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Shaping Climate Policy in Urban Infrastructure: an Insight into the Building Sector in China

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HIGHLIGHTS

URBAN INFRASTRUCTURE The decision made on the performance of long lifetime urban infrastructure (e.g. the built environment) today will have decisive influence on its future energy and climate footprints due to strong inertia, low efficient infrastructures risk the irreversible lock-in for several decades.

ENERGY EFFICIENCY Improvement in the energy performance of buildings (e.g. insulation, building design...) can allow reducing significantly the energy consumption and carbon emissions related to heating, cooling and other services while ameliorating the thermal comfort of resident.

TRAJECTORY We have tried to compare the different investment strategies in energy efficiency implementation in the building sector in a typical northern city in China, the simulated results allow us to evaluate the economic and environmental impacts of each strategy for decades to come.

CARBON FINANCE In the post-2012 regime, developed countries may provide incentives for China to adopt more stringent efficiency and emissions targets in its building sector. 'Technology Finance and Assistance Package' is to be designed to facilitate technology transfer and deployment of low carbon construction techniques.

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Summary

China is playing an increasingly crucial role in the global effort to combat climate change due to its sheer size and strong economic growth, which is primarily fuelled by coal. China alone will contribute 30% of the increase in global energy demand and more than 50% of the growth in coal consumption by 2030; carbon emissions in 2030 will be more than double those in 2005 under the BAU scenario (IEA, 2007). At the same time, China is experiencing rapid urbanisation: around 60% of Chinese people will live in cities by 2020 (UNEP, 2007; UN Habitat, 2008), meaning that 300-400 million rural residents will migrate to urban areas in the coming decades, a major driver of demand for urban dwellings in cities. Energy consumption and greenhouse gas (GHG) emissions will increase exponentially with unprecedented urban expansion and lifestyle changes as a result of the constant rise in living standards, unless drastic policies are implemented immediately. Empirical studies show that urbanisation has a significant impact on carbon emissions[1]. More specifically, the impact of population growth, urbanisation and economic growth on carbon dioxide emissions is more pronounced in developing countries than in developed countries (Shi, 2003; *Azomahou et al., 2006;* Martínez-Zarzoso, 2008). Given its long lifetime, the quality and performance of large-scale urban infrastructure with high inertia (e.g. buildings, transport) will be key factors in achieving the long-term objectives of GHG control, given the spectacular pace of urban development in China (for example, China will build the equivalent of the entire EU's existing housing stock over the 2005-2020 period).

While the trajectories pursued by China in the coming decades will have tremendous implications for global climate stabilisation, this paper attempts to address the question of the relationship between the capital investment decisions that enhance building energy efficiency (BEE) today and the subsequent creation of financial capacity to make it possible to scale up climate-friendly energy supply technologies tomorrow. This analysis shows how the shrewd allocation of financial resources can positively influence policies related to tackling climate change by managing the quality of developed urban infrastructure. By contrast, inaction or delays in investment to improve energy efficiency technology in infrastructure would have significant consequence in terms of future social costs, which may be avoided by anticipating the implementation of appropriate measures backed by strong public policy (Stern, 2007). Buildings have the largest potential for mitigating GHG emissions throughout the world, according to the IPCC's fourth report (IPCC, 2007). The trade-off between long- and short-term investment strategies should be addressed in the climate policy-making process, since the degree of environmental integrity of the infrastructure development will determine the trajectories of energy consumption and CO_2 emissions for decades to come.

The main purpose of this paper is to demonstrate the existence of a least-cost trajectory (denoted hereinafter as the optimal pathway) for energy performance improvement strategies in buildings in the context of extremely rapid urbanisation in China. In addition, it seeks to identify appropriate policy and economic instruments allowing cities to approach the optimal pathways of energy efficiency policy development. Based on a scenario analysis of the energy, environmental and economic consequences of different building efficiency

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[1] Cities produce almost 80% of global GHG emissions, although they account for only 2% of the earth surface area (World Bank, 2009).

implementation pathways, depending on the decisions made today, we demonstrate that maintaining the current BEE standards is not a rational decision from either an economic or an environmental perspective; more stringent efficiency requirements are needed to minimise the costs of the trajectory.

Findings from scenario analyses give rise to relevant recommendations for the energy and climate policymakers as to mitigation strategies and international climate negotiations, from the perspective of China's sustainable economic and urban development. Policy instruments are analysed with insights from the CDM/BEE procurement scheme and land use regulations. The key to the successful implementation of the carbon finance instrument will depend on adopting an integrated approach combining energy efficiency in buildings, climate-friendly technologies and urban planning strategies, backed by sound public policies and relevant institutions. Pricing reform is arguably indispensable for realising the potential of carbon emissions mitigation and sectoral transformation in the built environment in Chinese cities.

China can undoubtedly set its large cities on a sustainable pathway to energy supply and demand in the near future by constructing climate-resilient building infrastructure in its cities from now on, without necessarily incurring significant extra costs compared to the business-as-usual scenario. Avoiding a long-term technological and financial lock-in will require cities to immediately adopt high-efficiency building standards to facilitate investment in new technologies that provide a less carbon-intensive energy supply in the future. Considerably improving energy efficiency in buildings today will significantly enhance the prospective financial capacity to allow investment in innovative backstop technologies, such as Carbon Capture and Storage (CCS), in order to decarbonise the energy supply and meet the low-carbon economy (LCE) targets. In this respect, a shrewd reallocation of economic and financial resources is a critical determinant that will enable cities to embark on the optimal pathways. More specifically, altering the trajectory of the building sector to achieve the optimal target implies a fundamental revolution in the whole building supply chain, such that more emphasis should be given to the structure of the building and construction industry.

Overview

Urban growth and climate impacts

China is rapidly urbanising, and the urban population is projected to increase from 460 million in 2000 to 830 million in 2030, with an average annual growth rate of 2% (Toth *et al.*, 2003). Some 300-400 million rural residents are expected to migrate to the cities in the next 20 years. China is adding nearly 2 billion square metres of new buildings each year; it is estimated that half of the buildings existing in 2015 will have been constructed after 2000 (World Bank, 2001). Around 20 to 22 billion square metres of buildings are expected to be constructed by 2020, which is equivalent to the total existing building stock in the EU-15 today (Ecofys, 2006). The extremely rapid urban growth in many Chinese cities poses a daunting challenge in terms of the quality of urban infrastructure, which is characterised by a long lifespan and irreversibility. Failure to implement efficiency in the huge number of buildings constructed today would result in an irreversible technological and carbon lock-in for several decades to come. Therefore, a sound urban development policy must take energy efficiency into account at the stage of new construction, as the retrofitting or rehabilitation of existing buildings would be extremely costly and complex to carry out.

Currently, the share of residential energy demand is around 15-20% of total energy consumption in China, which is still fairly low compared to the OECD countries (more than 40% of total final energy demand) today. However, demand for energy services in Chinese households is very likely to increase as a result of the continually improving quality of life in the coming decades. China has experienced rapid growth in residential energy demand since 1990; energy demand in the housing sector increased at an average growth rate of 8.5% per annum during 1990-2003. In comparison, the world average is 3.6%, and 7.4% for Asian countries, and less than 1% in Europe and the US during the same period. This turns out to be consistent with the precedents in developed countries, which experienced a rapid rise in residential energy demand during 1950-1970, along with the steady economic growth over that period. In the meantime, space heating already accounts for almost 40% of energy consumption in the urban building sector in China[2]. Thus, the energy performance of buildings in northern Chinese cities represents a daunting challenge for ensuring energy supply security and combating climate change in the next few decades.

Property boom and housing price escalation

In 1998, the Chinese State Council promulgated the "Notice on accelerating the urban housing system reform and housing construction", which established the fundamentals of the market-oriented commodification of China's housing distribution system. This marked the shift in China's urban housing policy from government-led welfare distribution to market-oriented deregulation. Private ownership has grown steadily since the housing reform. One of the main drivers of the rapid increase in property ownership is the relatively low cost of a house during the operating stage. Unlike in developed countries, where the cost of house ownership is relatively high, since the property tax is levied in most of these countries, in China's property market the majority of the cost of house ownership is made up of acquiring land use rights (LUR) and various development fees at the construction stage. In other words, when someone buys a new house in China, he actually pays the implicit property tax of the house in advance, at the purchasing stage, instead of paying it year by year during the operating period, and the taxes during the operating stage are relatively low.

On the other hand, property prices have been rising sharply in all the major Chinese cities since 2003, and the housing price hike has become the primary concern of urban households in China. A CASS (Chinese Academy of Social Sciences) survey showed that the ratio of family debt to disposable income was 155% in Shanghai and 122% in Beijing in 2004, while five years ago very few Chinese families had any debt at all[3].In many cities, urban households have to undertake a 20 to 30-year mortgage to purchase a 100-120 m^2 apartment. Hu *et al.* (2006) conducted an empirical study by using a modelling approach to investigate the main driver of the housing price rise; they found that the rise is mainly due to market fundamentals, in addition to the existence of the bubble factor in the market. Zhang *et al.* (2007) model the fluctuation of housing prices in China to explore the mechanisms affecting these prices. Their research shows that the equilibrium price significantly influences the fluctuation of actual housing prices, which return to the equilibrium price through self-adjustment. Moreover, their model shows that the actual prices in China look set to go on rising in the future. Theses results imply that property market development will still be very attractive to the new entrants and households given their cultural reliance on property possession.

Some Chinese property experts estimate that taxes and fees account for around 30-35% of house prices in most property markets in China to date. They also argue that levying the property tax will not necessarily countervail current property speculation, since this tax is based on calculating surface areas instead of assessing property and land values, as is the case in the US and other countries. Also, the tax on property transactions is not high enough to discourage short-term property speculation. Although the central government has issued several directives aimed at curbing speculation[4], the house price hikes are still being observed in many cities, since the upfront land supply is still being tightly controlled by local authorities.

Admittedly, the national housing policy has specified that low-income urban households should be provided with low-rent housing so that modest-income households can buy economically affordable housing (EAH), with normal commodity housing for the other urban residents. Land designated for EAH construction is allocated by the local government through administrative means. In this case, the housing developer's profit is controlled and the sales price is capped by the government. Developers may benefit in turn from tax reductions

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[2] Energy consumption in buildings in rural China is excluded, as a large number of rural households still use biomass (straw, stalks and firewood, among others) for residential consumption, and little detailed statistical data is available.

[3] China Daily. China's housing price hike reasonable? 2004-12-19 www.chinadaily.com.cn/english/doc/2004-12/19/content_401454.htm

[4] For example, since 2007, some local governments issued a new regulation, which states that an EAH may not be exchanged on the secondary market within five years of purchase, to prevent speculation on houses that are designated to be sold to low- to modest-income urban households.

and/or fiscal advantages in exchange for selling houses at the regulated price. However, the rules of EAH distribution are ambiguous and have been frequently violated in many cities due to design flaws in the mechanism and institutional inconsistence. Some housing reform proponents therefore recommend abolishing this policy and replacing it with monetary subsidies for low-income households when purchasing housing. From the viewpoint of equity, neither the developer nor the low-income family truly benefit from the EAH, due to a lack of relevant facilities.

Land market

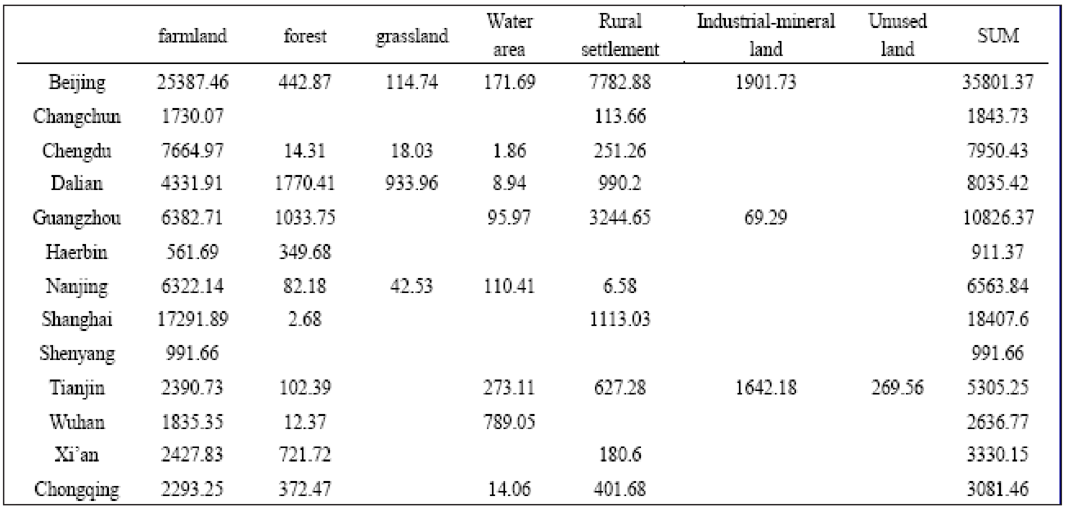
LURs were adopted in China in the late 1980s to promote land markets and to improve land management and land use efficiency (Ding, 2007). Since the 1988 amendment to the Chinese constitution, land leasing has been legalized so that urban land can be leased to developers or users for a fixed period after paying a lump sum rent to the State. Land leaseholds can be acquired through tender, auction or negotiation (Zhu, 2004). Fast-pace urbanisation and economic growth, motorisation, globalisation, the restructuring of the urban economy, policy reforms in land allocation and housing provision, and government decentralization are considered as the major forces behind the spatial transformation of cities in China.

Land acquisition (mainly land leasing and the purchase of LURs) is the foremost issue when starting a property development programme, and is considered the priority for a housing developer before proceeding to submit detailed construction feasibility plans to the relevant planning and construction authorities, since no construction project can take place without allocated land. It has been observed that more and more housing programmes are being launched on the outskirts and in the suburbs of the large cities, following the rapid urbanisation characterised by spatial expansion in the urban fringes; many rural lands have been turned into construction land designated for housing construction or industrial development. It should be noted that in China, agricultural land is owned by rural cooperatives rather than by the State. According to Chinese law, all development is prohibited on non-State-owned land; land acquisition, in which land ownership is converted from collective communes to the State, must take place prior to any land construction (Ding, 2007). Urban development, driven by the property boom across the country, has resulted in large-scale land use changes in Chinese cities, as shown in Table 1.

Property development procedure and BEE

According to the 1989 Chinese Urban Planning Act, prior permission is required for land and property developments. More specifically, before a property development commences, the developer must prepare a detailed land and property development project and submit it to the urban planning authority. Land development applications are evaluated by the plan-

Table 1 New built-up areas in the Chinese mega-cities during 1990-2000 (in ha) Source: Zhao *et al.*, 2004



	farmland	forest	grassland	Water area	Rural settlement	Industrial-mineral land	Unused land	SUM
Beijing	25387.46	442.87	114.74	171.69	7782.88	1901.73		35801.37
Changchun	1730.07				113.66			1843.73
Chengdu	7664.97	14.31	18.03	1.86	251.26			7950.43
Dalian	4331.91	1770.41	933.96	8.94	990.2			8035.42
Guangzhou	6382.71	1033.75		95.97	3244.65	69.29		10826.37
Haerbin	561.69	349.68						911.37
Nanjing	6322.14	82.18	42.53	110.41	6.58			6563.84
Shanghai	17291.89	2.68			1113.03			18407.6
Shenyang	991.66							991.66
Tianjin	2390.73	102.39		273.11	627.28	1642.18	269.56	5305.25
Wuhan	1835.35	12.37		789.05				2636.77
Xi'an	2427.83	721.72			180.6			3330.15
Chongqing	2293.25	372.47		14.06	401.68			3081.46

ning authority against the non-statutory Land Use Master Plan. A land use planning note will be issued with land use planning parameters attached, such as land use, plot ratio, site coverage and building height, etc. (Zhu, 2004). When all the formalities for the land transmission are cleared and the land site details finalised, a Land Development Permit and a Building Engineering Planning Permit are issued. With these permits, the developer can proceed to commission architects to design the building. After the building design has been examined by the planning bureau and the construction commission (for example, a review of the building EE design by selected experts), a building permit is granted and the project can proceed to the construction stage. The construction commission undertakes regular *in situ* inspections of the operating construction projects in collaboration with other municipal authorities in charge of planning fire precautions, and public works quality inspections in selected sites around the city. Guaranteeing the enforcement and implementation of BEE regulations is one of the main aims of these inspection processes. However, housing developers in general play no active role in energy supply infrastructure decisions (e.g. district heating), since energy planning has been undertaken prior to the land acquisition in the master plan of the urban development scheme, compromising the effectiveness of energy efficiency measures undertaken in buildings.

The challenge of energy efficiency in buildings

Rationale for curbing carbon emissions in China's building sector

Mitigating CO_2 emissions without hindering economic development is a major challenge for the world in this century, in particular in developing countries like China, for which the priority is economic development and improvements in social welfare. Large-scale urban infrastructure often needs to be developed as quickly and cheaply as possible in order to accommodate new urban dwellers and to meet their growing demand for energy services in urban areas. Given the timing and scale of these projects, energy efficiency and carbon emissions reduction are often considered as "secondary issues" for the society. Nonetheless, decisions made now concerning infrastructure performance will influence future consequences for energy and climate due to strong inertia; poor efficiency in buildings will have long-term consequences, since thermal rehabilitation and/or reconstruction may require huge capital investment and pose enormous implementation difficulties in retrofit programmes.

Indeed, implementing carbon mitigation options in urban infrastructure is associated with a wide range of co-benefits, including social welfare benefits for low-income households, increased access to energy services (housing and transport), improved indoor and outdoor air quality, improved comfort, health and quality of life, employment creation and economic competitiveness (IPCC, 2007). The energy performance of buildings is characterised by an irreversible process (inertia) and long operational life; once constructed, buildings will generally last at least 50 years or more before being demolished or rebuilt. Inappropriate decisions concerning investment in quality could result in an irreversible lock-in deadlock. On the other hand, retrofitting existing buildings is very costly and is related to long-term decisions. However, at present investment decisions are mainly oriented by the short-term objectives of meeting the mass market's demand and maximising developers' profits, without necessarily taking long-term consequences into account. Governance and the relevant institutional capacity of many local authorities are seen to be fairly weak when dealing with the quality management of urban infrastructure. Local governments should harness low-carbon transition opportunities to enhance their governance in urban development strategies, by redirecting sectoral investment choices towards high-efficiency and less carbon-intensive technologies and planning patterns.

Buildings will certainly play an overarching role in the process of transition to an LCE, given the long supply and value chains. For example, a building construction project will involve many private and public actors and related upstream and downstream industries: architectural design professionals, property developers, construction companies, subcontractors, regulatory authorities for urban planning, monitoring and land use regulations, financial institutions, manufacturers of materials, such as cement, steel and aluminium – which together produce nearly 80% of global emissions in the industrial sector – and residential and commercial energy suppliers (utilities and district heating services).

Status quo of BEE in China

Several regulations relating to thermal performance requirements in residential and commercial buildings have successively entered into force in China since the 1990s. Fig. 1 shows the building envelope heat transfer coefficient (*U*-value)[5] in a typical residential building complying with different building efficiency standards. Note that the building thermal performance is inversely correlated with the *U*-value. It is clear from the graphic representation that there are still significant gaps between the current Chinese building codes and the best practices in the world (e.g. the Swedish building code).

More specifically, heating consumption in residential buildings increases with the rise in average indoor temperatures (see Fig. 2), which is likely to occur with economic growth and the improved quality of living. Today, many Chinese buildings still have poor heating conditions in winter, when temperatures may fall below 14°C. In the long run, residents – in particular the younger generation – will require more thermal comfort as a result of an improved quality of life. Indoor temperatures are likely to rise steadily to eventually reach 20-22 °C (comparable with the current level in OECD countries). Energy demand will escalate sharply in buildings in the case of poor efficiency in new construction. In other words, the so-called rebound effect can be partly offset and minimised in more efficient buildings.

Figure 1 Comparison of overall envelope *U*-value for an 11-storey building complying with different efficiency standards

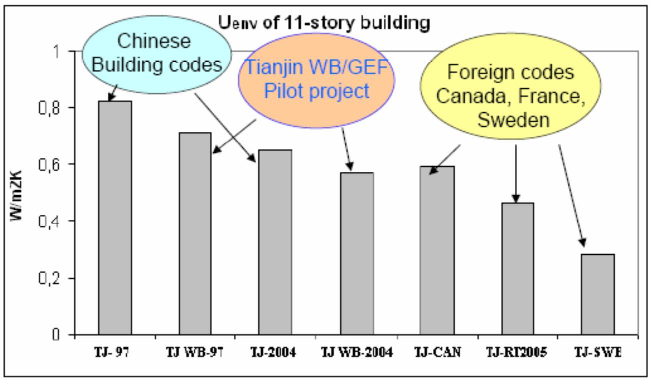
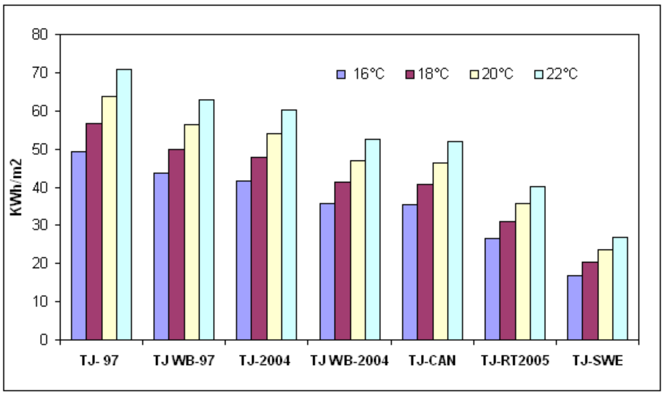


Figure 2 Useful energy demand in 11-storey building according to BEE levels under different comfort assumptions



Objective

Previous studies concerning forecasts of China's energy demand and environmental impacts explored energy demand scenarios and prospects for carbon emissions reduction in the building sector in China (ERI, 2003; NDRC, 2004; Jiang and Hu, 2006; IEA, 2007; IPCC, 2007; Zhou *et al.*,2007). However, they have not simultaneously addressed the questions surrounding optimal trajectories for building energy efficiency improvements and different strategies for energy supply infrastructure development using an integrated approach. This working paper aims to bridge the gap between the macroeconomic analyses and sectoral technology options in view of determining the optimal pathways for building performance, such that the social costs incurred during the trajectory may be minimised, thereby allowing the benefits to be used to finance investment in new technology R&D and deployment in order to accelerate sectoral transformation.

The issue of how to optimise investment portfolios consisting of different options in order to meet climate change mitigation targets with minimised costs is the centrepiece of climate policy, especially in developing countries, where the priority in the policy agenda is to ensure robust economic growth while alleviat-

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[5] The technical specification and calculation of thermal and appliance consumption in the residential and commercial buildings constructed in compliance with different BEE standards is explained in Li *et al.*(2009).

ing energy poverty as well as improving access to energy services for middle- and low-income households. From an economic analysis perspective, decisions on improving energy efficiency in long-lifetime infrastructure, such as buildings, raises the question of the rational choice of investment strategies relating to technological performance.

Our objective is to examine the dynamics of short- and long-term investment strategies in BEE and the creation of technical and financial capacities in energy supply technology innovation to tackle climate change. We seek to investigate the extent to which decisions on efficiency standards in buildings will ultimately have diverging consequences in terms of financing capacity for transforming the energy supply. Without loss of generality , improvement in building energy efficiency brought about by tightening building codes for energy performance may make it possible to integrate the whole building and energy services supply chain; subsequently, the benefits yielded may facilitate sectoral transformation by combining the political objectives and financing systems to overcome the barriers to the upfront costs associated with the technological learning process as well as institutional changes. A corollary question arises: what role will energy efficiency in buildings play in enabling cities to harness the benefits resulting from reduced operating costs in the early stages in order to facilitate investment in new technological research, development and deployment in the future?

Method

Building on scenario analysis, we compare a variety of strategies for managing energy performance in buildings and their environmental and economic consequences and policy implications based on a case study in a Chinese city. Ideally, improving building thermal efficiency should involve measures that make it possible to reduce both space heating and cooling consumption, while achieving a higher comfort level. This research deals only with heating efficiency in the residential sector in a northern city (Tianjin) with typical large-scale district heating infrastructure.

This techno-economic analysis is based on two different scales:

- First, we conduct a life-cycle analysis with respect to one-time investment decisions to meet energy demand for space and water heating in a typical new residential district in the city of Tianjin. The energy, environmental and economic performance of different BEE standards, coupled with different supply options, are compared. We test five BEE standards coupled with six supply systems (coal and gas-fired). The objective is to find out whether the current BEE standard implemented and the supply system in a typical Chinese city are the most rational choices, and if not, to what extent should a more stringent BEE standard be adopted for new construction projects?
- Second, we simulate a series of scenarios to compare the economic performance of relevant investment strategies across the whole city of Tianjin up to 2030, taking into account the dynamics of buildings (stock and turnover). Besides new construction after 2005, both the retrofitting of existing inefficient houses (built before 2005) and the penetration of new supply technologies will be considered in the model. The citywide analysis uses LEAP, a bottom-up simulation model. The primary objective is to investigate the economic and environmental performance of the BEE improvement portfolio, in order to identify the best choice in terms of minimising the total costs of the modelled trajectories over the period.

The two analyses share some similarities, but are also distinct from one another.

The first analysis assesses investment strategies for adopting the BEE standard in a new residential district developed in a city today. In this case, the housing stock is static, excluding the dynamics of movement. It examines how to adjust the initial building efficiency improvement level with the relevant energy supply system in order to minimise the discounted global costs for a period of 20 years.

In contrast with the first modelling analysis, the second exercise is conducted from a city-level perspective to investigate the optimal pathway to building efficiency improvements and investment in energy supply infrastructure in the longer run. Both dynamics in building development (new construction, demolition and the rehabilitation of old houses) and innovative technologies will be considered in different time spans. We compare the economic performance of the different investment choices both in buildings and in energy supply systems in five scenarios. The results will enable us to demonstrate the existence of a rationale for initial energy efficiency investment for housing construction in the context of rapid urban development.

Results

Case of the district-wide one-time investment

Without carbon constraint

Figure 2 provides a graphical representation of total discounted cost scenarios (the discount rate is 8% in the calculation) with coal- and gas-fired district heating options (both use cogeneration) respectively[6] in the district in question. Strikingly, we find that adopting the best BEE standard, or the equivalent energy performance prescribed in the Swedish BEE standard, is less costly than the current Chinese BEE regulations enforced in China and Tianjin, regardless of energy supply systems. All scenarios show that the national BEE standard (TJ-97 equivalent efficiency requirements) is not a rational decision and turns out to be the most costly choice, no matter which supply option is selected. Despite considerable progress against the national standard, the BEE standard implemented in Tianjin (TJ 2004) is not stringent enough to make it possible to achieve an optimal level, since the present value of total costs incurred over a 20-year period can be reduced by tightening the building code, given a discount rate of 8%. Without any imposed carbon price, the optimal choice turns out to be the equivalent of the current French RT-2005 building efficiency standard, coupled with district coal-fired CHP (cogeneration), which allows for the lowest present value of overall costs. Not surprisingly, we find that gas-fired systems are more costly than coal-based supply options if no carbon price is imposed.

Not surprisingly, from a carbon emissions performance perspective, the SWE equivalent BEE standard is the most effective technical specification, allowing a 22-29% overall reduction in carbon emissions relative to TJ-97 (equivalent to the national standards); gas-fired CHP supply systems strictly dominate the coal-fired system. The 20-year period cumulative carbon emissions in the gas-CHP supplied district would be reduced by 55-59% compared to the coal-CHP system over that period (see Fig. 3).

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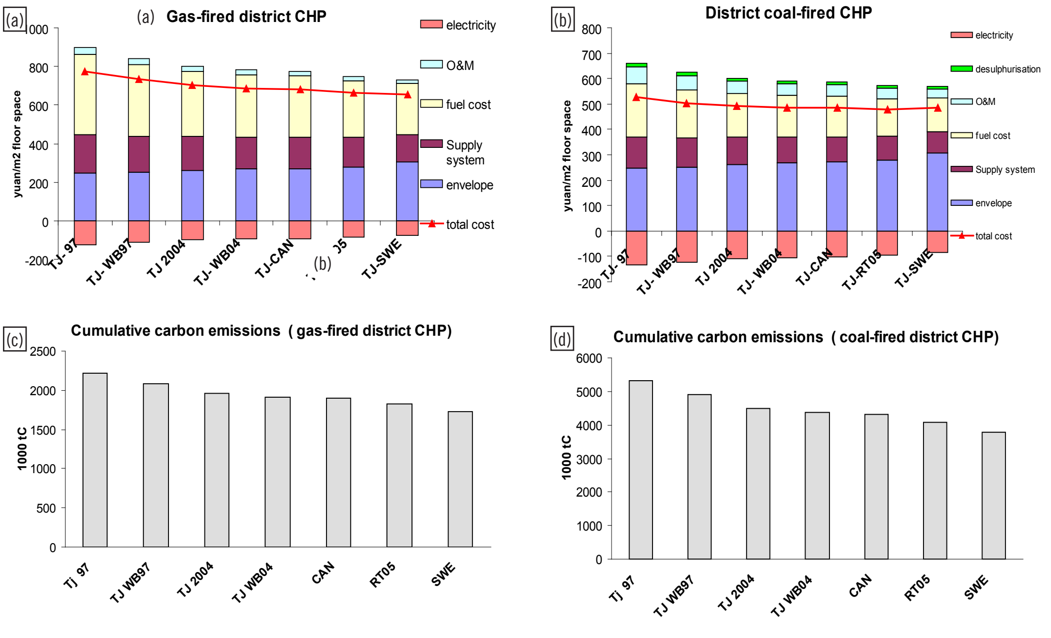
[6] A detailed technical description of all scenarios is provided in Li *et al.* (2009).

Figure 3 Total costs and implications for cumulative carbon emissions over 20 years in a residential district developed today with coal and gas supply options.



Fuel-switching under carbon constraint

In the current international climate negotiations arena, some policy analysts and researchers argue that coal use in China is a major obstacle to solving the climate problem, and advocate the immediate implementation of fuel-switching in China's energy sector. Their main proposals include massively substituting natural gas for coal in order to solve the GHG problem, particularly in power generation (e.g. Logan and Luo, 1999; Heller, 2007). From a domestic energy policy perspective, the municipal government of Beijing has implemented the switching policy by replacing coal-fired boilers in the centre of the city with natural gas-fired boilers[7]. Likewise, Guangdong Province has planned significant investments in LNG infrastructure development for power generation due to the coal-supply bottleneck in this region. This section assesses the economic impact of different fuel-switching strategies in the target residential district.

Under a likely climate constraint, which is represented by an imposed carbon tax on fuel combustion-related carbon emissions, Chinese energy policy will need to address decarbonising the district heating systems in the building sectors in the northern cities. One of the technical solutions that may be envisaged is opting for fuel-switching (coal to natural gas), which may imply two basic strategies, namely S1 and S2;

- S1: Complying with the current national BEE standards and switching directly from coal-fired boilers to gas-fired CHP systems.
- S2: Unlike S1, an integrated approach is taken in S2, which involves adopting state-of-the-art building efficiency practices (SWE BEE standard equivalent) and switching to gas-fuelled CHP supply systems.

The reference scenario refers to the TJ-97 BEE performance standard (equivalent to the national BEE standard requirement) supplied by coal-fired district boilers, and the alternative energy supply option is gas-fired CHP. We have shown in the previous section that the total cost of SWE BEE is lower than TJ97 and TJ04 BEE in the baseline energy supply case (coal-fired); this means that the first step of S2 will generate an economic gain (the difference between their respective total costs), which will partly offset the cost of switching from coal to gas. The pay-offs of the two strategies, without carbon prices and respective carbon emissions implications, are presented in Table 2. Note that implementing SWE BEE standards involves significant improvements in thermal comfort: indoor temperatures will be maintained at 22°C during the heating season, compared with 16-18°C in the Chinese building codes.

Table 2* Pay-off of baseline and decarbonisation strategies

	Total emissions kg CO2/m²	total cost (CO_2 price=0) Yuan/m²
baseline	583	570
decarbonisation strategy		
S1	206	770
S2	155	650

* Note: Levelised costs with a 6% discount rate

At present, China has no quantitative constraints on carbon emissions. However, it is likely that the nation will explicitly internalise the costs of carbon emissions in the post-Kyoto climate regime. Furthermore, the social costs (shadow price) of CO_2 emitted do exist, whether or not they are internalised in the cost analysis. In fact, the Chinese government has already put in place a resources tax on the consumption of domestically-produced or imported fossils fuels (coal/coke, gas and oil). Figure 4 presents the cost profiles of the baseline, S1 and S2, with an assumption of a moderate carbon emissions constraint (30 US$/t CO_2) imposed by local government to provide incentives to opt for fuel-switching.

Some key information can be derived from Table 2 and Fig. 3, as follows:

- when no carbon price is imposed, in terms of economic performance;
- $S_2 > S_1$ but $S_{baseline} > S_2$, which means that S2 strictly dominates S1, but is dominated by the baseline strategy, determined by the order of total costs. In this case,
  $S_2 = S_{baseline}$ if $P_{CO_2} =$ 18$/t,
  $S_1 = S_{baseline}$ if $P_{CO_2} =$ 65$/t,
- Table 1 shows that upgrading or retrofitting the coal-fired boilers to natural gas-fired heat-

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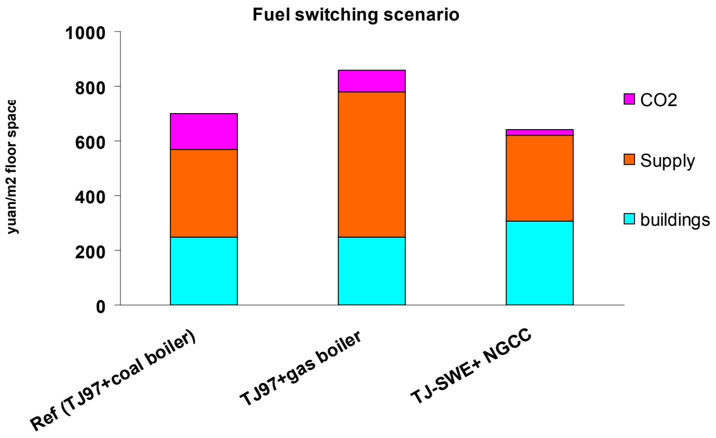
[7] The main driver of this policy is local atmospheric pollution control (reducing sulphur dioxide emissions) rather than for the sake of cutting carbon emissions.

Figure 4 Cost of different fuel-switching strategies at 30 US$/tCO$_2$



ing systems will require imposing a carbon price of 65 US$/t in the case of S_1 in order to be equal to the baseline, whereas the financing cost will be three times lower if S_2 is adopted.

- When a moderate carbon price (30 US$/t) is imposed, the order of preference of strategies will be changed, in this case $S_1 > S_{baseline} > S_1$, which means that S_2 becomes the strictly dominant strategy amongst the three options, whereas S1 will still be the most costly option.

This result has significant implications for climate policy-making in the building sector in China. If stakeholders need to find international carbon financing mechanisms (for example the Kyoto Protocol CDM, which will be discussed in detail later), S_2 will be more probable than S1.

The most striking point is that the environmental effectiveness of S2 in terms of CO$_2$ emissions reductions is significantly more pronounced than S1 with reduced total discounted costs. This conveys a very strong political message: Chinese decision-makers must reinforce the BEE standards on a par with the fuel-switching policy for decarbonising the energy supply in order to maximise the economic and environmental performance.

From the viewpoint of climate negotiations and technology transfer, international assistance should integrate improvements in BEE into the climate technology transfer package, by requiring Chinese construction stakeholders to first update to the best international practices in order to maximise the fuel-switching project performance for the implementation of carbon offset projects in China.

The long-term trajectory of city

Pathway to optimal trajectories

We compare five central scenarios for BEE implementation in the building stock in the city, namely:

- TJ-2004 (maintain the business-as-usual BEE standard in new construction): BAU scenario;
- RT-2005(equivalent to the French BEE standard);
- SWE (equivalent to the Swedish BEE standard);
- LC (equivalent to the Passivhaus level and more stringent BEE standards than the French or Swedish standards), and;
- A2 (gradually tightened performance standards)

Finally, a “pessimistic” scenario, ParCom (delay in the implementation of EE in buildings in new construction by 2015), is simulated to quantify the consequences of partial non-compliance in the early stages.

Thermal retrofitting is assumed to be carried out in the existing inefficient housing stock at the same rate in all the scenarios (500 000 m^2 per year); the total existing housing stock was around 141 million m^2 in 2005. BEE in commercial buildings is assumed to pursue the same trend in all scenarios, since our analysis is focused on residential buildings. Technical details concerning building thermal calculations are provided in Li *et al.* (2009). Like the calculation for the previous district analysis, the costs in the city-wide building simulation consist of the following components:

- costs related to building efficiency improvements;
- capital costs of newly installed heating capacity;
- costs of operation and maintenance (O&M);
- costs of energy resources (the market price is used as a proxy);
- external costs of environmental impacts (the exogenous carbon tax is used as a proxy).

Estimates of costs associated with thermal efficiency improvements and supply technologies are based on Liu (2006) and Li *et al.* (2009); the cost of CCS is based on IPCC (2005) and Rubin *et al.* (2007). The discount rate used is identical to the previous exercise (8%).

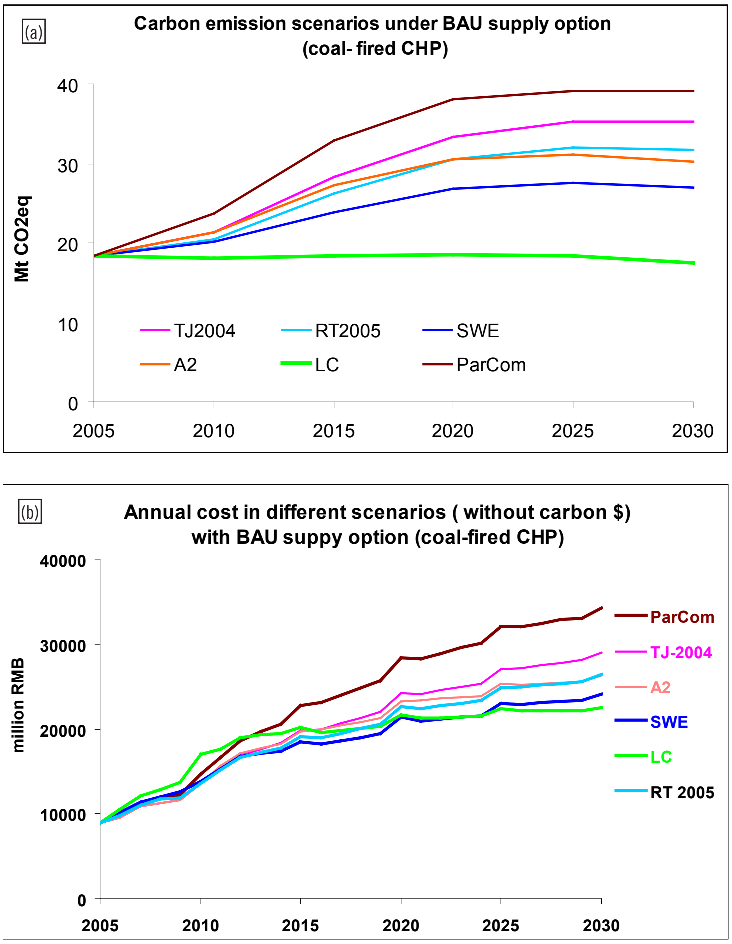
Describing how annual costs in each scenario evolve during the simulation period makes it possible to quantify the sequential results of the decisions made previously. It determines how the trajectory is likely to evolve over the period, which may be disguised in the analysis of total discounted costs. The annual cost profile in each of the simulated scenarios is presented in Fig. 5(a). We can see that the enhanced BEE in the case of RT-2005 and SWE will be far less costly than the reference case; the annual cost in 2030 will be 8-17% lower than in the reference case (TJ-2004). In practice, LC is more difficult to implement, despite the fact that the cost will be far below that of the reference from 2015, as the upfront cost during the first decade of the modelling period will be significantly higher than that of the reference case. In this case, the annual cost in 2030 will be more than 20% lower than in the reference case. This suggests that a more intelligent financial arrangement will be needed in order to reallocate the limited economic resources in order to achieve the optimal target. By contrast, failure to implement BEE in new construction in the first 10 years will entail a significant increase in annual costs. For instance, the costs of ParCom (the least effective case) in 2030 will be 19% higher than those in the reference scenario. More specifically, ParCom will never be cheaper than efficiency compliance and improvement scenarios, with a significantly higher emissions footprint over the entire period.

The modelling results clearly demonstrate that the current building efficiency standard used in Chinese cities is not an optimal choice, since both the costs and carbon emissions can be reduced simultaneously by upgrading the BEE standard. Achieving the optimal target requires the immediate uptake of efficiency technologies in the building and construction sector in order to minimise the costs of the trajectory.

Implications for low-carbon supply: the need to change pathways

As mentioned earlier, it is very likely (almost imperative) that China will need to decarbonise the energy supply infrastructure in order to minimise climate change risks. The cost trajectories in the case of the adoption of CCS and fuel-switching (GS) in the heat supply are plotted in Fig. 6. It is clear that the extra costs associated with these backstop technologies will be significantly higher in the less efficient cases if the city decides to opt for low-carbon supply systems from 2020 under carbon emissions constraints. It is likely that there would be a sharp jump in the annual cost in 2020, when CCS will begin to be deployed in some coal-fired power plants in the less efficient scenarios, including the ParCom scenario, among others. The annual cost in the case of reference+CCS and ParCom+CCS will entail a 14% and 30% jump respectively relative to the reference scenario in 2020 when backstop technologies come in. This is totally unacceptable for the local authority, since huge financial resources will have to be mobilised to cover the abrupt rise in operating costs of introducing CCS. In contrast to the less efficient scenarios, in which there will be a sharp increase in costs when new technology penetration is envisaged, higher-efficiency sce-

Figure 5 Annual (non-discounted) cost trajectories in the simulated scenarios

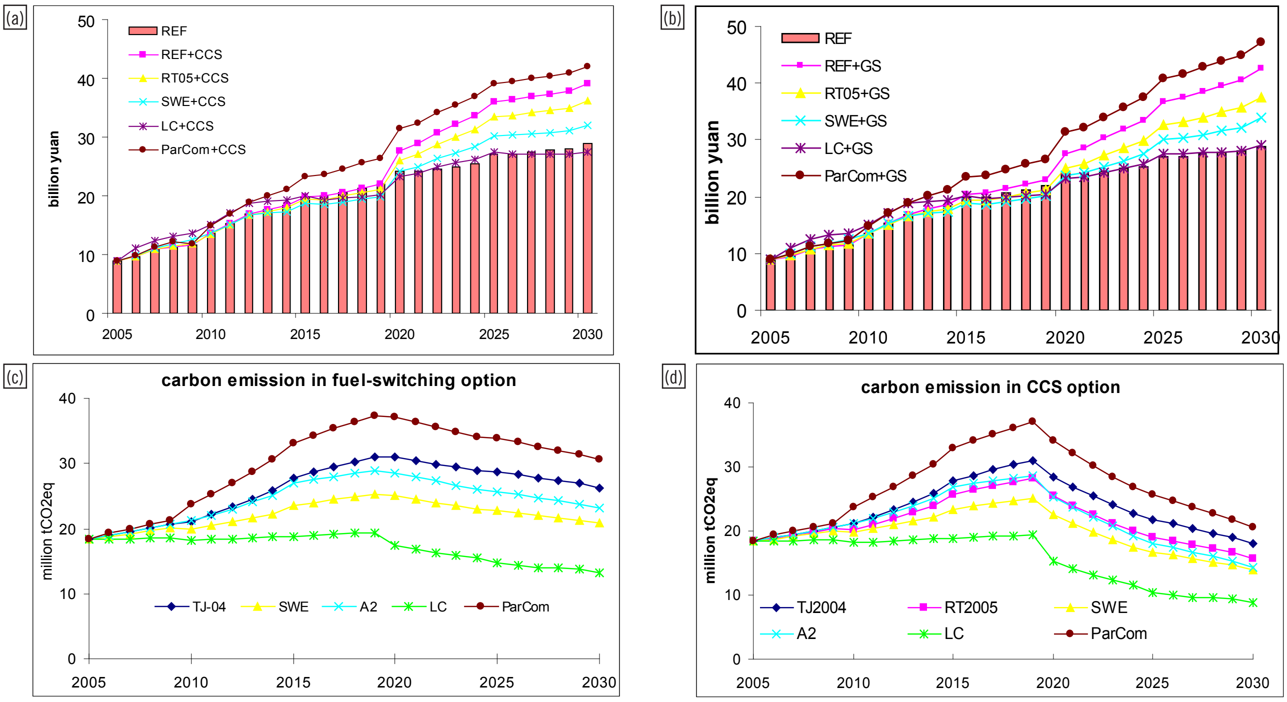


narios have more flexibility in facilitating technological transition in the energy supply in the long run. Strikingly, the annual cost of the LC +CCS option in 2030 will still lie below that of the reference level. Efficient buildings can help achieve the investment strategy that allows smoother sectoral transformation towards the gradual decarbonisation of the city's coal-fired supply system, without a significant impact on the available financial resources, thanks to appropriate reallocation over time. But our modelling results suggest that significant extra costs will be incurred when more ambitious BEE targets are pursued over the coming decades, which means a rational choice should be made rather than making unlimited efforts to invest in compliance with high-tech efficiency standards (e.g. the zero emissions house).(b)

The analysis of annual costs shows that a remarkable jump in investment costs will be shouldered in almost all scenarios when backstop technologies penetrate the energy supply. Notably, the carbon emissions from buildings (direct and indirect) could be reduced by nearly 50% in 2030 with the CCS option in the case of implementing a high-efficiency standard (LC) while stabilising the costs over the trajectory. Furthermore, this is far less abrupt in the higher efficiency case than in the lower efficiency case. To avoid an overly sharp jump in operating costs, such as in the ParCom scenario, upfront building energy performance is of critical importance and should never be ignored, otherwise the city would become trapped in a vicious circle: lower efficiency buildings result in capital-intensive investment in capacity addition and costly operations; less financial capacity could therefore be formed to invest in low-carbon technologies in order to mitigate carbon emissions in the future. It is interesting to compare the abatement costs of BEE enhancement scenarios relative to the baseline case. Table 3 summarises the discounted abatement costs and carbon emissions scenarios of implementing BEE standards coupled with different energy supply options.

In the BAU heat supply scenario (coal-fired large CHP), it is clearly demonstrated that the local governments need to tighten the BEE requirements immediately, since the abatement costs are generally negative. Interestingly, the more stringent building performances are even more necessary if the city is required to decarbonise the energy supply infrastructure with the scaled deployment of CCS installation and massive fuel-switching (GS) from 2020. The strategy matrix situated in the bottom-right area of Table 3 refers to the rational choices,

Figure 6 Annual cost and carbon emissions trajectory with the introduction of CCS and the fuel-switching option from 2020



since the costs of abatement will be significantly lower than otherwise. This means that the city must commit itself to embarking on the more stringent BEE development pathways as soon as possible in order to anticipate decarbonising energy infrastructure in the near future.

It must be pointed out that the cost-effectiveness of CCS and GS as shown in Table 3 may not be fully revealed until 2020, when the cost and availability will indicate their feasibility and cost-effectiveness. At present, it is still too early to decide whether to choose CCS or the massive shift to the NGCC, because the costs and availability of CCS are highly uncertain and a massive shift to the natural gas-based system also raises risks for the security of the energy supply. However, improvements in EE in buildings will make it possible to reduce the cost of transition in the future, when either of these technologies turns out to be mature and cost-effective. The main implication is that Chinese cities should anticipate the future carbon constraint by moving rapidly onto the trajectories within the dotted blue box, without necessarily showing *a priori* a definite preference for CCS or fuel-switching. In fact, engaging too early in one single supply option to reduce carbon emissions would involve an irreversible technological lock-in, with increasing risks of either technological unavailability (in the case of CCS) or the security of energy supply (in the case of massive gas-switching[8]). A portfolio combining several available mitigation technologies proves to be more relevant and risk-averse from an investment decision standpoint.

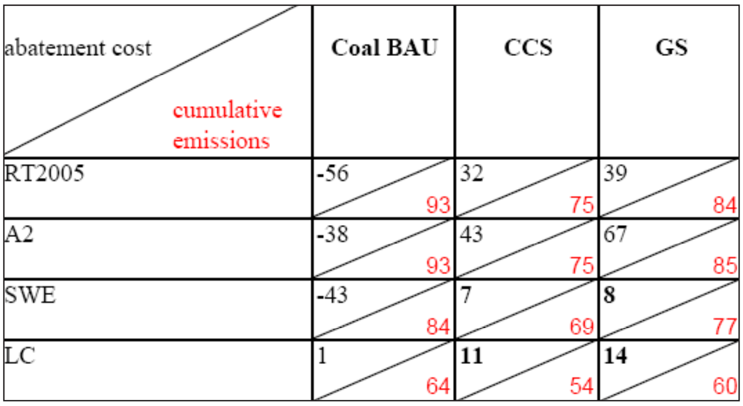
Policy instruments design and institutional change

The role of public policy in facilitating sectoral transition

The findings in the quantitative analysis suggest that building efficiency standards should be upgraded to become more stringent as early as possible from a social optimum perspective, and also to facilitate the transformation of energy infrastructure towards a less carbon-intensive energy supply. A subsequent question is how to make things happen, since the market is unlikely to adjust itself in order to move onto the optimal trajectories spontaneously. It is not surprising that various technical, financial and institutional barriers hamper the implementation of energy efficiency and the deployment and diffusion of efficiency techniques in the building sector. Richerzhagen *et al.* (2008) identified various market and non-market barriers.

In practical terms, improving energy efficiency in buildings and tightening the building code requirements will by no means be free and easy; issuing regulations and mandatory standards will make little sense if local authorities and construction industries are incapable of implementing them effectively. The success of the implementation of new energy efficiency policies in buildings requires both technical and financial capacities, backed by a sound institutional framework. There will inevitably be a transition period, during which the building and construction sector will adapt to new technologies through a learning-by-doing process.

Table 3 Comparison of abatement costs (US $/tCO2 in 2005 price) and cumulative carbon emissions over the trajectories in different scenarios (emissions for TJ-2004 + BAU supply option = 100)



abatement cost cumulative emissions	Coal BAU	CCS	GS
RT2005	-56 93	32 75	39 84
A2	-38 93	43 75	67 85
SWE	-43 84	7 69	**8** 77
LC	1 64	**11** 54	**14** 60

Note: Reference case is TJ-2004 equivalent BEE coupled with coal-fired large CHP

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[8] Fuel-switching policy is a potential threat to China's long-term energy supply security, since a significant proportion of natural gas will be supplied by Russia and Eurasian Countries. The frequent disputes between gas supply and consumption countries over price (in particular between Russia and eastern European countries) reveal the considerable geopolitical uncertainty risks and the supply fragility of high dependence on imported natural gas. The Chinese energy policy-makers must take long-term energy supply security into account in addition to the obligatory climate considerations. Some framework agreements on gas and oil supply have been signed between China, Russia and Turkmenistan. It is estimated that the pipeline between Russia and China will supply 80 bn m^3 of natural gas from Siberia to China annually from 2011.

For example, the manufacturing of efficient materials and equipment and innovative construction techniques need institutional and financial support in the initial stages. Public policy will therefore play a role as a facilitator/catalyst in accompanying the sectoral transition to a high-efficiency and low-carbon development pathway.

Appropriate policy instruments need to be designed to complement the enforcement of regulatory standards in order to help ensure the effective implementation of BEE policies. The relevance of institutions is a prerequisite to achieving improved efficiency in buildings and the related energy savings explored through the quantitative analysis undertaken previously. Implementing energy efficiency improvements requires an appropriate institutional framework, such that efficient technologies can be delivered effectively to the actors concerned in the building sector. Achieving an optimal trajectory for the whole building and construction sector in Chinese cities will necessitate an institutional framework and fundamental organisational restructuring in the building sector. This will require delivering new technologies and massive shifts in investment and financing, as well as appropriate institutions to enable policy implementation. The following section examines two types of incentive-based economic and policy instruments, namely the carbon financing tool and flexibility in land use regulations to create an enabling environment for improving the city's governance in the building performance enhancement programme.

Harnessing the climate finance mechanism

Estimates of CER price in BEE improvement projects

The carbon market can be used by means of international aid with technology transfer to facilitate energy efficiency improvements in the building sector in China. Local stakeholders can use the carbon market shrewdly to leverage carbon finance in collaboration with international financial actors.

Currently, there are many ongoing discussions about the possibility of introducing the CDM to finance energy efficiency in the building sector. An assessment of cost-effectiveness is necessary to provide the order of magnitude of carbon prices that would allow builders or property developers to adopt the best available techniques (BAT) in building energy efficiency (coupled with the most efficient energy supply system). Here we examine the Certified Emissions Reductions (CER) price of upgrading BEE to the equivalent of the Swedish building code with natural gas combined cycle (NGCC) energy supply (the baseline is coal-fired district boilers). The credits granted by implementing CDM projects should allow the investor to pay off the initial extra costs within a manageable risk range. In other words, the developer may be interested in the CDM if the adoption of non-mandatory higher BEE standards with a more efficient supply system can yield sufficient carbon emissions credits that are tradable at a competitive price that exceeds the marginal costs of emissions abatement by taking enhanced efficiency measures.

As far as a building efficiency improvement project is concerned, a builder will consider adopting a higher efficiency practice package (HEP) consisting of compliance with the best practice building techniques (equivalent to the Swedish standard), coupled with a 24-MW NGCC system, if he perceives the opportunity cost of forgoing these options to be higher than the upfront costs associated with investment in building efficiency improvements and more efficient energy supply options.

Li and Colombier (2009) tested the price of CERs that allows abatement costs to be covered, based on the data from Liu (2006) and the author's field study in Tianjin, which is used to estimate the cost of BAU and best practices and to calculate the emissions reduction potential and relevant costs. The calculation shows that the levelised abatement cost of CO_2 emissions in a typical residential building project in Tianjin through the adoption of HEP is around 16 US$/t$CO_2$ (a 6% discount rate at 2005 prices), which is fully compatible with the carbon price in international carbon markets, such as the EU-ETS Allowance (EUA) price, which was even close to 30 US$/t CO_2 (Point Carbon, 2008)[9]. In addition, the carbon

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[9] The EUA price has dropped significantly since the second half of 2008 due to the global economic downturn. However, with the economic recovery and the perspective of tightened EU mitigation targets, the price is likely to rise again. The EUA averages 16 Euros/tCO_2 at the moment of drafting this paper.

price in the European market is expected to rise continuously in the post-Kyoto period. Recent studies on climate change economics suggest that the global benchmark CO_2 price is expected to range between 30 and 40 US$/$tCO_2$ in the 2020-2030 time frame (Anderson, 2006; IPCC, 2007; Stern, 2007; Blanco and Rodrigues, 2008; Colombier *et al.*, 2008). The prospect of high carbon prices may be a strong incentive for changing the sector's growth trajectory in favour of high-efficiency and low-emissions pathways.

BEE procurement and programmatic CDM nexus

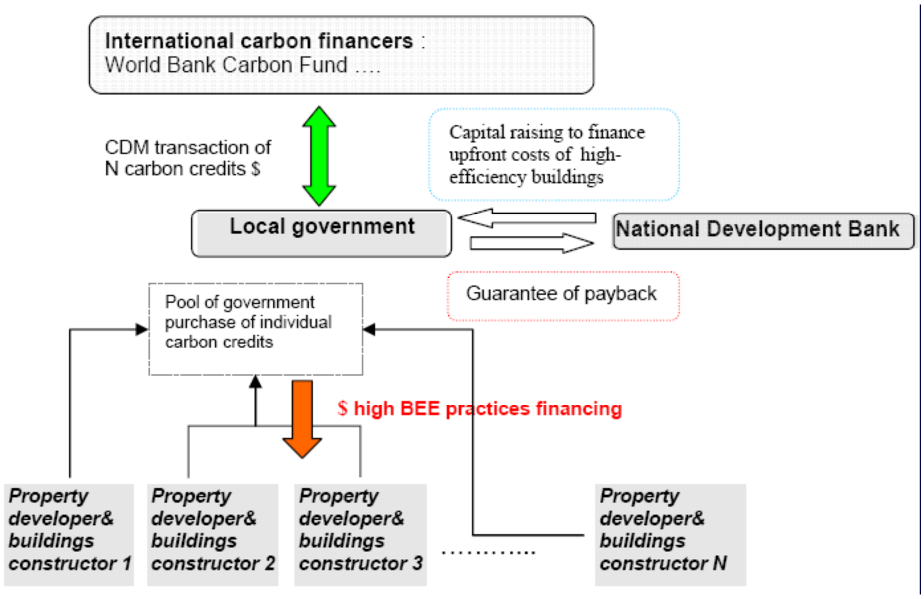
Although the CER price implied by introducing the CDM to the upgrading of residential BEE in northern Chinese cities appears to be quite competitive and attractive for carbon financers and investors, a critical look at the property market and the way the CDM functions suggests that the CER price *per se* can hardly trigger any effective individual uptake of this kind of initiative, contrary to what carbon finance proponents may imagine. The observation of carbon markets shows that the current CDM fails to provide market transformation in the urban infrastructure in developing countries.

There are currently hardly any CDM projects concerning energy efficiency in buildings, besides electrical appliances or equipment retrofitting. As pointed out by Colombier et al. (2007), by nature the CDM can only influence investment decisions if it brings significant additional revenue or guarantees. This is why most CDM projects in energy sectors focus on wind energy or other renewable energies, since the credits sold forward may cover up to 30% of investment, whereas the economic and financial characteristics of investment in infrastructure projects, such as improvements in energy efficiency in China's building sector, are considerably different due to their specific situation. Undoubtedly, the incremental cost of improving energy efficiency in buildings is far from enough to incentivise the property developers and construction companies, who are unlikely to be interested in accepting a low rate of return by taking a long-term investment risk. The rate of return on capital investment in the property market is significantly higher (more than 100%) for developers and speculators in the Chinese property market under the property boom climate, characterised by a short payback time. Therefore, the interest rate of return implied in the calculation (6%) can hardly influence the individual developer's decision to take measures concerning construction, such as enhanced building efficiency, whereby the carbon credits are expected to be issued over a long period (more than 10 years) that represents little interest for developers and entails high uncertainty that is generally avoided by rational private investors based on risk aversion preference. Moreover, the transaction costs of the CDM, associated with complex procedures (methodology formulation, registration, monitoring and evaluation, verification, issuance) and required technical competences, make the project-based CDM unattractive and difficult to implement in the real property development project.

Building on the analytical framework of the CDM's operating mechanism and underlying institutional and organisational structures, we suggest a scheme that will reaccommodate the CDM within the energy efficiency improvement package in the building sector by means of an integrated approach. The revenue from the CDM could be redistributed by the local public authorities in the form of different kinds of premiums to property developers (e.g. building labelling programmes). Local governments will formulate a medium- or long-term political objective and action plan with regard to improvements in BEE standards and the updating, enforcement and implementation of regulations with the support of rigorous technical intervention measures and emissions reduction metrics. Instead of treating the efficiency-related CDM projects individually, a programmatic approach is employed, in which local authorities will play an intermediate role by centralising the integrity of potentially issuable carbon credits from distributed individual house builders and property developers, and then bargaining the issues relating to financing public policies, such as implementing the policy on building energy efficiency improvements, with international climate negotiators and carbon financing institutions. This is in fact a public procurement scheme with the support of international carbon finance at the city or sector level. A schematic representation of the procurement operation is illustrated in Fig. 7.

Under this scheme, all would-be carbon credits issued in the individual BEE improvement

Figure 7 Schematic representation of BEE procurement-CDM coupling scheme



projects will be centralised in the repository pool, managed by the local government that commits itself to financing (by means of public banks or social development funds) the policy implementation costs associated with both the physical and institutional infrastructure for efficiency improvement in buildings and construction, the upfront extra costs of construction, the upskilling of the qualified workforce, the manufacturing capacity for efficient components and training in new construction techniques.

The aggregate carbon savings from improvements to all candidate buildings will be handled through international CDM financers (e.g. the World Bank Carbon Fund or other carbon trusts, etc.) by the local government. In other words, the CDM transaction activities are concentrated among the upstream stakeholders (local government, financers, bankers and other consulting companies). In contrast with the project-based individual investment project, carbon finance is mainly used as a leverage to bridge the gap between current domestic capacity and best practices, by temporarily covering the costs incurred when taking actions commensurate with the optimal trajectories during the transition period; the high efficiency building construction programme temporarily receiving subsidies from the municipality during the transition period will eventually be standardised after technological diffusion through the learning process.

What distinguishes this scheme from the current CDM paradigm is that the carbon credit revenues will not be confined to financing an individual, ultra-efficient building or one specific technology for demonstration purposes; instead local government needs to establish a strategic policy programme to induce sectoral transition. During the transition period, carbon finance will contribute to upgrading building codes, the learning and diffusion of best practices, raising the building supply chain and greening building-related jobs and working skills.

In this respect, a policy-oriented programmatic CDM aims to finance public policy implementation rather than a private monetary gain for an individual actor's carbon emissions reduction actions. Furthermore, both the so-called transaction costs and non-delivery risk (e.g. conflict of additionality) implied in the project-based CDM model can be significantly reduced, since the local government will ensure the implementation of a policy package consisting of performance compliance, credit delivery and revenue distribution, as defined in the provisions of the procurement scheme and the terms of the carbon credits transaction contract. Indeed, this policy financing scheme will need to engage as many property development programmes as possible to create economies of scale in order to eventually drive down the upfront costs of high-efficiency building construction relative to the prevalence of techniques practiced today.

In short, the revenue from carbon credits is used for financing the transformation and capacity building of the whole building sector and its supply chain by improving the learning curve for energy efficiency technologies in construction, in order to lower the cost of implementing efficiency policies in the transition period. Local government will commit itself to financing the extra cost of programmed housing construction during a transition period (the next 10 years) before instituting a higher level of mandatory BEE standards (more effective than the current Swedish code requirements). The CDM is finally used as a financial tool to accompany the Chinese building industry in transforming the sector into a high-efficiency and low-carbon infrastructure, by anticipating the BAT construction techniques instead of a purely project-based financial tool that generates additional carbon credits in the narrow sense. China's building sector offers tremendous potential for mitigating CO_2 emissions through the implementation of clean technologies under a properly designed BEE procurement programme combined with programmatic CDM offset. Institutional change is needed to enlarge the scope of CER-EUA linking on the global carbon market and to facilitate the programmed CDM based on a whole jurisdiction of local authorities.

The programmatic CDM, which is an option already recognised by the UNFCCC, appears to be a compatible instrument that is adapted to the transition to implementing the policies and measures (PAMs) in the future framework of Nationally Appropriate Mitigation Actions (NAMAs).

Policies concerning improvement in energy efficiency in infrastructure (residential and commercial buildings, among others) could be integrated into national climate actions plans such as NAMAs or pledged action packages in the sectoral approach (SNLT, among others) in order to achieve win-win targets by taking the building sector into the post-2012 climate regime (UNEP, 2008). This will open a broad perspective for international agreements on climate change policies and sustainable urban development trajectories in Chinese cities in the longer term. Nevertheless, the inclusion of the building sector in climate financing, such as a sectoral crediting framework, is not so straightforward. According to existing literature (Baron and Ellis, 2006; Baron *et al.*, 2008; Cheng *et al.*, 2008; Winkler, 2008; Ellis and Moarif, 2009), the issues surrounding methodology design, additionality, MRV, accountability, the inherent characteristics of disperse emission points in buildings, IPR in technology transfer, public-private partnerships and relevant institutional capacity building need to be addressed to ensure the successful implementation of carbon finance in the building sector.

Flexibility of urban development (land use) regulations and fiscal incentives

Aside from linking BEE to carbon financing, the local authorities may also introduce policy instruments based on "non-additionality" output, or rather an integrated package combining the regulations and incentives. For example, incentive-based land use and fiscal policies could also be introduced into the property market to induce developers and/or construction companies to build more efficient houses and to adopt low-carbon technology, whereby property developers may benefit from land use-related tax reductions or increased plot ratios[10] (PR) in the property development project, provided that more efficient buildings and low-carbon or carbon-free energy supplies are considered. One policy instrument that could be implemented is to integrate the BEE technical requirements into the city's urban planning and land use regulations. Some European countries have already implemented specific policies in favour of efficient building construction and renewable energy promotion in residential and commercial building construction projects. For example, the French Urban Planning Act stipulates that a developer can be partly exempted from land use regulatory restrictions, urban planning codes or other specified technical requirements such as PR when high-efficiency buildings are constructed, or when large-scale renewable energy use is included in the property development programme (Law 13-07-2005). A comprehensive approach is preferred in order to

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[10] The plot ratio (PR) is defined as the ratio of constructed floor area to the occupied land area in a property development project, which is one of the key parameters in the evaluation of urban planning and land development project submittal documents. In general, prescriptive minimum and ceiling PR values are defined a priori by local authorities (Bureau of urban planning) during the urban planning process for each specific land parcel category, depending on the nature of land use, the property types, the site location and so forth.

establish the linkage between the BEE policies and general and detailed urban development schemes through the land use specification. In fact, regulatory flexibility of land use can be regarded as an alternative economic tool that provides long-term incentives to property developers, although no cash inflow is perceived by developers, nor do they receive explicit tax rebates or reductions. Instead, the increased PR allocated to the property developer who commits to adopting higher efficiency techniques will allow him to sell more floor space to compensate for the incremental cost in the initial construction stage compared to the reference case. Like the instrument concerning the programmatic CDM-financed district and citywide BEE procurement, if a property developer will commit to complying with the most efficient building energy performance standards (equivalent to the Swedish building codes with gas-fired CHP systems) instead of continuing current BEE practices, mandatory PR values may be adjusted in accordance with the energy performance of buildings. To keep the housing sales price identical to the reference case[11] and to ensure that the developer will be better off compared to the business-as-usual case, the value of the plot ratio should be raised by at least 5% compared to the regulatory value[12].

Pricing reform: the road to climate-friendly technologies

Experiences in OECD countries show that energy efficiency improvements since 1973 are mainly the result of ongoing technological progress and responses to rising energy prices (Geller *et al.*, 2006). However, energy prices for end-users in China are often not cost-reflective due to government energy subsidies, in particular the district heating service in northern China. This constitutes a major deadlock for the uptake of energy efficiency investment by private actors, since no energy suppliers or property developers will engage in BEE investment if the energy prices remain artificially low. The improvement in energy efficiency in buildings will provide more possibilities for the energy suppliers to devise more flexible tariff building blocks for different customers in the new buildings. The whole energy pricing structure could be negotiated between energy suppliers and local authorities. New pricing structures for energy services can be imposed for the consumers moving into the new buildings complying with high-efficiency standards as well as adapted equipment (e.g. heat consumption billing), whereas consumers living in existing buildings will continue with the old tariff structure.

In order to address the institutional barriers and make it possible to implement the proposed instruments, an optimal pricing scheme is required, in that each stakeholder must be at least unchanged or better off compared with the previous situation (without extra efforts in BEE improvement). As such, a transparent energy pricing mechanism must be set up to allow the transmission of economic signals from the upstream energy suppliers to the downstream energy consumers in buildings, otherwise no rational decision will be made. Prices need to reflect the actual economic cost and internalise environmental externalities. Apart from government intervention and industry mobilisation in energy efficiency programmes in the building sector, private initiatives should also be encouraged through the energy pricing mechanism combined with fiscal incentives. Likewise, consumers will not be interested in energy efficiency programmes without a clear price signal or other market incentives. The energy pricing reform is a necessary means of accompanying private financing in the area of energy efficiency improvements in buildings.

As an illustration of the idea of pricing negotiations, let us imagine that an energy supplier (for example a heating company) commits to paying the upfront costs of building efficiency improvements. Consequently, the BEE measures taken will allow the company to reduce the capital investment associated with additional new capacity and related operating and management costs. However, the company will probably see a significant fall in the quantity of heat supply (the volume consumed by the end users) as a result of improved energy performance in buildings (reduction), thus the general turnover may fall sharply to reduce the company's profit margin, while the end users will be the only beneficiary (a reduction in their en-

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[11] It is assumed that the property developer will not be allowed to pass on the incremental costs to the final consumers (house buyers).

[12] The calculation is based on a residential district in the city of Tianjin. A detailed description is available upon request.

ergy bill). By contrast, a fairer mechanism aims to make both supplier and consumer better off, or at least unchanged. Our calculation suggests that the heating price needs to be raised by 16-21%[13] based on the analysis in the district, which is identical to the previous examples of BEE-CDM procurement schemes. Indeed, the price escalation of heat supplied will increase the heating company's margin, while the end users will be better off or unchanged, such that the heating bill will be lower or equal to the reference case with a significant improvement in thermal comfort[14].

More importantly, this scheme of reorganising investment resource allocation has significant implications for climate policy in the building sector in China, since the price increase will enable the heating company to create benefits without any loss of welfare for end-users, who will still pay the same energy bill with significantly improved thermal comfort. In turn, the increased profit will eventually give the energy company a higher margin to accelerate investment in innovative and low-carbon supply technologies, which are even more efficient than the current supply options (to further reduce the supply costs and increase the possibility of price rise in the future). For example, the benefits could serve in part to finance the retrofitting of inefficient district boilers and the adoption of environmentally-friendly supply technologies, such as NGCC or CCS, etc. This will create a virtuous catalyst to engage more heating companies in investment in BEE and state-of-the-art supply technologies to feed the efficiency market.

Conclusion and perspective

There are both challenges and opportunities in the building sector in China for the implementation of BEE improvements to ensure climate resilience in cities in the coming decades. China will have strong political and economic interests in enhancing energy efficiency in urban building infrastructure to facilitate the transition to socially optimal development trajectories in the fast-growing Chinese cities. The modelling results based on a case study in the city of Tianjin illustrate the importance of taking timely action instead of indefinitely deferring this action, since inaction or delayed action would result in tremendous irreversible extra costs compared to proactive approaches aimed at significantly improving the quality of energy performance in buildings in Chinese cities. The effort of investing in highly efficient buildings is justified by the fact that the "sacrifices" in terms of upfront costs incurred today will contribute to a significant reduction in costs over the whole operating period. Consequently, the savings can be used to strengthen financial capacity building in developing low-carbon energy supply technologies and retrofitting inefficient infrastructure (energy supply and buildings). Our analysis shows that it is imperative to first improve building energy efficiency before opting for low-emissions intensive supply technologies, such as directly switching from coal to gas.

It is argued that regulatory instruments (e.g. the building code) can be complemented by economic instruments such as carbon financing tools in order to achieve the optimal BEE uptake trajectory both effectively and efficiently. Economic and policy instruments are to be tailored appropriately to accompany learning in implementing the regulatory and compulsory standards. Carbon finance may play a substantial role in driving cities to approach the efficient and climate-friendly pathways leading to a sectoral transition; a precondition is that carbon emissions crediting through enhanced BEE should be integrated into the public policy framework with clear and evolving political commitment targets. The current CDM mechanism can facilitate the leverage of carbon finance into BEE investment in China through a programmatic or sectoral approach. The CERs should not be used as a direct offset transaction between private investors and property developers, but rather as a public policy financing tool to drive the sectoral transition towards high efficiency practices and raising the place of buildings in the supply chain. From the perspective of long-term economic development and welfare improvements, the incentives given to the property developers and energy supply companies should be conceived as a means for the public authorities and local govern-

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[13] The same assumptions regarding the technology portfolio as in the PR adjustment instrument are used.

[14] The underlying assumption is that end users will pay the energy bill based on real consumption. This poses both institutional and technical challenges.

ments, among others, to define the long-term energy policy and urban development strategy based on a BEE procurement model. The programmatic CDM and efficiency housing procurement programme proposals are based on the argument that all economic incentives should be coupled with the dynamics of the continuous development of energy efficiency and governance improvement in the property and energy markets.

Furthermore, local government could use the land use regulation shrewdly, as a non-monetary incentive for property developers to build much higher efficiency buildings. An integrated approach combining land use, urban development strategies, BEE and carbon finance should be designed as a key element of climate action plans in Chinese cities. In this respect, a synergy must be created between different stakeholders to ensure the effective uptake of appropriate decisions and the implementation of target policies. The outcome would be a win-win situation, in the sense that the government does not need to subsidise the efficiency programme thanks to the auto-financing mechanism, through the efficient allocation of economic and political resources.

Furthermore, the BEE policy should be integrated into a comprehensive policy framework of urban development in China to facilitate both technological and institutional transformation in the building sector in China. The implementation of BEE policies involves fundamental transformation in the whole supply chain of the building industry, from architectural design to building material manufacturing as well as skilled construction workers training. However, the current building market is extremely localised and fragmented, synergy between actors and transversal policy framework needs to be formulated to promote the sustainable buildings initiatives. High efficiency and low carbon buildings require highly skilled construction workers, owners and operators. In this regard, China will need to develop the skill levels in the construction and property owning and operating industry (Lönnroth, 2009). Coherent public policies will encourage R&D, innovation and sectoral capacity building in terms of personnel training in high efficiency infrastructure. Besides hard investment (materials, techniques, appliances & equipment etc), the soft capacity building (education and training of qualified engineers, architects, urban planners and construction workers) for EE management should receive special attention in terms of human capital investment. Accordingly, appropriate fiscal policies need to be implemented to make it possible to scale up private investment in the energy efficiency supply chain in buildings, ranging from the manufacturing of insulation products to high efficiency energy supply techniques.

Finally, it is argued that a pricing reform in the district heating energy supply should be implemented on a par with actions concerning energy efficiency improvements in buildings. Coherent energy pricing will make it possible to transmit transparent economic signals to the economic agents concerned along the whole supply chain, from upstream energy suppliers to downstream end users in buildings. The DH pricing reform should be undertaken to give heating suppliers incentives to participate proactively in improving energy efficiency in buildings and to also enable them to invest in high-efficiency supply technologies, including low-carbon or carbon-free generation technologies, such as NGCC, biomass co-firing, CCS and so forth.

In conclusion, the development of low-carbon building infrastructure in Chinese cities to avoid the long-term climate lock-in will require rapidly changing the sectoral development pathway, involving a profound transformation of institutions and governance throughout the whole urban infrastructure development process. An integrated approach should be adopted by the policy-makers with regard to the optimal trade-off between investment in BEE and low-carbon energy supply technologies over a different timeline. The sooner cities move towards an energy-efficient built environment, the more likely they will be and the easier they will find it to enhance their climate resilience in the future. ■

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Shaping Climate Policy in Urban Infrastructure: an Insight into the Building Sector in China

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