Potential and Cost Study on China's Carbon Mitigation Technologies

中国二氧化碳
减排技术潜力和成本研究

戴彦德　胡秀莲等　著

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前　言

IPCC 第四次评估报告指出，全球应对气候变化的实践表明，技术减排才是真正的长效手段。现在及未来的温室气体减排均将高度依赖于技术的革新与实践。人类减缓气候变化的成本和速度将在一定程度上取决于未来减缓排放的有益技术的成本下降、性能和可获取性（IPCC，2007）。麦肯锡 2008 年发布的“减排成本曲线”中明确列出了各种技术的减排成本，认为到 2030 年可以实现 270 亿吨 CO_2 的减排，其中超过 70% 可以通过现有技术实现，剩下的也可以通过即将商业化的技术的推广来实现。而且，通过应用能效技术，有 70 亿吨 CO_2 的减排量减排成本为负值，可以带来正的投资效益。国际能源署（IEA）在《能源技术展望 2010》中，对现有和先进的清洁能源技术等低碳技术的现状以及前景进行了深度评估并提出，能源可持续发展是有可能实现的，其中科技将是关键因素，能源效率、CO_2 捕获和封存、可再生能源和核电等低碳技术都非常重要。

在国家科技部气候变化领域“十一五”科技支撑计划项目中，应用由下而上和由上而下模型相结合的方法，在宏观和微观两个层面对中国终端部门减缓气候变化的关键技术及其减排效果进行了评价。国家科技部、国家气象局和中科院联合组织了国内近百名专家撰写的第二部《气候变化国家评估报告》和第二部《气候变化科学评估报告》中，均纳入了对中国能源供应与终端利用部门减缓技术与潜力的分析与评价的内容。另外，国家财政部 CDM 基金赠款项目，中科院应对气候变化等项目，以及众多国内外研究机构也从不同的角度开展了针对中国部门、行业或技术的减排潜力和成本的分析研究。

基于对上述相关研究成果和文献的回顾发现，由于各研究项目的范围、目标、要回答的问题、研究的重点、研究者所站的角度和应用的研究方法不同，致使研究结果的深度、广度、结论以及对政策制定的支持力度等均存在较大的区别。

减缓气候变化是符合中国可持续发展内在需求的自主选择。从长期发展角度看，中国必须走出一条适合中国具体国情的低碳发展道路，以促进低碳转型，实现可持续发展。国内外众多相关研究成果显示，在中国工业部门的钢铁、化工、水泥、有色金属等高耗能行业，以及建筑和交通领域提高能源效率和减排 CO_2 的潜力仍然很大。深入研究这些部门和行业节能减排技术的现状和发展趋势、减排潜力和成本、减排技术实施的优先顺序和时序、减排技术的减排效果对部门和行业减排目标的影响、对国家 2020 年实现碳强度比 2005 年下降 40% ~45% 目标的潜在影响以及持续发挥技术进步对节能减排的关键作用具

有重要意义。研究成果可为国家、部门和行业制定节能减排战略、规划和技术政策等提供相应的支持。

为此，在国家发展和改革委员会和美国能源基金会的支持下，国家发展和改革委员会能源研究所主持并组织了清华大学建筑学院建筑节能研究中心、清华大学核能技术研究院、人民大学资源环境学院、社会科学院数量经济与技术研究所、中国科学院工程热物理所、中国化工节能技术协会、中国有色金属工业协会、中国水泥协会、北京德瑞沃德低碳技术中心的专家共同开展了“中国主要部门和行业 2020 年 CO_2 减排技术的潜力和成本研究”。

研究以 2020 年为目标年，重点分析了中国交通和建筑领域，钢铁、化工、有色金属和水泥四个高耗能、高排放行业从目前到 2020 年的能源消费、CO_2 排放和减排技术的现状和发展趋势；根据既定的原则在这些部门和行业遴选出了 88 项关键减排技术；应用增量(边际)成本分析方法详细评估了每一项减排技术的增量减排成本、减排潜力和所需投资；评估了实施这些减排技术对实现主要部门和行业减排目标，以及中国 2020 年 GDP 碳强度下降目标的潜在贡献；基于调查研究，分析了实施这些关键减排技术的障碍和政策需求；有针对性的提出了促进部门和行业减排技术推广应用的政策建议。

本书是在这项研究成果的基础上完成的。全书分为综合篇、部门和行业篇以及调研报告三个部分。我们希望这项研究成果能够帮助政策制定者、企业领导者、学术界、工程技术人员以及其他对节能减排技术感兴趣的各个方面做出更完善的决策，并帮助他们找到经济可行、普及推广潜力大、可供优先选择的减排技术，以应对可持续发展过程中所面临的减缓 CO_2 排放的挑战。

课题研究过程中，我们有幸得到了国家发改委应对气候变化司、国家科技部社会发展司、国家环保部科技司、国家住房和城乡建设部科技司、交通运输部政策法规司、国家科技部中国 21 世纪议程管理中心、全国能源基础与管理标准化技术委员会、国家发改委能源研究、清华大学、社科院城市发展与环境研究所、中国建筑材料科学研究院、中国钢铁规划研究总院、中国石油和化学工业联合会、能源基金会低碳发展之路项目的领导和专家的大力支持和指导，在此一并先后向他们表示崇高的敬意和衷心的感谢！

由于对各部门减排技术的认知、识别、选择存在一定的局限性，特别是无法预测未来可能产生的更先进的技术；对技术本身的减排率、技术的普及率、技术的经济特性等的判断受到缺乏系统数据支持等因素的影响，在分析技术的减排潜力和成本过程中均存在扩大和缩小技术减排效果和成本高低等问题，进而导致分析结果的不确定性。这些问题有待在以后的研究和实践过程中加以克服和完善。

作　者

2013 年 4 月于北京

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Abstract

Practice of global response to climate change shows that the technological reduction is the real long-term means. The greenhouse gas emission reduction of the present and the future will be highly dependent on innovation and implementation of technology. To some extent, the cost, performance, and accessibility (IPCC, 2007) of some beneficial technologies for reducing the future emissions will be determined by the cost and speed of climate change mitigation. The "Abatement Cost Curve" (Mckinsey, 2008) issued by McKinsey clearly lists the abatement cost of various technologies, suggesting that 27 billion tons of CO_2 emission reduction can be realized by 2030, of which more than 70% can be achieved by available technologies, and the remaining can also be achieved by the promotion of the upcoming commercial technologies. Moreover, through the application of energy-efficient technologies, emission reduction cost of 7 billion tons of CO_2 is negative, which indicates that positive investment returns are achievable.

In "Energy Technology Outlook 2010", International Energy Agency (IEA) conducts an in-depth assessment about the current situation and prospects of the existing and advanced clean energy technologies and other low-carbon technologies, and proposes that sustainable energy development is possible, and science and technology will be the key factor, in which low-carbon technologies on energy efficiency, CCS, renewable energy and nuclear power are very important.

In the science and technology supportive projects of the 11th FYP in the field of climate change proposed by the Ministry of Science and Technology, the combination of the bottom-up and top-down models is applied to evaluate the key technology of climate change mitigation and its emission reduction effect of our terminal department in the macro and micro levels. Contents of China's energy supply and the analysis and evaluation of reduction technologies and potential of the terminal department are

included in the second part of the National Climate Change Assessment Report and the second part of the Climate Change Science Assessment Report, composed by almost a hundred experts jointly and organized by the Ministry of Science and Technology, the National Weather Service and the Chinese Academy of Sciences. In addition, the CDM Fund Grant project of Ministry of Finance, climate change coping project of the Chinese Academy of Sciences, the IEA, McKinsey, LNBL as well as numerous domestic and foreign research institutions have carried out the analysis and research of the reduction potential and cost for sectors, industries or technologies of China from different aspects.

Based on the related research results mentioned above and literature review, it can be seen that due to the differences in the range, goals, questions to be answered and focus on the research projects, the angles and the research methods applied by the researchers, the depth and the breadth of the research results, conclusions and the support for policies and so on are greatly varied.

The mitigation of climate change is an automatic selection that is in line with the internal demand of national sustainable development. From the long-term development perspective, China must take a low carbon development path suitable for its specific national conditions, to promote the low-carbon transition and achieve sustainable development. China has promised internationally the target of CO_2 emissions reduction in 2020, based on which the intensity of CO_2 emissions per unit of GDP will be decreased by 40% to 45% in 2020 compared with that in 2005. To achieve this goal, China has developed related strategic plans and policies. In the process of realizing emission reduction targets of China's 11th FYP, technological progress has played an important role. In the implementation of the 12th FYP and the more long-term future carbon reduction planning objectives, the contribution of technology will still continue to play a key role.

This study takes year 2020 as the target year, focuses on the analysis of energy consumption and CO_2 emissions trends of transportation and construction sectors and such four high energy consumption, high emission industries as iron and steel, chemicals, non-ferrous metals and cement from the present to 2020, selects and assesses in detail the reduction potential and cost of 92 key emission reduction technologies, analyses the obstacles, investment and policy requirements of implementing these key emission reduction technologies, estimates the potential contribution of the emission reduction potential of these technologies to the decrease of 40% to 45% of China's carbon intensity of GDP in 2020 compared with 2005, and comes up with policies and recommendations to promote the popularization and application of low-carbon emission reduction technology.

We hope that the results of this study can help policy-makers, business leaders, academics and other aspects with interest to make better decisions, and help them find economically viable emission reduction technology with clear priority to cope with challenges in the process of sustainable development.

The main conclusions and policy recommendations of this study are summarized below.

(1) From present to 2020, the potential of improving energy efficiency and reducing CO_2 emission in China's iron and steel, chemicals, non-ferrous metals and cement industries and transportation and construction sector will still be big.

Energy conservation contributes not only to the growth of the national economy greatly, but also to the mitigation of greenhouse gas emissions. However, compared with the needs of national economic development and the international advanced level, China's energy intensity of GDP, energy consumption per unit of major energy-consuming products, and the energy efficiency of major energy-consuming equipment are far behind with varying degrees of gap, and the potential of conserving energy and improving energy efficiency is still big. In 2012, the unit energy consumption of major products of China's iron and steel, chemicals, non-ferrous metals and cement industries was still higher than the international advanced level (the average of the leading countries in the world). The comprehensive energy consumption is 10 % higher in the large and medium-sized iron and steel enterprises, 6% higher in the cement industry, 10% higher in the caustic soda industry, 28% higher in the copper smelting industry and 34% higher in the ethylene industry.

Compared with developed countries, the overall efficiency of energy use of buildings in China is relatively low, including the insulation level of the building, the operating efficiency of the heating boilers and air conditioners and other electrical equipment which fall behind to a certain degree. And about 90% of China's current buildings are in the common problem of high energy consumption. From the technological level, the technological advance and backward of the energy use technology co-exist, while the proportion of the latter is much higher than that of the former. The results showed that during the 11th FYP period, apart from the significant decrease of energy consumption per unit area of centralized heating buildings in the northern town along with the promotion of energy conservation work, the energy intensity of the other types of buildings showed a rising trend year by year. In 2010, the energy consumption intensity per unit building area increased from 12.5kgce/m^2 · a in 2005 to 14.8kgce/m^2 · a, an average annual growth of 3.4%.

Due to the influence of many complex factors such as the macroeconomic development, urbanization process, China's transportation industry rapidly develops. Compared with 2005, in 2010, only the holding volume of civilian vehicles (including passenger cars, trucks and other cars) grew by nearly 2-fold, the holding rate of civilian vehicles per thousand people grew by 1.8 times, and the former is about the same level with that of United States in 1920s and that of Japan in 1965. In 2010, the average fuel consumption of China's passenger car's unit volume of service is about 14% higher than that in Europe in 2006 and nearly 50% higher than that in Japan in 2005.

According to the researching results, due to the continued growth of energy services demand of our industry, transportation and construction sectors from present to 2010, the energy consumption and CO_2 emissions will also show a growing trend. In 2020, the CO_2 emissions of the iron and steel, chemicals, non-ferrous metals and cement industries will increase from 3.21 billion tons in 2010 to 4.22 billion tons, and from 22 million tons in 2010 to 3.22 billion tons in construction and transportation sectors. The total CO_2 emissions of the four industries and two sectors will account for 64% and 70% of the required CO_2 emissions of the 40% and 45% emission reduction target scenario.

CO_2 emissions mitigation technologies and practices are in constant development, and many of these technologies focus on energy terminal departments such as industry, transportation and construction. The results show that in the iron and steel, chemicals, non-ferrous metals and cement industries, as well as construction and transportation sectors, continued popularization and application of the advanced, efficient and low-carbon emissions and cost effective CO_2 emissions reduction technology is an important way to achieve the goal of decreasing the carbon intensity per unit GDP in 2020.

(2) Before 2020, iron and steel, chemicals, non-ferrous metals and cement industries are the priorities and areas of focus on the realizing technological mitigation potential, because they have big emission reduction potential and relatively low abatement costs.

The evaluation results of this study on more than 40 selected emission reduction technologies of the iron and steel, chemicals, non-ferrous metals and cement industries suggest that through the implementation of these mitigation technologies, CO_2 reduction potential of 319 million tons can be achieved by 2015, with the proportions of iron and steel, chemicals, non-ferrous metals and cement accounting for 75.3%, 6.5%, 5.0% and 13.2% respectively; CO_2 reduction potential of 420 million tons can be achieved by 2020, with the proportions of iron and steel, chemicals, non-ferrous metals and cement accounting for 68.6%, 8.6%, 4.6% and 18.2% respectively. The focus is on the emission reduction technology which can bring positive investment returns among the selected technologies, and the emission reduction potential realized by a positive cost accounts for 18.3% and 23% of that in the current.

If the emission reduction technologies are ranked in accordance with the size of the emission reduction potential, the preferential emission reduction technologies in the steel industry are such as the low calorific value gas combined with cycle power generation, all blast furnace gas boiler combustion technology, coal moisture control technology, converter negative energy steel and dry coke quenching technology and so on; the preferential emission reduction technologies in the chemical industry are such as closed calcium carbide furnace, soda ash new shift gas alkali manufacturing technology, production of high purity CO gas technology with CO_2 as the gasification agent, caustic soda ion-exchange membrane electrolytic cell membrane electrode technology, synthesis of ammonia synthesis loop molecular sieve technology and carbon dioxide degradable plastics technology and so on; the preferential emission reduction technologies in the non-ferrous metals industry are such as enhanced and efficient technology of current prebaked aluminum electrolytic cell, aluminum reduction cell diversion structure technology and new regenerative vertical retort furnace combustion technology and so on; the preferential emission reduction technologies in the cement industry are such as cement industry priority mitigation technologies such as cement kiln co-processing waste technology, carbide slag instead of limestone technology, cement kiln co-sludge disposal technology and pure low temperature waste heat power generation technology and so on.

The analysis results of abatement cost of the selected technologies show that the abatement cost of the selected technologies of the steel industry in 2020 is negative, from negative 1086 yuan/ton CO_2 (all blast furnace gas boiler combustion technology) to negative 254 yuan/ton CO_2 (regenerative heating furnace of steel rolling technology); the abatement cost of the selected technologies of the chemical industry in 2020 changes from negative 923 yuan/ton CO_2 (carbon dioxide production of dimethyl carbonate two technology) to positive 814 yuan/ton CO_2 (caustic soda ion-exchange membrane electrolytic cell membrane electrode technology); the emission reduction potential of the emissions reduction technology with negative marginal abatement cost in the non-ferrous metals industry in 2020 accounts for 95%, and the cost is in the range of negative 530 yuan/ton CO_2 to negative 1935 yuan/ton CO_2; the abatement cost of oxygen bottom-blowing smelting technology is the highest, up to 2234 yuan/ton CO_2; the abatement cost of the five selected emission reduction technologies in the cement industry is in the range of negative 3.82 yuan/ton CO_2 to 439 yuan/ton CO_2. The abatement cost of pure low temperature waste heat power generation technology is negative 3.82 yuan/ton CO_2; the abatement cost of carbide slag instead of limestone technology is 439 yuan/ton CO_2.

In summary, before 2020, the cost-effective emission reduction technologies with bigger emission reduction potential of iron and steel, chemicals, non-ferrous metals and cement industries include technologies that can improve energy efficiency, new processes and new technologies, by-products and waste recycling technology, raw materials and fuel substitution technology.

(3) Before 2020, transportation is an area with fastest growing CO_2 emissions and technological emission reduction potential, whose abatement cost is relatively high.

With the continued growth of transportation volume of services and the energy demanded, the average annual growth rate of CO_2 emissions of the transportation sector is about 4.6% from 2010 to 2020; while in the same period, that of the whole nation, the industry and the construction sector is less than 3.9%. Therefore, from present to 2020, transportation is an area with fastest growing CO_2 emissions and technological emission reduction potential.

The analysis results of abatement cost of the 17 selected technologies in the transportation sector show that in 2020, the technological emission reduction potential will increase from 42 million tons CO_2 in 2015 to 113 million tons of CO_2. The five technologies with the maximum emission reduction potential are as following in order: efficient diesel trucks, to increase the proportion of cargo inland shipping commitments and to improve bus travel rate, homogeneous charge compression ignition technology HDDI-gasoline vehicle applications as well as non-plug-in hybrid automotive technology. The total emission reduction potential of the five technologies is about 83 million tons CO_2, accounting for about 70% of the total emission reduction potential of the transportation sector in 2020.

The analysis results of abatement cost of the selected technologies show that in 2020, to improve automobile fuel economy technology can bring positive investment returns, and the emission reduction potential of these technologies account for 45% of the total emission reduction potential. The abatement cost of technologies such as pure electric vehicles and cellulose ethanol fuel alternative class is relatively high, and the main factor is the high investment costs of these new technologies (including R&D costs, laboratory costs, technological facilities construction costs and equipment purchase costs) and limited penetration rate.

(4) Before 2020, the construction is a potential focus area on achieve the technological emission reduction potential, but the abatement cost of most technologies is greatly uncertain.

The analysis results of abatement cost of the 34 selected technologies in the construction sector show that in 2020, the technological emission reduction potential will increase from 188 million tons CO_2 in 2015 to about 414 million tons CO_2. The previous ten technologies on annual emission reduction potential in 2020 are new residential construction's implementation of the 65% energy efficiency standards, new public buildings with incandescent lamps eliminated, efficient refrigerators, household biogas digesters, efficient and energy-saving stoves, high efficiency cogeneration systems and related technologies, envelope structure transformation of houses in the north, passive design, urban residential solar water heaters and existing public buildings incandescent lamp transformation. In 2020, these 10 technologies will achieve emission reduction potential of 310 million tCO_2, accounting for 75% of the total emission reduction potential of the construction sector.

In the 10 technologies with bigger emission reduction potential, the abatement cost of the northern houses' envelope structure transformation, passive design, new residential construction's implementation of the 65% energy efficiency standards and household biogas digesters is 622 yuan/ton CO_2, 250 yuan/ton CO_2, 181 yuan/ton CO_2 and 16 yuan/ton CO_2, respectively. The emission reduction potential of these four technologies accounts for 47% of the emission reduction potential of the 10 technologies.

To calculate the abatement cost of the emission reduction technologies of the construction sector, in addition to the use of the technological area or promotion volume, the influence of project price changes on the incremental value of investment and larger differences between the practical application of emission reduction technologies and cost calculation modes and other reasons are also necessary. Therefore, the analysis result of the abatement cost of emission reduction technologies of construction sector is uncertain to some degree.

(5) The technological emission reduction potential contributes about 21% to 32% to the emissions under the country's emission reduction goal in 2020.

Based on the scenario analysis, the result show that in 2015, the emission reduction potential of the selected technologies of the four industries and two sectors accounts for 42% of the CO_2 needed to reduce under our country's emission reduction goal of 40% and 26% under 45%; in 2020, the emission reduction potential of the selected technologies of the four industries and two sectors accounts for 32% of the CO_2 needed to reduce under the emission reduction goal of 40% and 21% under 45%.

(6) The popularization and promotion of emission reduction technologies need to overcome a variety of obstacles.

The constant perfections of the external environment, systems and policies are needed to realize the technological emission reduction potential of terminal departments cost-effectively. Compared to traditional technologies, the constant popularization and application of advanced, efficient and low-carbon emissions and cost-effective CO_2 capture and storage technologies have larger potential for CO_2 emission reduction. But in reality, to achieve the emission reduction potential of these technologies, it depends on not only the improvement of energy efficiency of the technology itself, rate of reducing the abatement costs and technology promotion efforts, but also the tremendous efforts to overcome the economic, social, behavioral and (or) institutional obstacles.

(7) The analysis of CO_2 emission reduction potential and cost of the subject of the four industries and two sectors is uncertain to a certain degree.

Due to various departments' limited awareness, identity and selection, especially the impossibility to predict the future advanced technologies; factors lacking system data support of the judgment of the emission reduction rate of the technology itself, the penetration rate of the technology and the economic properties, there are problems of enlarging and mitigating emission reduction results and high or low cost in the process of analyzing the technological emission reduction potential and cost, leading to the uncertainty of the analysis results. These problems will be conquered and perfected in the future research and practice process.

To promote the popularization and application of low-carbon abatement technologies, the study proposes the following policy recommendations:

(1) Organizing as soon as possible to develop the sector and industry low-carbon emission reduction technology system, implementation road map, development strategy and plans, in order to promote the implementation of emission reduction technologies in order of priority and timing;

(2) Developing R&D capabilities of advanced low-carbon emission reduction technologies, promoting the innovation and development of low-carbon emission reduction technologies, to make the development of low-carbon emission reduction technologies better adapt to the international economic structure and industrial transition to low-carbon industry;

(3) Using energy savings, carbon trading, voluntary agreements of market mechanisms and the implementation of strong financial incentives to promote the promotion and application of the low-carbon emission reduction technologies;

(4) Creating innovative investment and financing system, strengthening and enlarging the carbon emission reduction benefits of energy conservation investment (synergies);

(5) Starting as soon as possible to study and establish a standard system in the low-carbon field and develop corresponding standards to regulate the development and application of low-carbon emission reduction technologies, monitor and evaluate, and promote the progress of low-carbon emission reduction technologies;

(6) Strengthening the capacity building of enterprise level and helping enterprises to establish greenhouse gas data collection and management system to lay the foundation for enterprises to implement low-carbon transformation strategy. Such a system should include data demand system, data source identification system, the responsibility system for data collection, data quality control system and the database system; guiding the enterprises to carry out the diagnosis and online monitoring of the energy consumption indicators and their benchmarking and analysis to identify weaknesses and take corrective action; strengthening energy consumption statistics and supervision; improving the energy consumption statistics in the whole production process of enterprises; ensuring the reality of statistics; building step-by-step analysis reporting system and reporting on time; assessing evaluation mechanism.

目　录

第一篇　综　合　篇

中国主要行业和部门2020年二氧化碳减排技术的潜力和成本研究