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Applying Abatement Cost Curve Methodology for Low-Carbon Strategy in Changning District, Shanghai

November 2013



The World Bank

ESMAP
Energy Sector Management Assistance Program

ASTAE
Asia Sustainable and Alternative Energy Program

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CONTENTS

FOREWORD

The government of China is committed to reducing the country's carbon intensity by 40–45 percent between 2005 and 2020. Energy efficiency and renewable energy are expected to contribute significantly to achieving this target.

Cities are at the core of the action to achieve the government's carbon-intensity-reduction target. China is experiencing rapid urbanization, with 300 million people projected to migrate to urban areas during the next 20 years. As a result, energy demand in buildings and for transportation will continue to increase rapidly. The speed and scale of urbanization provides an unprecedented opportunity in the coming years to invest in clean energy technologies to contain carbon emissions related to energy supply and consumption in the country's sprawling cities. The window of opportunity is narrow because urban form and infrastructure have long lifetimes. Introducing efficient low-carbon technologies into new urban infrastructure today would avoid locking cities into a high-carbon growth path for decades to come. Therefore, the government of China has put a high priority on low-carbon cities.

Shanghai municipal and Changning District governments are firmly committed to becoming a low-carbon city, and achieving their carbon-intensity-reduction targets is one of the highest priorities in their 12th Five-Year Plan. Shanghai municipal and Changning District governments requested World Bank support to benefit from the Bank's international knowledge and best practices. They seek the World Bank's assistance in becoming leaders in designing novel and efficient ways to achieve their carbon-intensity-reduction targets.

This report documents the methodology of and key findings from applying abatement cost curves and scenarios to set low-carbon targets and define cost-effective low-carbon investment programs in Changning District, Shanghai. At the request of Changning District government, the Bank team supported a Shanghai energy conservation institution, assisted by an international firm, in conducting a comprehensive survey of buildings in Hongqiao area in the Changning District, and in developing CO_2 abatement cost curves to identify the abatement potential, cost, and ease of implementation of various mitigation measures. Three alternative abatement scenarios were developed to establish an ambitious low-carbon target for Hongqiao area. The use of CO_2 abatement cost curves, bottom-up investigation surveys, and ease-of-implementation considerations for defining an investment program to reduce CO_2 emissions was the first of its kind at the time. The abatement cost curve developed under this upstream analytical work allowed the district government to make informed decisions about medium-term targets for CO_2 abatement and to identify priority actions and investments to meet them. This study also provided the solid analytical underpinning for the design of the World Bank/GEF Green Energy for Low-Carbon City in Shanghai Project.

Because the concept of a low-carbon city is still not clearly defined in China, this report could not be more timely. The methodology presented in the report has wide potential for replication in Chinese cities. Cities are at the forefront of action to combat climate change globally, so it is our hope that this study will benefit cities around the world in their quests for a low-carbon development path.

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ACKNOWLEDGMENTS

First, the team would like to thank the government of Changning District and the Shanghai Municipal Development and Reform Commission for their commitment, support, and guidance. The Changning District Government entrusted the Shanghai Energy Conservation Supervision Center, led by Chen Rumei (Director) and her team, to carry out a bottom-up survey and develop the abatement cost curves and scenarios. McKinsey & Company reviewed the analysis, validated the abatement cost curves and scenarios, and prepared PowerPoint presentations and a report on the abatement cost analysis.

The World Bank team that guided and supervised this work was led by Xiaodong Wang (Task Team Leader), Ximing Peng (co-Task Team Leader), and Noureddine Berrah (Advisor). This report was prepared by Susan Bogach (consultant) and Xiaodong Wang, based on the technical report prepared by the Shanghai Energy Conservation Supervision Center and the report prepared by the McKinsey team. Christophe de Gouvello (Senior Energy Specialist) and Pierre Audinet (Senior Energy Economist) provided valuable peer review comments. Photos were taken by Shaoxiong Du, and Sherrie Brown edited the report.

Finally, the team wishes to acknowledge the generous financial support from the Asia Sustainable and Alternative Energy Program (ASTAE), the government of Japan through a Policy and Human Resource Development (PHRD) grant, the Global Environment Facility, and the World Bank's Energy Sector Management Assistance Program (ESMAP).

ABBREVIATIONS AND ACRONYMS

BOS	Bank of Shanghai
CO_2	carbon dioxide
CO_2e	CO_2 equivalent
DG	Distributed Generation
EE	Energy Efficiency
EFFECT	Energy Forecasting Framework and Emissions Consensus Tool
ESCO	Energy Service company
ESMAP	Energy Sector Management Assistance Program
ETS	Emission Trading Scheme
FYP	Five-Year Plan
GDP	gross domestic product
GEF	Global Environment Facility
GHG	greenhouse gas
GoC	Government of China
GWh	Gigawatt-hour
HVAC	heating, ventilation, and air conditioning
IBRD	International Bank for Reconstruction and Development
K	kelvin
Km	kilow meter
ktce	Kilotonnes of coal equivalent
kton	kiloton
kW	Kilowatt
kWh	Kilowatt-hour
LED	Light-emitting diode
m^2	Square meters
m^3	Cubic meters
MACTool	Marginal Abatement Cost Curve Tool
MJ	megajoule

MWH	Megawatt hour
M&V	Measurement and Verification
NDRC	National Development and Reform Commission
NPV	net present value
NGO	nongovernmental organization
NZE	near zero emission
PFI	Participating financial institution
PMO	Project Management Office
POC	Province of China
PV	photovoltaic
RE	Renewable Energy
R&D	research and development
RMB	renminbi
SAR	Special Administrative Region
SPD Bank	Shanghai Pudong Development Bank
tce	tonnes coal equivalent
TRACE	Tool for Rapid Assessment of City Energy
TV	Television
VF	variable frequency
$W/(m^2K)$	Watts per square meter Kelvin
Wp	Watt-peak
XPS	extruded polystyrene
Y	yuan
yr	year

Summary Report: Applying the Abatement Cost Curve Methodology for a Low-Carbon Strategy in Changning District, Shanghai

This report summarizes the study that applies abatement cost curves and scenarios to set low-carbon targets and identify cost-effective low-carbon investments for Changning District, Shanghai. It includes the following chapters:

- Executive summary
- The objectives: 12th Five-Year Plan carbon intensity reduction target and beyond
- The methodology: a bottom-up and comprehensive approach
- The bottom-up survey: data collection and identification of abatement technologies
- The abatement measures: carbon abatement cost curves
- The abatement priorities: abatement technologies ranked by cost and ease of implementation
- The low-carbon targets: abatement scenarios for 2015 and 2020
- From abatement cost curve to implementation: Green Energy for Low-Carbon City in Shanghai Project
- The significance: potential replications in other cities

Executive Summary

The government of China is committed to reducing the country's carbon intensity by 40–45 percent between 2005 and 2020. Energy efficiency (EE) and renewable energy (RE) are expected to contribute significantly to achieving this target. Cities are at the forefront of the action plan to achieve the government's carbon-intensity-reduction target. China is experiencing rapid urbanization. The speed and scale of urbanization provide an unprecedented opportunity in the coming years to invest in clean energy technologies to contain carbon emissions from the country's sprawling cities. Therefore, supporting low-carbon cities is one of the government's top priorities.

Shanghai municipal and Changning District governments are firmly committed to the transition to a low-carbon city, and requested for the World Bank's support in making Changning District and Shanghai leaders in designing novel and efficient ways to achieve their carbon-intensity-reduction targets.

However, the concept of a low-carbon city is still not clearly defined in China. The Ministry of Environmental Protection and the Ministry of Housing and Urban-Rural Development both developed national standards for "eco-cities" with the intention of advancing the environmental agenda in cities. The National Development and Reform Commission is piloting low-carbon cities in 13 cities and provinces in the first batch, and 29 cities and provinces in the second batch. But clear standards and key indicators for assessing environmental sustainability in a comprehensive and comparable manner are still lacking.

In this context, and at the request of the Changning District government in Shanghai, the Bank team guided the Shanghai Energy Conservation Supervision Center, with assistance from McKinsey & Company, in developing CO_2 abatement cost curves and scenarios to set low-carbon targets and identify cost-effective, low-carbon investments for achieving these targets. This innovative and comprehensive study involved the following four steps:

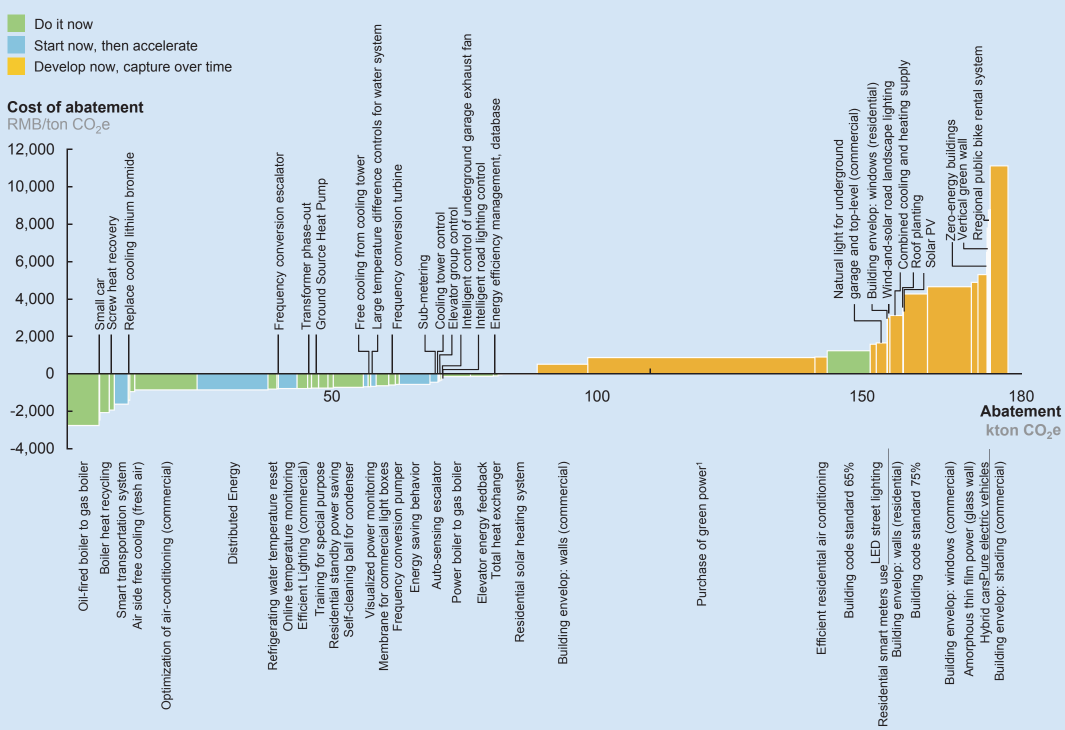
(1) Conducting a comprehensive, bottom-up survey of buildings in Hongqiao area in the Changning District to diagnose current energy use patterns in these buildings. A total of 58 abatement measures resulted from the survey.

(2) Developing CO_2 abatement cost curves to identify the abatement potential and cost of various mitigation measures (figure 1), based on the data from the survey;

(3) Prioritizing mitigation measures based on abatement potential, cost, and ease of implementation (figure 2); and

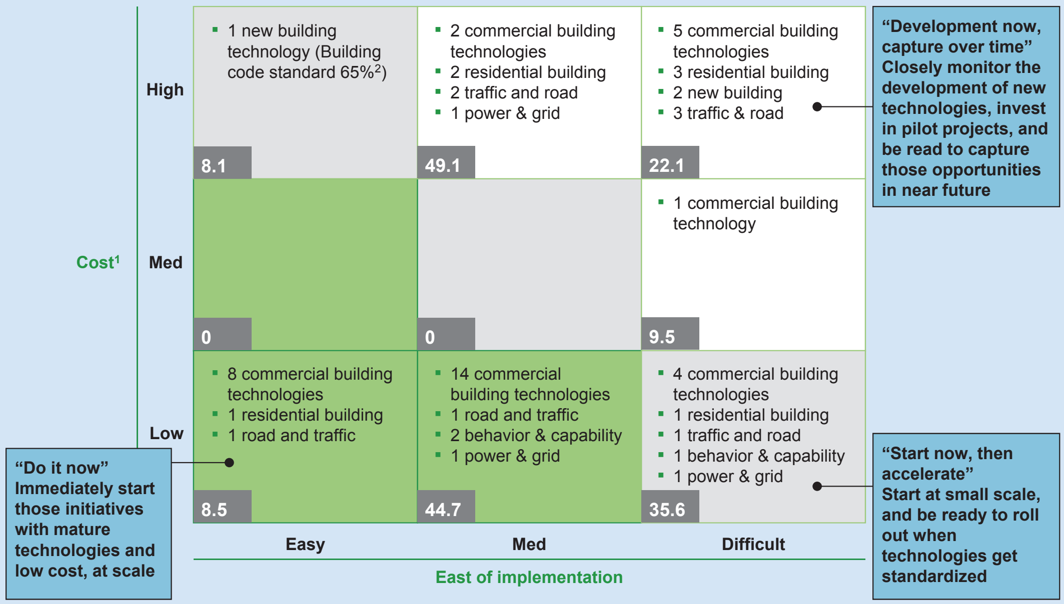
(4) Developing three alternative abatement scenarios (frozen technology scenario; baseline scenario for meeting the national government's carbon-intensity-reduction target; and the stretch scenario, which would exceed the national government's target) to establish an ambitious, low-carbon target for Hongqiao area (figure 3).

Figure 1 Abatement Cost Curve with Ease of Implementation in Hongqiao Area in 2015



1 Purchase volume is forecasted by surveys. Although emission reduction counts according to statistics rules, it is still debatable
SOURCE: Team analysis

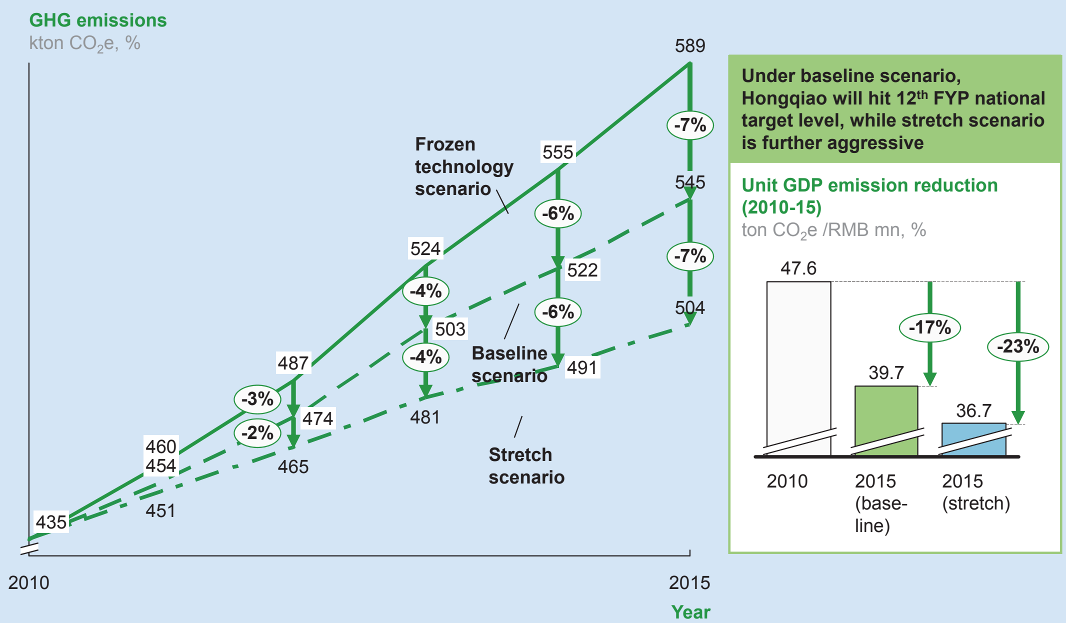
Figure 2 Technologies Can Be Prioritized into Three Groups by Cost and Ease of Implementation



1 Low: < 0 RMB/ton CO_2e; High: > 600 RMB/ton CO_2e, which is the weighted average cost of all technologies; Med: everything between Low and High
2 Will be categorized as "do it now", since government has already make this building code mandatory

SOURCE: Team analysis

Figure 3 Achieving Stretch Scenario Abatement Potential Can Reduce GHG Emissions by 15 Percent from the Frozen Technology Scenario in 2015



SOURCE: Team analysis

The use of CO_2 abatement cost curves, bottom-up investigation surveys, and ease of implementation considerations to define an investment program for reducing CO_2 emissions was the first of its kind at the time. The abatement cost curve developed under this upstream analytical work allowed the district government to make informed decisions about medium-term targets for CO_2 abatement and to identify priority actions and investments to meet them. The abatement cost curve analysis also provided a solid analytical underpinning for the technical assistance and investments selected for the IBRD/GEF Green Energy for Low-Carbon City in Shanghai Project to support Changning District in achieving its carbon-intensity-reduction target.

Changning District is an established district with mostly commercial buildings and few industrial activities. Hongqiao area is centrally located in Changning, contributing 28.5 percent of GDP in Changning District with less than 10 percent of its land and population.

Given the unique characteristics of the Hongqiao area, the study identified 58 abatement measures that could reduce greenhouse gas (GHG) emissions in Hongqiao area by 177,000 tons of CO_2e, or 30 percent of its total GHG emissions by 2015. The measures identified from the abatement cost curves can be grouped into the following four clusters (figure 4):

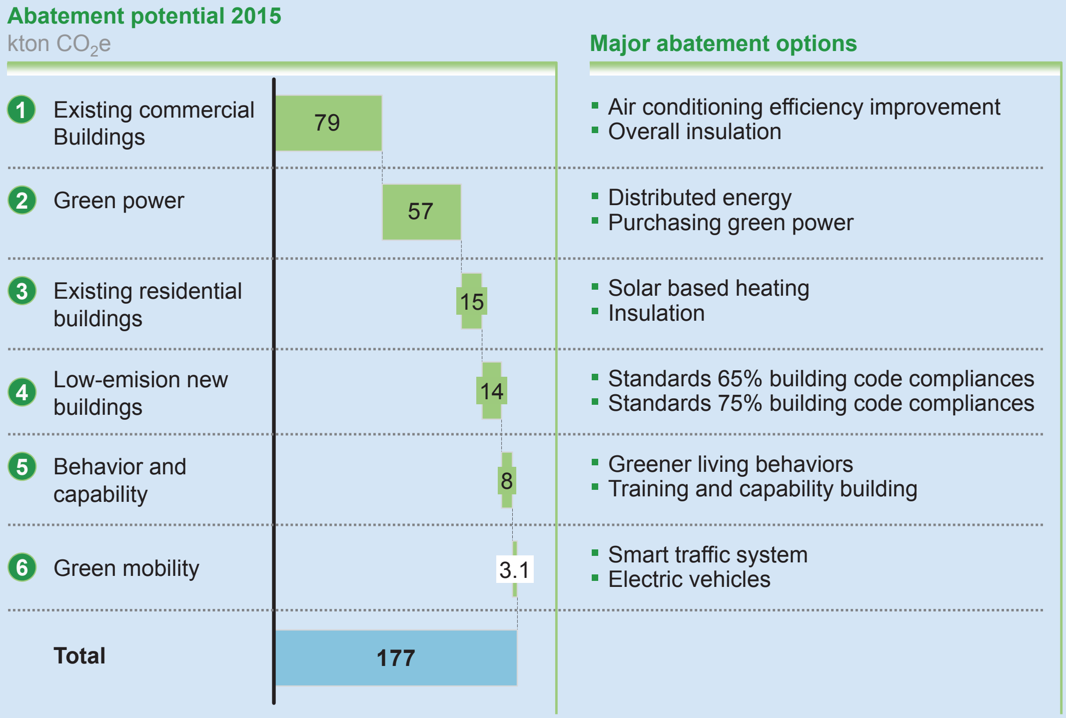
- Retrofitting of existing commercial and residential buildings, including measures to improve the energy efficiency of air conditioning systems, building envelopes, boiler systems, and so forth, which could reduce GHG emissions by about 95 kton of CO_2e, accounting for more than half of the emissions reductions between the frozen technology and stretch scenarios;

- Low-carbon energy supply from the purchase of green electricity and distributed generation from renewable energy and natural gas, which could reduce GHG emissions by about 57 kton of CO_2e, the second largest source of emissions reductions;

- Low-emission new buildings through enforcement of higher energy efficiency and lower emissions standards than existing national and municipal building codes to achieve deeper emissions cuts; and

- Green mobility measures.

Figure 4 Building Retrofit Presents the Largest Abatement Potential



SOURCE: Team analysis

Under the baseline scenario for meeting the national government's carbon-intensity-reduction target in the 12th Five-Year Plan (FYP), Hongqiao area would need to cut GHG emissions by 44 kton of CO_2e by 2015 from the level in the frozen technology scenario (figure 3). Those measures with low cost and high ease of implementation are encompassed in this scenario, with an estimated cumulative total capital investment of 500 million RMB between 2011 and 2015.

Under the stretch scenario, Hongqiao area would have to cut an additional 41 kton of CO_2e from the level in the baseline scenario (figure 3) to go beyond the national government's 12th FYP targets and become a leading low-carbon district. The cumulative total capital investment would be 900 million RMB between 2011 and 2015. Achieving this ambitious goal would require stronger commitment and intensified efforts to implement high-cost abatement measures, such as retrofitting building envelopes, switching to light-emitting diode (LED) lighting, and renewable energy and complex measures such as distributed energy, smart traffic management systems, and behavior change.

Based on a rough extrapolation from the 2010–15 analysis, the GHG emissions in Hongqiao area would decline from 750 kton of CO_2e under the frozen technology scenario to 530 kton of CO_2e under the stretch scenario by 2020.

Hongqiao area is representative of typical abatement measures in Changning District. Applying the analysis of Hongqiao area to the whole Changning District, the maximum potential CO_2e reduction in the district by 2020 is roughly estimated to be approximately 1 million tons, with a cumulative capital investment of about 12 billion RMB over the period 2011–20.

The abatement cost curves and scenario methodology adopted in this study are useful analytical tools for determining a low-carbon target and defining a cost-effective, low-carbon investment program to achieve the city-level carbon emission target. It should be noted that the focus of this study is not buildings, but achieving low-carbon cities. Because Changning District is an established commercial district with few industrial activities, where buildings account for more than 90 percent of total energy consumption, the abatement cost curve model indicated that building retrofit measures provided the greatest potential for reduction of emissions. If the same methodology were to be applied in another city with different characteristics, the conclusion could be quite different. Therefore, the methodology is flexible enough to be used in any city to define low-carbon cities.

This analytical work directly led to the design of the IBRD/GEF Green Energy for Low-Carbon City in Shanghai Project to implement the mitigation measures identified from the abatement cost curves. Subsequent to this analysis, a separate follow-up study was undertaken on building benchmarks, policy recommendations, and business models for building retrofit, given that retrofit was identified as the single largest emission reduction opportunity. A US$100 million IBRD loan will finance low-carbon investments in buildings using financial intermediaries, with the objective of piloting green energy schemes and scaling up low-carbon investments in buildings in Shanghai, with a focus on Changning District. A GEF grant is designed to focus on policy instruments, financing mechanisms, business models, and capacity building for green energy buildings, low-carbon energy supply, and green mobility, with the global environment objective of supporting Shanghai's low-carbon city development by promoting green energy schemes, with a focus on Changning District. This abatement cost curves and scenarios methodology has a wide replication potential for helping cities in China and around the world to develop their own low-carbon investment programs.

1

The Objectives: 12th Five-Year Plan Carbon-Intensity-Reduction Target and Beyond

The governments of Shanghai municipality and Changning District are firmly committed to the transition to a low-carbon city, and to becoming a leader in reducing carbon emissions in the 12th FYP period and beyond. The objectives of this study are (1) to help establish a target for carbon reduction; and (2) to assist in defining priority investment programs to achieve the low-carbon target, including those financed by the World Bank in Changning District, with the methodology of abatement cost curves and scenarios.

The issues addressed in the study

The government of China is committed to reducing the nation's carbon intensity by 40–45 percent from 2005 to 2020. Energy efficiency and renewable energy are expected to contribute significantly to achieving this target. Related ambitious targets include cutting energy intensity by 16 percent during the 12th Five-Year Plan (2011–15) and increasing the share of non–fossil fuels (renewable energy and nuclear) in primary energy from 8 percent in 2011 to 15 percent by 2020.

China is experiencing rapid urbanization, with 300 million people projected to migrate to urban areas during the next 20 years. As a result, energy demand for buildings and transportation will increase rapidly—energy demand and related CO_2 emissions would triple for buildings and appliances, and more than quadruple for the transportation sector because the vehicle fleet would increase 10-fold over the next two decades. The speed and scale of this upcoming urbanization provide an unprecedented opportunity to invest today in clean energy technologies on both the demand and supply sides to contain carbon emissions from the country's sprawling cities. The window of opportunity is narrow because urban infrastructure has a long lifetime. Introducing efficient low-carbon technologies into new urban infrastructure today would lock cities into a lower-carbon path for decades to come. Time is of the essence.

Cities are at the center of the action plan to achieve the government's carbon-intensity-reduction target. They account for 85 percent of China's commercial energy use. CO_2 emissions per capita in Shanghai, Beijing, and Tianjin are already higher than those of other leading cities in the world, and are three to four times higher than the national average. To this end, the National Development and Reform Commission (NDRC) has recently given high priority to lowering carbon emissions in cities.

Shanghai municipal and Changning District governments are firmly committed to the transition to a low-carbon city, and achieving the carbon-intensity-reduction targets is one of the highest priorities in their 12th FYP. Shanghai is piloting a carbon cap and trade scheme under NDRC's pilot program, which includes five cities and two provinces. Shanghai municipal and Changning District governments requested World Bank support to benefit from international knowledge and best practices. They seek the World Bank's assistance in making the Changning District and Shanghai leaders in designing novel and efficient ways to achieve their carbon-intensity-reduction targets.

In particular, the Changning District government has articulated a vision aimed at transforming Changning into a leading low-carbon district in Shanghai and the country, anchoring to green growth as the engine for the competitiveness of the district. The Changning government has specifically developed a low-carbon-district 12th FYP that focuses on improving the energy efficiency of buildings, shifting to a low-carbon economic structure and energy mix, and adopting innovative mechanisms in multiple sectors. It is also willing to pilot bold policies and incentives that are not yet implemented at the municipal and national levels. Using the knowledge of international experience, the Changning government plans to accelerate the speed and enhance the quality and success of this initiative.

Although many cities are aiming to respond to the challenge of becoming "low-carbon," the concept of a low-carbon city is still not clearly defined. The Ministry of Environmental Protection and the Ministry of Housing and Urban-Rural Development both developed national standards for "eco-cities" with the intention of advancing the environmental agenda. More recently, the NDRC announced the piloting of low-carbon cities in five provinces and eight cities in the first batch, and 29 cities and provinces in second batch. But clear definitions and key indicators for assessing environmental sustainability in a comprehensive and comparable manner are still lacking.

The objectives of the study

In this context, this study aims to demonstrate the use of abatement cost curves and scenarios to provide an analytical underpinning for the definition of a low-carbon target and investment programs. This methodology also helps decision makers identify and prioritize potential ways to lower carbon, to know when to apply which abatement technology, with what cost and impact. It allows the district government to make informed decisions about medium-term targets for CO_2 abatement and identify priority programs and investments to meet those targets.

The objectives of this study are (1) to help establish a target for carbon reduction; and (2) to assist in defining priority investment programs to achieve the low-carbon target, including those programs financed by the World Bank in Changning District, using abatement cost curves and scenarios.

2

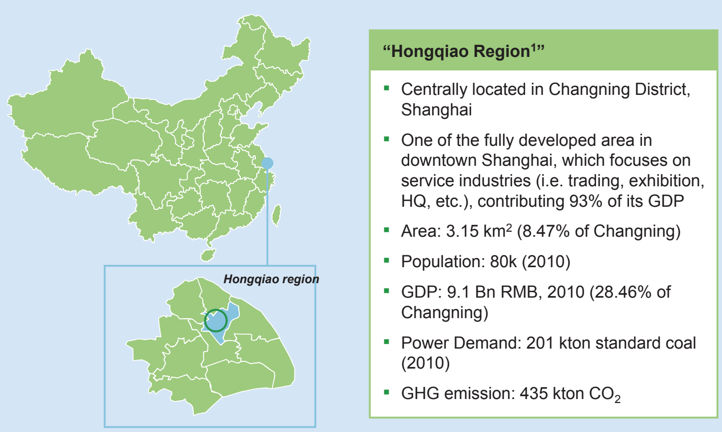
The Methodology: A Bottom-Up and Comprehensive Approach

This study adopted an innovative bottom-up, comprehensive methodology for determining low-carbon targets and investments in Hongqiao area, following four steps: (1) conducting a comprehensive bottom-up survey of buildings in Hongqiao area; (2) developing CO_2 abatement cost curves to identify the abatement potential and cost of various mitigation measures; (3) prioritizing mitigation measures based on abatement potential, cost, and ease of implementation; and (4) developing three alternative abatement scenarios (frozen technology scenario; baseline scenario to meet the national government's carbon-intensity-reduction target; and stretch scenario to go beyond the national government's target) to determine an ambitious low-carbon target for Hongqiao area.

Geographical scope of the study

Hongqiao area is located in the center of Changning District in the west of Shanghai. It covers the area from the Central Ring (Zhongshan Road West) in the east, to Gubei Road and Furongjiang Road in the west, to Yuping Road South in the north and to Huangjincheng Avenue in the south. The area covers 3.15 square kilometers, with a population of 80,000 people. It occupies 8.5 percent of the land area of Changning District and accounts for 28.5 percent of its economic output. Hongqiao's economic activities, like that of most of Changning District, are focused mainly on trading and commercial activities, including exhibitions (figure 2.1).

Figure 2.1 Hongqiao Area is a Commercial Zone Centrally Located in Changing District



ies of the area: Zhongshan W Rd (E), Gubei Rd, Furongjiang Rd (W), Yupin S Rd (N), Huangjincheng Ave (S)

The study focuses on identifying and quantifying the potential to save energy and reduce carbon emissions through technology and behavior-oriented solutions. It identifies the energy efficiency and emissions-reduction measures that are most likely to be applicable in Hongqiao area in the foreseeable future. The study considers a wide range of energy efficiency and emissions-reduction measures for both the demand and supply sides, as well as behavioral changes that could result in energy savings.

The study identifies the potential for carbon reduction in Hongqiao area by 2015. It extrapolates these results to 2020 for Hongqiao area, and expands them to Changning District as a whole to provide a rough estimate of the impact of rolling out the identified abatement measures.

Innovative and comprehensive analytical tools

There are a number of analyses of carbon abatement strategies using abatement cost curves. What makes this study different? This study has a number of unique characteristics:

(1) The priority abatement measures and investments identified from this study directly led to the design of the IBRD/GEF-financed Green Energy for Low-Carbon City in Shanghai Project.

(2) The identification of abatement measures, their carbon-reduction potential, and their cost were developed with a bottom-up approach, using specific data collected from on-the-ground surveys and investigations in Hongqiao area.

(3) The study not only considered abatement potential and cost, but also added a third dimension—ease of implementation—to help prioritize abatement measures.

(4) The study adopted a comprehensive multisector approach to integrate (1) demand-side energy efficiency measures in buildings; (2) clean energy supply from renewable energy and natural gas; and (3) sustainable transportation such as promotion of clean, efficient vehicles and public transportation, to achieve Changning District's low-carbon objective.

(5) The abatement measures under consideration included not only technological solutions, but also behavior changes for energy savings based on previous Chinese surveys and data.

(6) The analytical work was carried out by a Chinese team, then verified by the McKinsey team, all under the supervision of the World Bank team.

The abatement cost curves and scenario methodology are useful analytical tools for determining a low-carbon target and defining a cost-effective, low-carbon investment program to achieve the city-level target. It should be noted that the focus of this study is not buildings, but achieving low-carbon cities. Because Changning District is an established commercial district with few industrial activities, where buildings account for more than 90 percent of total energy consumption, the abatement cost curve model indicated that building retrofit measures provided the greatest potential for reduction of emissions. If the same methodology were to be applied in another city with different characteristics, the conclusion could be quite different. Therefore, the methodology is flexible enough to be used in any city to define low-carbon cities.

The study followed four steps:

(1) Conducting a bottom-up survey to collect data in Hongqiao area to identify current energy use patterns and to identify abatement measures to reduce carbon emissions;

(2) Developing CO_2 abatement cost curves to determine the carbon-reduction potential and costs for various mitigation measures, based on the survey data;

(3) Prioritizing mitigation measures based on abatement potential, cost, and ease of implementation; and

(4) Developing three alternative abatement scenarios (frozen technology scenario; baseline scenario to meet the national government's carbon-intensity-reduction target; and stretch scenario to go beyond the national government's target) for 2015 and 2020 to determine an ambitious low-carbon target for Hongqiao area and Changning District.

These tools were used to develop a program of potential priority carbon-reduction investments and to establish realistic targets for an ambitious carbon-reduction program in Hongqiao area and then in Changning District that goes beyond the targets in the 12^{th} FYP. Each step is summarized below and described in more detail in the following chapters.

- **Conducting bottom-up survey to collect data and identify emissions-reduction measures.** The analysis began in 2010 with a survey of a sample of 50 commercial buildings in Hongqiao area, which together account for 80 percent of the total energy consumption in commercial buildings in the area. Current energy use in Hongqiao area in 2009 was estimated based on the survey and data collected from other sources. Chinese experts then identified 58 different measures to reduce energy use and carbon emissions, estimating the abatement potential and cost of each measure. As part of this analysis, the potential effectiveness of behavioral changes in reducing energy use was also evaluated.

- **Developing abatement cost curves.** Carbon abatement cost curves were used as the core methodology for ranking the 58 measures for carbon reduction identified in the survey of Hongqiao area. Cost curves were used to depict and graphically compare the potential and costs of the 58 abatement measures. The

GHG abatement cost curve proved to be useful in undertaking the analysis in the study. However, it should be noted that the abatement cost curve is not a panacea and has drawbacks—it centers on abatement measures but excludes other nontechnology abatement options such as urban form, public transportation, and behavior changes, and does not cover transaction costs (the cost of designing and implementing policies and programs and the institutional changes associated with them).

- **Prioritizing mitigation measures.** To overcome some of the deficiencies of the carbon abatement cost curve methodology described above, this study included an estimation of the impact of behavior change to reduce individuals' energy consumption. Feasibility and ease of implementation were also added as key criteria for prioritizing abatement measures, in addition to abatement cost and potential. The abatement investments are grouped into three categories: (1) "do it now" or "no-regret" measures that are low cost and easy to implement: these measures should start to be implemented immediately at full scale ; (2) "start now, then accelerate" measures that are low cost but difficult to implement or high cost but easy to implement: these measures should first be piloted on a small scale, and be ready to roll out in the medium term when the measures mature (by 2015); and (3) "develop now, capture over time" measures that have high cost and significant implementation challenges, but high abatement potential: these new technologies should be closely monitored and pilot projects should be undertaken to be ready to capture those opportunities in the long term. The measures were grouped in a matrix, with cost per ton of CO_2e avoided along one axis and the ease of implementation along the other axis. Costs were categorized as low, medium, and high along one side of the matrix, while ease of implementation was categorized as easy, medium, or difficult.

- **Developing abatement scenarios.** To set low-carbon targets, the study defined and quantified three development scenarios for carbon emissions in Hongqiao area from 2010 to 2015: (1) a frozen technology scenario in which energy use is projected using forecasts of economic activity but no technological change; (2) a baseline scenario that assumes implementation of sufficient technological changes from the matrix to meet the carbon-intensity-reduction targets in the 12th FYP; and (3) a stretch scenario that reflects further technological change using higher-cost and more difficult technologies to realize the desire of the district to become a leader in carbon reduction, beyond the 12th FYP targets. Finally, the scenarios were extended from Hongqiao area to the entire Changning District and were also extrapolated from 2015 to 2020. These scenarios are not forecasts or government's plans. Their purpose is to enable policy makers to obtain a better understanding of the quantitative impacts of policy options.

3

The Bottom-Up Survey: Data Collection and Identification of Abatement Measures

This chapter summarizes (1) the design of the survey; (2) the main data collected on current energy consumption; and (3) a comparison of building energy consumption in Hongqiao with that in Shanghai and other international cities.

The design of the survey of carbon-reduction potential in Hongqiao area

Geographical range. The survey was conducted in the 3.15 square kilometer area occupied by Hongqiao area of Changning District in Shanghai. Given that buildings account for more than 90 percent of energy consumption in the Hongqiao area, the survey focused on 50 large commercial and government buildings (out of 85 large buildings in Hongqiao, with each ≥ 20,000 m^2 of floor space) while 12 smaller buildings (each with < 20,000 m^2 of floor space) that use less energy were spot checked. The 50 key commercial buildings, together with the 12 smaller buildings, account for about 80 percent of total energy consumption of all commercial and government buildings within Hongqiao area in 2009. Additionally, the survey covered one typical residential neighborhood within Hongqiao area, and one new building complex that is in the planning stage.

Technical scope. The survey covered current energy consumption in or the potential for savings from (1) existing commercial buildings; (2) new buildings; (3) existing residential buildings; (4) distributed renewable electricity generation; (5) street lighting; (6) carbon sequestration in green areas; (7) local transportation; and (8) behavioral changes through strengthening people's awareness of energy use.

Steps of the research. The research was divided into three stages: basic survey, estimate of current energy consumption, and estimates of potential for energy saving from abatement measures and their costs.

Basic survey. The main part of the survey covered existing and planned buildings. From site visits, data were obtained on characteristics of the building envelope, lighting fixtures, heating and air conditioning systems, as well as estimates of the energy used for different purposes. Data were also obtained from the gas and electricity companies. Finally, data were collected on street lighting fixtures and energy use in street lighting, transportation patterns and related energy use, green space in the survey area, and solar water heating.

Estimate of current energy consumption in 2009. Current building and equipment characteristics and energy consumption were analyzed by major technology and compared with relevant national and local design standards and international data. This analysis identified a number of inefficiencies and areas for potential carbon reduction.

Analysis of potential for energy savings and emissions reduction and associated costs by technology in 2015. Using the survey data as a basis, Chinese experts identified potential measures for reducing carbon emissions. The incremental investment and operational costs of each technology were estimated together with their potential to save energy and carbon emissions by 2015. Finally, meetings were held with different groups of experts to discuss and review the estimates of potential energy savings and their costs. Based on the analysis, 58 different energy-saving measures were identified.

Results of basic survey: Energy consumption and characteristics of energy-consuming facilities

The total energy consumption of Hongqiao area in 2009 was estimated to be 195,000 tons of coal equivalent (tce), which includes 495 GWh of electricity (84.4 percent), 1.6 million m^3 of town gas (6.0 percent), 0.7 million m^3 of natural gas (4.7 percent), 8.1 ktons of diesel (4.4 percent), and 0.6 ktons of gasoline (0.5 percent). Buildings (90.5 percent), industry (9 percent), and transportation (0.5 percent) are the main energy consumers. Buildings include hotels, shopping malls, shopping and office buildings, exhibition centers, schools, and government buildings. Transportation mainly includes personal cars.

Table 3.1 Buildings Accounted for More Than 90 Percent of Energy Consumption in Hongqiao, 2009

Classification		Electricity (GWh)	Diesel (1,000tons)	Natural Gas (million m^3)	Town Gas (million m^3)	Gasoline (1,000 tons)	Total Energy Use (1,000 tce)
Industry		43.12	2.45	0	0.14	0	18.01
Commercial buildings	Hotels	63.64	3.44	2.75	3.76	0	31.82
	Shopping malls	54.28	0	0	0	0	18.07
	Office buildings	105.38	0.76	0	0	0	36.20
	Office +shopping malls	92.01	0.54	0.38	1.75	0	32.88
	Exhibition centers	25.65	0.46				9.21
	Others	27.03	0.40	0.22	0.41	0	10.09
	Subtotal	367.99	5.61	3.34	5.92	0	138.28
Residential housing		83.93	0	3.74	9.89	0	38.17
Transportation		0	0	0	0	0.62	0.92
Total		495.04	8.06	7.09	15.95	0.62	195.38

The survey gathered data on the characteristics of the buildings, including their age, type of insulation and windows, structure, heating and cooling equipment, lighting, and escalators and elevators. Data were also gathered on characteristics of public lighting fixtures.

Energy consumption of commercial buildings in Hongqiao area. Because commercial buildings are shown to account for slightly more than 70 percent of all energy used in Hongqiao area according to table 3.1, it is interesting to examine these buildings by type. The 50 energy-intensive commercial and government buildings surveyed can be categorized into eight building types (table 3.2). Office buildings are the most prolific, accounting for 36 percent, followed by hotels with 22 percent, and office plus shopping malls with 10 percent. The other five building categories make up the remaining 32 percent: high-rise condos with 8 percent, shopping malls with 8 percent, schools with 6 percent, government buildings with 6 percent, and exhibition centers with 4 percent.

From the energy consumption perspective, the top three categories account for 70 percent: office buildings with 26 percent, office plus shopping malls with 23 percent, and hotels with 21 percent. They are followed by shopping malls with 13 percent, exhibition centers with 9 percent, high-rise condos with 5 percent, government buildings with 2 percent, and schools with 0.2 percent.

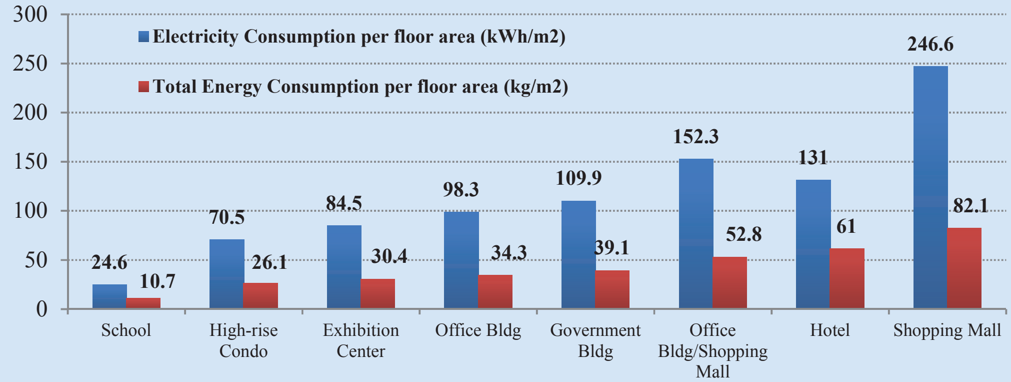
Table 3.2 Commercial Buildings Account for the Bulk of Energy Consumption of the 50 Buildings Surveyed

Building Type	Number	Share of Buildings(percent)	Energy consumption (tce)	Share of Energy Consumption (percent)
Office buildings	18	36	26,146	26
Hotels	11	22	21,119	21
Office + shopping malls	5	10	22,696	23
High-rise condos	4	8	4,983	5
Shopping malls	4	8	12,852	13
Schools	3	6	174	0.2
Government buildings	3	6	1,910	2
Exhibition centers	2	4	9,212	9
Total	50	100	99,092	100

The overall consumption of the buildings surveyed in 2009 was equal to 99,092 tce, including 269.1 GWh of electricity (90.9 percent), 5,608 tons of diesel (8.2 percent), 0.8 million m^3 of natural gas (1.1 percent), and 0.5 million m^3 of town gas (0.3 percent). The total building floor space is 2.25 million m^2; the average unit electricity consumption is 119.4 kWh/m^2, and the average unit energy consumption is 44 kgce (coal equivalent)/m^2.

The energy consumption per unit of floor area of the 50 buildings varies remarkably by building type because of their distinctive energy use patterns (figure 3.1). The unit energy consumption ranges from 10.7 to 82.1 kg/m^2. Of the eight building types, schools (10.7 kg/m^2) have the lowest energy consumption per unit of floor area while shopping malls (82.1 kg/m^2) have the highest. Shopping malls consumed twice as much energy per unit of floor area as office buildings, three times as much as high-rise condos, and eight times as much as schools. In between are high-rise condos (26.1 kg/m^2), exhibition centers (30.4 kg/m^2), office buildings (34.3 kg/m^2), government buildings (39.1 kg/m^2), office plus shopping malls (52.8 kg/m^2), and hotels (62.1 kg/m^2).

Figure 3.1 Energy (kg/m^2) and Electricity (kWh/m^2) Intensity by Commercial Building Type



The analysis showed that commercial buildings (26 percent of the total), hotels (21 percent), and mixed-use (office plus shopping mall) buildings (23 percent) accounted for 70 percent of the total energy consumed in the buildings surveyed (table 3.2). The 50 buildings were studied as energy systems, using energy flow charts to track the flow of each type of energy into different end uses.

Energy consumption of residential buildings in Hongqiao area. Household electricity consumption has been rising by 10 percent annually in recent years. One residential neighborhood was selected as the target of a survey of household electricity usage. Data from the electricity company were used to analyze the monthly consumption pattern of 378 households in this residential neighborhood in 2009. The statistics from the 378 households showed that the average household electricity consumption was 1,784 kWh per year, with 12.7 percent of the sample households consuming more than 3,000 kWh, 9.5 percent consuming 2,500 to 3,000 kWh, 15.3 percent consuming 2,000 to 2,500 kWh, 18.0 percent consuming 1,500 to 2,000 kWh, 19.6 percent consuming 1,000 to 1,500 kWh, and 24.9 percent consuming less than 1,000 kWh. Electricity consumption for air conditioning accounted for the largest share, about 30.3 percent of the annual total. Town gas use in households was also analyzed.

Energy consumption in new buildings. One new project (still to be built) was examined as part of the survey. The project will cover an area of 20,000 m^2, with planned constructed floor space of 70,000 m^2, including a shopping mall, office buildings, service apartments, and residential space. The shopping mall will cover 30,000 m^2. The building envelope structure is designed to save energy. The heat transfer coefficient of the outer walls is less than 1 W/(m^{2}K), of the roof top is less than 0.5 W/(m^{2}K), and the window-wall coefficient is less than 0.3. Low-e glass with a heat transfer coefficient of less than 2.0 W/(m^{2}K) will be used for windows or glass walls. All the equipment is high efficiency, to ensure the goal of achieving building code standards in all uses overall after completion.

Comparisons of building energy consumption in Hongqiao area with international and Shanghai data

A comparison of the energy consumption in buildings in Hongqiao area with other locations in China and with cities in other countries indicates that buildings in Hongqiao area are relatively inefficient. The evaluation of building characteristics during the survey found that the building envelope structures of many buildings do not meet current standards, air conditioning systems are oversized, and many air conditioners were installed years ago and do not meet current efficiency standards. (It should be noted that the comfort levels of buildings in China are usually lower than those in developed cities, that is, the indoor temperature in Chinese buildings tends to be colder in winter and warmer in summer, which results in less energy consumption per unit of floor area in Chinese buildings, but not necessarily as the result of greater energy efficiency).

Commercial building comparison. Shanghai has a database of 95 commercial buildings. Of the buildings, 20 are classified as general office buildings; the others are shopping malls, restaurants, banking, and the like. Figure 3.2 shows the percentage distribution of the 95 buildings as a function of energy consumption per unit of floor area. The majority of the buildings consume between 600 MJ/m^2 and 2,400 MJ/m^2, with a median value of 1,256 MJ/m^2 and a mean value of 1,356 MJ/m^2. The energy consumption per unit of floor area of 34 commercial buildings surveyed in Hongqiao area averaged 1,630 MJ/m^2, 20 percent higher than the consumption of buildings in the Shanghai database, mainly as the result of poor thermal insulation of the building envelope and the energy inefficiency of air conditioning systems.

Figure 3.2 Percentage Distribution of Energy Consumption of Commercial Buildings in Shanghai

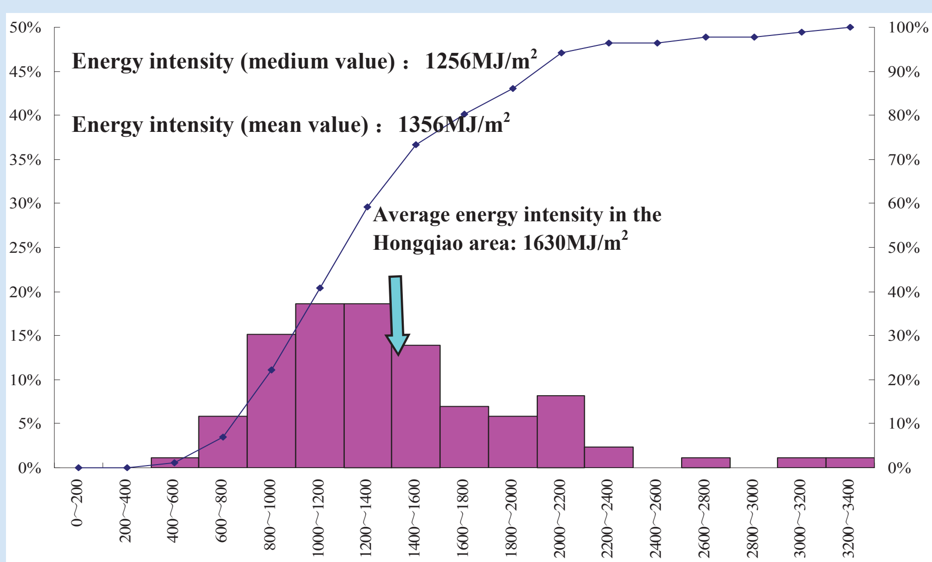
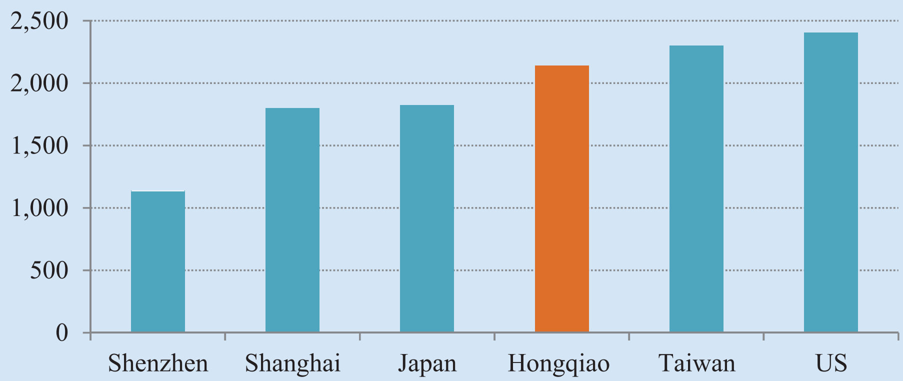


Figure 3.3 compares average energy consumption per unit of floor area of office buildings surveyed in Hongqiao area with those in other regions or countries. Within China, office buildings in Hongqiao area consumed more energy per unit of floor area than did those in Shenzhen and Shanghai. Hongqiao area consumption is close to that of buildings in Taiwan Province of China. Internationally, office buildings in Hongqiao area consumed more energy compared with Japan but less than the United States.

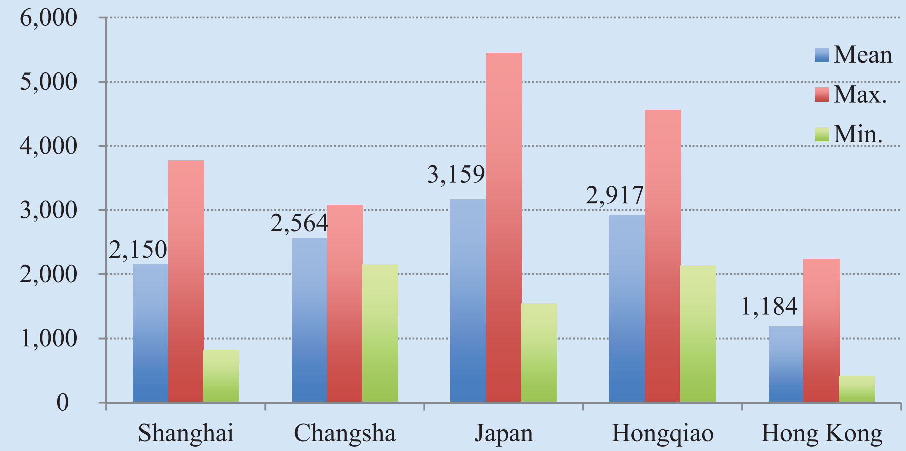
Figure 3.3 International Comparisons of Average Energy Consumption per Unit of Floor Area of Office Buildings



Note: Data for Shenzhen, Shanghai and Taiwan come from "Policy Research Report on Energy Savings in Large Public Buildings in China", by Energy Research Institute of NDRC. Data for Japan comes from surveys by Japanese Energy Saving Institution in 2004. U.S. data is based on an energy consumption survey of 4,645 commercial buildings in 2003 conducted by U.S. Department of Energy. The data is not normalized to local climate.

Figure 3.4 compares the energy consumption per unit of floor area of shopping malls in Hongqiao area with those in other Chinese cities and cities in other countries. Shopping malls in Hongqiao area consume more energy per unit of floor area than do those in Shanghai, Changsha, and Hong Kong SAR. The dramatically lower energy consumption of shopping malls in Hong Kong SAR is mainly due to its adoption of energy management mechanisms. In an international comparison, however, shopping malls in Hongqiao area consumed less energy than did those in Japan.

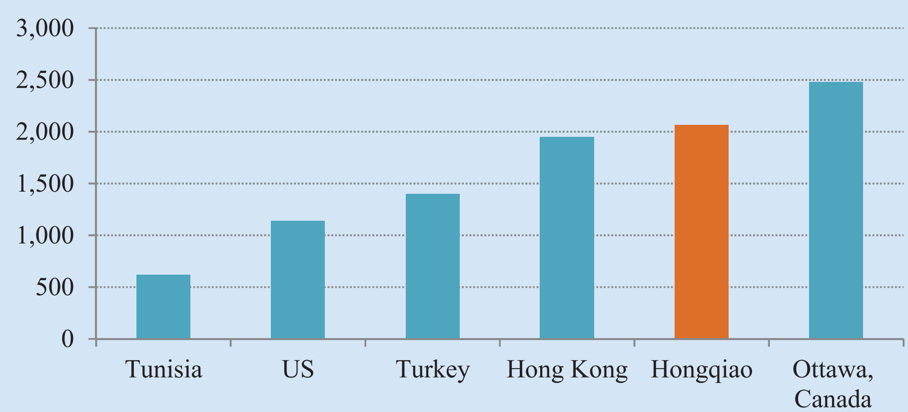
Figure 3.4 Comparison of Energy Consumption per Unit of Floor Area of Shopping Malls in 5 Locations (MJ/m^2-yr)



Note: The data is not normalized to local climate

Figure 3.5 compares the average energy consumption per unit of floor area of Chinese and international hotels with those in Hongqiao area. Of the six regions or countries studied, hotels in Hongqiao area consumed the second-highest amount of energy per square meter; only hotels in Ottawa, Canada, consumed more.

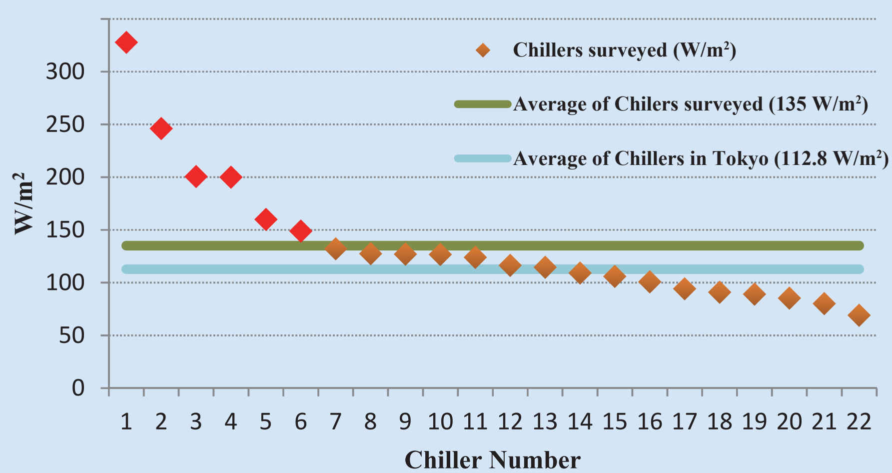
Figure 3.5 Comparison of Energy Consumption per Unit of Floor Area of Hotels in 6 Locations (MJ/m^2-yr)



Note: The data is not normalized to local climate.

A comparison was also made of the refrigeration capacity of air conditioning systems in the commercial buildings surveyed in Hongqiao area and those in Tokyo. Overcapacity leads to low energy efficiency of the air conditioning system because it is running below optimum capacity, especially under partial load conditions. According to the survey of 22 chillers in Hongqiao area, the installed refrigeration capacity averages 135.2 kW/m^2, ranging from 70 to 320 kW/m^2. This average is 19.6 percent higher than the installed refrigeration capacity of high-rise buildings in Tokyo, which averages 112.8 kW/m^2 (figure 3.6).

Figure 3.6 Chillers in Commercial Buildings in Hongqiao Area Have a Higher Average Refrigerating Capacity Than Those in Tokyo



The refrigeration capacity of installed chillers per unit of floor area was also analyzed for different building types. The refrigeration capacity of office buildings surveyed was 131.7 W/m^2, 65 percent higher than the standard level of 80 W/m^2. Ten out of 11 office buildings surveyed exceeded the standard levels. The refrigeration capacity of air conditioning in the hotels surveyed averages about 85.4 W/m^2, 22 percent lower than the standard level of 110 W/m^2. The refrigeration capacity of shopping malls surveyed averaged 213.8 W/m^2, 42.5 percent higher than the standard level of 150 W/m^2.

Residential building comparison. The on-site investigation revealed that none of the five buildings of the surveyed residential community, which were built in the 1990s, were thermally insulated. The envelope structure of those buildings was made of 240-millimeter (mm) perforated bricks in the center with 20 mm cement mortar on both sides. The windows are single glass with aluminum alloy frames. The thermal efficiency of the building envelopes was several times lower than those in other countries when compared with the heat transfer coefficients of international residential building envelopes, and was below the design standard for residential building energy efficiency in Shanghai (table 3.3).

Table 3.3 Comparisons of Heat Transfer Coefficients of Residential Building Envelopes of Several Countries

		Heat Transfer Coefficients (W/(m^{2}K)		
Country		Exterior Walls	Exterior Windows	Roofing
Sweden		0.17	2.00	0.12
United States		0.32 (interior)	2.04	0.19
		0.45 (exterior)		
Canada		0.36	2.86	0.40
Japan		0.42	2.33	0.23
Russia		0.44	2.75	0.33
China	Residential building surveyed (Hongqiao)	1.65	6.00	
	Energy-efficient residential building (Shanghai)	1.50	4.70	1.00

4

The Abatement Measures: Carbon Abatement Cost Curves

This chapter examines in detail the abatement potential and cost of the 58 measures identified during the survey. The abatement cost curves for reducing emissions are constructed. The chapter concludes that retrofitting the buildings presents the largest potential for emissions reduction in Changning District.

Analysis of potential and cost of abatement measures

For each measure identified, the Chinese expert team estimated the abatement opportunity to 2015 in three steps. First, the current penetration rate of each abatement measure was established, along with its efficiency, its cost, and its underlying drivers and constraints. Then, the growth curve of each abatement technology's penetration rate was projected. Based on this projection, the technical potential of each abatement measure was calculated, that is, how many tons of CO_2e the measure could eliminate. Last, the future cost of the measure was estimated. Each stage of the analysis drew on the insights and opinions garnered from the previous surveys and interviews.

Each abatement measure's technical potential to reduce emissions in comparison with the situation without the abatement measure (frozen technology scenario) was estimated, assuming strong government support, the applicability and maturity of the technology, and supply constraints. The incremental costs of the measures were then calculated by applying the formula in figure 4.1.

In this analysis, costs are referred to on a "societal basis." The net resource costs of each abatement measure were analyzed by examining its incremental initial investment costs, operating and maintenance costs, replacement cost, and avoided costs relating to energy efficiency or other benefits. An 8 percent discount rate was applied to account for the difference in time between the initial investment and the resulting savings. The societal discount rate was chosen because the client of this study is the Changning District

Figure 4.1 Calculation Assumptions for Carbon Abatement Costs

Abatement cost = **Full cost of abatement option** ÷ (**CO_2e emissions from frozen technology scenario** − **CO_2e emissions from abatement option**)

Full cost **includes**	Operating costs, including personnel and materials costs Investment costs calculated with economic amortization period and capital costs (similar to repayment of a loan) Possible cost savings generated by the measure (especially energy savings)
Full cost **does not include**	Social costs and transaction costs Communication and information costs Subsidies or explicit CO2costs Taxes Consequential impact on the economy (for example, advantages from technology leadership)
Other assumptions	Abatement costs for new technologies are consistently compared with the specific cost and emissions-intensity of displaced alternatives Full costs could be negative, that is, indicating a net benefit deriving from the use of the solution

government, and a sensitivity analysis using different discount rates was conducted.[1] The conversion ratios used in this report are based on actual Shanghai energy consumption data for 2009 (that is, electricity to CO_2e and gas to CO_2e, and so forth).

The abatement cost of each measure was calculated as the present value of its incremental capital, operating, and maintenance costs per ton of CO_2e abated per year. The abatement cost can be positive or negative. A negative cost indicates a net benefit or saving to the economy (compared with the situation without the technology) over the lifetime of a specific abatement measure. A positive cost means that capturing the abatement potential would lead to incremental costs (compared with the situation without the measure) over the measure's lifetime.

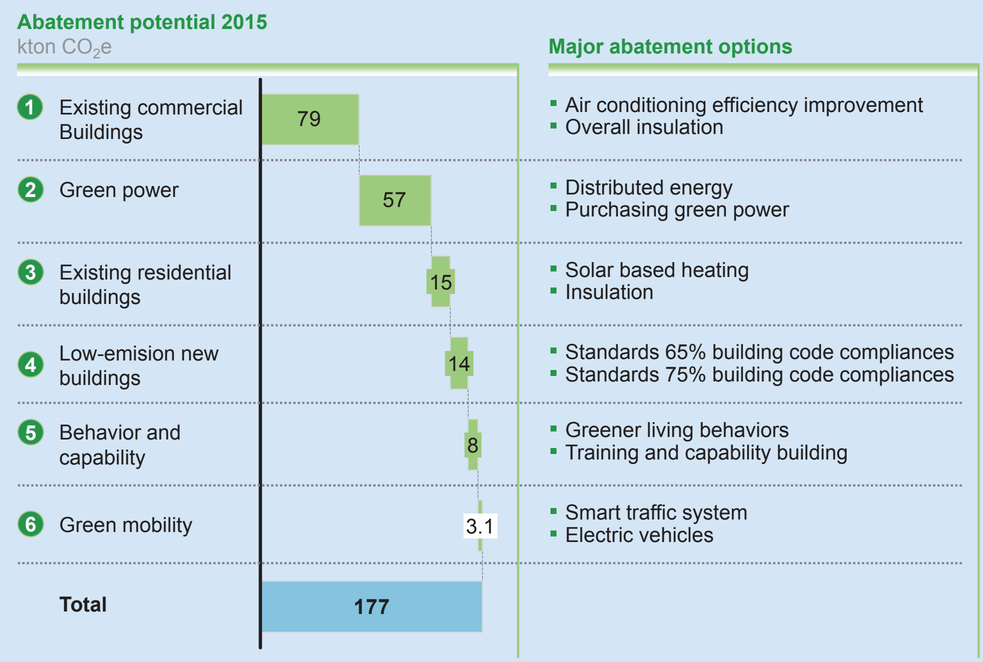
[1] When the discount rate is reduced from 8 percent to 4 percent, for example, high-cost abatement measures, such as zero-emission buildings, would become more economically attractive

The 58 measures are categorized into six main groups: (1) retrofitting existing commercial buildings; (2) green power; (3) retrofitting existing residential buildings; (4) low-emissions new buildings; (5) behavior changes; and (6) green mobility (figure 4.2). The total investment for all 58 of these measures is estimated to be about 2.5 billion RMB; their full implementation would result in energy savings of 72.6 ktons of coal equivalent, reducing CO_2e emissions by 177 ktons per year in 2015 (table 4.1).

Abatement measures

It is notable that 80 percent of the total abatement potential in Hongqiao is accounted for by two categories of measures—retrofit of existing commercial buildings and green power. The next two categories, retrofit of existing residential buildings and low-emission new buildings, account for another 16 percent. The remaining 4 percent is accounted for by behavior change and green mobility.

Figure 4.2 Abatement Measures Can Be Grouped into Six Clusters



SOURCE: Team analysis

Table 4.1 Potential Reduction in Energy Consumption and Carbon Emissions and Abatement Cost in 2015 Based on Implementation of 58 Measures

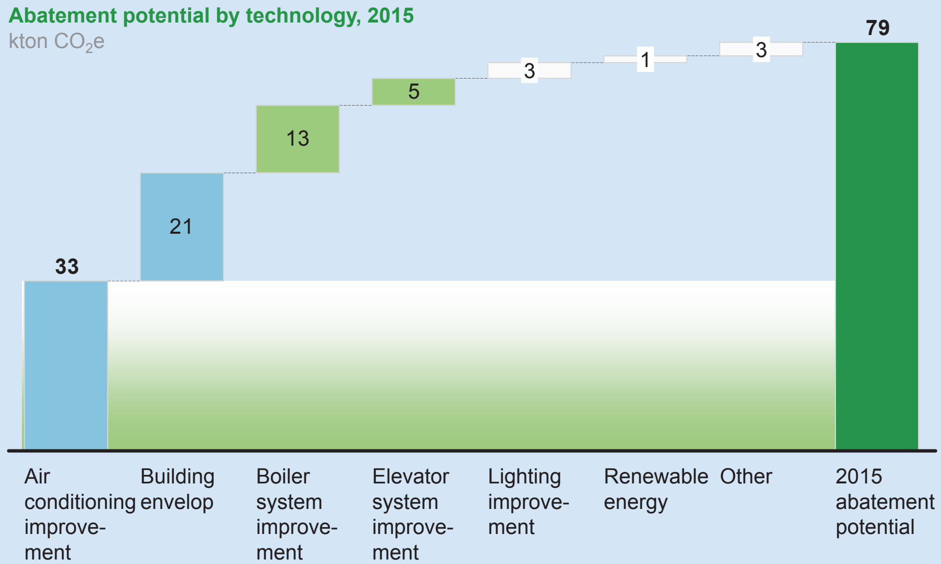
Measure		Abatement Costs (RMB/ton CO_2e)	Energy Saving Costs (RMB tce)	Total Investment (million RMB)	Emissions Reduction (ton CO_2e)	Energy Saving (tce)
Total 58 abatement measures				**2,516.8**	**177,495**	**72,645**
Existing commercial buildings subtotal				**1,096.9**	**79,423**	**33,595**
Air conditioning system	Replace lithium bromide with electric cooling	−1,406	−3,053	3.4	296	136
	Air-side free cooling	−953	−2,059	0.1	920	426
	Air conditioning optimization	−859	−1,690	7.1	11,766	5,981
	Refrigerating water temperature reset	−815	−1,762	1.1	1,654	765
	On-line temperature monitoring	−785	−16,98	5.9	3,542	1,638
	Heat recovery from screw compressor	−1,928	−4,187	5.0	941	433
	Ground-source heat pump	−765	−1,654	2.7	1,340	620
	Self-cleaning ball for condenser	−721	−1,558	12.1	5,667	2,621
	Total heat exchanger	−49	−106	3.5	665	307
	Free cooling from cooling tower	−684	−1,479	1.0	487	225
	Large temperature difference controls for water system	−662	−1,431	1.9	1,030	477
	Frequency conversion turbine	−596	−1,288	3.8	1,280	592
	Frequency conversion pump	−558	−1,206	2.7	738	341
	Cooling tower control	−384	−831	1.1	205	95
	Intelligent control of underground garage fan	−252	−544	0.2	88	41
Boiler system	Power boiler to gas boilers	−148	−495	1.7	5,301	1,583
	Oil-fired to gas boilers	−1,896	0	15.5	6,039	0
	Boiler heat recovery	−2,067	−4,488	7.9	1,838	847
Lighting system	Efficient lighting	−784	−1,695	1.2	1,984	917
	Natural light for underground garage and top-level shopping malls	1,582	3,420	26.3	1,150	532
	Membrane for light boxes	−640	−1,384	5.8	2,336	1,080
Elevator system	Elevator energy return	−138	−299	14.3	4,303	1,990
	Elevator group control	−329	−712	1.2	338	157
	Frequency conversion escalator	−797	−1,724	0.5	274	127
	Auto-sensing escalator	−392	−848	0.9	158	73

Measure		Abatement Costs (RMB/ton CO_2e)	Energy Saving Costs (RMB tce)	Total Investment (million RMB)	Emissions Reduction (ton CO_2e)	Energy Saving (tce)
Building Envelope	Outer wall retrofit	515	1,114	139.6	9,505	4,396
	Shading retrofit	11,113	24,027	233.8	3,367	1,557
	Window retrofit	4,659	10,074	496.1	8,253	3,817
Renewable energy	Solar photovoltaic (PV) generation	4,132	8,933	7.2	137	63
	Amorphous thin film	4,888	10,569	78.7	1,271	588
Others	Visualized power monitoring control	−692	−1,495	2.5	907	420
	Submetering	−451	−976	7.2	15,13	700
	Vertical green walls	6,469	16,700	4.0	90	35
	Roof planting	2,883	7,681	0.6	40	15
Power and grid subtotal				**469.0**	**56,965**	**213,321**
Purchase of green power		869	1,880	298.0	42,840	19,814
Distributed energy generation		−852	−9,777	165.5	13,391	1,167
Transformer phase-out		−772	−1,669	5.5	734	340
Existing residential buildings subtotal				**271.2**	**15,051**	**5,971**
Solar heating system		−23	−75	62.4	6,743	2,036
Outer window retrofit		1,658	3,262	52.0	2,014	1,024
Smart meter		3,039	6,572	19.0	482	223
Outer wall retrofit		3,123	6,753	97.0	2,413	1,116
Energy saving plugs		−758	−1,639	1.4	994	460
Efficient air conditioning		908	1,963	38.0	2,362	1,092
Combined cooling and heating supply		2,706	5,850	1.4	43	20
New buildings subtotal				**609.2**	**14,294**	**6,578**
65% energy efficiency improvement standard		1,242	2,709	210.0	8,064	3,696
75% energy efficiency improvement standard		4,275	9,244	280.0	4,536	2,098
Zero emission building		5,304	11,469	119.2	1,694	784
Behavior and capacity subtotal				**13.0**	**8,464**	**3,565**
Energy saving behavior		−558	−1,387	5.5	5,803	2,332
Training for special purpose		−759	−1,635	2.5	1,775	823
Energy efficiency management and database		−108	−234	5.0	886	410
Roads and traffic subtotal				**57.5**	**3,297**	**1,619**
Smart transportation system		−1,622	−3,295	16.0	2,640	1,300
Regional public bike rental system		8,757	17,785	21.0	244	120
Pure electric vehicles		7,777	15,791	12.8	162	80
Small cars		−2,469	−5,437	0	99	45
Hybrid cars		8,757	17,785	7.0	81	40
Light-emitting diode street lighting		1,516	3,277	0.3	14	7
Wind-and-solar road landscape lighting		2,473	4,865	0.3	9	5
Intelligent control		−245	−529	0.2	48	22

Cluster I. Retrofitting existing commercial buildings

Measures aimed at improving the energy efficiency of existing commercial buildings have the largest abatement potential in Hongqiao area. It is estimated that these measures, at the maximum technical limit, would cut 79 kton CO_2e from Hongqiao area's GHG emissions in 2015 (figure 4.3). This amounts to 45 percent of the total potential emissions reduction from all the measures analyzed.

Figure 4.3 Abatement Measures under Cluster I -- Retrofitting Existing Commercial Buildings



SOURCE: Team analysis

Air conditioning optimization. The main energy conservation measures for improving the energy efficiency of air conditioning systems include the following:

- Condensing heat recovery. Generate domestic hot water from the heat of the condenser of the screw compressor through the heat exchanger.
- Automatic cleaning ball technology of condenser. Schedule cleaning of the condenser during air conditioning seasons.
- Switching from lithium bromide refrigeration to electric refrigeration. The energy efficiency ratio of the thermoelectric refrigeration system is higher than that of the lithium bromide unit.

Further measures include the use of chiller control technology to optimize the water system, free cooling using cooling towers, frequency conversion of boilers, and full heat exchangers. These technologies are applicable to buildings fitted with terminal all-air systems or large air conditioning systems. Air conditioning optimization measures for commercial buildings would need a total capital investment of 58 million RMB to realize an emissions reduction of 33 kton CO_2e in 2015.

Improving building envelope by outer wall and window retrofits and shading. The survey identified 20 commercial buildings that have outer wall heat transfer coefficients greater than 1.41 W/(m^2C), well above the current standard of 1 W/(m^2C). It is proposed that the outer wall heat transfer coefficient be reduced to 1 W/(m^2C) by retrofitting the outer walls with insulation technology. For example, installation of 30 mm polystyrene board would reduce the coefficient from 3 W/(m^2C) to 1 W/(m^2C), preventing two-thirds of the thermal loss through the wall. Experts estimated that 30–50 percent of the energy use in commercial buildings was for air conditioning, of which 30 percent was lost through the envelope structure. Retrofitting these 20 buildings with insulation could save 5.9 GWh, or 1,971.4 tce, per year. If these results are extrapolated to all buildings in Hongqiao area, the total energy savings are estimated to be 13.18 GWh.

The study also recommended retrofitting inefficient windows with hollow, low-e glass or even "smart" windows with shading to reduce heat loss. The windows of 16 of the 50 large buildings surveyed could benefit from such changes. The total cost would be 225.5 million RMB. The annual energy saving would be 5.21 GWh, or 1,719 tce. Scaling up these results to the entire Hongqiao area would result in estimated energy saving of 3,815 tce per year and emissions reductions of 8.3 ktons per year.

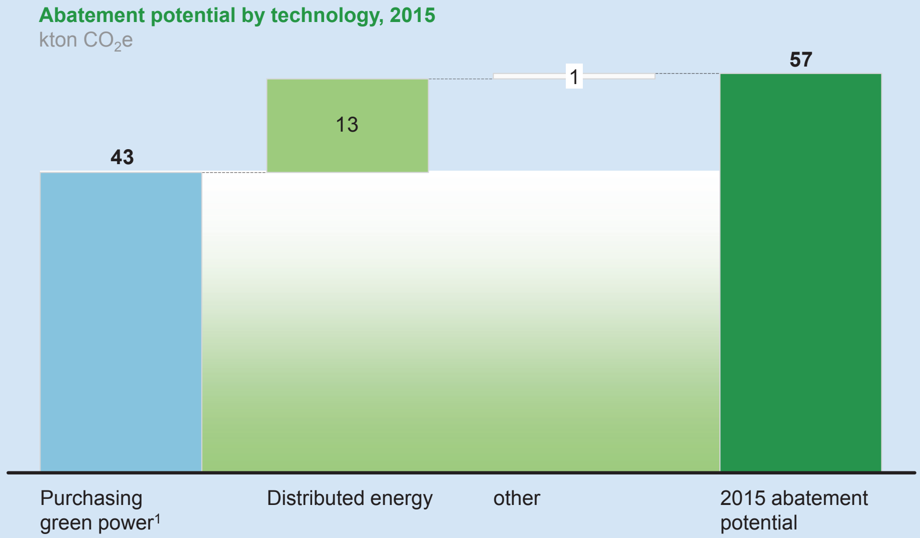
Potential energy saving from other energy efficiency measures. Similar analyses were conducted for other potential measures for saving energy in commercial and government buildings, including the following:

- Replacing oil-fired boilers with gas-fired boilers and recovering waste heat from boilers.
- Saving energy in elevators through improved controls to recover energy in operation and braking.
- More efficient lighting.
- Installation of intelligent power control system in buildings.
- Adopting building-integrated PV generation for glass wall and solar heat collection.
- Increasing purchase of green electricity by buildings to 1 percent of consumption.

Cluster II. Green Power

The green power category can help reduce emissions by 57 kton CO_2e, which amounts to 32 percent of Hongqiao area's total abatement potential in 2015. This cluster consists of two main measures: on-site distributed energy generation from renewable energy and natural gas and purchase of green power from outside the area (figure 4.4).

Figure 4.4 Abatement Measures under Cluster II -- Green Power



1 Hongqiao plans to purchase green power from out-of-region plants (i.e. solar, wind, etc.)

SOURCE: Team analysis

Purchasing green power. Large-scale power generation from alternative energy sources is not feasible in a developed urban area, but Hongqiao area can purchase green power from outside the region. The survey indicates that the average annual electricity consumption in the 50 buildings ranges from 4 to 5 GWh. Assuming 40 percent of the building owners subscribe to green power and each purchases 120 MWh of green electricity annually, the total purchased would be 2.4 GWh, about 1 percent of the total electricity consumption of the 50 buildings. This would save 799 tce and reduce CO_2e emissions by 2.2 kton. The total incremental cost would amount to 1.4 million RMB, based on the incremental cost of green electricity of about 0.53 RMB/kWh. Purchases of green energy can be further strengthened by promoting its use in one or two newly built energy-intensive buildings and two or three existing government buildings in Hongqiao area, for an annual total of 59.5 GWh of green energy. These combined measures would save 19.8 ktce, accounting for 6 percent of total energy consumption in Hongqiao area and would cut annual CO_2e emissions by 42.8 kton.

Distributed generation. Gas-based distributed generation solutions were investigated because gas is the most accessible fuel source in Hongqiao area. Based on the energy consumption patterns of the 20 buildings, three alternative distributed generation models were analyzed:

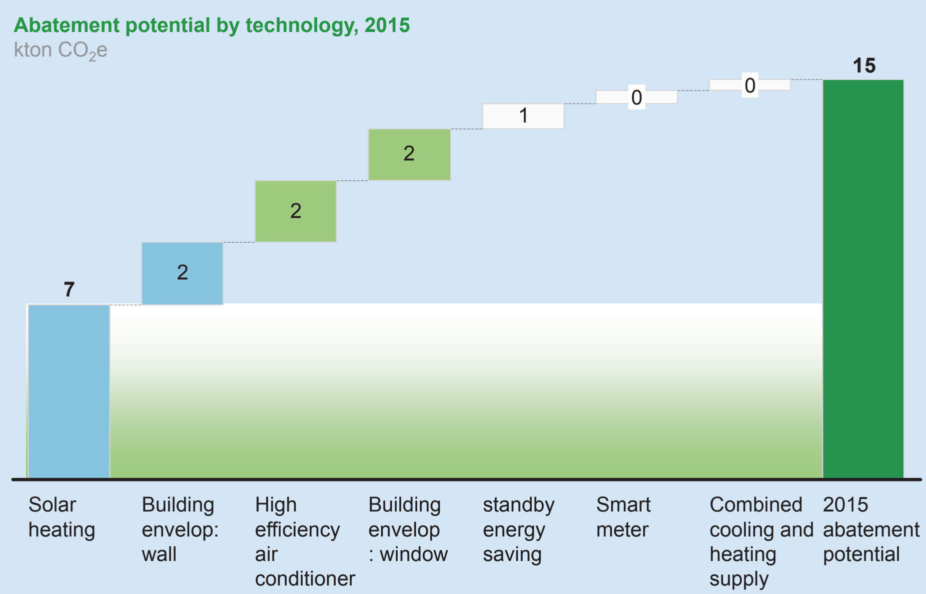
- The supply-center model would consist of one or two centralized energy supply centers to generate gas-fired power and heat. This model has the lowest cost because of its economies of scale, but requires high up-front costs for land acquisition and investment in equipment.
- The scattered model would locate small-scale generators close to groups of users.
- The single-building model is feasible for buildings that consume large amounts of energy.

A comparison of the three distributed-generation models concluded that the supply-center model is the most viable energy solution for Hongqiao area. This model is expected to lead to energy savings of 1,167 tce and an annual reduction in CO_2e emissions of 13.4 ktons.

Cluster III. Retrofitting existing residential buildings

If existing residential buildings were to be retrofitted with abatement technologies, 15 kton CO_2e could be avoided in 2015, which amounts to 8 percent of the total abatement potential for Hongqiao area. The main energy efficiency measures included in this category are solar heating, building envelope structure improvements, improvements in air conditioning, energy saving plugs, and smart metering (figure 4.5). Each measure is summarized below.

Figure 4.5 Abatement Measures under Cluster III -- Retrofitting Existing Residential Buildings



SOURCE: Team analysis

Solar heating. An on-site survey of the buildings in the area revealed that many roofs have good sun exposure and can be used to absorb solar energy. Solar systems can be installed close to the roof structure to reduce the adverse effects of the wind. Single-axis and dual-axis solar tracking systems can be applied to maximize the use of solar energy. Moreover, solar collector systems can replace the insulation layers that currently cover the buildings. The implementation of solar heating technologies will require an investment of 62 million RMB, cutting CO_2e emissions in 2015 by 6.7 kton.

Improving the thermal performance of the building envelope structure *(exterior walls and windows)*. According to the survey, most of the exterior surface material in the area is brick plus cement mortar, with a heat transfer coefficient of about 1.65, which does not meet the standard required by the government for residential buildings. An insulating material such as 25 mm extruded polystyrene (XPS) board can be added to the exterior surface. Plastic steel windows meeting particular specifications can be installed. These improvements to thermal performance are expected to reduce the heat transfer coefficient to 0.73, thereby reducing wall heat loss by 56 percent. Usually, one-third of the electricity consumed by air conditioners derives from the heat-transfer coefficient of the building envelope. Electricity consumption is expected to be reduced by 20 percent after the modification of the exterior surface. Improvements to the thermal performance of the building envelope for residential buildings require an investment of 149 million RMB, and would result in an emissions reduction of 4 kton CO_2e in 2015.

High-efficiency air conditioning. The survey estimates that the coefficient of performance of air conditioners could be raised and energy consumption in air conditioning reduced by 15 to 20 percent, which would result in an annual estimated saving of 3.28 GWh, equal to 1,092 tce.

Energy-saving plugs. The energy consumption of household appliances in their standby state derives mainly from color TVs, household computers, and household air conditioners. According to the survey of standby energy consumption within the whole city, 50 percent of household electrical appliances are usually in standby mode. It is suggested that intelligent, energy-saving plugs be promoted. These energy-saving plugs would require an investment of 1.4 million RMB, and would save 1 kton CO_2e in emissions in 2015.

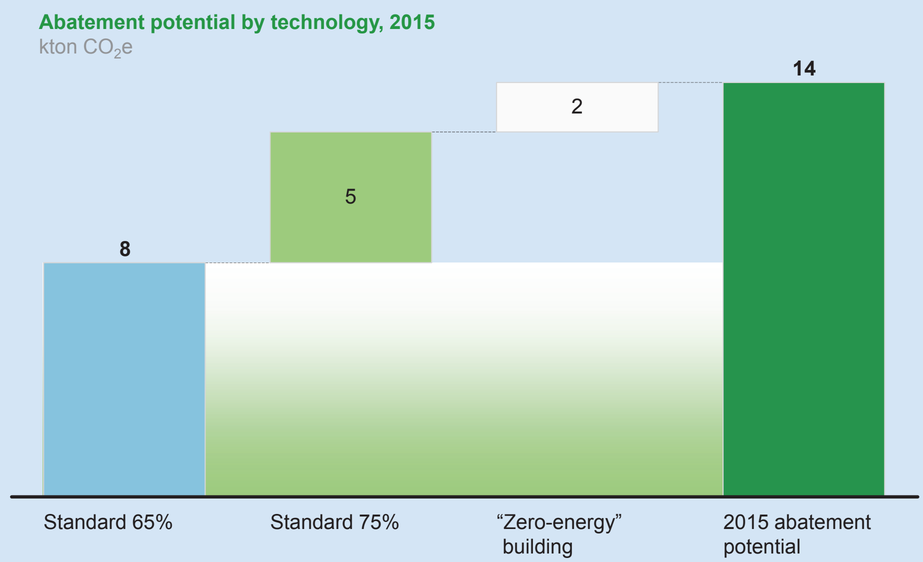
Other emission reduction measures. Other measures examined include the following:

- Reducing standby power;
- Installing additional solar water heaters;
- Installing household smart meters;
- Using residential co-generation for heating, cooling, and refrigeration and
- Encouraging green electricity consumption.

Cluster IV. Low-emission new buildings

The new building category has the potential to avoid 14 kton CO_2e, which amounts to 8 percent of the total abatement potential for Hongqiao area (figure 4.6). The main measures include implementation of the 65 percent energy efficiency standard for new buildings,[2] plus promoting a more stringent building code of 75 percent energy efficiency and zero-emission initiatives. These packages of solutions involve many building technologies. The more stringent building code and zero-emission initiatives include more advanced technologies and are hence more expensive.

Figure 4.6 Abatement Measures under Cluster IV -- Low-emission New Buildings



SOURCE: Team analysis

Measures to reach the 65 percent energy efficiency standard. To meet a more stringent building code of 65 percent, it is proposed to adopt measures such as LED lighting, air conditioning systems, geothermal pumps, cold and heat recovery systems, full fresh air system operation during transition seasons, and energy efficient elevators. These measures would save 1,380 MWh per year. The additional energy saving is 15 percent, roughly meeting the goal of 65 percent.

Measures to meet the 75 percent energy efficiency standard. To achieve 75 percent savings, it is proposed that more natural light (daylight inducement system) be used in underground garages and offices, to save 80 percent or 490 MWh per year of the lighting

[2] The Chinese government mandated that new buildings meet a target of 50 percent improvement in energy efficiency compared with buildings built in the early 1980s. Therefore, 65 and 75 percent building codes are a step further than the national building codes.

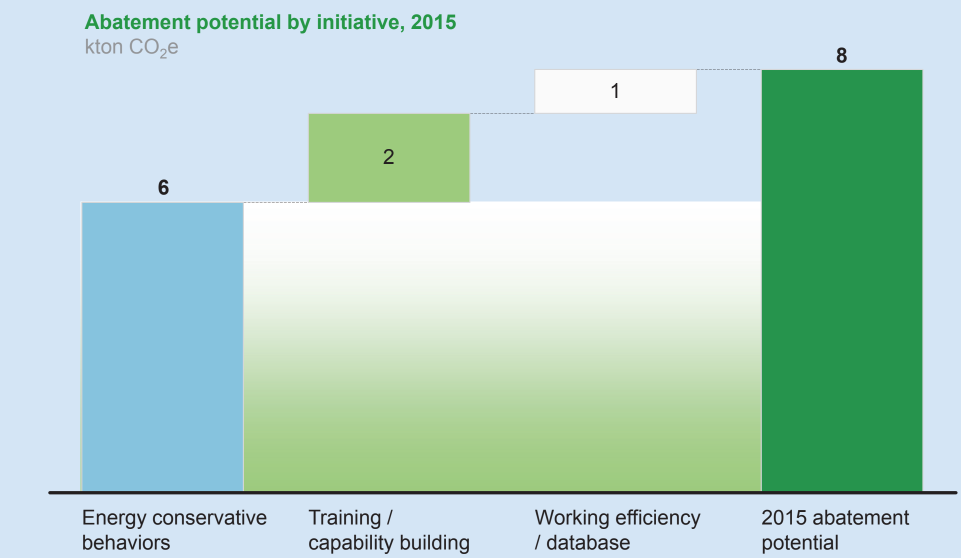
requirements. In the transition seasons, fresh air would be used to replace chillers. If the refrigeration load is 30 percent and the running time is 720 hours, 33.7 MWh per year would be saved. The total saving is 524 MWh/yr.

Measures for near-zero emission building. If the total energy needs of the building of 1,862 MWh were to be supplied by a solar PV system, the result would be zero emission. For solar PV generation, monocrystal silicon solar cells would be used, with a generating efficiency of 20 percent. The experts calculated that 13,300 m^2 of PV panels would be needed. The project area would provide more than enough rooftop, outer wall, and top of podium areas for the required solar panels.

Cluster V. Behavior change and capacity building

The behavior change and capacity building category comprises initiatives aimed at changing individuals' daily behavior, attitudes, and knowledge of energy use to result in energy conservation. This category has an abatement potential of 8 kton CO_2e, which amounts to 5 percent of the area's total abatement potential (figure 4.7).

Figure 4.7 Abatement Measures under Cluster V -- Behavior Change and Capacity Building



SOURCE: Team analysis

Energy-conservation behaviors. The study considered the following 19 energy-conservation behaviors, based on field surveys, "quantitative indicators of national energy conservation potential" developed by the Ministry of Science and Technology, and research conducted by the Shanghai Scientific Energy-Conservation Exhibition Hall. The research was used in particular to indicate what percentage of people would be likely to change their behavior, based on their responses to questions about willingness to adopt different measures. Capital investment for promoting energy-saving behaviors (for example, marketing expenses) will be 5.5 million RMB, which will bring about a reduction of 6 kton CO_2e in 2015. The measures include the following:

Energy-saving behaviors in government buildings

- Control indoor temperature to maintain a difference from the outdoor temperature not greater than 7–9 degrees Celsius
- Frequently optimize equipment based on the season or other conditions.
- Minimize the use of elevators.
- Pre-cool rooms with natural cold air at night.
- Adjust the air pressure balance to maintain positive pressure and avoid dissipating large quantities of hot or cold air.

Energy-saving behaviors in transportation

- Drive one day less per month.
- Travel more than 200 km a year using energy-efficient transportation.
- Increase the proportion of public transport use.
- Use cars rationally and pay attention to maintenance, such as the timely replacement of air filters, maintaining proper tire pressure, and other measures.

Energy-saving behaviors by residents

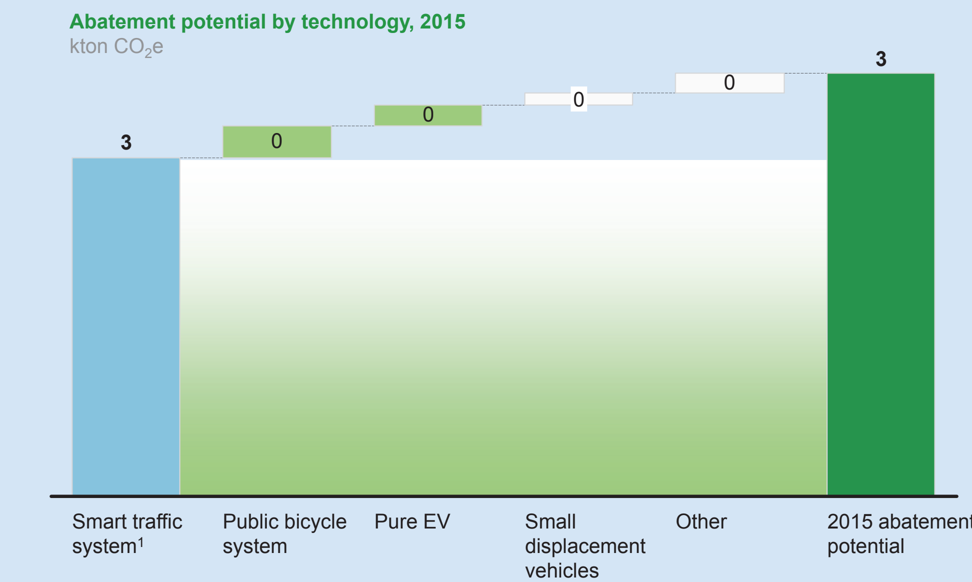
- Purchase efficient air conditioners.
- Avoid air conditioning in transition seasons.
- Launder by hand once a month.
- Use air conditioners rationally by raising the temperature 1 degree Celsius.
- Switch to energy-saving lamps for home lighting.
- Use TV less.
- Turn off electric appliances when not in use.
- Reduce energy consumption during standby mode for air conditioning and TV.
- Avoid opening windows when heating or air conditioning is on.

Capacity building and energy management. Building the capacity for energy efficiency broadly in society, and implementing energy management programs that use databases to track possible measures, activities under way, activities completed, and the resulting carbon emissions reductions and costs are estimated to result in carbon emissions reductions of 3 ktons per year.

Cluster VI. Green mobility

The green mobility category has an abatement potential of 3 kton CO_2e, which is 2 percent of the total. The main measures in this category are a smart transportation system, which accounts for almost all of the 3 kton reduction, together with a public bicycle rental system, electric vehicles, hybrid and low-emissions cars, and energy-efficient street lighting measures (figure 4.8).

Figure 4.8 Abatement Measures under Cluster VI – Green Mobility



1 Including traffic monitoring and optimization (e.g. traffic light control), parking information system and differentiated traffic pricing (e.g. parking fees)

SOURCE: Team analysis

Smart transportation system. This measure involves the following:

- Establishing a traffic guidance system to help road users reach their destinations more smoothly.
- Building a regional parking-information collection system. Information related to parking areas would be shared through regional global information systems and the Internet, making it possible to access information in real time.
- Developing a differential transport fare system on the basis of date and time.

Setting up the smart transportation system would require a total investment of 16 million RMB. An annual carbon reduction of 2.6 kton CO_2e can be expected after full implementation of the system.

Electric, hybrid, and small cars. This measure would encourage the use of pure electronic vehicles, hybrid electric vehicles, and low-emissions cars and other low-carbon vehicles. Low-carbon vehicles would be given priority access to conveniently situated parking places. Battery-charging locations should be established in public areas and in workplace garages.

Public bicycle-rental system. A public bicycle-rental system could be established within Hongqiao area, with rental and return stations set up at subway stations, office buildings, and near communities.

Intelligent power-saving controllers for road lighting. Because the city becomes quieter at midnight, with significant reductions in traffic flow, illumination could be reduced to the lower limit allowable under the road lighting standard. It is recommended that smart power-saving control devices be added to most lights. If such devices were installed on one-third of the roads in the area, an annual electricity savings of 66,000 kWh would occur, calculated on the basis of an energy-saving rate of 20 percent. The investment would be 0.18 million RMB, with annual electricity cost savings of 0.06 million RMB.

Light-emitting diode (LED) street light demonstration. The 29 street lights in a residential area on Ziyun Road and Ziyun Road West were selected to demonstrate LED street lighting. The current street lights, 250 W high-voltage sodium lamps, would be replaced by 100 W LED lamps, saving 60 percent of electricity consumed. The annual saving is 20 MWh and savings in the lighting bill is 16,000 RMB . The investment is 270,000 RMB , so the payback period is 17 years

Smart energy-saving controller on high-voltage sodium street lamps. This kind of controller has been deployed in Shanghai, resulting in energy savings of 20.5 to 35 percent. Because the controller runs the lamp at a voltage lower than that of the grid, it extends the life of the lamp and reduces the failure rate. Installing smart controllers on one-third of the street lights in Hongqiao area, with 20 percent energy saving, would result in annual savings of 66 MWh. The cost is 180,000 RMB . The electricity bill would be cut by 60,000 RMB, resulting in a payback period of three years.

Wind and solar generation for lighting in green areas. The survey team proposed to carry out a wind and solar generation project for street lighting on Xinyi Road. Six reflective garden lamps, 12 x 250 W high-voltage sodium lamps, and 11 x 20 W landscape lamps would all be replaced with 50 W LED, and 300W of wind turbines and 150 W of solar cells would be installed on poles. The total cost would be 464,000 RMB , resulting in an annual energy savings of 5.1 tce.

These findings are not an exhaustive estimate of the potential GHG emissions reduction for Hongqiao area. Estimates reflect the upper technical limit of the abatement potential of the measures covered in the analysis. New abatement solutions are likely to emerge in the sectors analyzed, further enhancing the area’s potential for low-carbon development.

5

The Abatement priorities: Abatement Measures Ranked by Cost and Ease of Implementation

In this chapter, the abatement cost curve incorporates a third dimension—ease of implementation—in addition to the abatement potential and cost estimates presented in the previous chapter. The emissions-reduction measures are ranked by their costs and ease of implementation, and categorized into three different priority groups for implementation. Key barriers to implementation are reviewed.

Ranking abatement measures by ease of implementation

The cost and level of difficulty of implementing the various possible actions provide a basis for prioritizing them into an abatement strategy. Actions that are economically beneficial to Hongqiao area and that are relatively straightforward should be implemented at once. Those that are more expensive or more difficult need a more phased approach to implementation.

Although each of the potential abatement measures are achievable, they are not equally easy to implement. Besides their costs, which vary widely, the abatement measures differ greatly in their relative ease of implementation, which is a combination of factors including economic feasibility, technology readiness, and market circumstance (figure 5.1).

These factors are discussed below.

- *Economic feasibility.* Those solutions with a positive net present value (NPV) are more attractive to investors, whereas ones within a reasonable cost range (that is, 600 RMB per ton of CO_2e abated, which is the weighted average cost of all 58 measures) can be promoted by supportive policies, such as subsidies, tax benefits, and the like. Measures with smaller capital investments and shorter payback periods are more accepted by the market. An example of such a technology is high-efficiency lighting for commercial buildings. Given that the client of this study is the Changning District government, the marginal abatement costs were calculated using a social discount rate of 8 percent. However, the investors would expect a higher rate of return. As a result, some abatement opportunities that seem to be win-win from a public perspective are not necessarily easily

Figure 5.1 Ease of Implementation is Driven by Three Factors

	Description	Examples
Economic feasibility	▪ Solutions generate positive NPV, or at least within reasonable cost range (i.e. RMB 600/ton CO_2e) ▪ Ones with relatively smaller Capex, and shorter payback period are considerably better choices	▪ High efficiency lighting for commercial buildings not only saves energy, but brings about substantial economic benefits
Technology readiness	▪ Mature technologies are easier to be accepted and rolled out ▪ Technologies with lower complexity and wider applications are preferred ▪ No foreseeable alternatives are available	▪ Air conditioner with converter motor has become a more standardized energy-saving technology, and hence widely applied
Market circumstance	▪ Supportive policy environment makes initiatives alive ▪ Market familiarity (i.e., market education, successful pilot projects) is also important, especially for new technologies	▪ Shanghai government provides substantial subsidies for purchasing EV

SOURCE: Team analysis

implemented by the private sector. In addition, even though most energy efficiency and renewable energy investments can be recovered by reduced costs from less fuel consumption, many investors still face upfront financing barriers. Investors are only interested in those mitigation measures with high rates of return and short payback periods, but such investments will not be sufficient to achieve the government's deep emissions-reduction targets. Therefore, government financial incentives are essential for making financially unattractive opportunities viable for private sector investors .

- *Technology readiness.* Mature measures will be more easily accepted and rolled out, mainly as the result of lower risks and commodity prices. Also, less-complex measures are easier to handle and thus more likely to be accepted. Furthermore, measures with a wider range of applications are more frequently chosen. However, even complex measures are also likely to be used if they are applicable only to very specific situations for which alternatives are not available.

- *Market circumstances.* Given the high cost and externalities involved in many green technologies, supportive government policies are key to driving their penetration. For instance, although the 65 percent energy efficiency improvement building code has a high cost (greater than 1,000 RMB/ton CO_2e), because the municipal government made it mandatory for all new buildings, developers are obligated to comply. Market acceptance is also important. Even though many green technologies have a positive NPV, management of enterprises often does not recognize or accept them because the technologies are too new to be well understood.

Based on an analysis of these factors, each of the 58 measures was classified according to its ease of implementation: easy, medium, or difficult (figure 5.2).

Figure 5.2 Technologies Can Be Classified into Three Levels of Ease of Implementation

	Technologies		
Easy	▪ Building code standard 65%[1] ▪ Air side free cooling (fresh air) ▪ Efficient Lighting Replacement ▪ Heat exchangers ▪ Replace electric refrigeration cooling lithium bromide	▪ Frequency conversion turbine ▪ Chilled water temperature reset ▪ Intelligent control of road lighting ▪ Residential standby power saving ▪ Elevator group control technology ▪ Elevator frequency control system	
Medium	▪ Public building shading ▪ Optimization of public air-conditioning ▪ Self-cleaning ball for condenser ▪ Free cooling from cooling tower ▪ Control of cooling tower ▪ Power boiler to gas boiler ▪ Boiler heat recycling ▪ Oil-fired boiler to gas boiler ▪ Incremental membrane for shopping mall light boxes	▪ Frequency conversion for pumpers ▪ Screw heat recovery ▪ Elevator energy feedback ▪ Auto-sensing escalator ▪ Intelligent control of the underground garage exhaust fan ▪ Smart meters for residential use ▪ Efficient residential air conditioning ▪ Wind-and-solar road landscape lighting	▪ LED street lighting ▪ Small cars ▪ Ground Source Heat Pump ▪ Energy efficiency management, database construction ▪ Purchase of green power ▪ Transformer upgrade ▪ Roof planting ▪ Special training
Difficult	▪ Building envelop: public windows ▪ Building envelop: public walls ▪ Building envelop: residential windows ▪ Building envelop: residential walls ▪ Building code standard 75% ▪ Zero-energy buildings ▪ Residential solar heating system ▪ Combined cooling and heating supply ▪ Distributed Energy	▪ Amorphous thin film power (glass wall) ▪ Solar photovoltaic ▪ Natural light for underground garage and top level ▪ Visualized power monitoring ▪ Sub-metering ▪ Online Temperature Monitoring ▪ Water large temperature difference controls	▪ Pure electric vehicles ▪ Hybrid cars ▪ Regional public bike rental system ▪ Intelligent Transportation Systems ▪ Vertical green wall ▪ Energy saving behavior

1 Shanghai government has made building code standard 65% mandatory for all new buildings

SOURCE: Team analysis

Analyzing implementation barriers

Challenges to building retrofit: Although retrofitting existing buildings presents the largest emission-reduction potential in Changning District and has a wide potential for replication in China, it is one of the most difficult EE market segments. In Changning District, retrofitting commercial buildings has a much larger emissions-reduction potential than retrofitting residential buildings, but the following market barriers arise:

- ***Reluctance of building owners to retrofit:*** The single largest barrier to retrofitting commercial buildings is that owners, usually multiple owners for one building, are reluctant to invest in EE measures, because (a) energy costs are a small share of operating costs and are usually passed through to the tenants; (b) building retrofit investments usually have long payback periods; and (c) owners do not want to interrupt commercial operation of the buildings for retrofit.

- ***Lack of mandatory policies:*** At present, national and municipal governments have mandatory building codes for new buildings, but not for building retrofit. In addition, current building codes in China need improvement. The national building codes require new buildings to be 50 percent more energy efficient than the baseline buildings from the 1980s, while Shanghai's building codes are a step ahead of national codes requiring 65 percent greater energy efficiency. These buildings codes focus on input-based individual technology requirements rather than performance-based energy consumption (e.g., in kWh/m^2). They, therefore, are not directly linked to total energy savings and emission reduction.

- ***Lack of sufficient financial incentives:*** Building EE projects, in particular the envisaged investments to achieve Changning District's ambitious energy saving targets, usually have a long payback period (8–10 years), while commercial investors are normally only willing to invest in projects with a 3–5 year payback. The current subsidies provided by the national and municipal governments seem insufficient to induce investments in this market on a large scale. Currently, the national and municipal governments provide a subsidy of 60 RMB/m^2 ($\$9.5/m^2$) for building retrofit achieving national building codes, or 500 RMB/tce ($80/tce) energy savings for energy service companies (ESCOs) that invest in EE measures (both industrial and building EE), equivalent to only 3 percent of the capital investment of an average building retrofit project. For renewable energy in buildings, the national and municipal governments offer a subsidy of 14 RMB/Wp (or $2.2/Wp) for rooftop solar PV, and mandate that all buildings of less than six stories install solar water heaters. Additional incentives are therefore critical to improve the financial viability of building retrofit investments and to motivate building owners, developers, and property management companies to invest in buildings on a large scale to achieve higher emission reductions.

- ***Lack of viable business models:*** A lack of viable business models also prevents large-scale market uptake of building EE retrofit. First, building EE projects typically face the split incentive barrier—the investors in EE measures and the beneficiaries of energy savings are usually not the same, for example, tenants typically pay energy bills so owners have little or no incentive to spend on EE investments. Therefore, it is critical to understand the intricate relationships among building owners, property management companies, renters, and ESCOs, so that policies and financing mechanisms will be targeted to the right groups. Second, individual building EE investments tend to be quite small and dispersed, typically about US$500,000 , so bundling these small deals is important to reduce transaction costs for financing. Therefore, it is critical to develop viable business models to identify the potential interested investors and find ways to bundle small-scale building EE projects.

- ***Lack of access to financing:*** Financial institutions are usually reluctant to finance building EE investments because of (a) the small size of each project (the average size of a typical building retrofit project usually ranges between US$500,000 and US$1,000,000) and high transaction costs; (b) high credit risks of ESCOs, which typically implement building retrofit projects but normally do not have major assets to offer as collateral; and (c) the perceived high technical risks and concerns about materialization of projected energy savings.

- ***Performance risk:*** Consumer behavior and management of the energy systems are two important factors that influence the actual energy savings of building EE projects, so there is some risk that projected energy savings may not be fully achieved.

High costs of low-emission buildings: The primary barrier to investment in near-zero-emission (NZE) buildings is the high incremental cost, which results in payback periods of more than 20 years. NZE buildings also face the classic split-incentive barrier—investors and developers bear the high incremental costs, while the renters enjoy the energy saving benefits. There is also a lack of demonstrated technical, financial, and commercial feasibility of these advanced building designs.

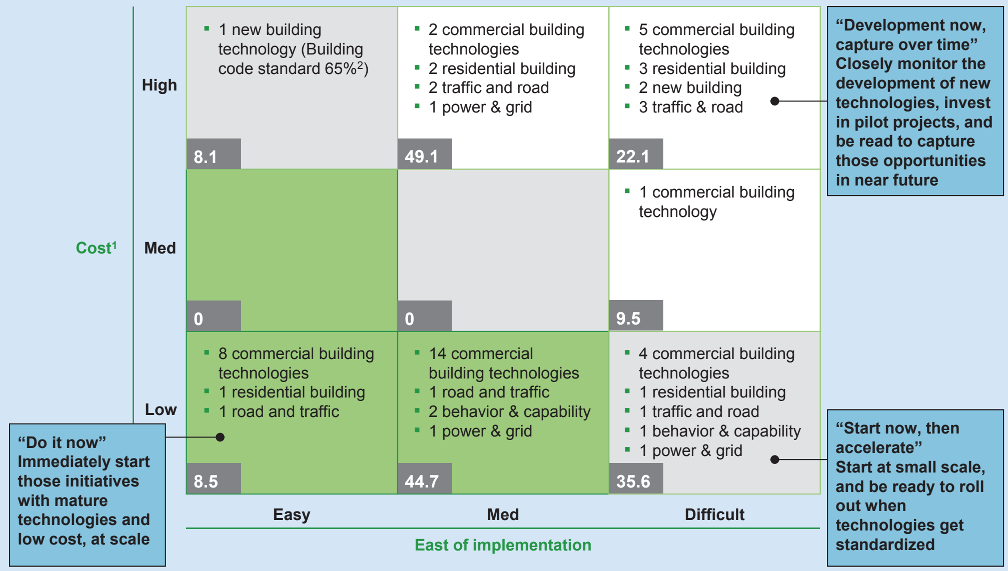
Barriers to distributed generation: Low-carbon distributed generation for urban applications can provide significant energy savings and emission-reduction potential through renewable energy generation; cogeneration of power and heat; and conversion from oil-fired to gas-fired boilers. However, the major barrier to distributed generation in China is lack of access to the grid, and lack of sufficient financial incentives to make it financially viable. The solution to this problem is closely linked with the envisaged power sector reform, but that will take time.

Bottlenecks to green mobility: Lack of integration and connection between various modes of urban transport is one the most significant barriers to high ridership of public transport systems in Changning District. This barrier is most evidenced by the "last mile" problem, where there is a one to two km gap between the metro station and most office buildings in the district. In addition, a convenient means or pathway for traveling this final distance is often unavailable. This is a key barrier that prevents more people from taking metro.

Grouping abatement measures into three categories

Based on this analysis, the 58 abatement measures can be grouped into three categories. One group consists of measures that are low on both axes of a matrix: they are cheap and not very hard to implement. The next group comprises those that are somewhat more challenging, either because they are more expensive or because they will be harder to implement. The last group consists of measures that are high on both dimensions:

Figure 5.3 Technologies Can be Prioritized into Three Groups by Cost and Ease of Implementation



1 Low: < 0 RMB/ton CO_2e; High: > 600 RMB/ton CO_2e, which is the weighted average cost of all technologies; Med: everything between Low and High
2 Will be categorized as "do it now", since government has already make this building code mandatory

SOURCE: Team analysis

they are expensive and challenging. This grouping provides the basis for a strategy that maximizes potential gains and minimizes risks. Hongqiao area can pursue an ambitious low-carbon growth strategy by tackling abatement measures on three distinct "frontiers" of prioritization: "do it now," "start slow, then accelerate," and "develop now, capture over time" (figure 5.3).

Grouping these abatement measures into three categories provides an analytical framework for sequencing abatement actions in the short, medium, and long terms. The main characteristics and elements in each group are summarized below.

Group 1 – Do it now

Group 1 encompasses measures that are based on existing technology and have low to modest implementation barriers and costs (< 600 RMB/ton CO_2e). Many of these measures are in Hongqiao area's best interests, even without taking emissions reduction into account—these are sometimes called "no regret moves." They cost little and will yield considerable benefits. These provide the most cost-effective, near-term abatement measures and are therefore a top priority for immediate action.

Taken together, all the actions in Group 1 achieve about 61 kton CO_2e of emissions reduction (34 percent of the area's total abatement potential). These actions include 22 abatement measures for retrofitting existing commercial buildings; one green power measure; one measure to retrofit existing residential buildings; one measure in the low-emissions new building cluster; two measures in the behavior change cluster; and two in green mobility:

- Retrofitting existing commercial buildings: 22 of the 33 identified measures are included in this "do it now" group—all boiler and elevator improvement measures and all air conditioning optimization measures except for two.
- Green power: Transformer phase-out is a mature technology upgrade with negative lifetime cost
- Retrofitting existing residential buildings: Energy-saving plug is a small device that reduces the energy consumption of home appliances while in standby mode.
- Low-emissions new buildings: The 65 percent energy efficiency improvement building code is included in Group 1 despite its high cost because it is already mandated by the municipal government.
- Behavior change: Only special training and the energy database are included in this group.
- Green mobility: Small cars and intelligent control of road lighting are included in Group 1.

Group 2 – Start now, then accelerate

Group 2 covers the measures that provide abatement at moderate cost with modest implementation barriers; they are either cheap but difficult, or expensive but easy. Many of these should be readily achievable around 2015 if small-scale or pilot projects are pursued now and then scaled up rapidly. Together, these measures account for about 36 kton CO_2e (20 percent of the total abatement potential). These mainly include measures with positive NPV that are difficult to implement, such as online temperature control, large water system temperature difference control for commercial air conditioning, visualized power monitoring, submetering for commercial buildings, solar heating systems for residential buildings, a smart transportation system, energy-saving behavior, and distributed energy generation.

The main barriers to these high-potential abatement measures are that renewable energy distributed generation systems are costly and lack grid access; and it is difficult to change people's behavior.

Group 3 – Develop now, capture over time

Group 3 covers the most challenging group of measures—those that both cost a lot and face high hurdles, either because they are not yet technologically available or because they pose great planning risks and demands on infrastructure. Nonetheless, they promise considerable abatement in 2015 and much greater gains thereafter.

Therefore, implementation should begin on small scale now, so as to be ready for quick implementation once they fall within reach. Together, these measures account for about 81 kton CO_2e (45 percent of the area's total abatement potential).

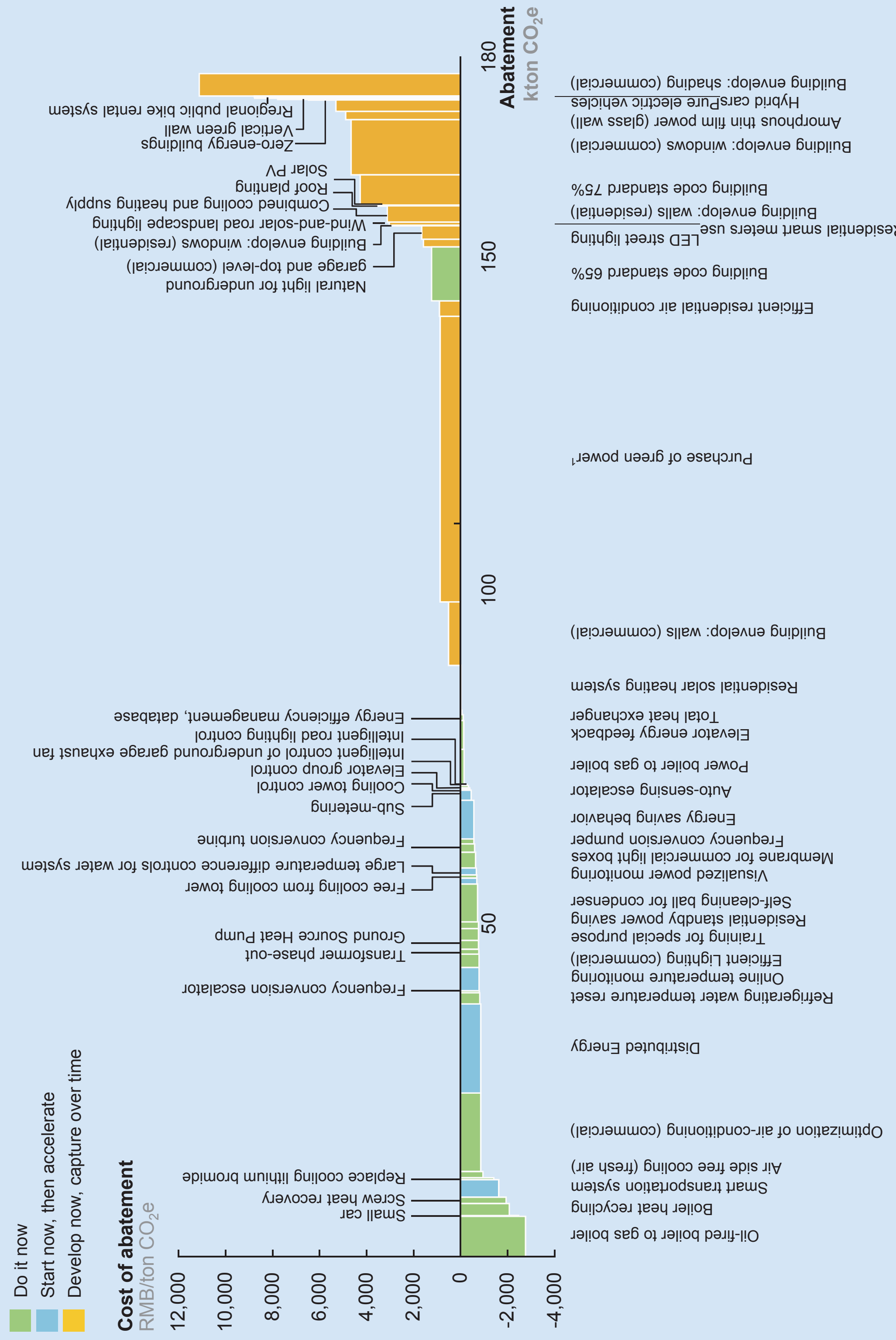
Group 3 includes eight measures for retrofitting existing commercial buildings, one green power measure, five measures for retrofitting existing residential buildings, two for low-emissions new buildings, and five for green mobility. The main barriers to implementing these measures are as follows:

- Retrofits to the building envelope (for example, exterior wall insulation, window replacement, and shading) for both commercial and residential building are very expensive, and not as cost effective in Southern China as they are in the North because weather conditions are not as extreme.
- Solar technologies (PV and thin film) are very costly to implement in Hongqiao area, but the costs are expected to come down significantly in the next 10 years.
- Higher standards for low-emissions new buildings (for example, 75 percent building energy efficiency improvement standard and zero-emission buildings) are not currently attractive because of their very high cost. The 65 percent standards have just been made mandatory by the municipal government, thus their implementation will be the focus for the next five years.
- Electric vehicle development is expected not to take off for about five to ten years because of high costs. Even with the subsidies provided by the Shanghai government, the total cost of owning an electric vehicle is still much higher than a conventional car, and the infrastructure (for instance, charging facilities) is still lagging.
- LED lighting technologies are still on their way to being fully commercialized. The cost today remains high, but is expected to decrease quickly by 2013–15.

Carbon abatement cost curve for Hongqiao in 2015

Based on the data in table 4.1 and the ease of implementation categorization above, a carbon abatement cost curve was prepared for Hongqiao for 2015 (figure 5.4). Abatement is measured in tons of CO_2e, and the cost of reducing emissions in RMB per ton of CO_2e. In the abatement cost curve, each of the 58 measures is represented by a bar. The height of each bar represents the cost per ton of CO_2 abated, while the width of each bar represents the amount of carbon abated by the technology in 2015. The measures are ordered beginning with those with the lowest cost per ton of CO_2 abatement and proceeding to the highest. Different colors are used to indicate the priority of the measures, with green indicating Group 1 "do it now," blue indicating Group 2 "start now, then accelerate" and yellow indicating Group 3 "develop now, capture over time."

Figure 5.4 Abatement Cost Curve with Ease of Implementation in Hongqiao Area in 2015



1 Purchase volume is forecasted by surveys. Although emission reduction counts according to statistics rules, it is still debatable

SOURCE: Team analysis

6

The Low-Carbon Targets: Abatement Scenarios for 2015 and 2020

The study developed three scenarios: the frozen technology scenario; the baseline scenario (to meet the national government's carbon-intensity-reduction target); and the stretch scenario (beyond the national government's target) to determine an ambitious low-carbon target for Hongqiao area from 2010 to 2015. These scenarios were then extrapolated to 2020 for Hongqiao area and extended to Changning District.

The frozen technology scenario is a theoretical scenario that assumes that no new carbon-reducing technologies are introduced between 2010 and 2015 and that current technologies remain at their 2010 penetration levels. Thus, carbon emissions per unit of production would remain at 2010 levels for all industries. Based on these assumptions, the carbon emissions were calculated based on the expected growth in production volumes of each industry to reflect the growth in the economy under this scenario, and the constant factors of carbon emissions per unit of production.

The baseline scenario assumes that local governments will take actions to meet the national government's carbon-reduction target in China's 12th Five-Year Plan (FYP), given that these commitments are already in place. Measures in the baseline scenario were included based on their ease of implementation and cost. The 2015 baseline scenario builds on the extensive data collection and analysis of real examples in Hongqiao area that resulted in identification of 58 measures for carbon reduction. It provides a bottom-up analysis of GHG emissions across six clusters: retrofitting existing commercial buildings, green power, retrofitting existing residential buildings, low-emissions new buildings, behavior change and capacity building, and green mobility. It assumes higher penetration rates for the "do it now" group of measures and progressively lower rates for the "start now, then accelerate" and "develop now, capture over time" groups.

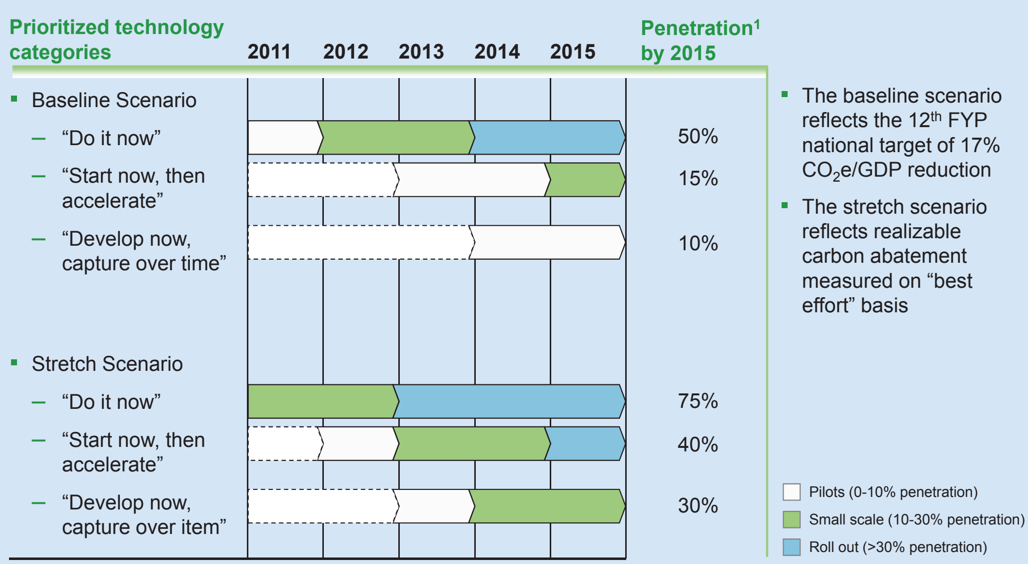
Achieving the baseline scenario is no easy matter; success will depend on concerted efforts by the government and the private sector. In particular, given the nature of social benefits and the externalities of many abatement measures, government will need to provide effective market incentives, create consistent regulations and policies, and ensure their enforcement.

The difference between the frozen technology and baseline scenarios represents the reduction in emissions "embedded" in current trends in regulation and market forces, including measures taken to meet 12th FYP targets. The baseline emissions figure for 2015 shows the substantial impact of measures and initiatives compared with the frozen technology scenario.

Nevertheless, Changning District and Hongqiao area are seeking a further reduction in emissions. This more ambitious target is analyzed in the stretch scenario, which estimates the potential impact and cost of the measures to reduce emissions using higher penetration levels than in the baseline scenario. The stretch scenario includes measures with higher costs (such as retrofitting the building envelope) and measures with more complexity (such as a smart transportation system). The 2015 stretch scenario does not assume any major technological breakthroughs. It focuses on abatement measures that are already well understood and likely to be commercially available in the future.

Each abatement measure will follow its own development path, with some taking relatively little time to be fully captured while others require longer. Figure 6.1 shows the paths for measures in the different priority groups, under both the baseline and stretch scenarios.

Figure 6.1 Technology Penetration Rate for Different Scenarios



1 "100%"=2015 max abatement potential

SOURCE: Team analysis

- "Do it now" measures ramp up quickly into the rollout phase, which might continue for a long or short period, depending on the difficulty of achieving full implementation and the turnover period for capital stock. The analysis assumes that 50 percent of the technical abatement potential of these measures is captured in the baseline scenario while 75 percent is realized in the stretch scenario.

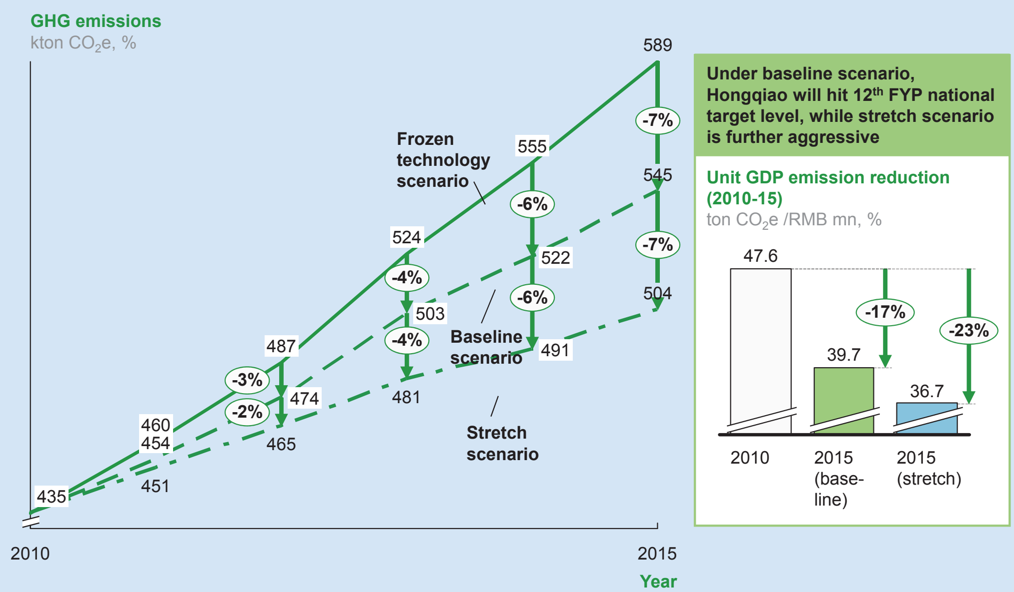
- Measures in the "start now, then accelerate" group, however, start with a small-scale implementation phase, then require some years before moving into a full rollout stage. Penetration rates of these measures are assumed to be 15 percent in the baseline scenario and 40 percent in the stretch scenario.

- Measures in the "develop now, capture over time" group are currently in the research and development or planning stages. Pilot projects are often a good way to test the waters before small-scale application begins. Measures in this category will need longer to fully penetrate the market. Penetration rates are assumed to be 10 percent in the baseline scenario and 30 percent in the stretch scenario.

Abatement Scenarios for Hongqiao Area in 2015

In the baseline scenario, carbon emissions in Hongqiao in 2015 are expected to be reduced to 545 kton CO_2e as compared with 589 kton CO_2e in the frozen technology scenario. Therefore, 44 kton CO_2e would be avoided in 2015, resulting in abatement of 7.5 percent. This scenario reflects the business-as-usual situation and assumes that the government provides the support necessary to achieve the 12th FYP national carbon-intensity-reduction targets (figure 6.2).

Figure 6.2 Achieving Stretch Scenario Abatement Potential Can Reduce GHG Emissions by 15 Percent from the Frozen Technology Scenario in 2015

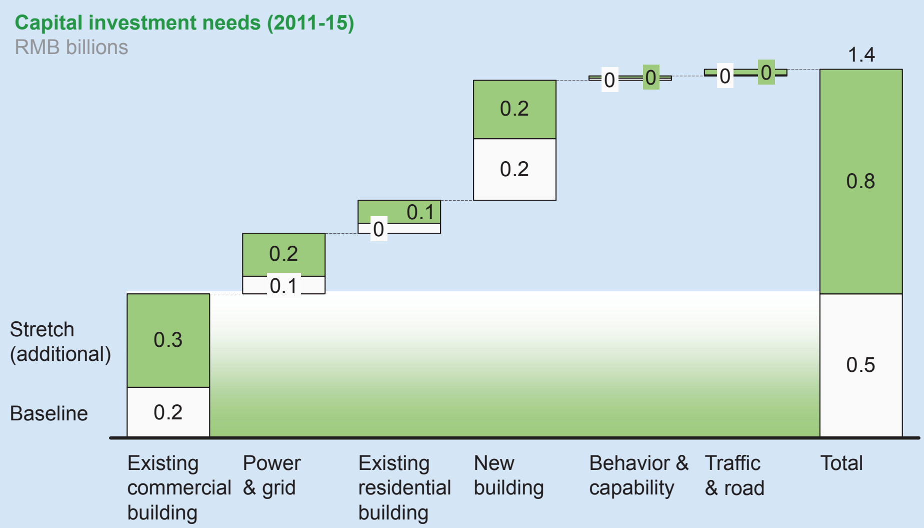


SOURCE: Team analysis

Under the more ambitious stretch scenario, about 41 kton CO_2e will be avoided on top of that in the baseline scenario in 2015. The total CO_2e reduction will be 85 kton off the frozen technology scenario, making up 15 percent of the total GHG emissions of Hongqiao area. Here, penetration of measures is considerable. It is assumed that the government pursues more aggressive targets and effectively stimulates private sector action.

Capital investment requirements for the different scenarios were also estimated. The total capital investment required under the baseline scenario is 0.5 billion RMB from 2011 to 2015; most solutions implemented in this scenario fall into the "do it now" group, having low to medium investment requirements. The total capital investment required under the stretch scenario is 0.9 billion RMB between 2011 and 2015 on top of that in the baseline scenario in 2015; more costly technology solutions in the "start now, then accelerate" and "develop now, capture over time" groups are implemented in the pursuit of more aggressive low-carbon growth targets (figure 6.3). Under both scenarios, the most capital-intensive abatement technology clusters are retrofits to existing commercial buildings, green power, and low-emissions new buildings.

Figure 6.3 A Cumulative Investment of 0.5 and 1.4 billion RMB is Needed Respectively, to Achieve Baseline and Stretch Scenarios, 2011-15



SOURCE: Team analysis

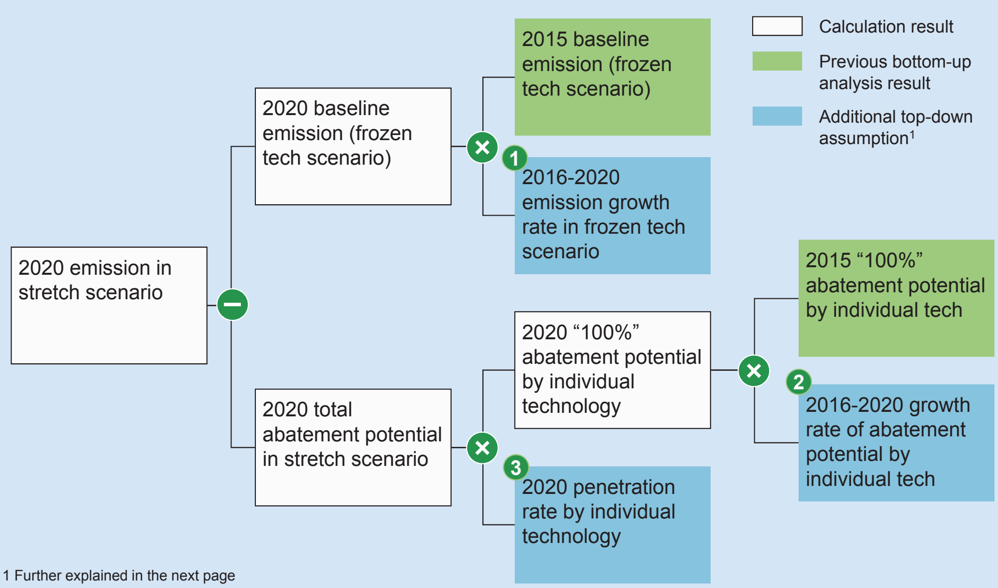
Abatement scenarios for Hongqiao area and Changning District in 2020

The abatement scenarios in Hongqiao area for 2015 are extrapolated to 2020, and expanded to the entire Changning District to provide a rough estimate of the potential impact of further rolling out the 58 identified measures.

Hongqiao stretch scenario 2020

To project the stretch scenario in Hongqiao area to 2020, results of the bottom-up analysis were combined with additional top-down assumptions. Then, CO_2 emissions under the frozen technology scenario and the abatement potential under the stretch scenario in 2020 were calculated to arrive at the projected CO_2 emissions reduction under the stretch scenario in 2020 (figure 6.4).

Figure 6.4 Extrapolation Assumptions from 2015 to 2020 in Hongqiao Area



1 Further explained in the next page

SOURCE: Team analysis

The CO_2e under the frozen technology scenario in 2015 is taken as the starting point for calculating emissions in 2020. For a fully developed urban area like Hongqiao, CO_2e is mainly driven by incremental building floor space, such as the construction of more commercial and residential buildings, and improvements to comfort levels, such as using more air conditioning as income levels continue to rise. The annualized growth rate of floor space is estimated to be 1.9 percent for the period 2015–20. Improved comfort levels are estimated to have an annualized incremental impact on CO_2e of 2.8 percent. Thus, the emissions growth rate is forecast to be an annualized 4.8 percent during 2015–20.

To estimate the abatement potential, the measures that will further penetrate markets as technologies mature and become more widely accepted are supplemented by the maximum potential of a further increase in the longer term as markets grow (for example, more buildings are constructed) and the technologies evolve (rapid improvement in the performance of electric vehicles, for instance).

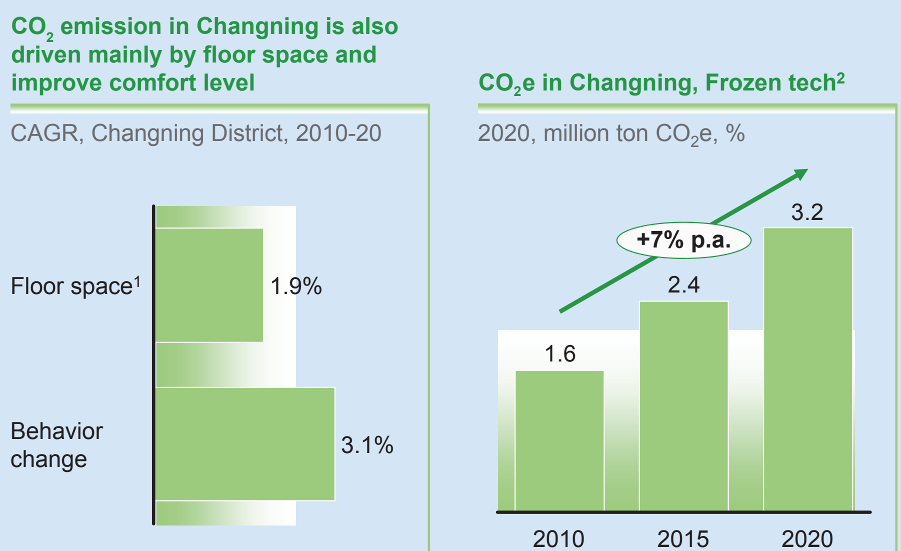
Overall, the maximum abatement potential is estimated to grow at an annualized rate of about 5 percent during 2015–20, with different growth rates for different measures (figure 6.4). Meanwhile, the penetration rates reach about 100 percent for the "do it now" and "start now, then accelerate" groups, and about 80 percent for the "develop now, capture over time" group.

Based on the estimates and assumptions, it is forecast that CO_2e in Hongqiao area will be about 750 kton by 2020 under the frozen technology scenario; with maximum technology implementation, the CO_2e in the stretch scenario will be about 530 kton in 2020.

Changning District stretch scenario 2020

It is assumed that Hongqiao area is adequately representative of Changning District. The same extrapolation methodology is used to forecast that CO_2e in the Changning District will reach 3.2 million tons by 2020 under the frozen technology scenario (figure 6.5).

Figure 6.5 Assumptions to Extend from Hongqiao Area to Changning District



1 Commercial floor space CAGR 3.9%; Residential CAGR 0%
2 CO_2e CAGR = (1 + commercial floor space CAGR)*(1+ behavior change CAGR)*weight + (1 + commercial floor space CAGR)*(1+ behavior change CAGR)*weight-1

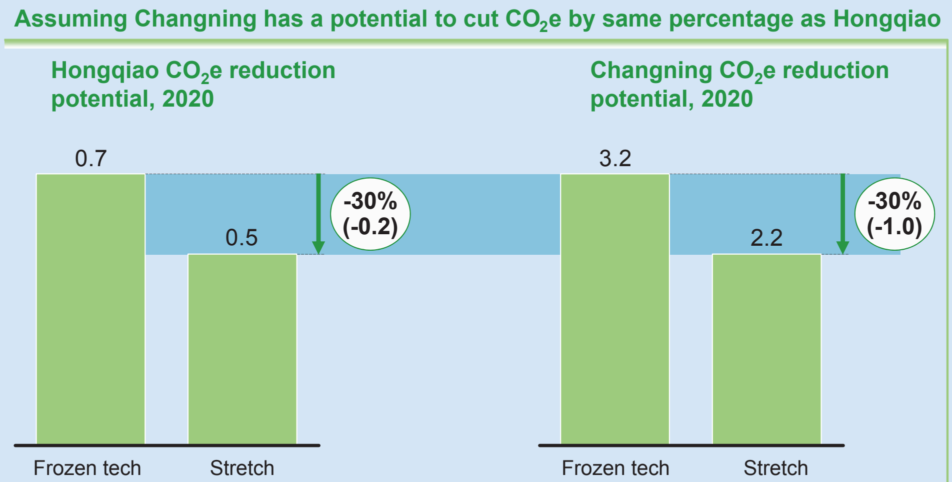
SOURCE: Changning DRC, McKinsey China carbon abatement cost curve 2030, Team analysis

It is further assumed that the same percentage reduction of CO_2e can be achieved in the Changning District as in Hongqiao area, yielding a potential 1 million ton CO_2e reduction for the Changning District under the stretch scenario (figure 6.6). It should be noted that the extrapolation of the analysis to Changning District is subject to significant uncertainty, but this is the best estimate given constraints on time and budget resources.

Figure 6.6 Carbon Reduction Potential in Changning District by 2020

~1 million ton CO_2e reduction is projected by 2020, assuming Hongqiao is representative of Changning District

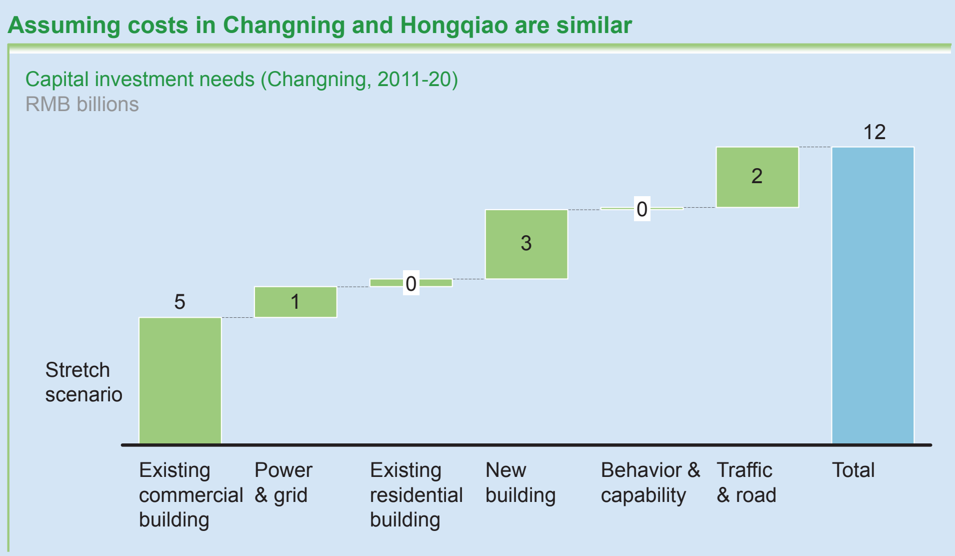
Million ton CO_2e, %



SOURCE: Team analysis

A rough estimate of capital investment. based on the assumption that similar measures will be implemented in Changning District as those in Hongqiao area, shows that an investment of 12 billion RMB would be required to achieve the stretch scenario, in 2011–20 (figure 6.7).

Figure 6.7 A Cumulative Investment of 12 billion RMB is Needed for Changning District to Achieve 2020 Stretch Scenario, 2011-20



SOURCE: Team analysis

7

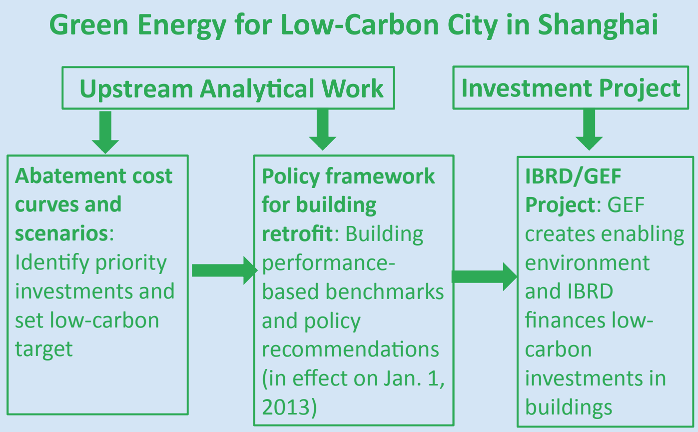
From Abatement Cost Curve to Implementation: Green Energy for Low-Carbon City in Shanghai Project

This chapter introduces follow-up studies and investments in the abatement measures identified from the abatement cost curve to take the study results into the implementation phase. It highlights (a) a building retrofit policy study, whose recommendations were adopted by the Changning District Government; and (b) an IBRD/GEF Green Energy for Low-Carbon City project, with a total investment of US$250 million, finances the implementation of the mitigation measures identified from the abatement cost curve.

As shown in Figure 7.1, the abatement cost curve and scenario methodology provides a solid analytical underpinning for the design of the International Bank for Reconstruction and Development/Global Environment Facility (IBRD/GEF) Green Energy for Low-Carbon City project. Following this study, a series of upstream analytical studies and project preparation work were undertaken to analyze technical, economic, and financial feasibility; identify implementation barriers; and recommend policy changes for the abatement measures identified from the abatement cost curve to take the study results into the implementation phase. These studies include the following: (a) a building retrofit policy study to develop building benchmarks, recommend policy changes, and identify business models for building retrofit, since building retrofit is identified as the single largest emission-reduction opportunity and the focus of the IBRD investments; (b) a technical, economic, and financial feasibility study on low-emission new buildings and near-zero-emissions buildings; (c) feasibility studies of typical investments in building retrofit in various building categories; and (d) consultations with key stakeholders, including building owners, property management companies, ESCOs, and financial institutions.

These upstream analytical and project preparation studies led to the IBRD/GEF Green Energy for Low-Carbon City project, which will assist the Changning District government in implementing the abatement measures identified by this study. The IBRD loans of US$100 million, together with an additional US$146 million from participating financial institutions and investors, will invest in building retrofit and new low-emission buildings in Changning District, using a financial intermediary approach, with the project objective of piloting green energy schemes and scaling up low-carbon investments in buildings in Shanghai, with a focus on Changning District. The GEF

Figure 7.1 Applying Abatement Cost Curve to the design of the IBRD/GEF Project



funding will focus on policy instruments, financing mechanisms, and business models of different measures identified from the abatement cost curves—retrofitting commercial buildings, near-zero-emission buildings, distributed generation, and green mobility, with the global environment objective of supporting Shanghai's low-carbon city development by promoting green energy schemes, with a focus on Changning District.

It should be noted that the objective of the project is not green buildings, but achieving low-carbon city. The focus on buildings is derived from the abatement cost curve analysis, which showed that building retrofit accounts for the bulk of the potential emission reductions in Changning District, an established commercial district with few industrial activities.

Building Retrofit Policy Study: Recommendations Adopted by the Government

To address the regulatory and incentives barriers to building retrofit, the Bank team, in collaboration with the Energy Foundation, has been supporting local counterparts in undertaking an upstream analytical study to (a) develop performance-based building energy efficiency benchmarks in kWh/m^2, which could be used to mandate building retrofit; (b) recommend policy frameworks for potential mandatory measures and additional financial incentives beyond existing national and municipal government policies that could be piloted under this project by the municipal and district governments; and (c) identify a number of viable business models to bundle small-scale building retrofit projects. This is the first attempt to tackle building retrofit in China. If successful, this will have the potential for wide replication nationwide.

Adoption of building EE measures requires decisions to be made and actions to be taken by many decentralized players; as a result, energy demand is less responsive to price signals. Regulations tend to be more effective. However, bringing about major changes in national building codes and introducing mandates for building retrofit will take time. In the short term, the Changning District government is willing to provide additional funding to achieve its vision as a leader of the low-carbon city paradigm. To this end, the district government has issued a decree to provide additional financial incentives for building retrofit in Changning District, effective January 1, 2013.

In addition, the Bank team, in collaboration with the Energy Foundation, has been supporting local counterparts to undertake an upstream analytical study to confirm the technical feasibility and to estimate the incremental costs of low-emission new buildings with higher energy efficiency and lower emissions than the municipal building codes requirements and near-zero-emission buildings in Shanghai. The study concluded that low-emission buildings achieving 70 percent energy savings (compared with the 65 percent municipal building codes) are financially viable with existing government subsidies, while near-zero-emission buildings are technically feasible.

The IBRD/GEF Green Energy for Low-Carbon City in Shanghai Project: Implementing abatement measures identified from the abatement cost curve

This project includes the following innovations:

(1) devising an abatement cost curve using a bottom-up approach and incorporating ease of implementation in the project design;

(2) adopting a multisector approach including demand-side energy efficiency, low-carbon energy supply, and green mobility;

(3) scaling up and mainstreaming green financing with dedicated credit lines through local financial intermediaries;

(4) establishing an online energy consumption monitoring platform, essential for measurement, reporting, and verification;

(5) developing innovative policies of performance-based building benchmarks; and

(6) piloting innovative technologies for near-zero-emissions buildings.

The project has two components: (1) technical assistance and incremental support for near-zero-emissions buildings funded by a GEF grant and (2) low-carbon investments funded by an IBRD loan. The GEF component will primarily provide technical assistance and capacity building on policies, financing mechanisms, business models for the key abatement measures identified in the abatement cost curve (green energy buildings, clean energy supply, and green transport) to support the Changning District government in achieving its carbon-intensity-reduction target. It will also cover part of the incremental cost for a pilot near-zero-emissions building. The IBRD loan will focus on low-carbon investments in buildings given that the bulk of emissions reductions in Changning District would come from building retrofits identified in the abatement cost curve. It intends to scale up building retrofit investments through commercial bank financing.

The technical assistance and capacity-building activities under the GEF grant are intended to (a) remove the market barriers and increase the market demand and uptake of the IBRD loan through policy support; (b) support pre-investment studies and due diligence review of the IBRD loan; (c) build capacity of various stakeholders, particularly the participating banks and the government officials, to facilitate project implementation; (d) facilitate measurement and verification of energy savings achieved through the investments; and (e) ensure sustainability and replication of these low-carbon investments on a large scale.

The project's main focus is the Changning District, with extension to and replication in the Shanghai municipality. The first component will be implemented by the Project Management Office (PMO), while the second component will be implemented by Shanghai Pudong Development (SPD) Bank and the Bank of Shanghai (BOS), the two financial intermediaries responsible for channeling the IBRD loan.

Component 1. Technical Assistance and Incremental Support for Near-Zero-Emissions Buildings

This component will focus on four subcomponents: (1) demand-side energy efficiency and renewable energy measures in buildings, including retrofitting existing buildings and piloting a new near-zero-emissions building; (2) low-carbon energy supply, including on-site distributed generation from renewable energy and natural gas and a pilot carbon cap and trade scheme; (3) green mobility with a focus on improving public transportation and nonmotorized infrastructure to discourage the use of private cars; and (4) capacity building for participating banks and government officials and project management support.

1.1 Green energy buildings: This subcomponent includes providing technical assistance for retrofitting existing buildings and covering part of the incremental cost of a new pilot near-zero-emissions building. For building retrofit, the GEF funds will be used for technical assistance and capacity building to (1) develop performance-based building energy efficiency benchmarks in kWh/m^2 for additional types of buildings and mandatory policies; (2) recommend business models and financing mechanisms; (3) undertake energy audits and diagnostic and feasibility studies for comprehensive building retrofit to achieve deep emissions reductions; and (4) support an on-line energy monitoring platform for measurement and verification (M&V) of energy savings.

For piloting the new near-zero-emissions building, the GEF funds will be used to (1) cover part of the incremental cost (incurred for energy efficiency and renewable energy) above the municipal building codes for technical design; marketing campaigns to increase the low-carbon awareness of suppliers, buyers, renters, and others; and investment in low-carbon technologies for the pilot near-zero-emissions building, while the remaining incremental costs will be covered by Changning District government and project developers; and (2) develop policies and financing mechanisms to ensure sustainability and replication.

1.2 Low-carbon energy supply: This subcomponent includes both on-site distributed generation (DG) from renewable energy and natural gas as well as a pilot carbon cap and trade scheme. The GEF funds will support (1) technical design of the pilot DG center in Changning District and (2) design and implementation of the pilot carbon emissions cap and trade scheme (ETS) in Changning under the municipal ETS framework. With the performance-based building energy efficiency benchmarks as the analytical basis for setting up a total energy consumption cap for each energy-intensive building, and the on-line energy monitoring platform to provide baseline and M&V data, Changing District is well positioned to pilot carbon cap and trade schemes in the building sector.

1.3 Green mobility: The GEF funds will be used for technical assistance to design and develop implementation plans to improve (1) local public transportation routes and systems to connect metro and light rail stations with office buildings to cover the "last mile" and (2) nonmotorized infrastructure and services (pedestrian areas and bike lanes).

1.4 Capacity building and project management support: This subcomponent will (1) support due diligence review and promotion of low-carbon investments; (2) build capacity of key stakeholders, particularly the participating banks (SPD Bank and BOS), government officials, and project developers; and (3) cover program management costs, donor coordination activities, and administration including fiduciary duties.

Component 2. Low-Carbon Investments

The low-carbon investments will focus on building retrofit and new low-emissions buildings, with the majority of the investments going to building retrofit.

A US$100 million IBRD loan will be on-lent by the government of China to Shanghai municipal government, then to Changning District government, and finally to the two participating financial institutions (PFIs): SPD Bank and BOS. These two banks in turn will lend the funds to eligible energy services companies (ESCOs) (including leasing companies), building owners, building developers, property management companies, energy efficiency and renewable energy equipment vendors, government agencies, government end users, and DG operators for low-carbon investment subprojects. Small and medium size enterprises would likely make up the bulk of the subborrowers.

The PFIs' on-lending rates will be determined based on market conditions and will adequately cover the financial and operating costs and provide for a reasonable profit margin for the PFIs. The PFIs have also agreed to match the amounts of their respective IBRD loan allocations for low-carbon investments. The subproject beneficiaries are also expected to contribute 20 percent of project costs in equity investments in the building retrofit component, totaling US$46 million.

2.1 Green energy retrofitting of buildings: This subcomponent will finance (1) building energy efficiency improvements in commercial and government buildings, such as lighting, HVAC (heating, ventilation, and air conditioning) systems, energy management systems, building envelope insulation measures (roof, walls, windows, and doors); (2) renewable energy applications in buildings (roof-top solar PV, solar water heaters, and ground-source heat pumps); (3) distributed generation from renewable energy and natural gas to provide power, cooling, and heating services to buildings; and (4) any other low-carbon initiatives proposed by counterparts and agreed to by the Bank.

2.2 New green energy buildings: This subcomponent will finance the incremental costs of low-carbon measures, primarily energy efficiency and renewable energy measures for new buildings above municipal building code requirements.

Framework Approach: Given that there will be many small-scale subprojects and subborrowers for the investment component, a framework approach will be adopted for project implementation. The implementing agencies, SPD Bank and BOS, have developed an Operational Manual that outlines selection criteria for subborrowers and subprojects, appraisal procedure and guidelines, roles and responsibilities of the PFIs and PMO, PFIs' internal institutional arrangement for project implementation, technical evaluation framework, environmental and social management framework, and procurement and financial management frameworks that are consistent with the World Bank and Chinese government rules and procedures. The Changning District government and the Bank have reviewed and approved the Operational Manual. During project implementation, the implementing agencies will be responsible for identifying, appraising, and financing subprojects that meet the criteria in the Operational Manual and receive government approval.

Institutional and Implementation Arrangements

Project Steering Committee and Project Executive Committee: A Project Steering Committee will be set up to coordinate and replicate policies at the municipal level. A Project Executive Committee will be established to coordinate the district-level government agencies and supervise day-to-day project implementation.

Project Management Office: The PMO will be responsible for implementing the GEF component of the project. Regarding the IBRD loan, the PMO will (a) assist the participating banks in identifying subprojects; (b) review and provide no-objection to the technical aspects of subprojects to ensure that the subloans follow the Operational Manual and achieve the low-carbon objective in Changning District; (c) conduct environmental and social safeguard due diligence and supervision of subprojects; and (d) verify energy savings of subprojects. The Changning on-line energy monitoring platform for building energy consumption provides an innovative tool for the district government and the PMO to measure and verify energy savings from the IBRD investments.

Participating banks: The participating banks—SPD Bank and BOS—are the implementing agencies for the IBRD loan, responsible for (a) generating a lending pipeline; (b) appraising and approving technical, financial, procurement, and financial management aspects of subprojects; (c) supervising and monitoring subborrowers and subprojects; and (d) fully disbursing IBRD funds and counterpart cofunding, according to the agreed-upon Operational Manual. The participating banks will bear 100 percent of the default risks. They will follow government policies and World Bank rules and procedures as detailed in the Operational Manual.

Subborrowers: The subborrowers will be eligible ESCOs (including leasing companies), building owners, building developers, property management companies, energy efficiency and renewable energy equipment vendors, government agencies, government end users, and distributed generation operators for low-carbon investment subprojects. Funding from the government and GEF will assist potential subborrowers in undertaking energy auditing and diagnostic and feasibility studies before they apply for loans from the PFIs. Shanghai has about 200 registered ESCOs on the municipal Development and Reform Commission’s list of qualified ESCOs eligible for receiving government subsidies.

8

The Significance: Potential for Replication in Other Cities

The use of abatement cost curves and scenarios has the potential to be widely replicated in cities within and outside China that aspire to become leaders in defining low-carbon targets and identifying cost-effective low-carbon investments. This chapter compares the abatement cost curve methodology with other methodologies and tools for low-carbon studies at the national and city levels, developed by the World Bank with Energy Sector Management Assistance Program (ESMAP) support, including the Energy Forecasting Framework and Emissions Consensus Tool (EFFECT), the Tool for Rapid Assessment of City Energy (TRACE), and the Marginal Abatement Cost Curve Tool (MACTool).

ESMAP has supported other methodologies and tools for low-carbon studies at the national and city levels,[3] for example, EFFECT, TRACE, and MACTool. EFFECT is a modeling tool for forecasting energy and greenhouse gas (GHG) emissions from a range of low-carbon scenarios. TRACE is a decision-support tool designed to help cities quickly identify underperforming sectors through energy benchmarking, to evaluate improvement and cost-saving potential, and to prioritize sectors and actions for energy efficiency interventions that are directly under the control of the municipal governments. MACTool is a transparent and flexible software tool that provides a user-friendly way to build marginal abatement cost curves and calculate breakeven carbon prices.

Energy Forecasting Framework and Emissions Consensus Tool (EFFECT)

EFFECT is an open and transparent modeling tool used to forecast GHG emissions from a range of development scenarios in low-carbon development. It focuses on sectors that contribute to and are expected to experience rapid growth in emissions. EFFECT was first developed under the India low-carbon study, and has since been used in 11 countries, including Poland, Georgia, the former Yugoslav Republic of Macedonia, Nigeria, and Vietnam.

[3] See ESMAP's low-carbon activities on its website: www.esmap.org.

EFFECT forecasts GHG emissions for given development scenarios or policy choices. In addition to forecasting GHG emissions, EFFECT enables consensus building among disparate government departments, and forecasts energy balances and amounts of energy-generating and -consuming assets in a country or sector.

Technically, EFFECT is a bottom-up accounting framework whose inputs are energy-consuming and -supplying assets in the country. It can provide national or sectoral results. As an Excel-based model, EFFECT can be customized to fit many different applications.

Tool for Rapid Assessment of City Energy (TRACE): Helping Cities Use Energy Efficiently

TRACE is a decision-support tool designed to help cities quickly identify underperforming sectors, evaluate improvement and cost-saving potential, and prioritize sectors and actions for energy efficiency intervention. TRACE covers six municipal sectors: passenger transportation, municipal buildings, water and waste water, public lighting, solid waste, and power and heat.

TRACE consists of three modules: an *energy benchmarking* module that compares key performance indicators among peer cities, a *sector prioritization* module that identifies sectors that offer the greatest potential with respect to energy-cost savings, and a *recommendation selection* module that functions like a “playbook” of tried-and-tested energy efficiency measures and helps select locally appropriate energy efficiency interventions.

Energy benchmarking. TRACE’s benchmarking module has a database of 28 key performance indicators collected from 64 cities. Data from the city being benchmarked are entered into the tool using a simple web-like interface, then analyzed to compare city energy use with a range of peer cities. The peer cities may be selected based on city population, climate, or scores on the human development index.

Sector prioritization. TRACE’s sector prioritization module uses “relative energy intensity,” “sector energy spending,” and “city authority control” to prioritize sectors with the most significant energy efficiency potential. The “sector spending function” allows the user to enter the total amount of money that the city spends in the sector, and the “city authority control” function allows the user to indicate the amount of control that the city authority has in the sector. The “relative intensity function” shows the potential energy efficiency improvement that the city may realize if its performance were to match the average of cities currently performing better. Based on these functions, TRACE provides the prioritized list of sectors with which the city can engage to realize potential energy savings.

Recommendation selection. TRACE contains a set of 59 energy efficiency interventions that blend both high-level strategic programs and specific activities that a city can pursue. These recommendations are supported by a database of 191 case studies that link to appropriate resources and tools. Each recommendation is rated on three attributes: (1) energy savings potential, (2) first cost, and (3) speed of implementation.

The energy savings assessment step allows the user to quantify the potential energy savings using spreadsheets that come with TRACE, and the final review process allows the city authorities to assess the viability of recommendations to come up with a final list of actions for prioritized sectors. Users can click on each recommendation to learn more about it and read applicable case studies.

Marginal Abatement Cost Tool (MACTool)

MACTool is a transparent and flexible software tool that provides an easy way to build marginal abatement cost curves and calculate breakeven carbon prices. It has a user-friendly interface that guides the user through a simple data entry process from which it automatically generates output. The output is Excel-based, making it is easy to embed in reports and presentations. MACTool was first developed under the Brazil Low Carbon study, and has been used in Colombia, the former Yugoslav Republic of Macedonia, Nigeria, and Uruguay.

The tool helps leaders compare the costs and benefits of emissions-reduction options that can be used to build low-carbon scenarios at a national or subnational level. It provides a cost-benefit comparison of these options using a social discount rate by calculating the "marginal abatement costs" and an estimate of the incentive needed to make these options attractive for the private sector by calculating the "breakeven carbon prices." It also enables government to assess the total investment needed to shift toward low-carbon growth scenarios and inform the physical sectoral outputs (for instance, installed power capacity) associated with the low-carbon options. MACTool can also be used to test the possible scope of domestic cap and trade systems, by exploring which sectors are likely to respond to a given carbon price, either on the demand side or the supply side of carbon offsets.

The MACTool enables the user to test the following:

- Economic criteria (for example, operating and maintenance costs, revenues, rates of return, required subsidies) for selecting a set of cost-efficient mitigation options,
- The net benefit of a selection of mitigation options for the national economy,
- Conditions under which options would become attractive for the private sector,
- Possible sectoral scope (for example, the appropriate technology) for a domestic cap and trade system and associated size of the potential volume of transactions.

The Changning study used an approach similar to the MACTool methodology, but somewhat different from EFFECT and TRACE. EFFECT is a macro-level forecasting modeling tool, and does not rank or prioritize abatement technologies, nor identify a cost-effective, low-carbon investment program like the Changning study does. TRACE uses benchmarking, and primarily covers those interventions under the direct control of the municipal government, which usually account for only a small portion of a city's GHG emissions. The Changning study looked at abatement interventions in all sectors, covering the bulk of the city's emissions. The basic methodology of this study is the same as the MACTool, but this study has the following unique characteristics: (1) the use of CO_2 abatement cost curves and bottom-up investigation surveys in conjunction with ease of implementation considerations to define an investment program for reducing CO_2 emissions were the first of the kind at that time in China; (2) the data inputs and assumptions were based on the Chinese data system, which is very different from other countries' and other international systems, and the low-carbon targets derived from the scenarios align with the Chinese government's carbon-reduction target; and (3) this analysis led to implementation of the abatement measures identified from the abatement cost curves through the IBRD/GEF project, local government, and the investors.

The abatement cost curves methodology used in this study requires voluminous data, particularly cost data. It is perhaps more appropriate to use this methodology in relatively large, sophisticated cities where data are readily available. It should be noted that the abatement cost curve is not a panacea and has drawbacks—it centers on abatement technologies, but excludes other nontechnology abatement measures such as urban form, and does not cover transaction costs.

Because the concept of a low-carbon city is not yet well defined in China, the use of CO_2 abatement cost curves and scenarios based on bottom-up surveys that also consider the ease of implementation to define low-carbon targets and investment programs in cities will have the potential to be widely replicated in cities in China and around the world.

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