10 years, followed by the agro-food processing industry and paper and paper products industry coming third (Figure 3.42). The tobacco industry and beverage industry was growing steadily.

Figure 3.42 GDP reference and predicted values for five light industries, Tianjin

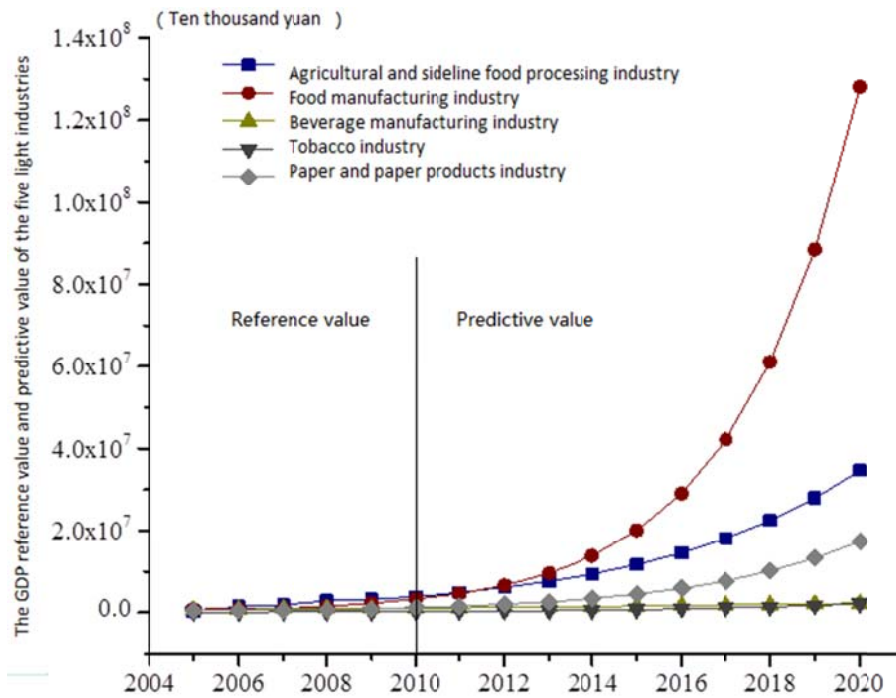
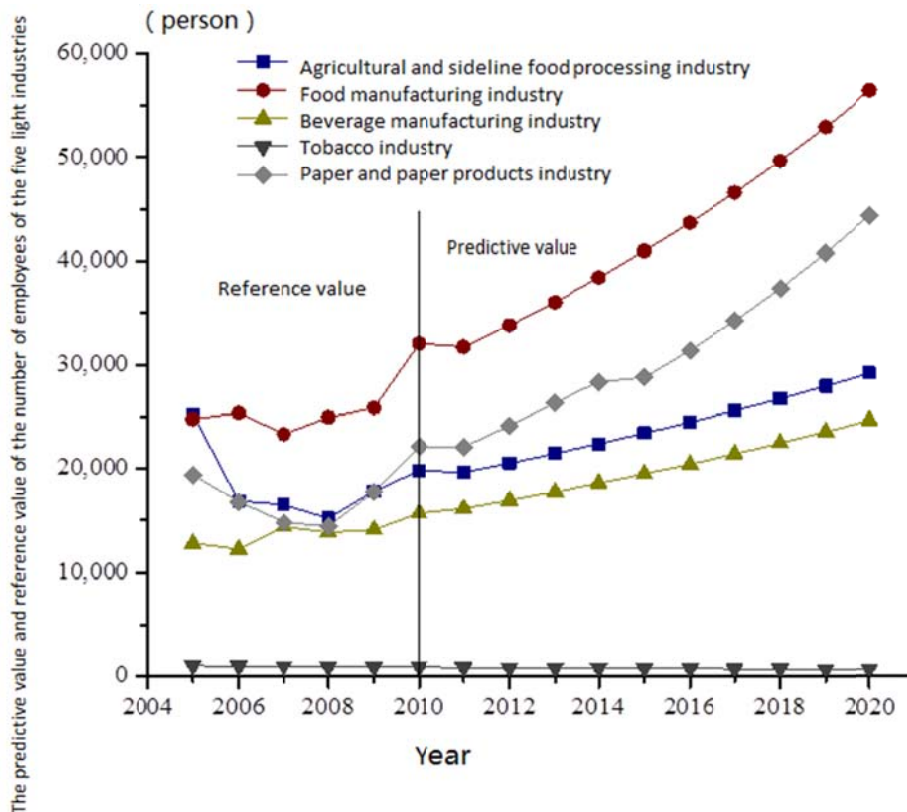


Figure 3.43 Five light industries' reference and estimated value and 10-year predictive value



According to the forecast for the existing industry development trend in the five light industries, the results show that in the next 10 years, for the food manufacturing and paper and paper products industries, industry employees and the size growth rates are the largest, followed by the agro-food processing and

beverage products industries (Figure 3.43 above). Due to the special nature of the products, the size of the tobacco industry over the years is in equilibrium. And in the next 10 years, the employment rate promoted by the first four light industry has great possibilities, because for light industry, the value added and growth of production is limited and technically less demanding.

- (1) The grey correlation between industry employees and grade carbon emissions per unit of GDP is very small, with the agro-food processing industry and the tobacco industry being $\zeta_i(k) < 0.5$. There is one thing in common between the two, that is the carbon emissions per unit of GDP and GDP are generally related to a degree, and therefore adjustment by countermeasures may be appropriate in the macro financial arena. The grey correlation degree between carbon emissions per unit of GDP and GDP of paper and paper products industry is high, $0.6 < \zeta_i(k) < 0.7$. Therefore, fine-tuning of macro and micro decision-making in the industry as a whole maybe feasible for promoting energy saving.
- (2) The two grey correlations in the five light industry of the food manufacturing industry are more prominent, as are the correlations between the industry's carbon emissions per unit of GDP and two factors.
- (3) The GDP and industry employees of the beverage manufacturing and paper manufacturing industry have influence on carbon emissions per unit of GDP, with the pulp and paper most affected. The beverage manufacturing industry generally has a large number of employees. We can strengthen the macro-and micro-control of an industry at the same time to achieve the underlying idealised state of carbon emissions reductions per unit of GDP.

Comparing the grey correlation degree between the proportion of the five sub-industries which are coal-based, petroleum-based, electric heating, natural gas energy light industry and carbon emissions per unit of GDP, we apply a policy backward derivation and performance assessment in the aspect of energy guidance.

In light industry, beverage products, the agro-food processing industry and the food industry had a proportion of coal-based energy that declined heavily, from 35.6 to 23.2 and 13.8 percentage points from 2005-2010. The petroleum-based energy source in the energy consumption in the light industry usually does not occupy a larger share, and can easily be replaced by other advantageous energy alternatives easily. The food manufacturing industry, agro-food processing industry and beverage manufacturing are the three whose electric heating proportion has increased to a large degree. Food is a main necessity of the people, but an upgrade in electric heating of the two products industries, which are paper and tobacco, is not the focus of the industry. It is obvious that natural gas has been applied in these industries. In 2007, the beverage industry, paper and paper products industry have begun to use natural gas, and the tobacco industry also uses natural gas, accounting for 7.0% of the total energy consumption in 2010.

In the light industry and sub-industries, there are different degrees of correlation between the proportion of carbon emissions per unit of GDP and energy use.

- (1) For the agro-food processing industry, the correlation between greater carbon emissions per unit of GDP and natural gas and petroleum-based energy usage is high, while that of electric heating and coal-based energy is medium, which explain why the gas processing industry is gradually unfolding and the trend shows maturity. The processing industry attribute determines the higher impact of petroleum-based energy industry on overall carbon emissions per unit of GDP, therefore measures

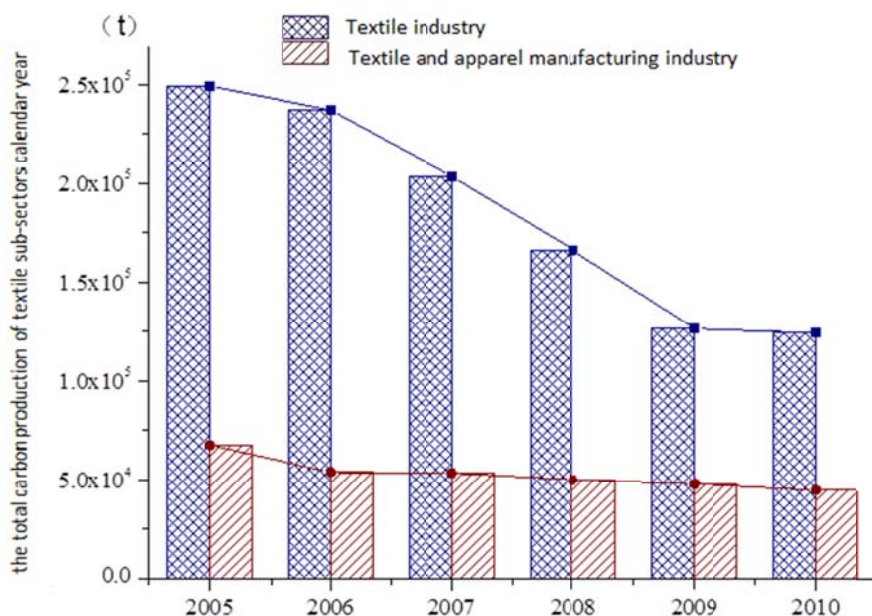
to improve energy efficiency and conversion rates of the petroleum-based energy usage should be taken.

- (2) The food and beverage manufacturing industries are similar in that electric heating is the most important influencing factor. But the difference in the four types of energy is that the second energy consumption factor in the food manufacturing industry is coal-based energy, while that of the beverage manufacturing industry is petroleum-based energy and natural gas, followed by coal-based energy. Gas has great influence in the beverage manufacturing industry, and although it began to be used in 2007, it is developing rapidly.
- (3) The tobacco industry's carbon emissions per unit of GDP are only associated with coal-based energy and electric heating, which is the key determinant, while coal-based energy shows little association. Gas has just been put into application, and its degree of influence on reducing carbon emissions per unit of GDP of the whole industry should be gradually increased.
- (4) The use of gas in the paper industry began in 2007. However, its association with energy carbon emissions per unit of GDP has been the first in the four categories, followed by petroleum-based energy. The introduction of advanced technology and the elimination mechanism of backward technology continue to be strengthened, along with upgrading and structural optimisation of energy efficiency.

3.8.7 Textile industry

In the textile industry sub-industries, for the total carbon emissions, the textile industry is 3.5 times that of textile clothing manufacturing industry (Figure 3.44). The average annual decline in the textile sub-industry is 13.0%, while that of the textile clothing manufacturing industry is 7.9%, which is about 1/2 of the former.

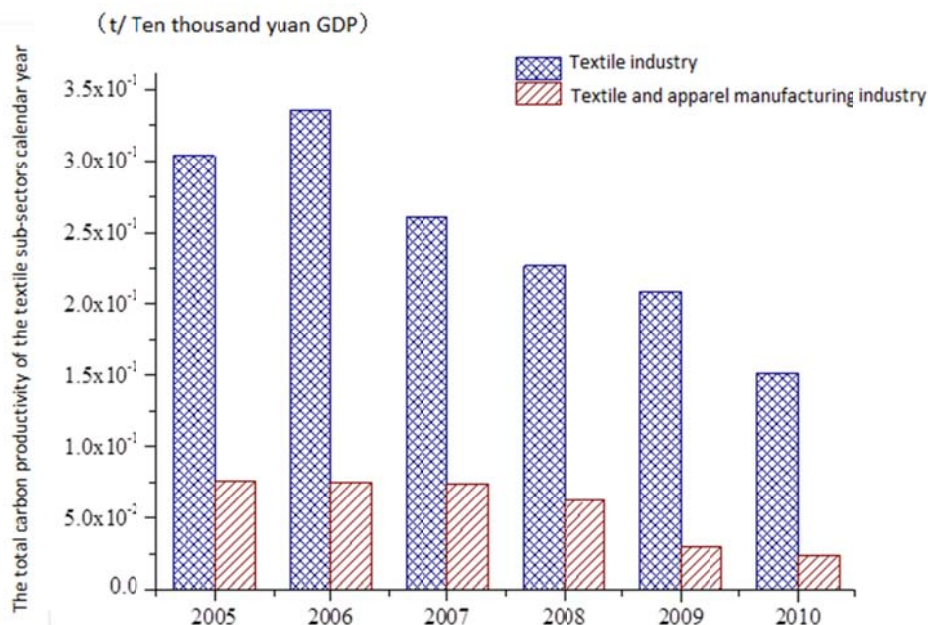
Figure 3.44 Total carbon emissions, textile sub-industries, 2005-2010



Carbon emissions per unit of GDP of the textile industry is about 4.3 times that of the textile clothing manufacturing industry (Figure 3.45). The whole industry has higher growth compared with the latter, and the average annual reduction is also lower than the latter. In 2005-2010, the textile industry energy conservation in Tianjin began to take effect. In 2006, the textile industry carbon emissions per unit of GDP had a brief improvement of 10.3%, which was an annual reduction of 22.1% after only one year. In 2009-

2010, the decline reached 27.4%. In comparison, the textile clothing manufacturing industry has development internal resources due to a diversified chain and the reduction of carbon emissions per unit of GDP is up to 20.3%, which shows how the association between the intra-industry and industry is strengthened and the effectiveness of maintaining overall energy savings is very significant.

Figure 3.45 Carbon emissions per unit of GDP, textile sub-industries, 2005-2010 over the years



There is a substantially upward trend in the textile industry year after year. In contrast, the textile and clothing manufacturing industry is at a relative disadvantage due to the lack of branding in the overall textile industry of Tianjin which is understandable. To develop the industry vigorously in Tianjin, a quality brand and publicity campaign is essential.

The effects of industry maturity and brand building are essential for the number employees and scale of the industry. The upward trend of the textile industry employees scale is associated with overall GDP promotion and we can take advantage of the textile industry's backward promoting and driving effect for the textile clothing manufacturing industry. In addition, the textile industry began growing in 2009 and 2010. To achieve the promotion effect for the latter requires a greater amount of time and funding.

Carbon emissions per unit of GDP in the textile clothing manufacturing industry has a greater correlation with GDP and the number of industry employees. There is a major and minor distinction between carbon emissions per unit of GDP of the textile industry: GDP occupies a larger position in the industry and there is a general association between the number of employees and scale of the industry.

Figure 3.46 GDP reference value and 10-year predictive value of textile sub-industries over the years

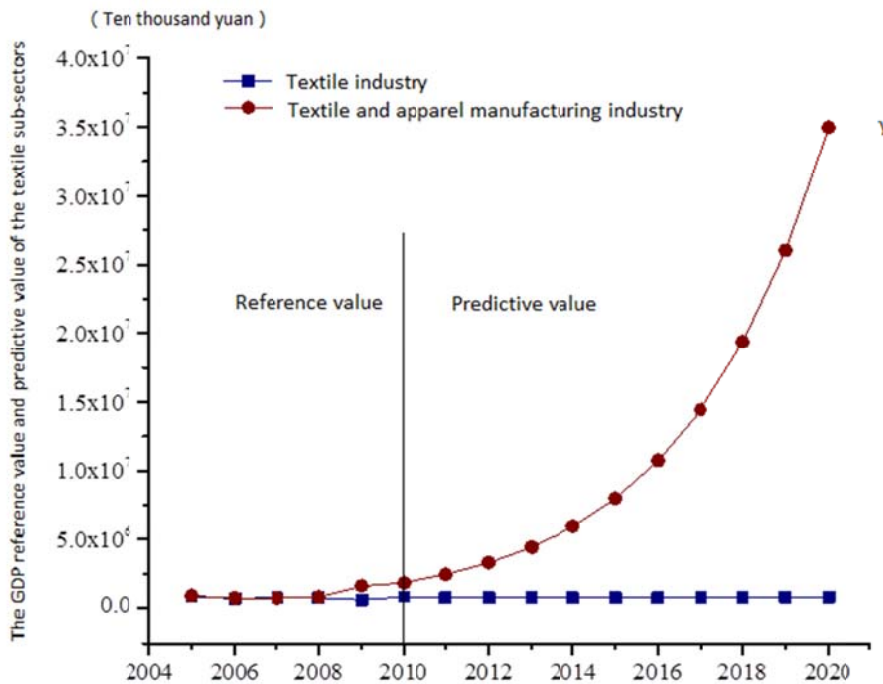
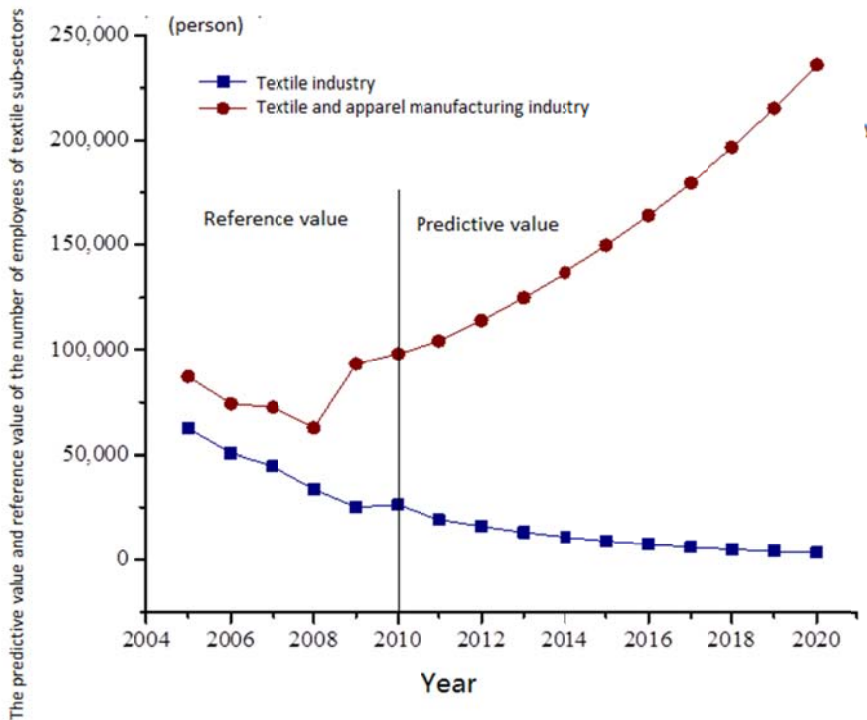


Figure 3.47 Industry employees' reference value and predictive value of textile sub-industries over the years



According to the Tianjin Program on Climate Change, during the 12th FYP, energy saving and technological transformation are key priorities in the clothing, cotton, chemical fibres, printing and dyeing industry and enterprises, as well as the elimination of high water consumption and high energy-consuming printing and dyeing equipment and under-developed chemical fibre processing equipment. In addition, polymer

construction is an imperative, along with the construction of optimised processed and routing. The comprehensive use of the convergence of resources and energy and raw materials needs to be strengthened to promote the consolidation and coordination of the industry chain development.

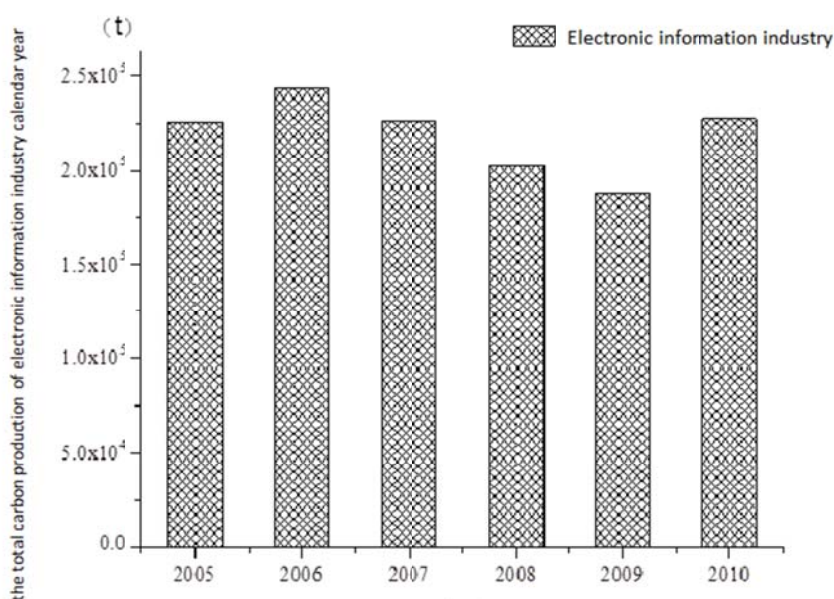
Comparing the grey correlation between the proportion of the above two sub-industries such as the petroleum-based, thermal electric and natural gas energy and carbon emissions per unit of GDP, we apply a backward policy derivation and performance assessment in the aspect of energy guidelines.

The energy consumption enhancement of electric heating and gas has weakened the energy pressure of coal-based and petroleum-based usage to a greater extent. The two industries show that there is a more balanced relationship in coal-based, petroleum-based and electric heating with carbon emissions per unit of GDP in the industry. A weaker association with petroleum-based energy and the greater impact of gas shows the relative maturity of the energy structure of the textile industry.

3.8.8 Information technology industry

The only manufacturing industry in the electronic information industry is the manufacture of communications equipment, computers, and other electronic equipment. The total carbon emissions of this industry fluctuates every year, due to the guidelines and input of macro industry (Figure 3.48). Carbon emissions of this sector increased by 21.2% during 2009-2010, while during 2006-2010 the average increase was only 0.2%.

Figure 3.48 Total carbon emissions, electronic information manufacturing industry, 2005-2010



It appears that the carbon emissions per unit of GDP are not necessarily related to production in this manufacturing sector. During 2005-2010, carbon emissions per unit of GDP were reduced by 1.1% (Figure 3.49).

During 2009-2010, the number of people working in the electronic information manufacturing industry increased by 38.8%, and industrial GDP increased by 15.9%, accordingly (Figure 3.50). As a result of the technology-intensive characteristic of the industry, future requirements of relevant technical personnel are high. During 2005-2008, the industry size and industry GDP were not relevant as expected. On the contrary,

these two factors were in a reciprocal relationship. In the future, this important industry will continue to play a leading role in the economic development of Tianjin.

Figure 3.49 Carbon emissions per unit of GDP, electronic information industry, 2005-2010

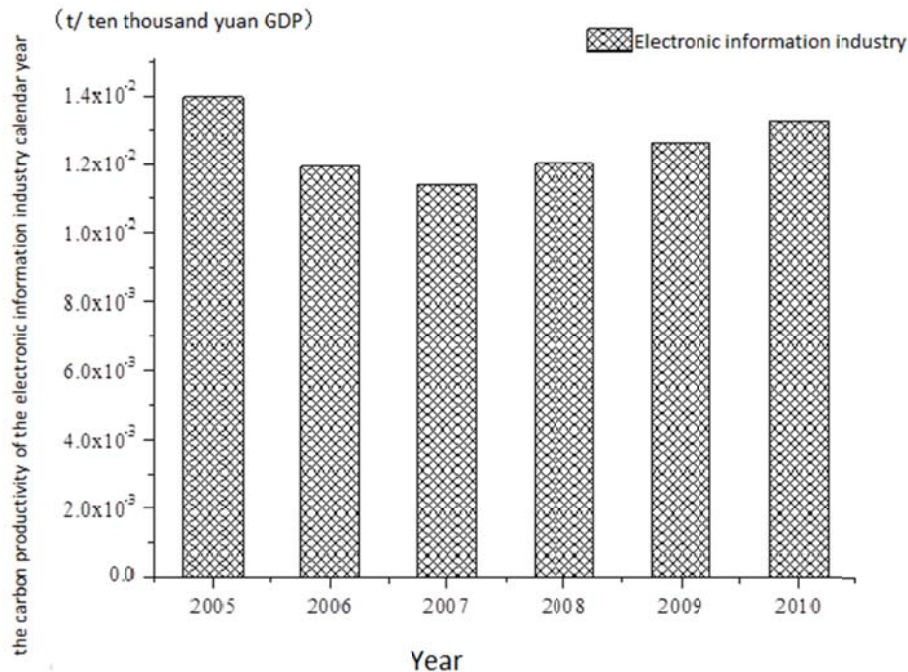
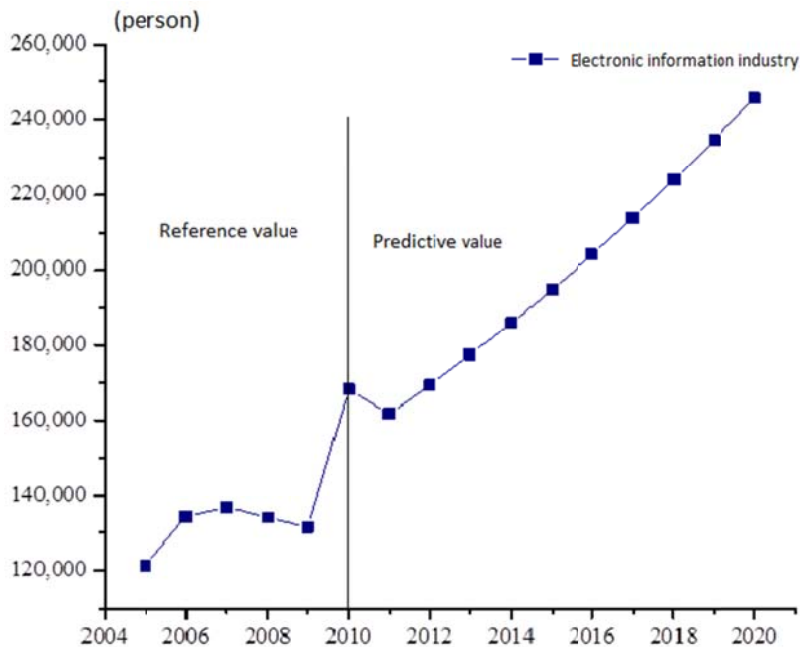


Figure 3.50 Industry employees reference value and predictive value of electronic information manufacturing industry over the years



Without exception, the carbon emissions per unit of GDP of this manufacturing sector are closely related to GDP, and slightly affected by the number of employees in general. This kind of technology-intensive industry should be dealt with differently than other types of industry. In addition to the macro-financial support, the simplicity of the scale of the industries, the technology guiding policy, and the energy guiding policy should be considered closely to reflect their own differences.

Comparing the grey relational analysis of the proportion of coal-based, petroleum-based electric heat and natural gas in electronic information manufacturing with that one of carbon emissions per unit GDP from the energy, we see a political contradiction and performance assessment in the energy guidelines.

In terms of energy policy adjustments, the replacement of rapid-developing coal- and petroleum-based energy led to a reduction of carbon emissions per unit of GDP of the entire industry, and the reduction of coal-based energy promoted the development of energy saving and an emissions reduction program. However, since the average reduction was insufficient, we should focus on electric heating to make further progress. One of the most important methods is to strengthen the emissions reduction from the source of it. The reduction brought by natural gas was largely offset by electric heating, which proved that electric thermal energy is efficient and irreplaceable in the whole industry.

3.8.9 Key industrial sectoral emission scenarios

Table 3.3 below) shows the factors associated with the sub-industries and subsectors.

Table 3.3 Carbon intensity-economic-energy matrix for 25 industries in Tianjin

Industry	Economy & scale		Energy structure			
	GDP	Number of employees	Coal	Petroleum	Electric	Gas
<i>Iron & steel & non-ferrous metals</i>						
Black metal mining industry	++	+++	++	+++	+++	---
Coal mining & washing industry	+++	++++	---	++	++	---
Ferrous metal smelting & rolling processing industry	+	++	+	+	++	+
Non-ferrous metal smelting & rolling processing industry	++	+++	+	+++	+++	+
Metal products industry	+	++	+++	+	+	++
<i>Petrochemical</i>						
Petroleum & gas exploitation	+	+	+	+	+	---
Petroleum processing, coking & nuclear fuel processing industry	+++	+	++	+	+++	++++
Chemical fibre manufacturing industry	++	+++	++	+++	++	---
<i>Chemical</i>						
Chemical raw materials & chemical products manufacturing industry	+	---	+	+++	+	+
Pharmaceutical industry	++	+++	++	+	+	++
<i>Construction</i>						
Non-metallic mineral products industry	++	++	+	++	++	+
Non-metallic mining industry	+	+	+	+	+	---
<i>Machinery</i>						
Instruments & cultural office machinery manufacturing industry	+	+	+	+	+	---
General equipment manufacturing industry	+	+	+++	++	+	+++
Special equipment manufacturing industry	++	++	++	+++	++	++
Transportation equipment manufacturing industry	+	++	++	+	+	+
Electrical machinery & equipment manufacturing industry	+	+	+	++	+	+
<i>Light industry</i>						
Agro-food processing industry	+	---	+	++	+	++
Food manufacturing industry	+++	++	++	+	+++	+
Beverage manufacturing industry	+	++	+	++	++	++
Tobacco industry	+	---	---	---	+	---
Paper & paper products industry	++	++	+	++	+	++
<i>Information technology</i>						
Communications equipment, computers & other electronic equipment manufacturing	++	+	+++	---	+	+
<i>Textiles</i>						
Textile industry	++	+	++	++	++	+++
Textile clothing manufacturing industry	+++	++	++	++	++	+

Notes: ++++ The factor and industry carbon emissions per unit of GDP are very highly correlated.
+++ The factor and industry carbon emissions per unit of GDP are highly correlated.
++ The factor and industry carbon emissions per unit of GDP are relatively highly correlated.
+ The factor and industry carbon emissions per unit of GDP are generally correlated.
--- The factor and industry carbon emissions per unit of GDP are extremely low or not correlated.

4. Monitoring the Implementation of a Low-Carbon City Development Roadmap

4.1 Introduction

As noted in chapters 1 and 2, governments across the globe have begun implementing a range of policy measures to address climate issues such as energy efficiency programs and setting carbon reduction targets. After a 19.1% improvement in energy intensity during the 11th FYP, China is committed to further reducing the intensity of carbon dioxide (CO₂/unit of gross domestic product, GDP) by 40% to 45% by 2020 from a 2005 baseline. In March 2011, China's 12th FYP established a carbon intensity reduction goal of 17% between 2011 and 2015. It has been noted that the success of the first decade of China's national energy efficiency reforms relied upon the so-called low hanging fruit of closing down small, unproductive and ageing power plants and industrial capacity (Climate Policy Institute 2011). Further improvements in energy efficiency are expected to require more comprehensive policy and market responses, combined with adjustments to the energy mix and fundamental behavioural shifts, as well as structural economic change. At the same time, local government leaders are realising that they are increasingly being held to account for implementation gaps. It is therefore no surprise that municipal policy makers and government leadership are seeking strategic guidance and direction for realising the national carbon and energy intensity targets.

This chapter explores the role of indicators and benchmarks as tools for assisting municipal leaders and governments better understand the existing structure of local energy use and demand. Benchmarking cities in terms of global competitiveness and the adoption of low-carbon indicators provide both direction as well as a system of monitoring progress. To date, such targets and indicators are playing a critical role in shaping government policy and priorities both in terms of compulsory targets as well as guidance targets. In addition, by tracking progress towards low-carbon city targets, city authorities can adjust policy and market settings accordingly. Integrating low-carbon city development with a city's global city status and quality of life is critical because local government leaders are unlikely to sacrifice the short-term competitiveness and attractiveness of their city for curbs on investment and development unless they can appreciate the relative gains. Therefore, prior to exploring the more comprehensive low-carbon city indicator systems, this chapter undertakes a brief comparative analysis of Tianjin, Beijing and Melbourne using a simple key performance indicators (KPIs) approach. The analysis then moves to the more comprehensive low-carbon city indicator systems, of which there has been considerable discussion in China and elsewhere (e.g. World Bank 2012). The three index systems currently well known in China (one each developed for Beijing and Tianjin and one developed for more general application by the Chinese Academy of Social Sciences) will be reviewed and compared, before discussing and analysing a number of other, more detailed index systems that have been developed by other authors in China. This is followed by the presentation of a comprehensive index system for Tianjin which was developed for this project, as well as a brief discussion of the potential uses of such an index systems. In the final part of this chapter, a global city peer comparison is undertaken to demonstrate the development strategy and achievement paths for a city's mitigation goals, and to provide experience and a reference for the energy strategy research of Beijing.

4.2 Key performance indicators for low-carbon city development in Tianjin, Beijing and Melbourne

In order to reach the goal of low-carbon city development, a unified key performance indicator (KPI) has been developed to facilitate comparisons of the low-carbon level of different cities. For the purpose of this report, the KPI is applied to the cities of Beijing, Tianjin and Melbourne. Background details for Beijing and Tianjin are introduced in Chapter 3 and are found in Appendix 2 for Melbourne.

The KPI adopted the OECD's driving forces- state-response (DSR) model. The DSR model basically helps to identify and analyse the key human activities that consume energy and produce carbon emissions. According to the different development situations of Tianjin, Beijing and Melbourne, the KPI of a low-carbon city should be systematically developed, so that it can reflect the low-carbon level of these cities by combining the respective development patterns. On the basis of the DSR model, several key low-carbon indicators were selected (see Table 4.1), which consists of fields such as economic structure, energy consumption, carbon emissions, etc.

Table 4.1 KPI of a low-carbon city

Object	Factors	Indicators
Low-carbon city evaluation	Driving forces	GDP per capita (RMB/per capita)
		Population density (people/km ²)
	Status	Energy consumption intensity (tce/RMB10,000)
		Clean energy proportion (%)
		Carbon emissions intensity (ton/RMB10,000)
		Service sector's proportion of emissions (%)
		Days of air quality reaching or better than Grade 2 (%)
	Response	Energy system efficiency (%)
		Reclaimed water utilisation rate (%)
		Utilisation rate of industrial solid waste (%)
		Recycling rate of industrial water (%)
		Green coverage rate (%)

Beijing and Tianjin are clearly defined administrative jurisdictions, including for statistical purposes. In contrast, the city of Melbourne is not a typically defined statistical area except for the CBD area which is sometimes used for city comparisons. Instead it is probably more accurate to adopt statistics for the state of Victoria or assign a generic proportion to Melbourne, say 75% of Victorian data. All approaches have their respective weaknesses. Much of the analysis in this chapter includes comparisons between Tianjin, Beijing and Victoria instead of Melbourne. Therefore, there is a strong need to illustrate the comparability of these three cities, by explaining the basic information and the driving forces in KPI such as population density and economic structure.

Table 4.2 below illustrates the area, population, and density in Tianjin, Beijing, Melbourne and Victoria, respectively.

Beijing has the largest area and population among the three cities, while Melbourne has the smallest. However, when comparing population density, the density of these three cities is roughly the same (where population density of Melbourne's urban area is 1,567/km²). When contrasting the area and the population

of Melbourne and Victoria (the population density of Victoria is 24.51/km²), it can be seen that most people in Victoria live in Melbourne and it therefore acts as a better proxy for comparison.

Table 4.2 Population density

	Tianjin	Beijing	Melbourne	Victoria
Area (km²)	11,760	16,801	8,806	237,629
Population	12,938,224	20,186,000	4,077,036	5,603,100
Density	1,100/km ²	1,200/km ²	1,567/km ²	24.51/km ²

4.2.1 KPI analysis: The economy

Economic indicators are presented in Table 4.3. As the table shows, the per capita GDP (GDPpc) of Tianjin and Beijing are actually very high in China respectively ranked at 1st and 3rd. It is not surprising that the human development index (HDI) for Tianjin and Beijing is respectively 3rd and 2nd within China. This suggests that Tianjin and Beijing are two developed cities. Victoria, as a state, has the second-largest gross state product (GSP) of Australia with 23% (2008-09). Melbourne represents around 77% of the Victorian economy. Therefore, the comparison of Tianjin, Beijing and Melbourne is more credible.

Table 4.3 Economic situation

	Tianjin	Beijing	Melbourne
GDP (billion RMB)	1,119 (20 th ; 2011)	1,600 (13 th ; 2011)	1,878 (2010)
GDPpc (RMB/per capita)	84,337 (1 st ; 2011)	80,394 (3 rd ; 2011)	338,708 (2010)
HDI	0.875 (3 rd ; 2008)	0.891 (2 nd ; 2008)	0.938 (2013)

In 2010, Melbourne's GDP was RMB1,878 billion, which is higher than Beijing's RMB1,600 billion and Tianjin's RMB1,119 billion. When comparing per capita GDP for the three cities, the gap is more obvious. The GDP per capita of Melbourne in 2010 was RMB338,708 per capita, which is almost 4 times of Tianjin's and Beijing's GDP per capita in 2011. Clearly, Melbourne is at a higher level of economic development compared with Tianjin and Beijing.

4.2.2 Low-carbon city analysis

By synthesising the relevant data and its association with the low-carbon concept, two aspects of the KPI have been selected to analyse the low-carbon status for each city: carbon emissions and energy consumption. The emission/consumption conditions and emission/consumption intensity of these two aspects are then respectively analysed.

In 2010, Victoria's emissions of CO₂ equivalent (see Figure 4.1) totalled 121.9 million tonnes—an increase of around 4% from 1999. Victoria has the third highest CO₂eq emissions of all Australian states and territories, producing 22.5% of national emissions. Victoria's emissions were almost 50 million tonnes less than Tianjin's and Beijing's. Due to a lack of carbon emissions data, the level of carbon emissions for Tianjin and Beijing are calculated by multiplying each city's energy consumption by a conversion coefficient.

The per capita carbon emissions provide a more accurate picture for comparison (Figure 4.2). Victoria's per capita CO₂ emissions are the highest at 17.58 tonnes due to its dependency upon brown coal, its low population and high standard of living. In contrast, Beijing has the lowest carbon emissions per capita at 8.71

tonnes and Tianjin is 12.9 tonnes per capita largely due to the dominance of the industrial sector in its economy.

Figure 4.1 CO₂-e (10 thousand tonnes) emissions in Beijing, Tianjin and Victoria, 2010

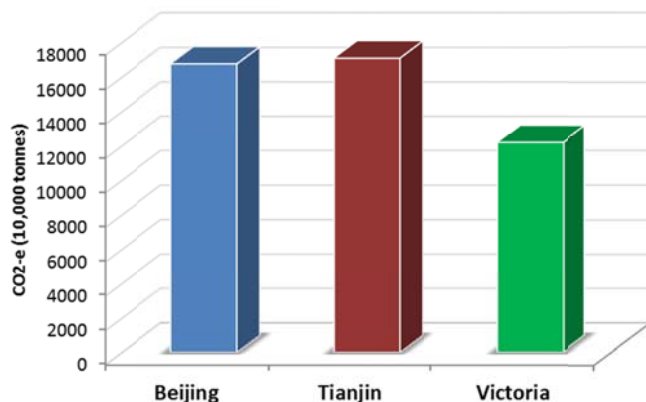


Figure 4.2 Carbon emissions per capita in Tianjin, Beijing and Victoria

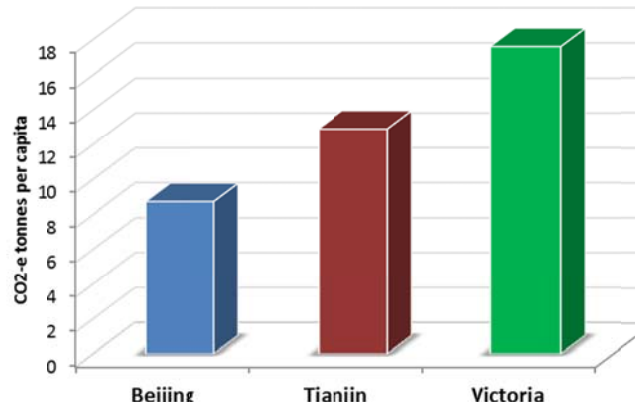


Figure 4.3 Carbon emissions intensity in Tianjin, Beijing and Victoria, 2010

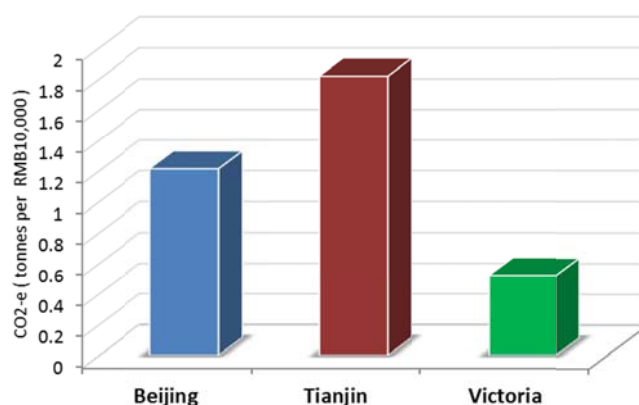


Figure 4.4 Energy consumption in Tianjin, Beijing and Victoria

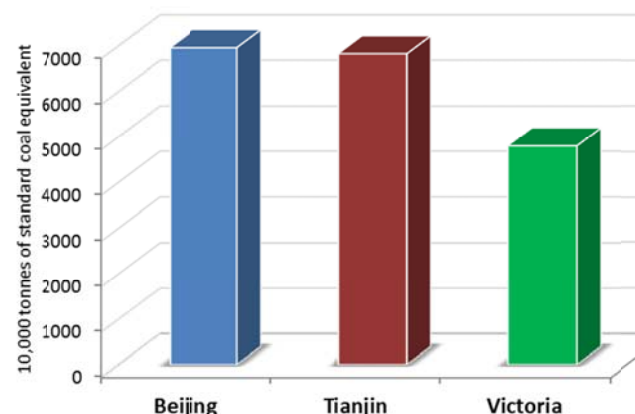


Figure 4.5 Energy consumption intensity in Tianjin, Beijing and Victoria

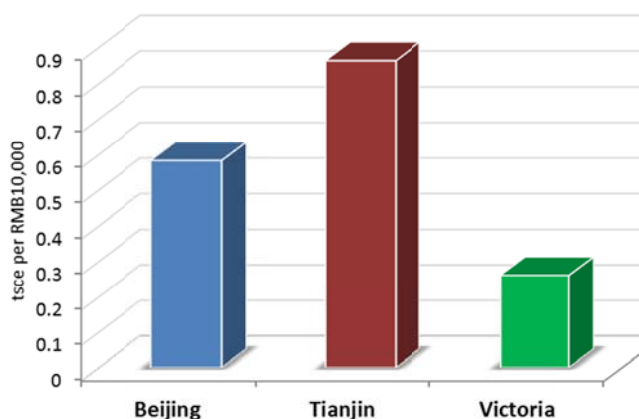


Figure 4.3 shows the carbon emissions intensity (carbon emissions per unit of GDP) for Tianjin, Beijing and Melbourne. Melbourne's carbon emissions intensity is the lowest (0.51 ton/RMB10,000). Beijing's carbon emissions intensity is 1.21 tonnes/RMB10,000, which is more than 2 times that of Victoria's. Tianjin has the highest carbon emissions intensity (1.82 tonnes/RMB10,000), which is more than 3 times that of Victoria's. The high value added contribution of the services sector and the high level of economic wealth explain the relatively low-carbon intensity for Victoria's economy.

In terms of total energy consumption (see Figure 4.4), Victoria's energy consumption in 2009-10 totalled 1.4 thousand petajoules, which is equivalent to around 47,960 tsce or almost 20,000 tsce less than Tianjin's and Beijing's. Victoria's energy consumption dipped slightly from 2008-09, but remains the second highest of all states and territories in Australia, consuming 23.6% of the total Australian net energy consumption in 2009-2010.

Figure 4.5 illustrates the energy consumption intensity for Tianjin, Beijing and Melbourne. Energy consumption is the energy consumption per unit of GDP, which indicates the relative level of energy efficiency. Victoria's energy consumption intensity is the lowest at 0.26 tce/RMB10,000. Beijing's energy consumption intensity is 0.58 tce/RMB10,000, which is more than 2 times Victoria's figure. Tianjin has the highest energy consumption intensity of 0.86 tce/RMB10,000, which is more than 3 times that of Victoria.

In the 20 years to 2010, Victoria achieved a 28 percentage point reduction in the state's energy intensity. The main explanation for this trend is the growing role of the services sector and rising levels of wealth. It is likely that this trend has continued through to 2013 due to decreasing output by the aluminium, steel and cement sectors in the state.

The previous section showed that Beijing has the highest carbon emissions, Tianjin has the highest energy consumption and Victoria has the highest per capita carbon emissions. At the same time, Victoria has the lowest carbon emissions intensity and energy consumption intensity. This section uses the "Kaya decomposition" formula to analyse the causes behind these results.

4.2.2.1 Kaya formula

The Kaya formula was developed by the Japanese energy economist Yoichi Kaya. It is the subject of his book *Environment, Energy, and Economy: Strategies for Sustainability* co-authored with Keiichi Yokobori as the output of the *Conference on Global Environment, Energy, and Economic Development* (1993: Tokyo, Japan). The Kaya identity is an equation relating to factors that determine the level of human impact on the climate in the form of carbon emissions.

The formula is expressed in the form:

$$C = \sum_i C_i = \sum_i \frac{E_i}{E} \times \frac{C_i}{E_i} \times \frac{E}{GDP} \times \frac{GDP}{P} \times P$$

where:

- C = carbon emissions
- C_i = carbon emissions of "energy-i"
- E = energy consumption
- E_i = energy consumption of "energy-i"
- GDP= gross domestic product
- P = population

The carbon emissions intensity is expressed by:

$$G = \frac{C}{GDP} = \sum_i \frac{C_i}{GDP} = \sum_i \frac{E_i}{E} \times \frac{C_i}{E_i} \times \frac{E}{GDP} = \sum_i S_i \times F_i \times R$$

where:

- G = carbon emissions intensity
- $S_i = E_i/E$ = "energy-i" in a share of energy consumption (energy consumption structure)
- $F_i = C_i/E_i$ = carbon emissions per unit "energy-i" (carbon emissions intensity of energy)
- R = E/GDP = energy consumption per unit of GDP (energy consumption Intensity)

By decomposing the Kaya formula it is possible to note how the carbon emissions of different industries can also be an important factor contributing towards the carbon emissions intensity. The decomposition of different industry's carbon emissions intensity is expressed in the form:

$$R = \frac{E}{GDP} = \sum_j^m \frac{E_j}{GDP_j} \times \frac{GDP_j}{GDP} = \sum_j^m R_j \times e_j$$

where:

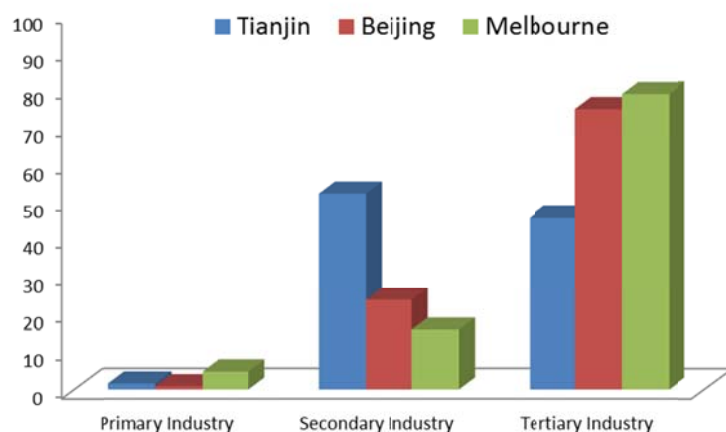
- $R_j = E_j/GDP_j$ = energy consumption intensity of "industry-j"
- $e_j = GDP_j/GDP$ = value added proportion of "industry-j" (industry structure)

These formulas state that the total emissions intensity can be expressed as a product of four inputs: energy consumption structure, carbon emissions intensity of energy, energy consumption intensity and industry structure. Among these factors, carbon emissions intensity of energy is constant, so the only the other three factors will be analysed.

4.2.2.2 Economic structure

The difference in economic structure between the three cities is critical to explaining their respective energy and emissions intensity figures (see Figure 4.6). Secondary industry has a strong presence in Tianjin at 52.4% of total, compared to Beijing where it is less than half (24%) Tianjin's figure or Melbourne where it is less than a third (16%). The economic structure of Beijing and Melbourne are dominated by the tertiary or services sector. It is likely that this sector will continue to grow in both cities as secondary industry declines. The contribution of primary industry to the GDP of each city remains insignificant as a percentage, but still plays an important indirect and supporting role, especially for Melbourne.

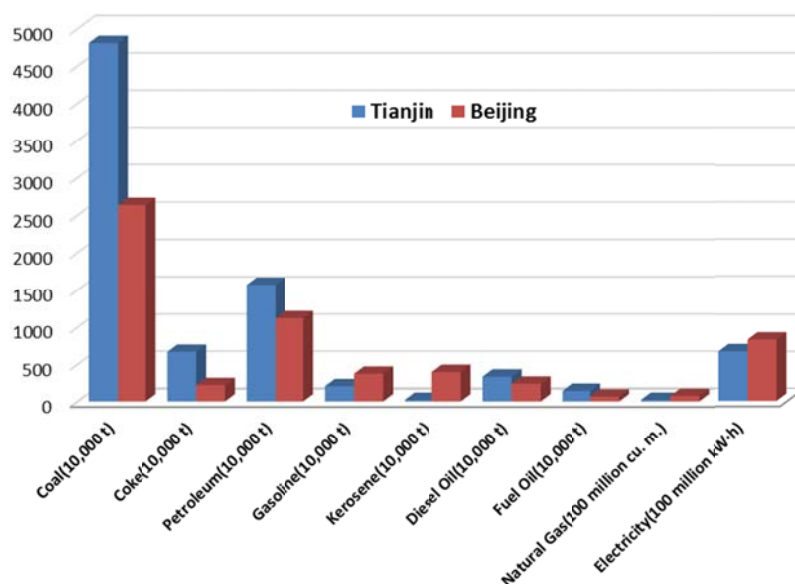
Figure 4.6 Structure of local economy, 2010



4.2.2.3 Energy consumption structure

The two largest energy consumption sources in Tianjin and Beijing are coal and petroleum. These two energy sources dominate total energy consumption in both cities (see Figure 4.7). In 2010, coal consumption in Tianjin reached 48,071.5 thousand tonnes, which is almost double that of Beijing.

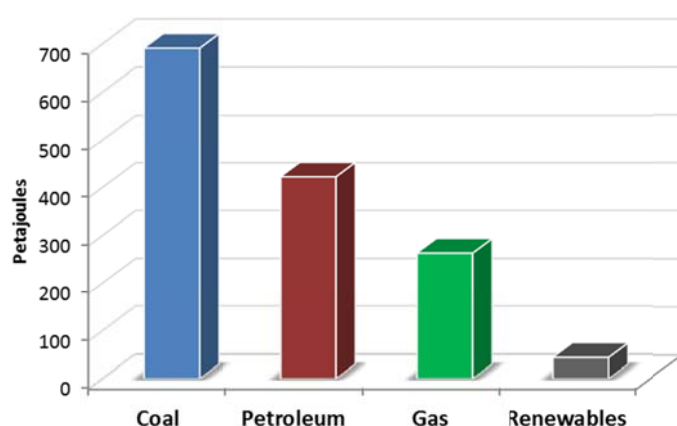
Figure 4.7 Energy consumption structure



Petroleum is the second major energy source with Tianjin consuming 15,659 thousand tonnes and Beijing consuming 11,169 thousand tonnes.

The final total energy consumption in Victoria is shown in Figure 4.8. In 2009-2010, the main energy source is coal which accounts for 49% of total primary demand, followed by petroleum at 30% and gas at 19%. It is noted that almost all of the energy consumed is generated from these three types of energy with renewable energy contributing just 3%, consisting mainly of wind (49%), hydro (23%) and biomass (27%). The share of renewables grew to 5.5% of total consumption in 2012 and is targeted to reach 20% by 2020. The City of Melbourne (COM 2012) claims that renewable energy contributes around 28%-29% of its consumption, however, this figure only refers to the activities of the municipal government and not residents, nor the commercial, industrial, transport and retail sectors.⁴ While overall energy consumption in Victoria has declined during the past four years, the share of renewables has been steadily rising due to state subsidies, lower costs and the renewable energy target.

Figure 4.8 Total primary energy demand in Victoria, 2009-2010

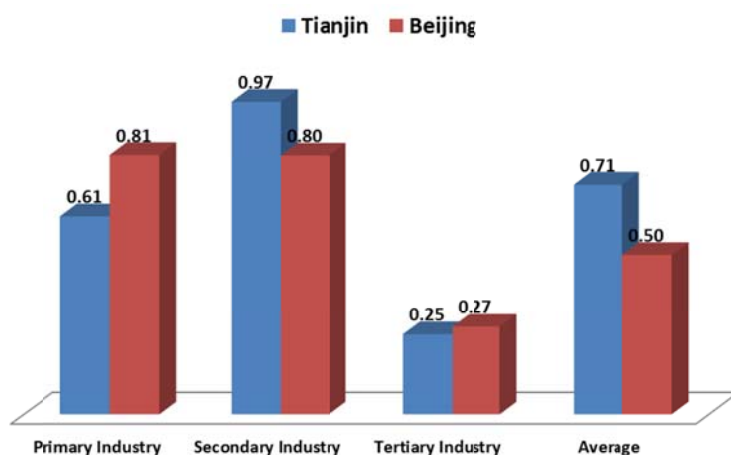


4.2.2.4 Energy consumption intensity by industry

Due to data limitations for Melbourne, the analysis on energy intensity by sector in this section focusses on a comparison between Tianjin and Beijing (Figure 4.9). The energy consumption intensity in Tianjin is 0.71 stce/RMB10,000. This is significantly higher than Beijing's 0.50 stce/RMB10,000. As can be seen from the figure, the main explanation for this disparity is the high energy intensity figure for Tianjin's industrial sector (0.97 stce/RMB10,000), which consumes the most and exceeds Beijing's secondary industry level (0.80 stce/RMB10,000). While the disparity partly reveals the potential efficiency gains that could be achieved in Tianjin, it also reflects the presents of dominance of energy intensive industries in the city, such as steel, cement and petrochemical.

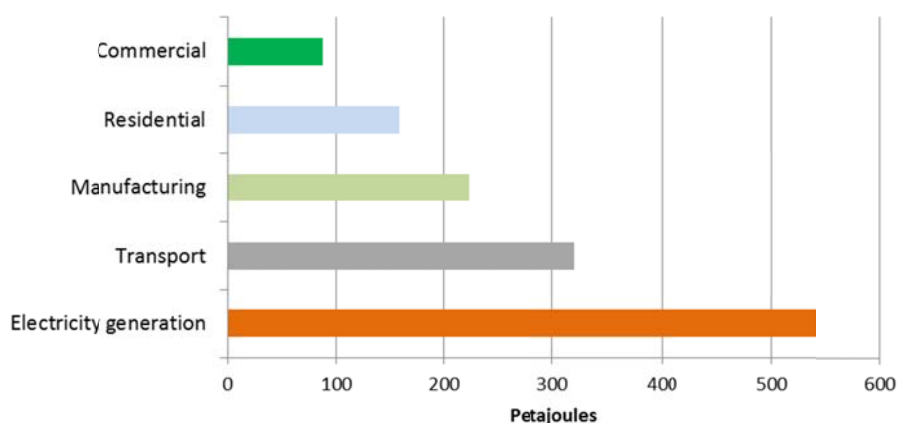
⁴ Source: COM Annual Report 2011-12.

Figure 4.9 Energy intensity (tsce/RMB10,000) by industry In Beijing and Tianjin, 2010



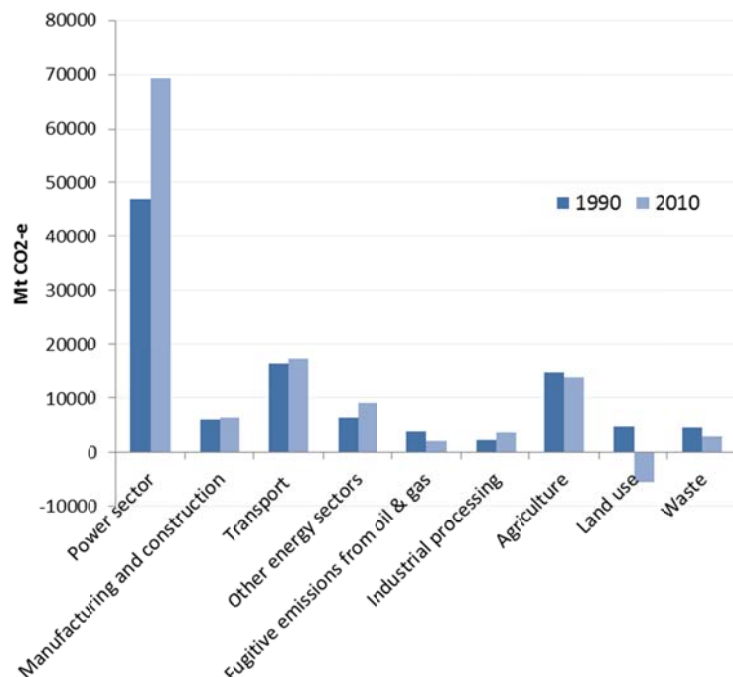
As noted in Figure 4.10, Victoria's primary energy consumption reached 1405.6 petajoules in 2009-2010 and was mostly used by five sectors of electricity generation (38.5%), transport (22.7%), manufacturing (15.8%), residential (11.3%) and commercial (6.3%).

Figure 4.10 Energy consumption by industry in Victoria, 2009-2010



Between 1990 and 2010, Victoria's emissions grew by 22.8% from 100.8 Mtsce to 123.7 Mtsce and contribute to 22.4% of national emissions (Figure 4.11).⁵ The main area of growth came from energy consumption which rose from 75 Mtsce in 1990 to 103.6 Mtsce in 2010. There has been little change in the emissions from Victoria's sectors with the exception of the power sector. Emissions from power generation in Victoria during the past twenty years have grown by 47% from 44 Mtsce in 1990 to 65 Mtsce in 2010 due to an ongoing heavy reliance upon the relatively inefficient and highly polluting (especially in terms of carbon emissions) brown coal.

⁵ The emissions growth is less dramatic at around 12.1% for this period if land use, land-use change and forestry are taken into account: 1990 = 105.5 Mtsce; 2010 = 118.3 Mtsce.

Figure 4.11 Victoria CO₂ equivalent emissions, 1990-2010, Mt CO₂-e

4.2.3 Summary

Through the construction of a simple key performance indicator for Tianjin, Beijing and Melbourne it is clear that all three cities still have considerable room for improving the efficiency and intensity of their carbon and energy footprints. While Melbourne would appear to be more advanced along the pathway towards becoming a low-carbon city, this conclusion relies upon the distortion of its status as a wealthy and advanced economy. The dominant role of the services or tertiary sector in Melbourne and Beijing offers greater value added and lower carbon emissions per unit of GDP, but both cities continue to be heavily dependent upon coal and oil for their energy consumption. Accelerating the structural adjustment of the energy sector requires the use of low-carbon energy instead of high carbon energy, which means a change from coal to gas and renewables. Tianjin shares a similar challenge in cleaning up and reducing the carbon intensity of its energy structure, but equally challenging is how it can undertake industrial restructuring to move up the value chain of production whilst cleaning up its industry and reducing its energy and carbon footprint. Most analysis of Tianjin's economy would argue that the city needs to undertake structural economic change by moving away from manufacturing and industry and towards services, but this would ignore the high levels of investment in recent years in the former sectors. The industrial sectors are likely to remain a core part of Tianjin's economy. Therefore the challenge remains to ensure that production is clean, efficient and involves greater value adding.

Based upon the KPI analysis in this section, it is clear that the low-carbon level of all three cities needs to be improved. However, the analysis is limited in offering solutions. In order to better understand the complexity of alternative pathways for making the transition to a low-carbon economy, additional or more sophisticated indicator systems and models need to be adopted. This

task is undertaken in the following section which focuses on a low-carbon city evaluative index system.

4.3 Low-carbon city evaluation index systems

An evaluation index system is a useful tool for monitoring, reporting and evaluating a city's low-carbon development status, progress and challenges. The index system needs to be simple and accurate so that it can both assist governments in improving decision making and guide cities on progress towards low-carbon development. In the initial stages, a representative, reliable and accurate statistical system is critical because progress is difficult to measure without an accurate baseline (Chinese Society for Urban Studies 2011; Zhou et al. 2012).

In China, two low-carbon indicator systems have been developed by the Ministry for Environmental Protection and the Ministry of Housing and Urban and Rural Development. In addition to these two main indicator systems, several cities and provinces have developed their own monitoring and reporting indicator systems. Prior to developing an evaluation system for low-carbon cities, the low-carbon evaluation systems operating in Beijing, Tianjin and the national system China are compared (see Table 4.4).

Table 4.4 Comparison of low-carbon city index systems

	Beijing	Tianjin	China
Index system	Beijing low-carbon city evaluation index system	Tianjin low-carbon planning index system	Low-carbon city standard system
Source	Yang Yanfang (2012)	Li and Yu (2011); Zhuang et al. (2011)	MoHURD (2004); MEP (2007)
Low-carbon city concept	Low-carbon city is a city under the premise of high-speed economic development, to keep at a low level of energy consumption and carbon dioxide emissions.	Realise sustainable development in the process of urban development, emphasising low-carbon as a guiding concept for technological advancement and production, whilst mitigating carbon emissions developing the local economy and improving the quality of people's lives.	MoHURD scheme is eco-garden city review focussed on green infrastructure, but no energy, industry and economic index. MEP focuses on eco-construction and environmental indicators promoting best practice, but neglects local climate or transport.
Source of low-carbon city concept	WWF	<i>Low-carbon City Concept and International Experience</i> (Liu et al. 2009)	MoHURD/MEP
Structure	Target layer-criterion layer (5 directions)-index layer, quantitative index.	Target layer: criterion layer-index layer, qualitative and quantitative indices, governance coordination.	Both qualitative and quantitative indices. MoHURD stratified with cumulative score. MEP measures gap between index and standard.
Indicators	14	16	22/12
Commenced	2011	2011	2004/2007

In view of the differences in classification methodology of the three index systems, the same indicator could belong to different layers in different index systems. Therefore this paper broadly classified the various indicators of the above three index system into four dimensions – environment-friendly, economic sustainable, social harmony, and policy guide. Then to classify three index system indicators according to the four dimensions. Through a comparison between different

indicators under the same category, the similarities and differences of the various system could be seen more intuitive. The results are shown in Table 4.5 below.

4.3.1 Indicators for evaluating low-carbon city development

It is helpful to divide the indicators into core and guiding so that they provide clear guidance for decision makers and are aligned with existing performance criteria for officials. Core indicators need to contain four core characteristics which should be: scientifically valid; systematic; practical for use across different cities and regions; and sufficiently comprehensive. There needs to be a balance between stability and adaptation in the selection of indicators. While it is beneficial for indicators to be adopted as new understanding of low-carbon development and methodologies for data analysis emerge, there remains a need for indicators to be stable long enough to provide longitudinal detail for analysis and to understand emerging trends. An accurate and effective evaluation index system needs to be:

- 1) *Scientifically credible* and objectively based upon best available scientific advice and data.
- 2) *Systematic*. The development of low-carbon city is a complex task. The evaluation index system must be able to grasp the essence of the low-carbon city concept whilst reflecting the complex social, economic and environmental considerations involved in developing a low-carbon city. The index system also needs incorporate low-carbon targets, at appropriate scales and levels.
- 3) *Practical and relevant*. It needs to identify current and emerging trends and include key, representative indicators that are usefulness for decision makers in a timely manner. The indicator system should be able to clearly communicate assessments and useful information to the public, government, business, industry and civil society.
- 4) *Comprehensive*. The evaluation index system needs to provide both a baseline and direction of not only a city's economic development and energy use, but include other environmental and social aspects or characteristics of low-carbon urban development.

Indicators attempt to simplify complex environmental, social and economic interactions so that we can gain an understanding of trends and patterns. In terms of low-carbon urban development, the criteria for selection of indicators needs to be based upon two basic principles. Firstly, that they are well understood and regularly measured so they can reveal trends. And secondly, they need to improve communication and ensure decision making can effectively monitor programs and respond to problems in an accurate and timely fashion. There will always be shortcomings with indicators such as scientific uncertainty, inconsistent methods and limitations with the data, but such weaknesses should be mitigated by innovation and evolution over time arising from publications such as this and others studies. To remain relevant however, the criteria and selection of the indicators should be regularly reviewed by asking questions about their significance, the justification for inclusion, the status of monitoring and if they involves any interpretation, methodological or development issues or biases.

To date, there is still no single index system for evaluating low-carbon cities in China or internationally. As a result, different evaluation systems have emerged which generally reflect local government priorities, the respective understandings of the low-carbon city concept and the

disciplinary interest of proponents. The official low-carbon indicator systems for Beijing (Low-carbon City Evaluation Index System) and Tianjin (Tianjin Low-carbon Planning Index System) are presented below in Table 4.5 and compared with the systems proposed by the Chinese Academy of Social Sciences (Low-carbon City Standard System). This is then followed by a brief review of the three systems as well as alternative proposals and studies by Chinese researchers.

Table 4.5 The rearrangement of low-carbon indicators in three index systems

		Beijing low-carbon city evaluation index system	Tianjin low-carbon planning index system	Low-carbon city standard system, Chinese Academy of Social Sciences
Environmental quality	Energy	Proportion of clean energy	* Renewable energy utilisation rate	Zero-carbon energy in the proportion of primary energy
		Energy intensity	Energy intensity	Unit of economic energy consumption
		Building energy efficiency design standards	* Proportion of green buildings	Compliance with building energy efficiency standards
				Per capita energy consumption
		Energy consumption elasticity coefficient		
				Per capita household energy consumption
			Urban centralised heating penetration rate	
			* O ₃ and O ₄ standard vehicles proportion	
	Water		Industrial water recycling rate	
		Sewage disposal rate		
	Air quality	Percentage of air quality achieve or better than secondary		
	Waste treatment		Industrial solid waste comprehensive utilisation rate	
		Treatment rate for non-hazardous waste	Treatment rate for non-hazardous waste	
	Green space	Green coverage ratio	Green coverage ratio in built-up area	Forest coverage ratio
			* Rehabilitation rate of degraded land	
	GHG emissions	Carbon productivity		Carbon emissions per unit of economic output
		Per capita carbon emissions		
		Life carbon emissions per capita		
				CO ₂ emissions factor of the unit energy consumption
Economy	Industrial structure	Proportion of tertiary industry to GDP	Proportion of tertiary industry to GDP	
			* Leading industry agglomeration rate	
Social harmony	Urban space		Population density	
	Transportation		Average commute time to work (one-way)	
		Proportion of trips on public transport	Proportion of trips on public transport	
			* Average speed of the whole road network during peak hours	
	Social evaluation	Penetration of low-carbon concept		Public awareness of low-carbon economy
Policy guidelines	Green economy			Low-carbon economic development planning
	Supervisory mechanism			Establishment of carbon emissions testing, statistic and regulatory mechanisms
	Green energy			Non-market energy incentives

Note: Under the Tianjin index system, mandatory indicators are shown without *, leading indicators are shown with *.

Based upon an analysis of the two respective low-carbon cities evaluation index systems for Beijing and Tianjin and the national system developed by CASS, the following conclusions can be made:

- Neither Beijing nor Tianjin has adopted policy considerations with their respective systems. Only the index system developed by CASS involved this category. However the economy category has not been considered by CASS's index system.
- While it is expected that there would be some variation because the three index systems have been applied to different geographical regions, they have all adopted the same thematic approach, but with variations in the number of indicators for each: environmental protection (11:10:8), economy (1:2:0), social harmony (2:4:1) and policy guidelines (0:0:3).
- The largest emphasis for all three index system is environmental protection at around 60% of total indicators or over 75% for Beijing.
- In addition to the focus on the issues of urban development, industrial structure and consumption situation of Beijing and Tianjin, the Beijing low-carbon evaluation index system put more emphasis on the evaluation of carbon emissions from tertiary industry and household consumption with its inclusion of elasticity of energy consumption, sewage treatment rate, per capita carbon emissions, etc. This emphasis reflects in part the stronger role of services and consumption in Beijing, especially in comparison to Tianjin where the index has emphasised the industrial sector with indicators for industrial water recycling rate, the comprehensive utilisation rate of industrial solid waste, the leading industrial agglomeration level, all of which are not covered in Beijing evaluation index system.

Song Weixuan developed a low-carbon city index for 28 prefecture-level cities in the Yangzi Delta. The index was divided into three themes: a production and living carbon index; carbon emission reductions; and carbon capture. These three themes included a total of 25 indicators consisting of two layers. Fu Yun et al. built a system for evaluating low-carbon cities with 8 states and 23 specific indicators by using the composite index method. This evaluation system considered the three aspects of economy, society and the environment. Wang Yufang proposed a low-carbon city evaluation index system which took low-carbon development as the core, economic development as a means and social development as a foundation. Wang's low-carbon city index contained three subsystems: an economic development index, a low-carbon development index and a social development index. Each of these subsystems contained a variety of indicators. Zhao Xianchao developed a comprehensive low-carbon evaluation index system for the city of Changsha (Table 4.6). This index system consisted of five criteria layers covering population, resources, environment, economy and social welfare together with 10 sub-criteria layers including indicators measuring low-carbon demographics, energy use and forest carbon-sink. In addition, a further 12 specific indicator layers measuring per capita carbon emissions, the proportion of non-fossil fuels in primary energy and forest coverage were also included so that there were a total of 68 indicators.

Table 4.6 Comprehensive index system for evaluating low-carbon cities

Criterion layer	Index layer
Social and economic development	GDP
	GDP per capita
	Annual per capita disposable income of urban residents
	Industrial value added per capita
	Social labour productivity
	Impact of natural disasters
	Gini coefficient
	Urban unemployment rate
	Arable area per capita
City construction scale	Population density
	Construction area
	Natural population growth rate
	Urbanisation level
Consumption pattern	Car ownership per capita
	Individual energy consumption per capita
	Individual power consumption per capita
	Average passenger travel distance
	Average freight travel distance
	Public transportation efficiency
	Urban residential per-capita floor space
	Engel coefficient
Pollutant emissions level	CO ₂ /SO ₂ /COD emissions intensity per GDP
	CO ₂ emissions intensity in secondary industry
	CO ₂ /SO ₂ /COD emissions load per capita
	Life CO ₂ /SO ₂ /COD emissions load per capita
Industry/energy structure	Fuel mix: oil/coal/gas proportion
	Renewable energy mix
	Tertiary industry contribution
	Proportion of value added and employment in secondary industry as a proportion of GNP and total labour
	Proportion of value added, employment in the tertiary industry as a proportion of GNP and total labour
	Low-carbon industry proportion
Resource consumption intensity	Energy/power/water consumption per GDP
	Energy/power/water consumption per unit of secondary industry GDP
	Energy/water consumption per capita
	Per capita household electricity consumption
Environmental quality	Average annual temperature variation
	CO ₂ concentration
	Air pollution index
	Regional air quality rating
	Number of days per annum that ambient air quality was at least Grade 2 or below
	Rate of water quality meeting standards in "Water Environmental Function Zone"
	Biodiversity index
Social evaluation	Public awareness of low-carbon city
	Public awareness of low-carbon consumption
	Public satisfaction with environmental quality

Dematerialisation	Energy system efficiency
	Efficiency of energy conversion
	Elasticity of energy consumption
	Unconventional water utilisation rate
	Comprehensive utilisation rate of industrial solid waste
Pollution control	Carbon capture/sequestration proportion of total emissions
	Utilisation rate of low-carbon energy
	Proportion of low-emissions and zero-emissions transportation
	Energy efficient buildings
	Green coverage
	sewage discharge compliance rate
	Centralised wastewater treatment rate
	Organised atmospheric emissions control rate
	Garbage treatment rate
	Safe disposal of hazardous waste rate
	Environmental protection investment index
Management system	Low-carbon urban construction planning
	Carbon dioxide emissions trading scheme
	Energy tax system
	Large-scale enterprises ISO14000 certification rate
Infrastructure construction	Rate of urban infrastructure development
	Rate of social service facilities
	Per capita public green area

The evaluation index system developed by Zhao Xianchao has formed the basis for evaluating economic development, energy consumption and carbon emissions in Beijing and Tianjin. A low-carbon evaluation index system was then adapted with a focus on economic development, energy consumption and industrial structure for the city of Tianjin which is presented in Section 4.4.

4.4 Tianjin low-carbon city evaluation index system

The 32 indicators presented in Table 4.7 have been developed for the city of Tianjin based upon the stage of economic development and the industrial structure of the city. These indicators are based upon an analysis of existing low-carbon city indicator systems and the local circumstances of Tianjin. The central role of the industrial sector in current economic growth and projected economic development require the setting of different sets of indicators and priorities compared to service orientated cities such as Beijing.

Table 4.7 Tianjin low-carbon city evaluation index system

Subject		Indexes	Significance	Calculation method
Environmental protection targets	Energy	Renewable energy utilisation rate	Level of clean energy development	Renewable energy usage /energy usage amount
		Energy system efficiency	Effective utilisation of region's entire energy system	Final effective energy consumption/energy supply
		Energy consumption per unit of GDP	Level of energy use, energy saving status and economic structure relating to energy efficiency.	Energy consumption/GDP (¥10,000)
		Energy intensity within secondary industry	Efficiency of energy use in secondary industry	Energy consumption in secondary industry/secondary industry GDP (¥10,000)
		Proportion of green buildings	Resource efficient buildings affects carbon lock-in	Green building area/building area
		Household energy consumption per capita	Rising living standards	Household energy consumption/population
		Energy consumption elasticity coefficient	Proportional relationship between energy consumption growth rate and the growth rate of the national economy	Average annual growth rate of energy consumption/average annual growth rate of GDP
	Water	Industrial water recycling rate	Regional wastewater resource conservation/utilisation level	Recycled water consumption/(water consumption + recycled water consumption)
		Reclaimed water utilisation rate	Regional non-conventional water resources development and utilisation efficiency and the ability to ease water shortages	Renewable water resources amount/The total amount of sewage treatment
		Water use per unit of GDP	Water use efficiency	Water consumption/GDP
	Air quality	Days of air quality meeting or better than Grade 2	Urban air quality is directly related to urban health and productivity.	Days that API (air pollution index) less than 100/365
	Waste treatment	Comprehensive utilisation rate of industrial solid waste	Regional solid waste resource utilisation levels	Industrial solid waste utilisation /(industrial waste output + comprehensive utilisation of normal storage)
		Treatment rate for non-hazardous waste	Non-hazardous waste to total waste ratio	Non-hazardous waste treatment amount/living garbage output
	Green space	Green coverage ratio	Carbon sequestration and reducing impact of UHI	Green area/gross area
	GHG emission	Carbon emissions per unit of GDP	Regional carbon emissions intensity	Carbon emissions/GDP
		Per capita carbon emissions	Regional carbon emissions intensity	Carbon emissions/population
		CO ₂ emissions factor as a unit of energy consumption	Efficiency of energy use and presence of non-fossil fuels	CO ₂ emission/energy consumption
		Per capita scale factor for GDP growth and CO ₂ emissions growth	Degree of low-carbon economy development	Per capita GDP growth rate/CO ₂ emissions gross rate
		Per capita car ownership	Area of growing carbon emissions and air pollution	Total car/total population

		Value added share of secondary industry in GDP	Moving up the value chain of industrial production	Value added of industry/GDP
		GDP	Regional economic level	Official statistics
		GDP per capita	City's development level	GDP/population
	Economic development	Engel coefficient	Social stability	Total food expenditure/total consumer spending
		Gini coefficient	Equity consideration	Official statistics
		Ratio of income	Economic and social development stage	Disposable income for urban residents/per capita net income in rural areas
	Income level	Population density	Urban population pressure on resources and urban form	Built up area population/gross area
		Average commute time	Urban sprawl, congestion, poor public transport planning poor public transport planning.	Average one-way commute times for residents
		Low-carbon level of transportation usage	Proportion of trips using public transport	Number of people using public transportation/the total number of travel
Social harmony targets	Urban space	Penetration of low-carbon concept	Support and understanding of low-carbon concept	Public survey
		Public acceptance rate of low-carbon consumption	Willingness of public to make behavioural changes in line with low-carbon concept	Public survey
	Transportation			
	Social evaluation			

4.5 Becoming a low-carbon global city

4.5.1 Introduction

Beijing has also set a goal of becoming a World City by 2020, so that it reaches comparable levels of development (or at least minimises discrepancies) between itself and other global cities focusing on population and economic development, low-carbon industry and technology development, low-carbon energy and carbon emission, as well as pollution emission, etc. Currently, most definitions of global cities rely upon indicators such as wealth, level of development, population size and globally integrated trade and investment. For this study, the focus is instead on a comparative analysis of the energy development experience of New York, Tokyo, Paris, London and Beijing through aspects of energy development and targets, power and energy supply security guarantee measures and low-carbon energy development strategies. The aim of the peer comparison is to demonstrate the development strategies and implementation pathways for a city's mitigation goals, and to provide experience and a reference for developing low-carbon pathways for Beijing and other Chinese cities.

4.5.2 Feasible study on Beijing as a low-carbon world city

4.5.2.1 Comparative analysis on low-carbon energy development between Beijing and other world cities

This section includes an analysis on the gap between Beijing and the top world cities, from a low-carbon energy development perspective, so as to explore and identify the gap between Beijing and

the top world cities on energy development, economic and environment development related to energy, with the goal for Beijing to catch up with others.

Choices of evaluating indicators

Previous research findings in comparative analysis on city level development focus on the evaluation of a city's social and economic development and its competitiveness. Very few have carried out a comprehensive and systematic evaluation from a city's energy development perspective. This study will try to evaluate the low-carbon energy gap between Beijing and other world cities by adopting a series of quantitative indicators, in a bid to reflect Beijing's low-carbon energy development situation comprehensively and systematically, and at the same time show the gap of Beijing becoming a world city.

This study has set two levels of indicators to compare and evaluate low-carbon energy development characteristics and the levels between Beijing and other world cities, including energy consumption of the city and the economic and environmental development circumstances that closely related to energy consumption. The primary indicator has four aspects including:

- population and economic development;
- low-carbon industry and technology development;
- low-carbon energy; and
- carbon pollution emissions.

These primary indicators include secondary indicators.

On the *population and economic development side*, the primary indicator includes six secondary indicators: population; area of the city, population density; GDP; GDP growth rate; and per capita GDP. These six indicators will describe the development level of a world city from the perspective of population scale and density, economic development scale and speed, etc.

In the *low-carbon industry and technology development*, this primary indicator includes six secondary indicators: the proportion of tertiary industry; the value added of modern manufacturing; the proportion of the modern service industry GDP on gross GDP; the operational mileage of track traffic; the proportion of funding on low-carbon technology and R&D in the gross GDP; and the proportion of high and new technology in gross GDP. These indicators are used to describe the development level of a city's high and new technology, and its low-carbon technology in industry, transportation and service industry.

In *low-carbon energy*, this primary indicator includes ten secondary indicators, which are used to describe the energy consumption level, the cleanliness of the energy structure, the energy efficiency level, as well as the energy security level. These indicators include: total energy consumption; the growth rate of total energy consumption; per capita energy consumption; the proportion of coal on total energy consumption; the proportion of natural gas and electricity on energy consumption; the proportion of natural gas on heating energy consumption; the proportion of renewable energy consumption on total energy consumption; the energy consumption elastic coefficient; energy consumption of RMB10,000 GDP; as well as the annual average power-off time per family.

In *carbon and pollution emissions*, this primary indicator includes seven secondary indicators: local carbon emission; carbon emission per GDP; per capita carbon emission; per capita carbon coefficient footprint relating to trade (lack of data); air pollution index; annual concentration of atmospheric pollution; as well as inhalable particulate matter.

Evaluation method

In view of the above indicator system, the purpose of this evaluation is firstly, to clarify the development level and characteristics of a world city on energy use and environmental aspects through a quantitative analysis. Secondly, the study will present an objective evaluation of the current gap between Beijing and other world cities. The gap will be shown by the relative comparative approach. In this research, this comparative method will be to fix a comparative benchmark value, using an average value of a quantified evaluation indicator from the three top accredited world cities, i.e. New York, Tokyo and London. This value is to reflect the average level of the world cities, and be used as a relative comparative value. The research compares Beijing's situation to the average level of the world cities by certain indicators, and a proportion will be presented to show how much effort Beijing should be making to reach a world cities level for that particular indicator. For comparative results see Table 4.8. Moreover, the research will try to work out a proposed level for multi-indicators to reflect Beijing's capacity and its direction towards becoming a world city on issues of energy use, and economic and environmental development.

Result of the comparative analysis

1) Population and economic development comparison

Beijing's GDP in 2010 reached US\$224 billion, which was far lower than New York (US\$1262.6 billion), Tokyo (US\$1874.7 billion), and London (US\$751.8 billion). Generally speaking, the GDP of these three world cities has reached 1129.9 billion, while Beijing's GDP only accounts for 18% of the world cities GDP. Likewise, Beijing's per capita GDP is only equivalent to 12.6% of that of the world cities, which shows its economic development level is far behind the world cities. This indicates that Beijing's strong and substantial economic development is one of the important challenges that it is facing to become a world city. In spite of this, Beijing is equipped with many factors to meet this challenge as it has kept its GDP at a higher growth rate. Its growth remains at 16% of the growth rate in 2000-2010, which is much higher than New York (4%), Tokyo (1.6%), and the average level of the world cities (2.8%). This number is 5.7 times higher than the average level of the world cities, which shows Beijing's strength and vitality as a developing city.

2) Low-carbon industry and technology development indicators

One of the important measures of improving Beijing's economic competitive strength and inspiring the vitality of the city is to readjust the economic structure and develop a low-carbon industry, leading to high value added and low energy consumption. In 2010, the proportion of Beijing's tertiary industry reached 76% (Tokyo and London were 85% and 90%, respectively). Compared to the average level of the world cities, Beijing has reached 86.5% of being a world city in this regard. It can be seen that although Beijing has made remarkable achievement in industry restructuring, it still has a comparatively large span to cover. Beijing's value added in modern manufacturing reached

US\$13.1 billion in 2010, which was 64% of the average level of the world cities. Compared to New York (US\$23.8 billion) and London (US\$38.8), Beijing still has a long way to go. In terms of the value added in the modern manufacturing proportion of GDP, Beijing accounts for 5.8%, which was higher than the average level of the world cities (3.4%). However, it was lower than the level of London (6.2%). By comparison, it can be seen that Beijing's modern manufacturing level has almost reached the level of the world cities, which shows a strong advantage. However, from another perspective, Beijing needs to put more effort into the modern service industry in future. A city's effort in its promotion of energy saving technologies in the transportation sector can be seen from a city's track record in traffic operational mileage. Beijing's data on this was 228 km, only reaching 23% of the world cities' level, far less than New York (1344 km), Tokyo (1179 km) and London (407 km). So we can identify a big gap between Beijing and world cities in the development of low-carbon transportation, which is one of the priorities for Beijing in the future. We are unable to discuss the proportion of the low-carbon technology R&D funding on GDP and the high and new technology industry because of the lack of data. Summarising, this study has tried to reflect the city's low-carbon development strength from the above indicators. However, because of the difficulties in data collection, some of the important indicators which measure a city's low-carbon development level will not be discussed here. More information is to be explored to reflect the advantage and the gap between Beijing and the world cities on low-carbon economic development in a more comprehensive way.

3) Low-carbon energy indicators

The comparative analysis of the energy development level and low-carbon energy development level of the world cities is a focus of this research. This study has selected eight energy indicators to make comparisons and analyse the world cities' energy development status, energy structure, energy efficiency and energy security. These indicators are: total energy consumption growth rate; per capita energy consumption; proportion of coal on total energy consumption; proportion of natural gas and electricity on energy total consumption; proportion of natural energy on the heating energy consumption; proportion of renewable energy consumption on total energy consumption; and annual average power-off time per family.

Per capita energy consumption is usually used to measure the energy consumption level of a city. Beijing's per capita energy consumption (103 kilomegajoule/per person per year) is close to the general level of the world cities (105 tce/per person per year). Tokyo is the most energy efficiency city, with the lowest energy consumption per capita (69 GJ/per person per year). Both London and Paris' per capita energy consumption is lower than Beijing's, with a higher level of energy saving. Beijing still has a large potential on energy saving and emission reduction compared to these world cities.

The growth rate of total energy consumption is an indicator reflecting energy consumption growth of a city. Beijing's average energy consumption growth was 4.8% between 2000-2010, which has greatly supported rapid economic growth. Some data shows that with economic development, New York's power consumption reached by 54869 GW in 2007, an increase of 23% over 10 years. According to energy statistics data from Tokyo, Tokyo increased 0.25% on total energy consumption between 2000-2009. According to Li Xin, London experienced a 2.3 % decrease in total energy

consumption in 2007 compared to 2006, and 3.5% decrease compared to 2005. From the above growth rates of the cities' energy and power consumption, a different level of energy consumption (its speed of energy growth and reduction) from each city has been reflected. From this, we can conclude that the world cities have moved to a 'post-industrial' era. The economic transition and industrial update of these cities have been completed (or nearly completed) and energy consumption growth is moving towards a relatively stable or decreasing trend. By comparison, Beijing is in a period of under development, so its energy consumption growth rate is much higher than Tokyo's. However, seen from an energy saving and emission reduction angle, Beijing still has a large potential for controlling total energy consumption growth. What we want to clarify is that Tokyo's energy consumption growth is based on the calculation of Tokyo's statistical data. If we could also use each city's statistical data to calculate the energy consumption and growth of New York, London and Paris, the uncertainty in this comparative analysis can be reduced.

Energy consumption per unit of GDP is the key indicator to measure the level of a city's energy utilisation. In 2010, Beijing's energy consumption per capita GDP (0.58 tce/10 thousand RMB) was at a higher level than Tokyo and London's data in 2007 which were 0.04tce/10 thousand RMB and 0.08tce/10 thousand RMB respectively. New York's energy consumption per unit GDP in the same year was 0.26. Beijing's energy consumption per unit GDP is normally 4.6 times higher than the world cities, which means there's still a big gap for Beijing to reach energy efficiency at a world city level. A city's development experience shows that its energy consumption level is largely dependent on its economic structures. The energy consumption of value added from the service industry is just 1/3 of that from secondary industry. While in the service industry, the unit consumption from Finance, Insurance, etc., is much lower than the average level of the service industry. New York, Tokyo and London are all the largest global financial and management centres of the world, with the percentage of their tertiary industry reaching over 85%. At the same time, high-end service sectors such as Finance and Insurance, and Real Estate are in a prominent position, which leads to a lower energy consumption per unit GDP. Seen from this, Beijing still has a long way to go to catch up with the world cities on economic restructuring.

This study uses an energy consumption structure indicator to reflect the clean and low-carbon level of a city's energy utilisation. In 2010, Beijing's energy consumption structure comprised of coal 32%, natural gas and electricity was 36%, renewable energy accounted for 3% and clean energy was nearly 40%. To 2015, the percentage of coal consumption in Beijing will reduced by 20%, and the proportion of clean energy will increase to over 55%. In spite of this, the gap between Beijing and world cities on clean energy utilisation is still large. At present, the percentage of coal consumption, and natural gas and electricity has reached 6% and 54% respectively, while renewable energy generation takes up 19% of the total generation (2006). Tokyo has almost stopped utilising coal, and its natural gas and electricity consumption makes up 70% of its energy supply. All their heating energy comes from natural gas. In London, natural gas and electricity consumption also accounts for 75%. Seen from this, a high level of clean energy utilisation has become a common and important indicator for world cities. Comparatively, Beijing's non-clean energy utilisation is 15 times higher than the general level of a world city, while its clean energy utilisation, e.g. natural gas and electricity consumption only reaches 55% of that of world cities. Compared to New York, Beijing's renewable energy utilisation has a big gap, 19% lower.

The security of a city's power supply requires ongoing security. One of the key indicators to measure a city's power supply security is the power-off time per family. In recent years, world cities such as Tokyo and Paris have been able to keep a stable power-on status. Their power-off time per family per year is only 3-5 minutes, while Beijing's figure is 3 hours (180 minutes), indicating a big gap in power supply security.

4) Indicator of carbon emission and pollution emission

In order to prevent air pollution caused by energy consumption, world cities are promoting energy efficiency and development of renewable energy. Tokyo is famous for its comparative advantage in energy saving and emission reduction. Its CO₂ emissions level is 5.42 million tons locally. Compared to Tokyo, London and New York have higher CO₂ emissions, 7.736 and 21.7 million tons, respectively. New York has a higher CO₂ emissions level than Beijing, which does not equip it with a low-carbon advantage rating as a world city. The CO₂ emissions of Beijing (17.3million ton) are 3.2 times higher than that of Tokyo, and accounts for 80% of that of New York, as well as being 50% higher than the general level of the world cities.

According to data from the World Bank, per capita CO₂ emission of Paris, Tokyo, New York and London in 2010 was 3.5t, 4.3t, 6.1t and 6.5t, respectively. This research has collected data on GDP and CO₂ emissions, and the calculation shows that the CO₂ emissions per 10 thousand US\$ GDP of New York, Tokyo and London was 0.83t, 0.18t and 1.11t, respectively. Per capita carbon emissions and per GDP carbon emissions at a lower level are also some of the indicators quantifying world cities. In 2010, Beijing's per capita CO₂ emission reached 9.8t, which was nearly double the world city level. Its CO₂ emission per 10 thousand US\$ GDP reached 7.72t, which was 10 times more than the average level of the world cities. This indicates that Beijing is facing a challenge to improve its environment and reduce carbon emissions in order to become a world city.

Beijing's air pollution emissions are also higher than that of the world cities. According to the data from the World Bank, air pollution status of the main cities worldwide in 2009 showed that the air pollution indexes of New York, Tokyo and London were 125me/m³, 124me/m³ and 121me/m³, respectively, while Beijing reached 302me/m³, which was 1.5 times higher than these world cities. Some data shows that in 2006, annual concentration of air pollution in New York, Tokyo, London and Beijing was 0.027me/m³, 0.005me/m³, 0.0125me/m³ and 0.047me/m³, respectively, with Beijing's data is more than 2 times higher than average level of the world cities. In terms of inhalable particulate matters, the annual concentration in Beijing (0.14me/m³) was also higher than that of London, New York (0.082me/m³) and Tokyo, which was 1.7 times higher than New York. One of the main reasons is that in the cold seasons especially, a large amount of coal is consumed in Beijing.

5) A city's competitiveness indicator

This study has done a comparative analysis on Beijing's world city qualification gap and the effort required to become a world city from several aspects, i.e. population and economic development, low-carbon industry and technology development, low-carbon energy, as well as carbon emission and pollution emission. In order to show the gap between Beijing and the world cities on overall performance, we have used the city's competitiveness index from The World City Competitiveness Report 2009-2010 as an indicator. According to the ranking of this report, New York ranks no. 1 with

an index 1.000, London no. 2 with 0.957, Tokyo no. 3 with 0.919, Paris no. 4 with 0.815, Seoul no. 9 with 0.744, Beijing no. 68 with 0.592 (500 cities join the ranking). Beijing's competitiveness only reaches 64% of the average level of world cities, and 80% of Seoul. However, in 2007-2008, Beijing's score was only 0.537, and its rapid rise from 0.537 to 0.592 in two years shows strong improvement in competitiveness and ample room for further development in the future.

Table 4.8 Comparative analysis on world city low-carbon development

Indicators I	Indicators II	New York	Tokyo	London	Beijing	Average level	Difference
Population and economic development indicators	Population (10k person)	1988	3520	1209	1961	1400	140.1%
	Area (km ²)	17405	2178	1577	16411	8290	198.0%
	Population density (person/km ²)	1115	6056	7666	1195	3942	30.3%
	GDP (\$100m)	11288	18747	7518	2240	11299	19.8%
	GDP per capita (\$10K/person)	5.82	5.33	6.22	1.14	6.10	18.7%
	GDP growth rate (%)	3.9%	12%		16.7%	8%	209%
Low-carbon industry and technology development indicators	Proportion of the tertiary industry (%)	—	84.8%	89.7%	75.5%	87.3%	86.5%
	Value added of modern manufacturing (\$100m)	238	192	388	131	205	64%
	Proportion of modern manufacturing value added (GDP) (%)	0.9%	0.6%	5.6%	5.8%	2.4%	246.2%
	Rail transit operating kilometre (km)	1344	1179	407	228	977	23.3%
	Proportion of low-carbon technology R&D share of GDP (%)						
	High and new technology industry share of GDP (%)						
Low-carbon energy indicators	Total energy consumption growth rate (%)		0.3%	-3.50%	4.8%		Big
	Energy consumption per capita (GJ/person)	178	69	85	103	105	98.6%
	Coal accounts for the proportion of the total energy consumption (%)	6%	0.02%		32.0%	2.0%	1595%
	Natural gas and electricity accounts for the proportion of energy consumption (%)	54%	70%	75%	36.3%	66%	55%
	Natural gas accounts for the proportion of the heating energy consumption (%)		100.0%		40.0%	100.0%	40.0%
	Renewable energy consumption accounts for the proportion of the total energy consumption (%)	19%			3%	19.0%	15.8%
	Energy consumption per GDP (tce/¥10,000)	0.26	0.04	0.08	0.58	0.13	459.5%
	Power supply security, annual average power outage time per household in the city (minutes)		3-5		180	3-5	
Indicators on carbon emissions and pollutants emissions	Local carbon emissions (10000tCO ₂)	21700	5420	7736	17300	11619	149%
	CO ₂ emissions per GDP (tCO ₂ /\$10000)	0.83	0.18	1.11	7.72	0.71	1093%
	Per capita carbon emissions (tCO ₂ e/person)	6.1	4.3	6.5	9.8	5.1	193%
	Air pollution index (MCG/m ³)	125	124	121	302	123	245%
	Annual average concentration of air pollution (mg/m ³)	0.027	0.005	0.013	0.047	0.01	317%
	Particulate matter (mg/m ³)	0.082			0.140	0.082	171%

Note: Data in the table are mostly 2009 and 2010 data. The indicators of population and economic development are the average value of the four cities of New York, Tokyo, London and Paris. The indicator of per capita energy consumption is also including the average of the four cities of New York, Tokyo, London and Paris.

Several research conclusions

This study has produced a comparative analysis on Beijing's effort of becoming a world city. The study selected 25 quantitative indicators to reflect the characteristics and development level of Beijing and New York, Tokyo, London and Paris, and evaluated the gap between each city, from a range of perspectives: low-carbon energy development, low-carbon industry and technology development, as well as a population, economic and pollution emissions. The evaluation results provide an understanding of key low-carbon energy development characteristics for world cities. The most outstanding and consistent characteristics show that world cities not only have a high GDP, but also low energy consumption per unit of GDP, as well as low-carbon emissions per unit of GDP. This provides a solid foundation for world cities to lead on global low-carbon development.

The evaluation results show that Beijing's current policies regarding energy saving and emissions reduction, GDP growth rate, the proportion of tertiary industry, value-added of modern manufacturing, per capita consuming capacity on energy, the proportion of natural gas and electricity on energy consumption and the percentage of natural gas on heating energy consumption, are close to the average level of other world cities, reaching 40% to 86%. However, on some indicators such as GDP, energy consumption per unit of GDP, carbon emissions per unit of GDP, per capita carbon emissions, operational mileage of track traffic, and others, there is still a big gap, which suggests further policy work is required before Beijing becomes a world city. Although Beijing has a long way to go to achieve its goal of becoming a world city, as a leading global metropolis, it needs to continue to strive for a low-carbon status, and developing a low-carbon energy system alongside economic growth, to catch up with other world cities under a new development environment.

This comparative study has collected research results for analysis and differentiation between several world cities. Based on a range of literature and criteria evaluating the energy systems and energy-related economic, social and environmental development of Beijing against other world cities, this chapter provides certain reference value for exploratory research on how Beijing can become a world city.

5. Conclusion

5.1 Making the transition

Adopting and implementing low-carbon measures in China's cities is not necessarily self-evident to most city leaders. Instead a low-carbon agenda competes with a wide range of urgent and important demands. For example, competing priorities include generating employment and economic growth, attracting industrial investment, maintaining social stability, building infrastructure, such as public transport, communication and waste management systems, as well as the provision of basic housing and social welfare. Cities have traditionally relied upon land transfers and land developments for fiscal revenues to fund these programs, which results in distorted priorities. However, such land options are becoming increasingly constrained and partially restricted through national policies (Kamal-Chaoui et al. 2009; OECD-CDRF 2010). Unless alternative sources of local revenue are identified, more local governments will experience budgetary shortfalls. It is therefore critical that any implementation road map for low-carbon development appreciates this complicated context and the competing demands of city authorities. Against such a background, it is necessary to identify complementary and symbiotic measures and policy responses that tackle these competing demands whilst presenting a solid business case of the direct and indirect costs and benefits of low-carbon policies. Making the transition towards a low-carbon pattern of development in China's cities therefore needs to emphasise economic competitiveness, liveability, resource efficiency and at the end of the day, all of these considerations need to reinforce sustainability.

Today, most Chinese cities confront serious limitations in the supply of available land and clean air, water and food. And yet they continue to pursue industrial and urban policies, such as urban sprawl, with a general disregard for the impact upon land, water and the lock-in of future resources to sustain these communities. This failure to adequately manage the existing stresses between resources and consumption will make the transition to low-carbon development in China and elsewhere very challenging. The global city comparison revealed that Beijing has made important progress in becoming a World City, but still requires significant effort to ensure this status follows a low-carbon pathway. The challenge for China's cities, including Tianjin and Beijing, of resolving the apparent contradictions between economic development and sustainability, liveability and low-carbon cities and lifestyles are echoed across most Australian and North American cities. It is increasingly evident that a failure to appreciate the fundamental resource constraints between consumption and resources remains widespread. It is therefore critical that cities actively share and learn from the lessons, success and failures experienced in these cities and regions in implementing low-carbon strategies, policies and regulatory measures.

5.2 Key findings

The performance of cities is critical to China's attempt to reduce emissions and to improve the quality of life of its citizens

In 2012 there were over 700 million people, or 52.6% of the total population, living in China's cities. The Chinese Government continues to support increasing urbanisation, and before 2030 it is likely that one billion people, or about 70% of China's population, will live in cities. Around the world

emissions per capita are 3-4 times higher for those living in cities than for those living in the countryside, and about 70% of global emissions are due to cities. This continuing shift of population into high emissions urban areas in China means that the performance of these cities is critical to China's ambitions to reduce emissions and to improve the quality of life of its citizens.

The pursuit of 'low-carbon city' status is widespread in China

It has been reported that, in 2011, 276 of the 287 cities in China with municipality status had proposed low-carbon or eco-city goals (Li Yu 2011). The concept has clearly become a fashionable one, which municipal governments use to pursue a wide range of goals and activities under this general banner. This trend has been strongly reinforced by central government support. In July 2010 the NDRC established low-carbon city pilot programs in eight cities (Tianjin, Chongqing, Shenzhen, Xiamen, Hangzhou, Nanchang, Guiyang and Baoding) and in December 2012 more than 20 additional cities were added to the pilot program, including Beijing. The Ministry of Environmental Protection has also been running an 'eco-city' program for a decade and the Ministry of Housing and Urban-Rural Development has been implementing an 'eco-garden city' program since 2004 (Zhou et al. 2012).

The concept of a low-carbon city has several different elements, related in complex ways

As it has been developed and applied in China and elsewhere, the concept of the low-carbon city is an attempt to bring together many different elements, one or other of which might be emphasised by particular authors or cities. The main elements are those relating to energy use and emissions intensity, to the long-run sustainability of the economic and social life of the city and to the quality of life of the population, the 'liveability' of the city. In principle, these and other elements might pull in different directions, and a city might achieve highly on one element while being poor on others.

The NDRC notice of December 2012 establishing the second round of pilot low-carbon city programs covered all of these elements. It noted the importance of adjusting the industrial and energy structure and pursuing energy efficiency; of incorporating the low-carbon concept into transport, land use and other urban planning; of building green environmental protection and recycling systems; of emphasising the development and application of new technologies in green buildings, low-carbon transport services and emerging industries more generally; and of promoting the use of low-carbon lifestyles and consumption patterns, including low-carbon housing, public transport and other low-carbon travel (NDRC 2012). The vagaries of the low-carbon city concept raise the possibility that it might mean very different things to different people. To ensure the concept remains relevant and effective, the experiences from the pilot cities need to be rigorously monitored and reported.

The low-carbon city focus in China sits within a broader and developing policy framework

The official emphasis on low-carbon cities in China sits within a complex and ongoing framework of plans, targets and initiatives. Operating within the 12th FYP the government has provided medium-term targets for energy use and emissions, both nationally and at the provincial level, and has broken these down in the Energy Plan into more specific targets for the different forms of energy use, and for different industries. The central government has also put in place a wide range of

initiatives, including the establishment of pilot emissions trading programs, to assist in meeting these ambitious targets. The low-carbon cities pilot programs being pursued by NDRC and by other agencies of the national, provincial and municipal governments must be seen as significant components of this broader policy agenda.

The Beijing low-carbon energy roadmap suggests that Beijing could become a global low-carbon city by 2030

This report includes, in Chapter 3, an outline and discussion of a low-carbon energy roadmap for Beijing out to 2030. This study uses a version of the IPAC model to develop and analyse the roadmap, which is based on an assumed annual rate of growth of Beijing's GDP of 8.3% over 2010-20 and of 6.5% over 2020-30. The plan has a strong focus on developing Beijing's high-end manufacturing sector, especially high tech industry, a low-carbon service sector and a low-carbon energy sector. It envisages a rise in the service sector share of real value added from 74.4% in the 12th FYP period to 86% by 2030. According to the roadmap, Beijing's total energy demand would peak in 2020-25, and then decline, with CO₂ emissions also peaking in 2025 and coal consumption falling rapidly. If achieved, the roadmap outlined here would set Beijing on a path to become a global low-carbon city by 2030. While the level of emissions would remain relatively high for the stage of development, total energy use and emissions would fall before 2030 and many other aspects of the low-carbon model would be put in place. But the roadmap is an energy roadmap, and does not give detailed consideration to other aspects of sustainability and liveability.

The Tianjin low-carbon energy roadmap shows how Tianjin could achieve national energy and emissions intensity targets by 2020, but with continuing strong growth in emissions.

By comparison with Beijing, Tianjin is a city strongly focused on the industrial sector, and within that on heavy industry. In 2011 the industrial sector accounted for over 50% of GDP in Tianjin, by comparison with less than 25% in Beijing, and over 80% of industrial output was in heavy industry. GDP, energy use and CO₂ emissions have all been growing more rapidly in Tianjin than in Beijing, based on strong growth in industrial output, with the industrial sector being responsible for 73% of energy demand in 2011. Over the five years 2006-2011, GDP growth was 16.1% per annum in Tianjin compared to 9.1% in Beijing, with the comparative growth rates for energy use being 11.0% and 3.5% respectively. The Tianjin authorities plan to continue strong growth both in industrial output and in GDP, but to restructure industry towards more knowledge intensive, and less energy intensive, products. This makes the task of shifting to a low-carbon city very challenging.

Given the commitment of the Chinese Government to reduce national energy consumption per unit of GDP by 45% over 2005-2020, Tianjin is committed to reducing energy intensity by 14.6% over 2010-15 and by a further 11.8% over 2015-2020. The low-carbon energy roadmap for Tianjin (Chapter 3) uses backcasting and decomposition analysis to show how the city can achieve the targets for energy and emissions intensity with continued strong growth in GDP (of 12% and 15% per annum in two scenarios), but also with continued growth in emissions. The industries that dominate Tianjin's emissions are iron, steel and non-ferrous metals, followed by the chemical and petroleum industries. Reductions in energy use and emissions are achieved by both shifting the structure of industry away from these sectors, by making them more energy efficient and by reducing the

emissions intensity of their energy use. But again this roadmap is an energy roadmap, with a particular focus on energy and emissions from industry, and does not give detailed consideration to other aspects of sustainability and liveability. Achieving the targets imposed by the national government for energy and emissions intensity will be far from sufficient to transform Tianjin into a low-carbon city.

One limitation of the focus on low-carbon cities is that city level emissions can be reduced by shifting energy generation and production outside the city limits

While a high proportion of emissions are generated in cities, one limitation of the use of cities as a policy instrument is that targets for cities can be achieved by shifting industries, power generation processes or other activities outside city boundaries. Even sharply reducing emissions in Beijing and Tianjin will not reduce pollution in the North China plain, nor contribute much to reducing China's overall emissions, if the reduction is substantially achieved by shifting polluting activities to surrounding neighbourhoods.

It is important that indicators of city emissions be based on consumption rather than production measures

One response to the emissions shifting issue is to ensure that the focus for city-based measures is on the emissions embodied in the goods and services consumed in the city, rather than on the level of emissions generated within the city boundary. But this important principle is difficult to pursue in practice, because there is little data on inter-regional trade in energy sources or in emissions-intensive products.

In terms of energy use, emissions and other forms of pollution, absolute targets are to be preferred to intensity targets, as achieving intensity targets may or may not be consistent with falling emissions.

The energy roadmap for Tianjin illustrates the well-known fact that it is easier to achieve a given energy or emissions intensity target with a high rate of growth than with a lower one, and hence with higher rather than lower emissions. If the economy is growing rapidly it is possible to add new capacity with more energy efficient and cleaner technology, thereby reducing overall intensity levels. But if the economy is growing slowly, more of the adjustment needs to occur through closing or retrofitting older plant and equipment, which is much more difficult. But ultimately it is the absolute level of emissions that influences both local pollution and global warming.

Index systems for monitoring low-carbon cities

There have been many attempts at developing index systems for evaluating low-carbon cities, including the Tianjin system presented here. These provide a good framework for monitoring and evaluating progress, although much work needs to be done to develop satisfactory quantification of individual indicators. Because of the many dimensions of low-carbon city development these are inevitably complex sets of indicators, and difficult to compress into a single measure.

So-called model North American and Australian cities actually bring out the conflicts within the low-carbon city concept, between carbon intensity, sustainability and liveability

While North American and Australian cities are often held up as achieving high recognition for their global-city status, liveability and the quality of life, most are certainly not a low-carbon city and its urban model may well not be sustainable. For example, even the city lauded as the most liveable, Melbourne, has achieved its high quality of life through its heavy use of coal-based energy, land, water and other resources. The challenges this implies for cities such as Melbourne are echoed across most Australian and North American cities and are increasingly evident in many Chinese cities. For instance, a failure to appreciate the fundamental resource constraints between consumption and resources as well as the significant emissions costs of carbon lock-in arising from poorly considered or short-term policy and infrastructure decisions. For example, most of these cities are confronting limited supplies of clean water and available land, yet continue to embrace ongoing urban sprawl with a general disregard for the impact upon land, water and the lock-in of future resources necessary to sustain these communities.

Given its complexity and multidimensionality, the concept of the low-carbon city can be misused. But the attempt to get cities to focus on achieving progress in all three elements – falling emissions, enhanced sustainability and improved quality of life – should be a central element in policies for cities, in China, and elsewhere.

This report illustrates the dangers that can arise from such a multidimensional concept as that of the low-carbon city, which can be misused in many ways. In particular cities can use it to promote their own advancement at the expense of surrounding regions, or focus on success in one aspect of it, such as low emissions intensity or liveability, at the expense of other aspects. Yet as cities become larger, as the need to reduce various types of pollution grows and as resource constraints intensify, it will be increasingly important that cities make progress in achieving each of the three low-carbon city goals: reduced emissions, enhanced sustainability and better quality of life for all. While this broad concept remains difficult to define, measure and implement, the evidence suggests that it should become, or remain, a central element in national and local policies for cities in China and elsewhere.

5.4 Remaining challenges and further research

It is clear that China, like other countries, is at the beginning of a long but necessary road in terms of reducing emissions generally and moving to low-carbon cities in particular. We conclude with some comments on the outstanding challenges.

1. China has set an apparently ambitious program for realising carbon intensity reductions in the country generally, including peak and decline objectives for cities such as Beijing. But serious risks remain especially if high levels of GDP remain, especially if driven by narrowly focussed and coal-based industrial expansion as shown in Tianjin and Hebei province.
2. There are many good policies, regulations and even market mechanisms available, but a gulf remains between policy and regulatory design and practical implementation. The main

challenge is ensuring government leaders better understand the economic costs and benefits of choosing a low-carbon development pathway. But serious climate adaptation challenges remain:

- Extreme heat events during summer on the vulnerable and infrastructure.
- Increasing water restrictions due to prolonged drought on the Northern China Plains.
- Rising sea levels impacting upon key infrastructure in low lying areas of Bohai, especially in Binhai.
- Flooding events in Beijing and Tianjin due to intense storms.

There are also barriers to energy efficiency schemes:

- Lack of awareness about energy use and available options for green buildings.
- Widespread misconceptions about the cost of green retrofitting and building standards.
- Financing of energy efficiency schemes is often viewed as high risk by building developers and local governments, with limited incentives (including split incentives) for covering the high up-front capital expenditure costs and medium to long-term payback periods.
- Local government barriers include planning and zoning codes and regulations, as well as a failure to support mixed use approaches.

3. The low-carbon roadmap for Beijing may well be successful as it has shifted the emphasis to achieving global city status, but it is the experience in Tianjin and neighbouring Hebei that are more important and yet challenging. CO₂ emissions growth in Tianjin and Hebei remains exponential, with significant ongoing investment in an industrial and energy-intensive pattern of rapid growth and development.
4. Transboundary problems remains of serious concern, as highlighted by the air pollution crises of 2013. For example, Beijing's local efforts to tackle the city's deteriorating air quality over the past decade have failed in the absence of a systematic approach at a regional or national level. Attempts by Beijing to clean up the local environment were often counterproductive, by just shifting the problem beyond the city limits to neighbouring Hebei province or Tianjin in a phenomenon referred to as *pao Beijing* (跑北京) or running away from Beijing. This is a form of pollutant and carbon leakage. This is not just a Beijing phenomenon but an international and national issue. For example, around 80% of emissions relating to goods consumed in the wealthier eastern seaboard being imported from the less developed hinterland. Nationally, nearly 60% of emissions are related to goods that are consumed outside of the province where they were produced (Feng K et al. 2013). If trade embedded emissions were included in the global GHG calculations, then the US would remain the largest emitter and China's emissions would be reduced by 20%. As such, China argues that the West needs to share some responsibility for such emissions (Davis and Caldeira 2010).

Tianjin and Hebei have not only welcomed some of these fleeing energy intensive polluting industries, but in recent years they have been building up their own industrial capacity especially in the petrochemicals and steel sectors. This industrial expansion is evident in Hebei

hosting six of China's top ten polluted cities (MEP 2013). Beijing and Tianjin were also in the top ten. The real challenge for Beijing is to work on a regional scale. Without the cooperation of Hebei, Tianjin and neighbouring Shandong, Beijing's air quality is unlikely to improve in the short to medium term. It is estimated that between 40-80% of the air pollution in the capital is transboundary. Only after severe air pollution in early 2013 has the political momentum shifted towards seeking a regional approach to the problem.

5. In terms of transport, both cities have locked in car dependency, and significant ongoing grid lock and productivity losses, due to policies protecting local road construction and car manufacturing industries. Investment in public transport is impressive but will continue to lag behind private vehicle transport in the short term. The focus should move towards building and developing urban residential-employment hubs to avoid commutes and to return confidence to neighbourhoods as key activity zones.
6. In terms of energy options, there is an ongoing shift to natural gas for local transport, peak power provision and domestic and industrial heating. But the critical focus is the need to ramp up the investment and connectivity to solar, wind and other renewable energy projects. For example, the need to provide "enabling infrastructure" in the energy sector for demand management, energy efficiency and renewable energies has often been cited as a constraint for local action. Enabling infrastructure refers to financial support mechanisms, supportive transmission networks and a favourable planning system. While China has introduced a wide range of supportive national policies in this area, many argue that the State Grid Corporation's position has not sufficiently shifted to accommodate the necessary regulatory and bureaucratic reforms for realising low-carbon reforms.
7. The structural change in the composition of GDP is equally important. Tracking government spending on health, education, environmental protection and welfare is a critical area of moving towards a liveable, global and low-carbon city. For example, one would expect that Shenzhen is making such a move, especially following the city's recent announcements that it was shifting to quality growth over quantity growth with the lowest growth target during the past 30 years of just 9% for 2013. But the city is only planning to increase spending on education, social welfare and public health by 7.5% despite increasing revenues by 9.5%. The city will aim to reduce energy intensity by 4.25% and water consumption by 5% in 2013.
8. Improvements to existing urban planning and economic governance arrangements are urgently needed. Such reforms should emphasise the strategic consideration of the relationship between cities and reducing GHG emissions, whilst promoting approaches to planning that transgress departmental silos and adopting broad engagement strategies. There is also a need for improved alignment of urban planning and design with national and international best practice and principles, and changing community values and expectations, and also to strategic transport planning and employment growth centres.

Given this situation of ongoing challenges facing both the implementation of China's policy in many areas touched on above and in the evolution of China's cities, further research is necessary on a range of critical issues. Here we just highlight two which seem of particular relevance.

1. After the bulk of this report was finalised, it became clear that the Chinese Government is taking further measures, going beyond those contained in the 12th Five Year Plan and associated documents, to address China's massive air pollution problems. These measures have taken on a new urgency given the depth of public concern about air pollution, sparked particularly by severe air pollution in Beijing and surrounding areas in January 2013. In September 2013 the State Council issued *The Airborne Pollution Prevention and Control Action Plan 2013-17*, which contained a new range of measures and targets for addressing air pollution, and for changing the structure of economic growth and of energy use to help achieve that goal. While providing tighter targets for the country as a whole, this Plan focuses particularly on three regional clusters – Beijing-Tianjin-Hebei, the Yangtze Delta region and the Pearl River Delta region – in an attempt to address the transboundary problems within these regions discussed above. Cities within these clusters have subsequently released specific plans or work programs to achieve the objectives set out for them in the Central Government plan. Further work is necessary to examine the implications of these newly introduced measures on energy use, emissions and low carbon programs in key cities. The new initiatives seem likely to result in an acceleration of investment in clean energy generation, especially of renewables and natural gas, as well as the introduction of stricter environmental standards on energy generation and industrial production.
2. For a long while most policy making in China has been based on a simple conception of development, as reflected in the growth rate of measured GDP, without any real consideration of the resulting quality of life, the environmental and other costs being incurred but not measured or the distribution of outcomes. Further work is necessary to place the analysis of low carbon initiatives in a richer development framework, and hence to provide better tools for economic analysis by policy makers. This would involve, inter alia, economic quantification of benefits arising from green infrastructure and low-carbon development, including the quality of life benefits arising from health gains resulting from improving environmental quality, such as the quality of air, water, soil and food supplies.

5.3 Project outcomes

This project 'Developing a low-carbon roadmap for China's cities' has focussed on pathways for breaking the link between economic growth and rising carbon emissions whilst improving the quality of life in cities. The project has attempted to develop a deeper understanding of innovative solutions to address the major industrial, energy planning and development challenges confronting cities in a carbon constrained environment. These understandings and solutions are specifically designed to contribute to the effective implementation of low-carbon policies in China's cities to conserve energy, reduce emissions and improve living standards whilst strengthening economic, environmental and social sustainability. This final report includes several specific results pertaining to these issues.

First, detailed industrial roadmaps have been developed for the transition to low energy development by 2030 for the cities of Beijing and Tianjin. The roadmaps explore the options for reducing energy use and emissions, primarily in the industrial sector, and bring out some of the economic costs and benefits of emission reduction options. Both roadmaps incorporate an assessment of future carbon emissions under a variety of scenarios in order to determine the scope and scale of carbon emission reductions, actual investment costs and actual achievable goals within a specific time frame. These assessments can assist decision makers understand the economic, employment, investment and emission impacts of different economic and planning scenarios in the industrial sector for Tianjin and energy sector for Beijing.

Second, a reasonably comprehensive low-carbon city index system has been developed with the aim of guiding planning and decision-making for the development of low-carbon cities. The index system could offer a useful evaluative and monitoring tool to help urban planners understand the broader impacts of incremental changes to the city's energy demand, supply and mix on GHG emissions, as well as monitor and measure progress on achieving the carbon emission reduction targets. Existing index systems are heavily weighted towards traditional environmental considerations rather than measuring best practice energy, emissions and industrial innovation technologies, policies and measures. Greater emphasis needs to focus on these considerations as well as the consumption of resources rather than production so as to not discriminate against cities that have an industrial base, such as Tianjin compared to a service-orientated city like Beijing. Additional benefits of clearly identifying the key steps and priority areas of a city's emissions profile highlights areas of progress, or lack thereof, but also includes, for example, the ability to better plan and integrate investments in infrastructure, such as energy supply, public transport and parks as well as the provision of social services.

Third, the roadmap and index system may provide a helpful platform and guide for urban planners and economic decision makers in determining the efficiency of alternative development pathways for reducing emissions as measured by cost per tonne of GHG abatement in the medium and long term. This is an important consideration because of the limited time available for making efficient decisions and cost-effective use of existing technological opportunities and therefore avoiding the potential implications of carbon lock-in due to delayed action. Time sensitivity therefore remains a critical issue in making effective decisions regarding urban planning and development during the current period of rapid development. To meet the expected growth in urban demand, China will further expand the construction of new power plants, transport networks and buildings. Because such infrastructure will largely remain in place for the next 40-plus years, there is a need to ensure that such investments are carefully planned, executed and adopt global best practice. The roadmap and index system is designed to help to ameliorate the risks associated with such strategic planning and decision making.

Fourth, China has introduced a comprehensive range of policy measures and ambitious targets aimed at reducing energy intensity, slowing emissions growth and rebalancing its economic structure. The successful realisation of these measures is of immense importance to China and the world. This collaborative project has attempted to improve access to and the knowledge of effective implementation and policy pathways in China's cities. It also helps to cement the relationship

between China and Australia in this key area, to provide a closer understanding of China's plans and initiatives and to provide insights relevant to Australia's own policies, both at home and abroad.

Fifth, both the low-carbon roadmap and the index system have been designed so that it can be applied to other cities in China and internationally. The roadmap and index system has been demonstrated to government, business, academics and the local community groups as well as participants of the three low-carbon development workshops in Beijing, Tianjin and Melbourne. Feedback arising from this engagement has provided an important opportunity to adjust the roadmap and index system to better reflect the current and future demands of users and the community.

Sixth, a key feature of this collaborative project has been to promote engagement and collaboration between economic decision makers, planning authorities, urban planning and design firms, the local community and researchers in China and Australia. The development of lasting partnerships between levels of government, parts of government, government and business, civil society and the local community has been a critical consideration for project delivery and impact. The comparative study of urban development in Tianjin, Beijing and Melbourne has provided important networking, commercial and learning opportunities as well as partnerships for action and planning where these have not previously existed. These opportunities have arisen from lessons learned in confronting urban planning challenges and also from the introduction of innovative solutions and pilots in each of the three cities. So, what are the lessons for Beijing and Tianjin? Can a bigger Beijing or a bigger Tianjin be a sustainable and healthy city? The answer to this question will depend on how the people of Tianjin live in the future. In turn, this will depend on the way we plan, design, develop and manage our city today. If we transform our city – and enable people to live in more compact and active ways – both cities could house a bigger population and be sustainable and healthy. However, if each city's population grows without investing in good planning and infrastructure, future generations of city dwellers will be left to deal with the health and environmental consequences. They will not thank us.

Appendices

Appendix 1 Urban layout, planning and design for low-carbon cities

Most discussions of urban planning, design and low-carbon cities focus on density and urban form. While it is clear there are obvious low-carbon benefits from higher density residential development, every city is distinct in both its form and pattern of development. A local scale approach to low-carbon cities emphasise the creation of healthier, liveable and pedestrian friendly mixed use and diverse neighbourhoods. This is in stark contrast to the earlier analysis of the industrial and energy structure of cities. Rather than being a separate issue, a local neighbourhood focus is a critical third consideration in making the successful transition to a low-carbon city. Once a city has transformed its energy and industrial structure to a low-carbon pathway, it needs to ensure that the layout and urban form encourages low-carbon lifestyles.

First, let's start with the question of what makes for a successful neighbourhood? Are there design features that can improve liveability whilst contributing towards a low-carbon and sustainable city? In 1961 Jane Jacobs wrote in "The Death and Life of Great American Cities" that "cities have the capability of providing something for everybody, only because, and only when, they are created by everybody". In a criticism of the urban planning fraternity, Jacobs argued that "there is a quality even meaner than outright ugliness or disorder and this meaner quality is the dishonest mask of pretended order, achieved by ignoring or suppressing the real order that is struggling to exist and to be served." Jacob's argued for the inclusion of four simple ingredients to ensure a successful neighbourhood:

1. A street or district must serve several primary functions.
2. Blocks must be short.
3. Buildings must vary in age, condition, use and rentals.
4. Population must be dense.

Imbedded in Jacob's argument is a call for rich and dense social and functional diversity to ensure a vibrant and dynamic community. The basic requirements for such a neighbourhood are really quite simple, but as Jacobs also argued "designing a dream city is easy... Rebuilding a living one takes imagination."

The challenge for many proposed Chinese ecocities or low-carbon cities is that they are typically sited in greenfield areas rather than within existing established cities. Moreover, Jacob's four simple ingredients are largely at odds with most proposals. A modern Chinese city, regardless of whether it is low-carbon, an ecocity or otherwise, is typically composed of the following four characteristics which are antithetical to Jacob's suggestions.

First, single activity zones dominate with an emphasis on industrial, logistics, retail, commercial, manufacturing, residential, governmental, educational, medical or cultural functions. This style of "functional zoning" typically results in land use fragmentation into large, specialised, single-use urban areas. China's master plans have reinforced this approach and many of the ecocity proposal continue to adopt this approach to manage urban growth (Yokohari et al. 2008). The combination of functional-zoning and urban sprawl results in fragmented cities as exhibited in Tianjin-Binhai where

half a million workers commute daily between the two regions. Such spatial segregation reinforces car dependency and exacerbates social inequity due to differentiated access to urban services (Leaf and Hou 2006). Mixed use neighbourhoods encompassing jobs, housing, retail, social-recreational facilities and public services, especially in downtown and other commercial districts but also in residential neighbourhoods easily result in convenient and attractive places to live and work.

Second, blocks are typically long and singular use with little variety and few opportunities for street level activity. Chinese block sizes are often referred to as super blocks because they are typically four to five times the length of a Manhattan block. Long blocks are less attractive for pedestrian use reinforce path dependency which reduces potential commercial activity (Handy, Paterson & Butler 2005). Well connected street networks providing easy pedestrian access to nearby destinations such as high quality public transport, shops, community services, schools and parks etc; We already know that people walk and cycle more if they live in compact, pedestrian-friendly and safe neighbourhoods.

Third, most buildings are of a single age and rental prices vary little in each area on a square meter basis. Jacobs argued that old buildings support a variety of uses and activities and are more likely to foster creativity and innovation. Moreover, a mix of new and old buildings accommodates broader socio-economic households as well as small and large businesses – all of which seem to better coexist.

Fourth, while population density would appear to be a dominant characteristic of most Chinese cities, residential housing is increasingly spate from retail, finance and commercial centres. In addition, many new residential areas are being built on a compound or gated community approach which provides limited opportunities for the diverse social and economic interactions that Jacobs believed were crucial for supporting dynamic street-level activity which ensured people felt safe and welcome to visit.

Ironically, urban planning officials, academics and government officials can often agree on the core criteria of how to improve the liveability of their cities: provide affordability and accessible housing, health services and education; improve employment opportunities for all abilities; narrow the distances travelled between work, study, shopping and housing; improve the quality of urban air and water; reduce road congestion and provide quality transport services, in particular for pedestrians, cyclists and public-transport users; and include more accessible open space and recreational opportunities. The issue is less about the visions and more about specific details and implementation.

Current Chinese residential housing construction is largely taking place in peri-urban satellite towns in a scenario somewhat familiar to Australian suburban cities. While Chinese cities will have the advantage of being high density, there are still several considerations that need to be considered to ensure these new greenfield developments result in the best possible outcomes in terms of meeting the above criteria whilst reducing resource inputs.

Behind the new housing developments around Chinese, North American and Australian cities are property developers who are primarily concerned with selling off these new homes. It is generally a very conservative sector that sells largely on the basis of meeting consumer medium-term lifestyle

dreams and short-term affordability. Affordability means that there needs to be targets for social housing; which generally exist as part of the ecocity criteria. In order to ensure these targets are met, economic mechanisms need to support their construction by local governments and property developers. Ironically, the lower immediate cost of outer suburban housing quickly evaporates due to the high cost of petrol, isolation from basic services such as quality education, reduced physical activity, greater obesity problems (Jago Dodson and Neil Sipe 2011).

It will be very difficult in Australia for these developers to shift to a new alternative vision and design which embodies some constraints on the “lifestyle dreams” and expectations. While similar problems present themselves in China, the property industry is younger and more sensitive to changing market demands. Moreover, the popularity of the ecocity concept with over 200 pilots currently at play across China, presents a wonderful opportunity for an alternative dream. A dream based upon a more sustainable lifestyle built around community and neighbourhood. If several of these ecocities can successfully develop an attractive alternative model of urban development that is both affordable and sustainable, then it is likely that the market will adjust accordingly.

In the following sections, several key approaches including specific details and evidence based policy suggestions are suggested for creating successful, liveable and low-carbon neighbourhoods that hopefully go some way towards making the transition to a low-carbon pathway of urban development.

A1.1 City planning, urbanization and land use

A key component of low-carbon cities relates to the design of the city. As Chinese cities continue to grow, especially in and around existing massive urban centres, such as Beijing and Tianjin, it is critical that the design of these cities can accommodate future residents in a sustainable manner. Understanding the recent experience of post-industrial cities and service orientated cities provides important clues for the changing demands and lifestyles of residents. A simplified analysis of the defining features of urban zones in Melbourne provides important insights into the strengths and weaknesses of the city's urban planning approach. Simplistically, the city could be divided into three zones: an inner city, a middle suburbia and the growth corridors or peri-urban regions.

During the past decade the inner city has shifted from low and medium density housing to medium and high density in multi-storey developments. Gentrification has taken place bringing greater street-level activity and cultural options, but making affordability an issue. Demands for improved walking and cycling options are generally accommodated incrementally with little need to invest in additional public transport due to historical concentration in the inner city. Demands for additional childcare and schools remain an issue because many of these services were closed or scaled back following the combined decline of inner city manufacturing and the residential population in the 1980s.

The middle suburbs of Melbourne provide the greatest contrast between the upper and middle class suburbs on the one hand which are well provided for in terms of infrastructure and social services, such as health centres, schools and libraries as well as local parks and gardens. However, on the other hand are the areas of middle to lower socio-economic demographic where much of the public infrastructure is aged and there is very little new investment. Employment opportunities are also

limited in these areas and public housing often dominates. Attempts to revitalise these areas is often let down by a failure to understand the close relationship between low income and the lack of retail activity opportunities.

The outer suburban growth areas and peri-urban areas are experiencing stress in terms of access to basic services, such as health, schooling and transport. Car dependency is highest but so too are travel times and costs. Local governments are generally struggling to keep up with demand even for recreational services and open space provision against ever increasing sub-divisions and new allotments in often remote and isolated areas.

Employment isolation is becoming an increasing concern in Melbourne, especially in the western suburbs where suburban sprawl is occurring fastest whilst manufacturing employment is shrinking. State and Federal government strategies could remedy some of these issues by investing in new schools and hospitals in these regions whilst encouraging the activities of public servants to be located in these regions.

A1.2 Policy tools

There a range of policy mechanisms, regulations, incentives and standards for shaping more sustainable urban development. Building zoning, building permits, public consultation, height restrictions, mixed use land and occupation, housing construction guidelines, heritage and environmental overlays are all commonly used to manage local scale developments. Whilst they are meant to operate within a broader policy and regulatory context, decisions regarding individual sites are typically made independently and in isolation. For many cities, the major urban policy driver has been land use zoning and the elasticity of the city's urban growth boundary. Previously, greenbelts and corridors were established throughout the city to protect important agricultural land and eco-sensitive zones against physical disruption by construction activities. However, the increasing pressure on land availability and prices has placed the government of the day under significant pressure to continue to unlock these liminal urban spaces in an unsustainable manner in terms of social inequity, environmental and resource damage and economic waste.

The design of a city needs to work not only with the economic structure of the city but also acknowledge cultural considerations such as social preferences which will shape the behaviour of the residence. For example, expectations about the size and location of housing, the construction of parks and open spaces, the preference for quality schools etc. Traditionally, statutory planning approaches and regulations emphasise site specific development parameters such as plot ratios, density and setback requirements. Combined with short-term market priorities of property developers to maximise neither of these approaches considers quality of the living environment nor low-carbon planning objectives such as pedestrianisation, waste reduction, energy and water efficiency.

Portland's 20-minute neighbourhood acknowledges the importance of planning neighbourhoods that support vibrant local communities and reduces car dependency. Portland's 20-minute neighbourhood prioritises walking or bicycle routes so that most residents are able to access all basic daily, non-work needs and transit in a safe and convenient manner.

A similar proposal has been picked up in other cities, including Melbourne (Municipal Strategic Statement, CoM 2012), which outline key directions for each city's future development including: identified areas for growth and renewal; developed strategies for improving connectivity and accessibility within the city; new developments to complement public places and spaces; creating an 'eco-city'; supporting a vibrant diverse and complementary mix of uses. In contrast to municipal strategies in Chinese cities, these documents typically contain little or no quantifiable targets, restrictions or goals to meet such directions. It should instead be seen as a strategy document. Unfortunately, this is not the first, and nor will it be the last "strategy document" for the city of Melbourne. During the past forty years Melbourne has produced eight planning documents or a new one every five years on average. The penultimate "strategic planning document", Melbourne 2030 included similar vague propositions for prioritising inner city redevelopment and high density living, protection of suburban heritage character, improved public transport services and less distance between homes, workplaces, schools and shops etc. Unfortunately, most of these documents, especially the more recent ones, have generally played second fiddle to urban growth boundary realignments and a transport policy that continues to prioritise freeway construction. For example, vehicle kilometres travelled in major Australian cities has increased by 65% since 1980.

Strategic planning documents are important, because they can play a role in directing public and private investment in a complementary and efficient manner for funding public services, such as transport, schools, libraries, open space, communication systems and hospitals. They can also identify causes and solutions for local and regional inequality and approaches to protecting the natural environment. In their presence or absence, government policies, regulations and market mechanisms need to reinforce the key messages and approaches to ensure there is consistency.

If urban sprawl is to be accepted as inevitable, then it is critical that governments start charging the true costs for private transportation, pollution and resource use; they tax land, rather than buildings, and focus on taxing the value of the actual land use (such as forest and agriculture) rather than focusing on "value adding" which typically removes agriculture from peri-urban areas. At the same time fiscal incentives and tax breaks should be offered to local governments and private developers for cleaning up and developing abandoned urban sites or so called brownfield sites.

Brownfield infill and contiguous growth are a social and affordable approach to keeping the urban footprint compact. Rather than demolishing older districts, the focus should be on preservation, renovation, and re-use of existing structures that accommodate a variety of uses whilst reflecting local history and culture. This should be inclusionary development for a mix of incomes and age groups. Urban infill allows for the upgrading and maintenance of public utility infrastructure in older parts of the region.

A1.3 Transport planning

Reducing the incentives to exacerbate urban sprawl, while taking up some of the slack in inner city areas can then be balanced with moderate development of medium and high density along mass transportation route and at train stations (transport oriented development), which provide diverse retail, commercial, residential and community services focused around train stations. In addition, new incentives need to be introduced to encourage investment in train stations and along train lines for private developers.

Breaking car dependency in North American and Australian cities and discouraging the surge towards this phenomenon in Chinese cities could easily be seen as the single most important challenge for making the transition to low-carbon cities. However, it is helpful if car dependency is seen as symptom of a poorly planned city rather than the cause. Individually, private cars make enormous sense in terms of the efficient movement in and around cities. As a result, cities have accommodated cars by levelling hills for bitumen, building freeways around, through, over and under cities, widening roads, providing enormous car parking lots, facilitating traffic flow and essentially designing the urban fabric around the motor car. Aerial views of Melbourne reveal vast swaths of land covered in impervious bitumen with the sole purpose of parking a car, especially around large shopping centres and the international airport, which all generally lack efficient connections with public transport.

Cars are important symbols of wealth and modernity and conversely public transport is often a symbol of depravity which caters to the poor, students, the retired or unemployed – all of whom have plenty of time to frequent poorly managed and infrequent services. Basic policies can be adopted to shift the transport balance back towards mass transit, pedestrians and cycling. For example the following suggestions are fundamental.

- sustainable transport needs to be safe, reliable, frequent, accessible to all and affordable;
- transport planning requires better coordination at the local, corridor and regional levels as well as integration with land use planning;
- pricing of transportation, private road use and parking to reflect its full costs (including environmental costs and congestion);
- reduce priority of the car over and above all other forms of movement and land use;
- improved on and off-street parking management to ensure safety but also smarter designs;
- preferential signal timing to prioritise trains, trams, bus, cycling and pedestrian use above vehicle movements;
- traffic calming and speed control; and
- programs to keep streets, sidewalks, and transit systems well maintained so that everyone feels welcome and safe to use.

In addition to the general requirements for overall transport, there are several considerations that are critical to ensure the sustainability of public transport services, including:

- transit-oriented development (TOD) so that services are aligned with urban densities and demand;
- strategically connected through nodes in terms of networks and operations;
- multi-modal designs to provide access for pedestrians, bicycles, other modes of public transport as well as cars;
- services need to be aligned for inter-nodal transfers, yet service frequency should prevail over schedules;
- easy and accessible pedestrian pathways should feed public transport stations, hubs and stops;

- pedestrian access should be prioritised, wide enough to meet demand, safe in terms of crossing designs, with quality shelters, well lit and clearly visible, covered by shade trees and include seating; and
- communication systems should work across all modes of transport and be regularly and clearly communicated to users.

The construction of higher-density TOD clusters of housing are preferential to dispersed houses, but more importantly they need to be designed with sustainability as their foundation, in terms of construction, design and post-occupancy use. Commercial and residential buildings account for nearly a quarter of all GHG in a city mainly for heating, cooling and lighting. The introduction and monitoring of minimum standards and retrofitting programs are often cost effective when they focus on the installation of energy efficient lighting, air-conditioning and heating, centralised power management systems for computers, aerated tap and shower heads, cistern modifiers in toilets and waterless urinals.

A1.4 Open space

A risk for developing higher density residential areas is that open space becomes constrained. While massive expanses of open space are attractive and have added greatly to the liveability of many cities, they are not essential. In fact, large parks and open spaces can in fact worsen spatial segregation as much as large freeways can. Moreover, many large parks continue to struggle to provide a welcoming and safe recreational environment for half the population, women, who often remain reluctant to enter these areas due to concerns for their personal safety. Therefore, we need to rethink the quantity issue for open space and instead focus on the quality of and access to all open spaces (parks, play grounds, recreational sports grounds and school grounds). Open spaces are often narrowly understood to be parks and gardens, but most cities also contain extensive blue spaces or creeks, lakes, rivers and beaches. These spaces provide significant potential for linear linkage roles in terms of open space, recreation and biodiversity. As such it is critical that these areas are linked up with easy pedestrian and cycling access as well as making people feel welcome and most importantly safe.

Given these concerns, it is important for the current indicators to move away from basic open space calculations or green space quotas or targets for new developments. Instead, open spaces and parks should be suitable to the local demographic as well as be multi-use in purpose, so that can be used by different groups at different times. Small community parks that include areas and activities for both passive and active recreation for a variety of ages and abilities should be encouraged, but most importantly they need to be connected up to other pedestrian, recreational corridors and open spaces. The spaces need to be visible and surrounded by active functional areas (mixed residential, retail, cultural - library, recreational – pool, sportsground) and include retail opportunities, such as small markets and shops.

Appendix 2 The Melbourne story

Melbourne is the second most populous city in Australia and capital of the state of Victoria. It is often referred to as a "Garden City" and the "cultural capital of Australia". From 2011 to 2013, it was ranked as the world's most liveable city in ratings published by the Economist Intelligence Unit (2012). This ranking was based upon an aggregated figure from several key indicators including: education; health care; transport and communications infrastructure; crime, threat from instability or terrorism; environmental conditions; recreational and cultural activity; and, traffic congestion etc. Melbourne's aim as a city is building a bold, inspirational and sustainable city, and a great place for people to live, work and visit. As the world's "most liveable city" should it not already be sustainable? Unfortunately, liveability does not necessarily equate to sustainability, especially from a low-carbon perspective. This chapter explores this issue, firstly through the historical experience of planning and environmental protection for Melbourne. Some specific urban planning lessons arising from the city's experiences are then introduced for consideration.

Established as a city in 1835, today Melbourne's population is over 4.2 million and expected to reach 5.4 million by 2031 and 6.5 million in 2051 (Victorian in Future 2012). The vast majority of the city's population growth has come from migration with over 36% of the population born overseas from over 160 different countries. Urban sprawl characterises the historical form and development of the city which covers around 8,806 km² with a density of 1,566 persons per km². The economy was traditionally manufacturing based, but is today dominated by the mixed services sector including, finance, education, health, logistics and transportation, research, IT and tourism.

Urban planning decisions are generally made by the state government and implemented by 31 local governments. While there has been significant criticism of urban planning, or the lack thereof, over the past thirty years, it was the early strategic planning that has been acknowledged as critical to the liveability of Melbourne today. For example, the vast majority of the cities clean and reliable water supplies and sewage disposal were developed over one hundred years ago. The city's drinking watershed and catchment were closed to development and forestry shortly after establishment of the city. Similarly, the city's separate sewage disposal system was developed. One of which today operates as the state's largest livestock farm (11,000 ha) and is also an international registered Ramsar wetland site.

After declaring the city a 'good place for a village', Melbourne's urban form was laid out like a bicycle wheel with the CBD the hub and the suburban corridors spoke on the wheel along train lines. To ensure that its residents could enjoy opportunities for recreation and a quality of life, most of the city's current parks and gardens were set aside in 1856 as legacy for the city's future, representing nearly a third of the inner city being designated as parklands.

To facilitate the movement of people a comprehensive transport system was built, partly on the back of property developers keen to lure residents out to new suburbs. By the beginning of the twentieth century, the city had a vast network of tram and train lines that today are a respective 250km and 372km in length, much of which was built over a hundred years earlier. With the advent of the private car, public transport patronage has slowly dwindled to around 25% in the 1940s to less

than 7% in the 1990s. In recent years, public transport use has rebounded to around 15% with 187 m annual trips on trams and 225 m annual trips on trains. This recent growth in patronage is unfortunately unlikely to grow further without new public and private investment.

Urban sprawl is the defining characteristic of Australian and North American cities and Melbourne is no exception. Sprawl is the outcome of economic development policies promoting urbanisation in a strategic policy vacuum, unsustainable spatial development models and weak planning regulation (Couch 2008). Australia population is highly urban, at around 80-85%. Cities remain centres of high population growth and yet they are all essentially low density cities, for example, the urban density of Melbourne and Sydney is around 70% of the North American density figure and 35% of the European average. The key drivers for this outcome are poor land planning and very high car dependency, both of which are interconnected and locked in to a self-sustaining positive feedback loop.

While there has been a gradual trend towards using public transport, walking and riding bikes to work, these “alternative” modes of transport remain exactly that, alternatives. In Melbourne, cycling to work represents less than 2% of all journeys, walking around 3.5%, public transport 16% and driving around 80% (ABS 2011). Growth in train patronage between 2006 and 2011 was strong (50,000 more) but only half as much as the growth in private car usage which was up by 125,000. Disturbingly, public transport patronage, walking and cycling by younger people has been declining since the 1970s. This trend paints a grim picture for the potential to reverse these patterns of transport movement. These figures are representative of other Australian cities where car usage varies from around 80-90% of all journeys to work (ABS 2011).

In Melbourne, the government has added new bus routes as well as increased the frequency of tram and train services in recent years. While there has been a gradual increase in public transport usage, the public transport systems fails to adequate service the scale and needs of a constantly sprawling city. The design of the system is based upon a spoke with most services going into the CBD and with very little nodal or inter-connectedness between services. Despite Melbourne having an integrated public transport system, there are significant failings in the design and planning of routes, timetables and connectivity with changes typically incremental and poorly coordinated. A good example of the failing of the public transport system is the absence of train stations from several large university campuses and most large suburban shopping centres across Melbourne. This gap in services highlights the severe failings of the transport department and private operators to even capitalise on potentially “profitable” services. For example, since 2008 Melbourne University funded its own 2km shuttle bus service between a major train station hub and the University because of the absence of connecting services. The very successful service runs every 2-3 minutes during peak hour and every five minutes at other times.

Even the pre-GFC oil price hikes did little to change industry and household behaviour during the past decade. The reasons for this behavioural inertia away from private motor vehicles are numerous. The fundamental drivers for private car usage are convenience, economy and also financial incentives to drive. Government subsidies to motor vehicle drivers include the fringe benefits tax rebate for businesses and employees who lease cars. The costs however to society from car dependency and urban sprawl are enormous.

Rising levels of obesity, a growing urban footprint due to sprawling suburbs, productivity losses, declining air quality (Wirth 2013) to rapidly rising rates of car use and the resultant air pollution are just some of the negative externalities associated with car dependency and urban sprawl. Additional social concerns include spatial employment divides that exacerbate inequity and access to services, as well as the division of neighbourhoods. In addition, the heavy reliance upon the car results in lifestyle lock-ins. A depressing feature of Melbourne's urban sprawls is that new house sizes have actually increased to now exceed the American average at 252 m². Ironically, average urban household size is constantly decreasing and is now around 2.25 persons per dwelling. It is not surprising that obesity is an increasingly serious problem in suburbia as people drive more, walk less and maintain a more sedentary lifestyle. A prerequisite for each of these new suburbs is the final ingredient in the triple combination of car dependency and sedentary lifestyles, the large shopping mall. This ritual typically involves a weekly drive to the large shopping centre with easy and plentiful parking and a large trolley to transport all the purchases typically from a single retailer.

This brief survey of Melbourne's experience shows that even without taking into consideration a carbon intensive energy system, the city's residents maintain a lifestyle dominated by high rates of material consumption, waste generation and carbon emissions. Many of these lessons could just as easily be learnt from other Australian and North American cities. However, it is Melbourne's recent accolades that require a somewhat closer examination of the low-carbon – sustainability – liveability nexus.

To a large extent Melbourne continues to rest upon an inherited legacy from its colonial planners and decision makers, which ensured the city was equipped with adequate infrastructure and a layout that accommodated growth. Today, the city is undergoing an important debate about the current pattern of development and its future direction. The implications of decisions made today will decide to large extent whether this city can make the transition to a low-carbon economy. Unfortunately the institutional and community inertia remains significant. Moreover, climate change is reshaping the way we understand urban planning and design, so that whatever solutions and ideas we start to introduce it is unlikely that the city will effectively tackle the serious challenges of carbon mitigation and adaptation until the costs are much greater.

The city of Melbourne, Australia, provides an interesting insight into the low-carbon-liveability-sustainability nexus. It shows that on the one hand incredible foresight and significant early investment in good planning and public infrastructure can service a city and its people for over a century. At the same time, the Melbourne experience shows that cities can simultaneously increase their wealth and improve liveability with little concern for sustainability or a low-carbon pathway. Despite a broad and deep understanding of the social and economic processes and modes of behaviour that fuel this unsustainable pattern of development and the urgency of tackling climate change, significant societal inertia continues to impede fundamental adjustments in thinking and behaviour towards a low-carbon pathway.

Appendix 3 World city comparisons

A3.1 The low-carbon energy path of New York City

Energy development target

New York's pursuit is to be "the example for 21st Century city development". For this, the energy demand target for the state of New York is to increase renewable energy in the energy consumption structure from the current 10% to 15% in 2020; the longer term target would be 50%. The CO₂ emission reduction target in 2030 would be 30% of 2005 emissions (58.3 million tons 2005) (PlaNYC 2030).

Measures to guarantee electric power supply

The following guarantee measures are presented by New York City:

- (i) to add power generation equipment or modernise the technology, so to maximise the productivity of current power generation plants, including improving the energy efficiency in the current power plants by 40%, and at the same time reduce the GHG emission and improve air quality;
- (ii) to increase the energy supply of clean power plants;
- (iii) to construct a power plant outside of New York City to supply its electric power grid and not purchase power from severely polluting plants;
- (iv) to support the construction of big scale natural gas facilities; and
- (v) to develop renewable energy.

The usage of renewable energy in New York City has advanced:

- in 2010 about 6% of electric power was from a local renewable energy source
- 50% of New York State's primary energy is from renewable energy; and
- in order to promote solar cell usage, New York City will provide tax exemptions for the installation of solar panels, with increased usage in urban buildings, at the same time as conducting research on garbage energy generating, and the development of waste power generation and technology.

The path to low-carbon energy

New York City is a pioneer in mid- to long-term energy development planning and is leading in energy sustainable development. In 2007, the city published the "New York 2030 Plan" (PlaNYC) with an emphasis on an energy strategy including:

- to implement an energy efficiency strategy, and reduce the general amount of energy consumption;
- to establish an energy planning committee, and implement and improve an energy plan;
- to enhance the administration, legislation and training in the reduction of energy waste; and

- to speed up the development of renewable energy and new energy, and expand the supply of clean energy.

A3.2 The low-carbon energy path of Tokyo

Energy development target

In 2007, Tokyo published the “Tokyo Climate Change Strategy”, aspiring to be the future leader in the least environmental polluting city and an advanced city in addressing climate change. The targets in this strategy included a CO₂ emission reduction of 25% in 2020 from the 2000 level, and 20% renewable energy in the energy consumption structure (Tokyo Climate Change Strategy).

City power supplying security

The main power supply in Tokyo comes from the Tokyo Electric Power Company (TEPCO). Since nuclear power was developed in 1960, the power supply shift to low-carbon electric power included coal and petrol oil power generation gradually being replaced by natural gas, with the nuclear power proportion higher than 20% (from 2008). After the Fukushima nuclear accident in 2011, Tokyo was forced to change the power supply structure. Measures to guarantee power supply security included: reconsidering the existing strategy of increasing the proportion of nuclear power; weakening the monopoly of TEPCO on the electric power management; and constructing a super-scale natural gas power generation plant to amend the loss of nuclear power generation.

The low-carbon energy strategy

Being a resource deficient country, Japan’s emphasis in its energy strategy is:

- (i) to internally focus on both of energy saving and develop new energy;
- (ii) to externally seek a stable energy supply; and
- (iii) at the same time, strictly control CO₂ emissions.

Its energy strategy emphasises energy saving equipment in the building industry, transportation and civil life. From 2005, Tokyo introduced the “Tokyo Green Energy Plan” and the “Tokyo Renewable Energy Strategy”, including encouraging big scale facilities and public facilities to use renewable energy, and the use of tax and finance policy to support the development and usage of renewable energy. The Tokyo metropolitan government is implementing the “Reduce the CO₂ Emission of Tokyo Plan” and the “Tokyo Climate Change Strategy”, setting a target of reducing GHG emissions by 25% of 2000 in 2020. The measures to reach this target include:

- set the emission reduction mechanism for commercial facilities and industrial equipment covering a population of 14 million;
- over 1300 companies with 45% emissions as a proportion of Tokyo must implement a reporting system and publish this on their website;
- establish a commercial carbon trading system;
- establish energy saving regulations for the highest building in the world
- implement an environment allocation project;

- reduce the amount of transportation in Tokyo with joint delivery of cargo; and
- provide a large subsidy to families installing solar power generating equipment, etc.

A3.3 The low-carbon energy path of London

Energy development target

In London, the city announced an energy strategy stating that they will promote “heat and power integrated” energy equipment and passive solar measures, and realise a “self-supplying energy supply system”. In the mid-term the city plans:

- (i) to realise the low-carbon energy security: “become a worldwide leading low-carbon capital city and low-carbon finance city”;
- (ii) to provide participation opportunities for businesses, internal investors and London citizens to become low-carbon businesses, while at the same time developing a low-carbon economy; and
- (iii) to provide work opportunities and revenue increases for businesses in London and in the whole country.

With the higher efficiency, and affordable and secure low-carbon or zero-carbon supplies to meet the energy demand of London citizen, business and basic facilities, 25% of urban energy consumption will come from distributed energy. Energy security refers to low-carbon conditioned energy security. For the long term, the city will establish a totally new energy system compared to the 20th Century. In the report of “The Perspective of London in 2050”, London will establish a totally new energy system from the 20th century to 2050, mainly using renewable energy and hydrogen energy. They aim to reduce CO₂ emissions by 60% of 1990 levels by 2025 and 80% by 2050.

City power supply security

The power supply of London has experienced three stages of private or public ownership. Currently, the result of transforming the power supply of London is that the four biggest private supply companies have taken this role of suppliers. Seventeen power generating plants supply 40% of the electric power of London (among these, the four largest companies supply 20%), the other 60% is supplied by power plants outside of London. After 1990, coal and oil generation was replaced by a highly efficient power plant outside of London, co-generating and supplying 6% of the heat and power supply. Currently the power from the plants outside of the national grid is about 20% of the electric power consumption of the whole city. The government insists on purchasing highly efficient electric power.

The low-carbon energy strategy

The main measure of guarantee of the London low-carbon energy supply is the distributed energy plan (DE). London plans to have distributed energy be about 25% of urban energy (about 29TWh). Distributed energy was chosen as the energy strategy because it is applicable to an intensive city environment and the variable energy demand of London. The policy measure of distributed energy is: to design a comprehensive development roadmap; and that all newly constructed power

generating facilities either support the expansion of the current distributed energy system or develop a new one.

The detailed city energy strategy includes:

- (i) a directive that the terminal energy user implement sustainable energy use;
- (ii) plans to widely improve energy equipment efficiency to gradually reduce the consumption of fuel or power;
- (iii) to oppose the new nuclear power project, preferring to improve energy efficiency and develop renewable energy, heat-power co-generation and other low-carbon energy technology to take the place of nuclear power;
- (iv) to promote extensive renewable energy power generation and import renewable energy; and
- (v) to promote fuel battery technology to be an additional supply of renewable energy.

London currently:

- supports distributed energy as the core component of a sustainable energy supply, and promotes grid development to match the increasing distributed energy;
- promotes “community heating supplying”, i.e. to use a heating allocation network to supply heating to several buildings;
- focuses on transportation in order to improve air quality, with a target for 2010 to reduce the traffic flow from 10% to 15% in the downtown area; and
- encourage citizens to buy low-emission capacity cars, promoting highly efficient and clean engine technology and a low pollution vehicle with alternative fuels such as natural gas, electric power or fuel batteries.

A3.4 The low-carbon energy path of Paris

Energy development target

The energy development target set by Paris to 2020 includes:

- to increase the renewable energy in the energy consumption structure to 30%;
- to reduce the energy consumption of road lighting and municipal services to 30% of the 2004 level;
- to reduce CO₂ emissions to 30% of the 2004 level; and
- for 2050, to reduce CO₂ emissions to 75% of the 2004 level.

The low-carbon energy strategy

Currently, the efficiency of the energy usage of the Paris Big Region is not high. Annual per capita CO₂ emission is over 1.5 times the international average level, with waste emissions 2.8 times more than the international average level. Only 12% of the waste is reused annually, and just 41% of the heating from burning is recycled and reused. Therefore, in 2009 France announced the “Big Paris

Plan” mainly targeting the establishment of a “compact city” and a “balanced city”. The measures for low-carbon energy include:

- (i) to establish a new energy consumption and production system based on the guidance of two targets: “ diversify the energy use ” and “reduce the energy demand”;
- (ii) to optimise the recycling system function in consumption to let waste be recycled as much as possible;
- (iii) for the circulation of products, to control the input of the food, energy and daily necessities to the city, reducing the flow as much as possible;
- (iv) for energy consumption, to use renewable energy as much as possible; and
- (v) through all the distribution channels, to maintain energy consumption pollution and waste to a minimum with scientific and centralised management.

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