China’s green revolution

Prioritizing technologies to achieve energy and environmental sustainability

McKinsey&Company

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Preface

China's rapid pace of urbanization and economic development over the past three decades has lifted hundreds of millions of people out of poverty, and catapulted the nation into the ranks of the world's largest economies. Yet, rising demand for energy, increasing emissions of greenhouse gases, and the deterioration of critical natural resources such as arable land and water, pose enormous challenges for China. Like many countries, China faces the challenge of finding solutions that adequately address these issues without compromising its economic development goals and the living standards of its people.

To provide a quantitative, fact-based analysis to help policy makers and business leaders identify and prioritize potential solutions, McKinsey & Company, in cooperation with leading researchers in China and across the world, undertook a study of the range of technologies that China could deploy to address its energy and environmental sustainability challenges. Over the past year, the team studied over 200 efficiency and abatement technologies, with a special focus on five sectors: residential and commercial buildings and appliances; transportation; emissions intensive industries (including steel, cement, chemicals, coal mining and waste management); power generation; and agriculture and forestry. In the course of their research, the team interviewed more than 100 experts from government, business, and academia.

The methodology we employed in this report is consistent with the climate change abatement cost curve research that McKinsey has conducted globally over the past three years. In this report we use greenhouse gas (GHG) emissions as a consistent metric for evaluating the full range of different technologies that we studied, from wind turbines to LED light bulbs. This metric also serves as a proxy for assessing the impact of these technologies on other aspects of sustainability, such as energy savings, pollution control, and ecosystem preservation.

Our estimates are of the *maximum* technical abatement potential of each option. Several factors could limit the realization of the full abatement potential, such as labor market disruptions, budget constraints, and environmental concerns.

Our cost analysis only considers capital, operating and maintenance costs, and excludes taxes, tariffs and subsidies. We did not include positive or negative social costs (e.g., unemployment or public health), administrative costs, transaction costs associated with switching to new technologies, and communication costs. We also have not assumed any “price for carbon” (e.g., a carbon cap or tax) that might emerge due to legislation, or the impact on the economy of such a carbon price. Hence, the abatement cost does not necessarily reflect the exact cost of implementing that option.

We do not intend our findings to serve in any way as a forecast or target for GHG emissions abatement. Our analysis does not attempt to address broad policy questions with regard to the regulatory regimes or incentive structures the Chinese government might consider. This report does not endorse any specific legislative proposals or mechanisms to foster sustainable growth. The purpose of our study of energy security and environmental sustainability in China is not to present opinions or advice on behalf of any party.

In addition, this report does not endorse any specific proposals or frameworks for a global agreement regarding climate change. The purpose of this report is to facilitate the definition and prioritization of economically sensible approaches to address the challenges that China faces with regard to energy security and environmental sustainability. We hope this report will help policy makers, business leaders, academics and others to make more fully-informed, fact-based decisions.

Our research has been greatly strengthened by contributions from many outside experts and organizations (they might not necessarily endorse all aspects of the report). We would like to thank our sponsor organizations for supporting us with their expertise as well as financially: ClimateWorks, Vanke Group, and Shanghai Electric Corporation. We would also like to thank Dr. Jiang Kejun and his team from the Energy Research Institute of the NDRC for their close collaboration throughout the process to assist in the validation of our methodology and data. We also acknowledge the invaluable advice provided by Professor He Jiankun (Tsinghua University), Professor Zou Ji (Renmin University of China), Professor Lin Erda (China Academy of Agricultural Science), Professor Jiang Yi (Tsinghua University), and Professor Qi Ye (Tsinghua University; The Energy Foundation). Finally we would like to thank our many colleagues within McKinsey who have helped us with advice and support.

Jonathan Woetzel
Director

Martin Joerss
Principal

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Summary of findings

China has made enormous strides in the three decades since launching its program of economic reform. Rapid economic growth and massive urbanization, however, have placed enormous strains on energy resources as well as on the environment.

Over the next several decades, as urbanization and economic development continue, China will need to ensure that it has the energy resources it needs to fuel this growth, while mitigating the impact on the environment and contributing positively to the global effort to combat climate change.

Like many other countries, China faces the challenge of finding solutions that adequately address these issues without compromising its economic development goals and the living standards of its people. The sheer enormity of the population and the scale of its economy, however, place China in a uniquely challenging position. Indeed, China's policymakers have declared these challenges as a top priority. In recent years, China has installed an extensive body of regulations and policies aimed at improving energy efficiency. These, coupled with continuous advances in technology and actions by industry leaders, are expected to yield substantial improvements to China's energy efficiency and a significant reduction in greenhouse gases (GHG).[1] The estimates of energy efficiency improvement and GHG abatement potential from these policies and initiatives comprise the "baseline scenario" in this report.

Our baseline scenario estimates show that, for every five-year period over the next 20 years, China could achieve a 17 to 18 percent reduction in energy intensity per unit of GDP. While this represents a substantial improvement in energy efficiency over today, even if China manages to achieve these improvements, it is still expected to consume 4.4 billion tons of coal and 900 million tons of crude oil by 2030. Satisfying demand for these critical commodities could push China to rely on imports for as much as 10 to 20 percent and almost 80 percent of its coal and oil requirements, respectively.

In addition, estimates in the baseline scenario show that China could emit up to 15 gigatons of CO_2e by 2030. (Exhibit 1)

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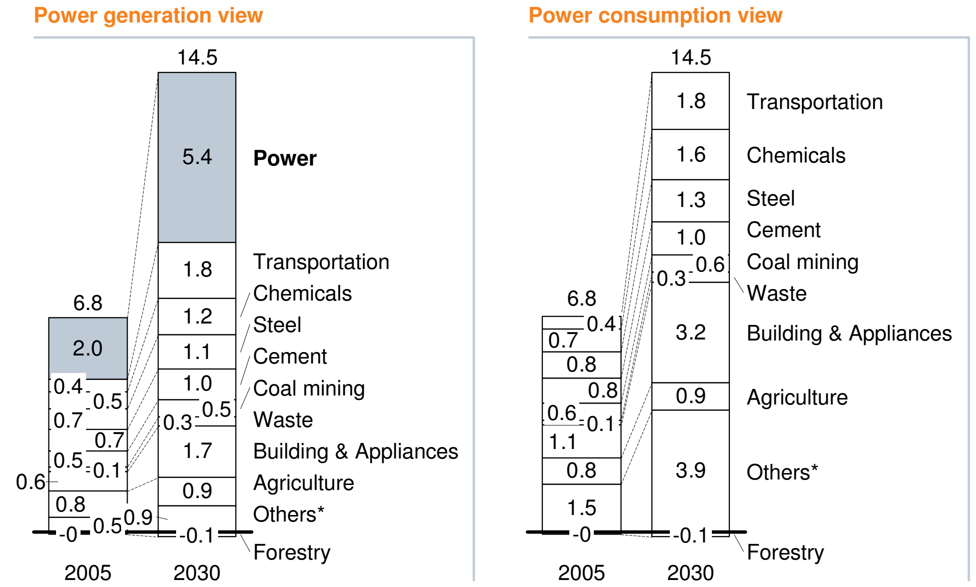
[1] We measure GHG abatement in tons of CO_2e, and measure the cost of reducing GHG emissions in euros per ton of CO_2e. We use CO_2e as a common metric to measure the intensity of the greenhouse effect of a variety of greenhouse gases other than carbon dioxide, such as methane and nitrous oxide.

Exhibit 1

BASELINE EMISSIONS SPLIT BY SECTOR IN 2005 AND 2030

Gigatons CO_2e per year



Note: Generation view shows direct emissions from each sector; consumption view shows both direct and indirect

* Including emissions from other manufacturing industries, construction industry, other mining industries, non-road transportation, and agriculture energy consumptions; including auxiliary power consumption from the power sec

Source: China Energy Statistical Year Book; expert interview; McKinsey analysis

The purpose of our analysis was to identify technologies that could enable China to make step-change improvements in energy efficiency and GHG abatement above and beyond the baseline scenario. All of the technologies that we studied are technically feasible and likely to be commercially available by no later than 2030. We explicitly excluded those technologies, such as hydrogen fuel cells, that have not yet been fully developed technically or commercially.

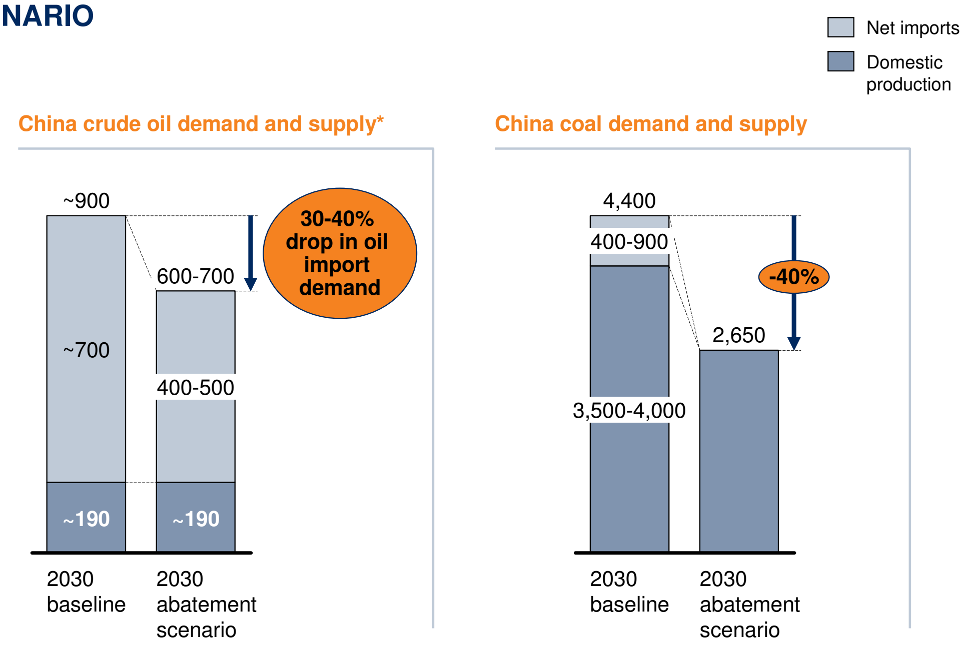
Many of the technologies we studied have not been deployed widely because of the high level of upfront investment, a lack of understanding regarding their potential efficacy, a lack of experience in deploying them, and shortages of technical and managerial talent necessary to implement them, among other barriers.

This report highlights the additional potential for China to substantially improve energy efficiency and reduce GHG emissions beyond the levels that we forecasted in the baseline scenario. The methodology we employed is consistent with similar research that McKinsey has conducted in several other countries over the past 1–2 years. In this report, we refer to this substantial improvement potential as the “abatement scenario.”

By fully deploying the technologies we studied in the abatement scenario, China could reduce its need for imported oil by up to 30 to 40 percent by 2030 over the baseline scenario. China could also stabilize coal demand at current levels, substantially reducing the proportion of coal in its overall power supply mix to as low as 34 percent by 2030, down from over 80 percent today. (Exhibit 2)

Exhibit 2

CHINA OIL AND COAL DEMAND AND SUPPLY IN THE ABATEMENT SCENARIO



* 2030 production is based on demand forecast of gasoline, diesel and other oil products

Source: EIA; IEA; expert interviews; McKinsey analysis

In addition to achieving substantially greater energy security, realizing the maximum potential of all the technologies we studied could help China hold its greenhouse gas (GHG) emissions to roughly 8 gigatons of CO_2e by 2030, a level that is roughly 10 percent higher than it was in 2005. This would represent a nearly 50 percent decrease in emissions in 2030 compared to our baseline scenario. (Exhibit 3)

Achieving the substantial improvements outlined in our abatement scenario will require considerable investment. We estimate that China will need up to 150-200 billion euros on average each year in incremental capital investment over the next 20 years. According to our analysis, approximately one-third of these investments will have positive economic returns; one-third will have a slight to moderate economic cost, and an additional one-third of the technologies will have a substantial economic cost associated with them. (Exhibit 4)

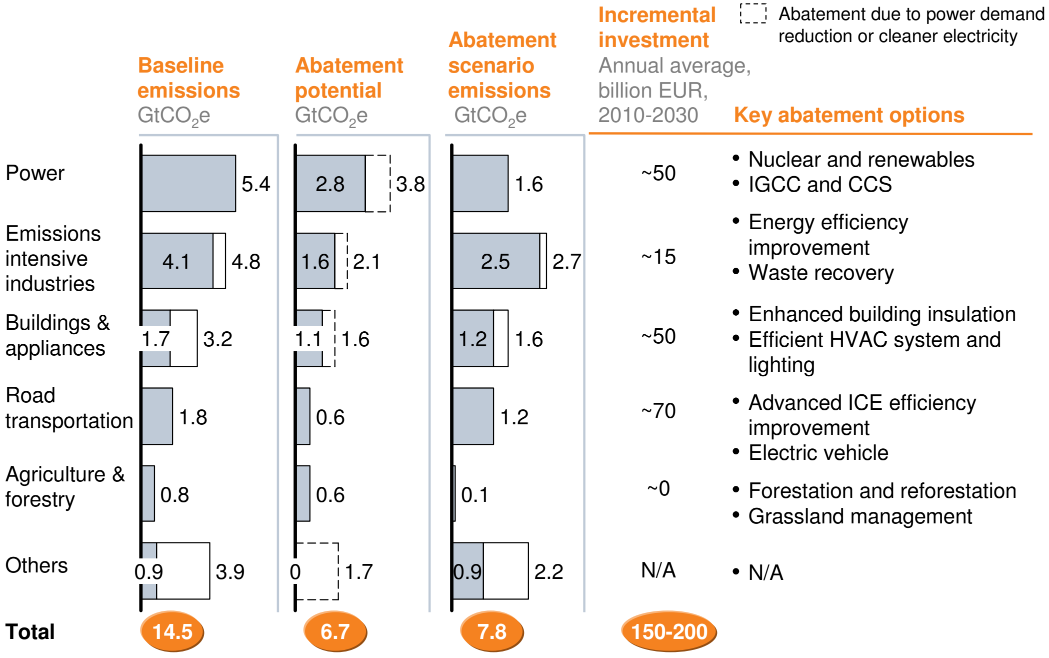
In addition to economic costs, several barriers stand in the way of the adoption of most of these technologies, including social costs such as employment dislocation associated with the implementation of new technologies, government administration costs, and information and transaction costs. All of these will limit the ability of China to realize the full potential of these technologies.

Exhibit 3

KEY FINDINGS BY SECTOR – 2030

☐ Indirect (power generation) emissions

⬚ Abatement due to power demand reduction or cleaner electricity



	Baseline emissions GtCO$_2$e	Abatement potential GtCO$_2$e	Abatement scenario emissions GtCO$_2$e	Incremental investment Annual average, billion EUR, 2010-2030	Key abatement options
Power	5.4	2.8 3.8	1.6	~50	• Nuclear and renewables • IGCC and CCS
Emissions intensive industries	4.1 4.8	1.6 2.1	2.5 2.7	~15	• Energy efficiency improvement • Waste recovery
Buildings & appliances	1.7 3.2	1.1 1.6	1.2 1.6	~50	• Enhanced building insulation • Efficient HVAC system and lighting
Road transportation	1.8	0.6	1.2	~70	• Advanced ICE efficiency improvement • Electric vehicle
Agriculture & forestry	0.8	0.6	0.1	~0	• Forestation and reforestation • Grassland management
Others	0.9 3.9	0 1.7	0.9 2.2	N/A	• N/A
Total	14.5	6.7	7.8	150-200	

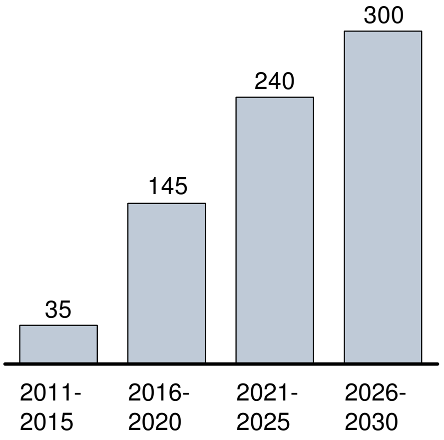
Note: Numbers do not add up exactly due to rounding
Sources: McKinsey analysis

Exhibit 4

INCREMENTAL CAPITAL INVESTMENT NEEDED FOR IMPLEMENTING ABATEMENT OPTIONS IN 2010-2030 PERIOD

Incremental capital needed to capture the technical potential

Real 2005 EUR billions, annual average of each 5-year period



Key findings

- **Capital requirements increase over time mainly driven by**
  - Higher implementation shares of abatement levers over time
  - Implementation of high cost technologies such as CCS
- **Incremental capital investment needed is up to EUR 150-200 billion on average each year over the 2010-2030 period**
- **Capital investment needed in the year of 2030 represents 1.5-2.5% of forecast China GDP in that year**
- **Capital investment cash needs will be to a great extent offset by energy savings**

Source: McKinsey analysis

The window of opportunity for capturing the full potential of these technologies is limited. This problem is particularly acute in the building, industry and power generation sectors. Over the next 5 to 10 years, China will continue to rapidly add to its stock of commercial and residential buildings, expand industrial capacity, and construct new power plants. Given the expense and difficulty of retrofitting existing buildings and plants, most of the energy efficiency and GHG abatement gains depend on building it right the first time. We estimate that just a 5-year delay in starting to implement the abatement technologies we describe in our study would result in a loss of as much as one-third of the total abatement potential by 2030. If China waited 10 years before beginning to implement these technologies, it could lose up to 60 percent of the total abatement potential by 2030.

Making the leap from the baseline scenario to the abatement scenario will require no less than a "green revolution." From our analysis, we identified 6 major categories of energy efficiency and greenhouse gas abatement opportunities between now and 2030, opportunities that would put China on a path toward achieving this "revolution": the replacement of coal with clean energy sources; comprehensively adopting electric vehicles; improving waste management in high-emission industries; designing energy efficient buildings; restoring China's carbon sink (forestry and agriculture), and rethinking urban design and adjusting consumer behavior.

1. "GREEN POWER" – REPLACING COAL WITH CLEAN ENERGY SOURCES

With concerted action by the government and industry in the investment and deployment of clean energy technologies, China can substantially reduce its reliance on highly-polluting coal for power generation.

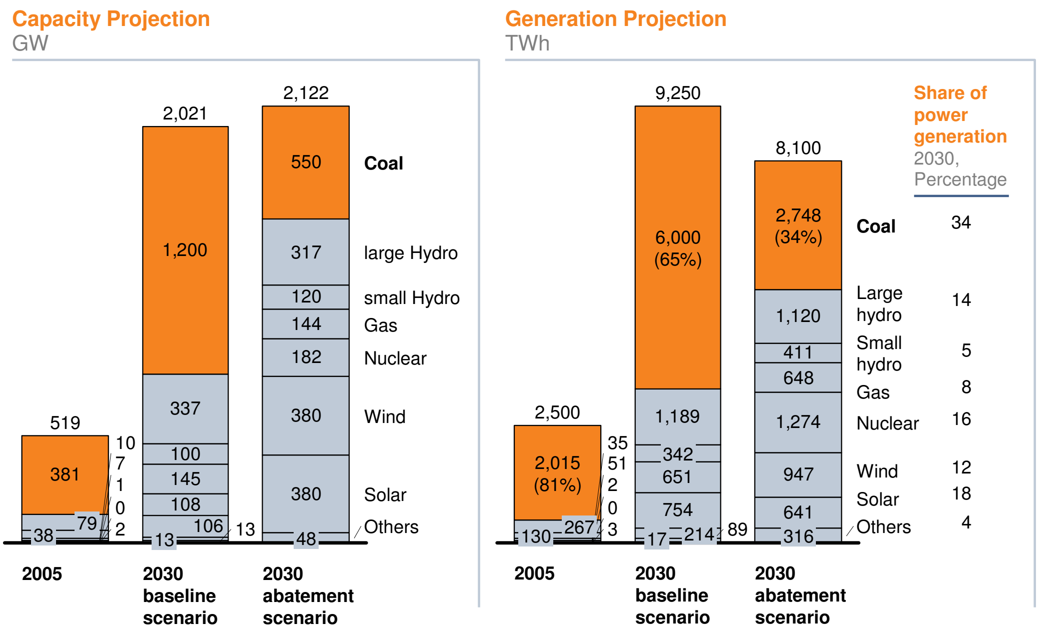
As manufacturers ramp up production and lower manufacturing costs through process and technological innovations, the cost of clean energy technologies such as wind, solar and nuclear will come down to a level that will make them attractive alternatives to coal.

Our analysis shows that if China were to comprehensively deploy these technologies, the share of coal as a percentage of China's total power generation could drop substantially, from 81 percent today to 34 percent by 2030. By 2030, China's coal demand could stabilize at about 2.6 billion tons, the amount it consumed in 2007. The reduction in coal supply would be met by a range of clean energy sources: solar could rise from just over 0 percent today to 8 percent in 2030; wind power could increase from just over 0 percent to 12 percent; nuclear will rise from 2 to 16 percent; hydropower will increase slightly, from 16 to 19 percent; and natural gas will rise from 1 to 8 percent. (Exhibit 5)

We estimate that in addition to a 1 Gt reduction coming from falling demand for power in end-user sectors such as buildings and industry, the GHG abatement potential in this sector is 2.8 Gt of CO_2e by 2030. These combined can lead to a reduction of coal consumption by 1.2 billion tons, or 27 percent of baseline coal demand.

Exhibit 5

CHINA POWER MIX



* Including geothermal, CBM, MSW, LFG and biomass

Source: Expert interviews; literature research; McKinsey analysis

Due to the capital intensive nature of this sector, the incremental investment needed to achieve the full potential in efficiency improvements and GHG abatement would reach roughly 50 billion euros on average each year. Due to the reliance on expensive technologies such as renewable energy technologies and CCS, this sector has one of the highest average costs, in the range of 30 to 40 euros per ton of CO_2e.

Achieving this vision would have significant, positive “knock-on effects” for other aspects of China’s energy strategy. For instance, as China gradually shifts to cleaner sources of energy to power its electricity grid, the rationale for accelerating the movement toward a broad-based roll-out of electric vehicles gets stronger. On top of the positive environmental impact of a shift to electric vehicles, China will substantially reduce its reliance on imported oil to power its rapidly-expanding transportation fleet.

In addition to replacing coal with sources of renewable energy, deploying clean coal technologies can be another source of GHG abatement. Although their technical and economic feasibility is not yet completely proven, emerging technologies such as integrated gasification combined cycle (IGCC) and carbon capture and storage (CCS) have made noticeable progress in recent years.

2. “GREEN FLEET” – COMPREHENSIVELY ADOPTING ELECTRIC VEHICLES

Although transportation is not a big source of China’s GHG emissions yet, this is about to change. By 2025, China is expected to replace the US as host to the world’s largest auto fleet. By 2030, over 330 million vehicles will ply China’s roads. China will therefore need a strategy to avoid the path to oil dependence that developed markets have followed.

Internal combustion engine (ICE) vehicles that have undergone significant technological improvement are still more affordable than electric vehicles. However, even with all possible cost-effective efficiency gains to ICE technology by 2030, which will cut today's average passenger car fuel requirement by 40 percent, we estimate that China would still have to rely on imports for 75 percent of its oil demand, assuming a continued reliance on ICE vehicles.

If, however, China were to begin to widely adopt electric vehicles starting in 2015, ramping up adoption to 100 percent of China's new vehicle fleet by 2020, our analysis shows that it could reduce its demand for imported oil by an additional 20 to 30 percent from what would be needed to support high-efficiency ICE vehicles. By leveraging its large supply of low-cost labor, fast-growing domestic market, proven success in rechargeable battery technology, and with substantial investments in R&D, China has the potential to emerge as a global leader in electric vehicle technology.

In addition, bio-ethanol will play a substantially smaller role as a future source of energy for China's transportation fleet. The bio-mass raw materials that would otherwise be used to make bio-ethanol could be allocated primarily to more economically feasible industrial uses.

Vehicle exhaust is the major source of urban air pollution in China today. By widely adopting electric vehicles, China could substantially improve the quality of air in its cities, resolving one of the most vexing environmental and public health issues facing China today.

However, electric vehicles still face a number of barriers. Until further technological breakthroughs are realized, the performance of electric vehicles will continue to lag behind ICE vehicles. Putting a battery recharging infrastructure in place will pose an additional challenge. Ultimately, cost will remain one of the biggest obstacles. By 2030, we expect an electric vehicle will cost 1000-3000 euros more than an advanced ICE car. If China were to extensively roll-out electric vehicles starting from 2016 through to 2030, this would require incremental capital investment of over 70 billion euros on average each year.

3. "GREEN INDUSTRY" – MANAGING WASTE IN HIGH-EMISSION INDUSTRIES

China's emissions-intensive industry (EII) sector – which in this report includes steel, chemicals, cement, coal mining and waste management – plays a crucial role in China's sustainable development. It represented about one-third of China's total energy consumption and 44 percent of China's total annual emissions in 2005. It is also one of the major sources of air and water pollution in China.

Our analysis identifies abatement opportunities in the sector to reduce emissions below our baseline scenario. The total maximum abatement potential is 1.6 Gt of CO_2e by 2030. Our research shows, that after actively improving energy efficiency in the baseline, recovery and reuse of by-products and waste will become the crucial driver of additional abatement potential beyond the baseline scenario.

China produces a lot of industrial and municipal waste that it currently does not recycle or does not manage properly. New technologies allow China to adopt innovative approaches to destroying waste or increasing the amount of waste that is converted into useful material. For example, blast furnace slag left over from steel production, and fly ash from the burning of coal during power production, are both currently being used as a substitute for clinker (the primary material in cement) in China. However, technological advancements may allow for a much higher rate of substitution.

Another example is the recovery of coal-bed methane, which could be used as a substitute for natural gas or as a source of energy in power generation. Coal-bed methane recovery could also substantially reduce both GHG emissions as well as reduce the casualties from gas explosions in mines.

China also has the opportunity to substantially reduce municipal solid waste landfill. Our analysis shows that with the adoption of technologies that burn waste to generate power, China could reduce its waste on a per unit volume basis to just 5 percent of the space that it currently requires. In addition, by employing these technologies, China could substantially reduce the pollutants such as methane that are generated from landfill.

The abatement potential of waste recovery is 835 million tons of CO_2e, accounting for more than 50 percent of the potential in the EII sector.

At the same time, improving energy efficiency still remains important for industries such as steel and chemicals. The total GHG abatement potential of energy efficiency improvements across the EII sector, beyond the baseline reductions, is 390 million tons of CO_2e, These improvements would also reduce energy consumption by up to 200 million tons of standard coal equivalent. Lastly, industrial CCS and other measures will cut another 340 million tons of CO_2e.

Incremental capital investment required to achieve these improvements would reach approximately 15 billion euros each year on average. While this is considerably less than the total capital investment required in other sectors, many of the technologies, such as waste recovery, will have higher ongoing operating costs.

4. "GREEN BUILDINGS" – DESIGNING ENERGY EFFICIENT BUILDINGS

As a result of rapid urbanization, China has undergone one of the biggest building booms in the history of mankind in the past decade. Going forward, as hundreds of millions more migrants move into China's cities, new apartments, office buildings, and commercial centers will be needed to accommodate them. As living standards rise, consumers will demand larger living and working spaces. As a result, per capita floor space is expected to double from 2005 to 2030, stoking consumer demand for energy.

By introducing energy-efficient designs in newly-constructed buildings, retrofitting existing buildings with customized technologies, installing energy-efficient lighting and appliances, and upgrading heating, ventilation and air-conditioning (HVAC) systems, Chinese consumers could enjoy higher living standards while consuming the same levels of energy per square meter as they do today.

One of the biggest areas of improvement will come from better insulation in walls, windows and roofs. This can be accomplished by complying with building codes, implementing passive design concepts, or retrofitting existing buildings. China mandates certain levels of energy efficiency in new buildings. However, by managing passive design elements in new buildings, China could achieve even greater energy savings than simply complying with building codes, and at approximately the same cost. For example, by orienting the position of buildings in a way that manages the absorption and deflection of sunshine, employing natural shading and ventilation devices, and sizing windows and doors appropriately, buildings can be naturally warmed or cooled while using less energy.

Retrofitting existing buildings with customized, economic insulation solutions that rely less on energy-consuming technologies is another important source of energy efficiency gains.

Because they consume much more energy, residential buildings in northern regions, and commercial buildings throughout the country, should be the focus of China's efforts for all of these insulation technologies.

In addition to building design, our analysis shows that lighting and appliances can provide additional savings in energy consumption. By switching from incandescent light bulbs to compact fluorescent lighting (CFL), and then eventually to LED lighting, China could save 190 billion kilowatt hours of electricity, or 2 percent of total expected power demand in 2030. The cost of an LED light bulb is expected to drop to 3-4 euros by 2015 as the technology is more widely commercialized.

HVAC system optimization can prove to be another source of higher energy efficiency. Examples of technologies include expanding the deployment of district heating, using better heating controls in district heating systems and household thermostats, and upgrading the building automation systems installed in today's commercial buildings.

This sector represents the best economics among all sectors. According to our analysis, the technologies responsible for generating about 70 percent of total abatement potential would have positive economic returns. While up to 50 billion euros each year on average will be required to make buildings "green", for most of the technologies that we studied, the savings they would generate from reduced energy consumption would more than offset the upfront investment.

5."GREEN ECOSYSTEM" – RESTORING AND PRESERVING CHINA'S CARBON SINK

China faces a delicate balancing act when it comes to managing its land resources. It needs to allocate enough arable land to agricultural production to ensure food security. At the same time, it is seeking to substantially increase forest coverage and preserve grasslands to maintain ecosystem sustainability. China has expanded its forest area from 14 percent of total land in 1993 to over 18 percent in 2005, and intends to increase forest coverage to 26 percent of total land area by 2050. These competing forces will be working against the backdrop of urbanization, which will only put further pressure on the supply of China's land resources.

By proactively preventing deforestation, reforesting marginal areas of land, recovering grasslands, and changing agricultural practices, China can substantially increase the level of natural carbon sequestration. This is a major abatement opportunity.

At about 10–20 euros per ton of CO_2e abated, the average cost of this sector falls into the medium range of all sectors. Because of the complexity involved in managing agriculture and forestry, much uncertainty surrounds the cost estimates in this sector. However, much of the benefits of ecosystem preservation, such as cleaner air, land and water, cannot be measured in monetary terms alone.

6. "GREEN MINDSET" – RETHINKING URBAN DESIGN AND CONSUMER BEHAVIOR

While most of the opportunities mentioned above will require the deployment of technologies, by rethinking approaches to urban planning and through encouraging a handful of small behavioral changes among consumers, China could reap additional savings in energy consumption and an additional almost 10 percent abatement in GHG.

Planning for denser urban areas calls for more high-rise buildings, which are generally 10 to 15 percent more energy efficient than their low-rise counterparts. In addition, denser cities could also cut private car use in favor of public transportation systems (as has been the case in Tokyo and Hong Kong). We estimate the abatement potential of increased urban density is about 300 million tons of CO_2e.

Through a combination of government policies, incentives, and public education, China could influence consumer behavior to encourage more efficient uses of energy. For instance, through such simple measures as adjusting room thermostats, buying more fuel-efficient cars, using mass transportation, and by adopting car pooling, consumers can individually and collectively reduce the energy they consume. They could also deliver a potential 400 million tons of GHG abatement.

While some investment will be required to initiate a number of these efforts, in general, the on-going investment and operating cost to deliver these reductions will be minimal, and will not require that consumers sacrifice their living standards.

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We discuss the principal findings of our analysis of energy and environmental sustainability in China in the following five chapters:

1. Scope and methodology
2. The rising challenge of sustainability
3. Overview of China's sustainability improvement opportunities
4. Five clusters of sustainability improvement potential
5. Areas of further research