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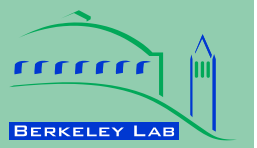
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China's Pathways to Achieving 40% ~ 45% Reduction in CO_2 Emissions per Unit of GDP in 2020: Sectoral Outlook and Assessment of Savings Potential

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Abstract

Achieving China's goal of reducing its carbon intensity (CO_2 per unit of GDP) by 40% to 45% percent below 2005 levels by 2020 will require the strengthening and expansion of energy efficiency policies across the buildings, industries and transport sectors. This study uses a bottom-up, end-use model and two scenarios -- an enhanced energy efficiency (E3) scenario and an alternative maximum technically feasible energy efficiency improvement (Max Tech) scenario – to evaluate what policies and technical improvements are needed to achieve the 2020 carbon intensity reduction target. The findings from this study show that a determined approach by China can lead to the achievement of its 2020 goal. In particular, with full success in deepening its energy efficiency policies and programs but following the same general approach used during the 11th Five Year Plan, it is possible to achieve 49% reduction in CO_2 emissions per unit of GDP (CO_2 emissions intensity) in 2020 from 2005 levels (E3 case). Under the more optimistic but feasible assumptions of development and penetration of advanced energy efficiency technology (Max Tech case), China could achieve a 56% reduction in CO_2 emissions intensity in 2020 relative to 2005 with cumulative reduction of energy use by 2700 Mtce and of CO_2 emissions of 8107 Mt CO_2 between 2010 and 2020. Energy savings and CO_2 mitigation potential varies by sector but most of the energy savings potential is found in energy-intensive industry. At the same time, electricity savings and the associated emissions reduction are magnified by increasing renewable generation and improving coal generation efficiency, underscoring the dual importance of end-use efficiency improvements and power sector decarbonization.

Introduction

As a country undergoing industrialization and economic development, China's energy use and energy-related CO_2 emissions will continue to be interlinked with its economic growth and urbanization. In recent years, China has taken serious actions to reduce its energy consumption and carbon emissions resulting in over 19% reduction in energy consumption per unit of GDP from 2006 to 2010 as a result of energy efficiency efforts across sectors. In November 2009, China committed to reduce its carbon intensity (CO_2 per unit of GDP) by 40% to 45% percent below 2005 levels by 2020. In support of the 2020 goal, China has also committed to reducing its energy and carbon intensity by 16% and 17%, respectively, under the 12th Five Year Plan (FYP) period (2006-2015) along with an 11.4% goal for non-fossil penetration of total primary energy consumption for 2015 from its current share of 8.3%. Achieving the 40% to 45% carbon intensity reduction goal will require the strengthening of energy efficiency policies in industry, buildings, appliances, and motor vehicles, as well as further expansion of renewable energy and nuclear power capacity.

In order to understand China's possible energy and emission pathways to 2020 and what policies and technical improvements can help achieve the 2020 carbon intensity reduction target, this study uses a bottom-up, end-use model and two scenarios to represent energy supply and demand sectors. This study is organized as follows: a review of the modelling methodologies and the two scenarios adopted for evaluating savings potential is presented first, followed by detailed characterization of each economic sector (residential, commercial, industrial, transport) in terms of key energy drivers, technology and efficiency trends. The

resulting sectoral energy and emissions trajectories to 2020 are then discussed, with particular focus on the energy savings and emission reduction potential from an end-use or subsector level.

Modeling Methodology

The basis for evaluating China's future energy and emissions trajectory and the span of cross-sectoral efficiency gains lies in a bottom-up, end-use model of the Chinese energy system to 2020. By adopting an end-use approach to energy and emissions modelling, this study is able to separate out and decompose different magnitudes of potential efficiency gains by sector and by technology. At the same time, scenario analysis enables the modelling of a pathway where efficiency improvements are maximized across sectors on a path of reaching the highest technically feasible levels before or shortly after 2020 in order to assess the combined effects of efficiency on energy and emissions reduction. This study uses the China Energy End Use model developed and continually refined by the Lawrence Berkeley National Laboratory China Energy Group since 2005.[1]

In order to assess how different measures and sectors can contribute to the energy savings and CO_2 emissions reduction needed to achieve the 40% to 45% carbon intensity reduction target, two key scenarios were developed, the enhanced energy efficiency (E3) and maximum energy efficiency technology (Max Tech) scenarios. Both scenarios share the same demographic and macroeconomic characteristics in terms of population, urbanization and GDP growth as well as subsector energy drivers such as building floor space, car ownership and industrial production. Specifically, China's population is expected to reach 1.43 billion in 2020 with an urbanization rate of 63% and average annual GDP growth rate of 7.7% from 2010 through 2020 (UNDP 2008). The scenarios differ primarily in efficiency improvements as measured by terms such as equipment unit energy consumption (kWh/year) or energy intensity per ton of industrial product output, as well as technology mix (such as electric vehicles and more efficient electric arc furnaces for iron and steel) and fuel mix.

The E3 scenario was developed to represent a pathway in which the Chinese economy continues and strengthens its "market-based" energy efficiency gains in all sectors, pursuing aggressively all announced energy efficiency policies and goals such as continuing the recent pace of appliance standard revisions and meeting the 2020 goal of rail electrification. The E3 scenario reflects the outcome of decisions to obtain the largest practicable savings from existing programs (e.g., setting appliance efficiency standards at high levels, performing sufficient tests of models to assure compliance) as well as developing new policy approaches (e.g., for appliance standards, offering incentives for products that are more efficient than required by the standards). The Max Tech scenario serves as an alternative pathway for development in which efficiency improvements are maximized to the highest technical potential across end-uses in the residential, commercial, industrial, and transport sectors in 2020 as a result of aggressive policies and programs that identify, develop and bring to market advanced energy. The Max Tech scenario does not consider current economics of the technology or commercial deployment barriers on the assumption of very aggressive policies and success in developing and/or reducing costs of advanced technologies. For specific end-uses such as residential appliances, heating and cooling equipment and transport vehicles, the Max Tech scenario means adopting the highest efficiency level available or cutting-edge technology such as all electric vehicles or light-emitting organic light emitting diode (OLED) televisions that are not yet commercially deployed. For energy-consuming processes such as the various industrial production processes, the Max Tech scenario embodies the adoption of current international best practice energy intensity levels by 2020. Table 1 outlines the main differences in key assumptions for each of these two scenarios.

[1] This model is based on LEAP software and enables detailed consideration of technological development—industrial production, equipment efficiency, residential appliance usage, vehicle ownership, power sector efficiency, lighting and heating usage—as a way to evaluate China's energy and emission reduction development path below the level of its macro-relationship to economic development. More detailed information on the China Energy End Use Model can be found in Zhou, et al., 2011 and Fridley et al., 2011.

Table 1. Key Assumptions for 2020 Scenario Modeling

	Enhanced Energy Efficiency Scenario	Max Technology Scenario
Residential Buildings		
Appliance Efficiency	Moderate efficiency improvements for new equipment	Accelerated efficiency improvements for equipment and shift towards more efficient technologies
Building Shell Improvements: Heating	Moderate Efficiency Improvement (1/3 improvement relative to Max Tech)	75% improvement in new buildings by 2020.
Building Shell Improvements: Cooling	Moderate Efficiency Improvement (1/3 improvement relative to Max Tech)	37.5% improvement in new buildings by 2020.
Commercial Buildings		
Heating & Cooling Efficiency	Moderate Efficiency Improvement by 2020	Current International Best Practice by 2020
Building Shell Improvements: Heating	50% improvement in fraction of new buildings growing to 60% per year by 2020	67% improvement in all new buildings by 2020
Building Shell Improvements: Cooling	25% improvement in fraction of new buildings growing 35% per year by 2020	same as E3 case
Transport Sector		
ICE Efficiency Improvements	Moderate efficiency improvements in fuel economy of aircrafts, buses, cars, and trucks through 2020	Accelerated efficiency improvements in fuel economy of aircrafts, buses, cars and trucks to 2020
Electric Vehicle Penetration	Electric vehicle penetration to 5% by 2020	Accelerated electric vehicle penetration to 12%% by 2020
Power Sector		
Thermal Efficiency Improvements	Coal heat rate drops from 350 to 323 grams coal equivalent per kilowatt-hour (gce/kWh) in 2020	Coal heat rate drops from 350 to 307 (gce/kWh) in 2020
Renewable Generation Growth	Installed capacity of wind, solar, and biomass power grows from 2.3 GW in 2005 to 113 GW in 2020	Installed capacity of wind, solar, and biomass power grows from 2.3 GW in 2005 to 157 GW in 2020
Demand Side Management	Total electricity demand reaches 5930 TWh in 2020	Total electricity demand reaches 5290 TWh in 2020
Industrial Sector		
Cement	Meet 2005 world best practice of 0.101 tce/ton cement for Portland cement after 2020.	Meet 2005 world best practice of 0.101 tce/ton cement for Portland cement by 2020.
Iron & Steel	16% production from EAF by 2020, with declining energy intensity in both EAF and BOF.	19% production from EAF by 2020, with faster decline in energy intensity in both EAF and BOF.
Aluminum	Reaches 70% primary and 30% secondary production by 2020. Reaches final EI of 3.95 tce/ton for primary and 1.9 tce/ton for secondary by 2020.	Reaches target of 48% primary production and 52% secondary production by 2020. Reaches 3.44 tce/ton for primary and 1.3 tce/ton for secondary by 2020.
Paper	China reaches energy intensity (weighted by current production process and output shares) of 0.608 tce/ton by 2020.	China reaches current world best practice energy intensity (weighted by current production process and output shares) of 0.572 tce/ton by 2020.
Ammonia	China reaches energy intensity of 1.51 tce/ton output by 2020.	China achieves energy intensity of 1 tce/ton by 2020.
Ethylene	China meets energy intensity of 0.6 tce/ton of output by 2020	China meets current world best practice energy intensity shortly after 2020, with 0.535 tce/ton of output by 2020.
Glass	China reaches a national average energy intensity of 0.316 tce/ton of output by 2020.	China reaches a national average nearing Shandong Top 1000 best practice energy intensity with 0.298 tce/ton by 2020.
Other Industry	~50% decline in other industry economic energy intensity (kgce/value added GDP) from current levels due to some efficiency gains and continued economic development (shift to higher value-added production) in trends consistent with other developed countries	Additional 10% decline in energy intensity by 2020 due to maximized technological improvements in motors for manufacturing industries and in balance of system (e.g., heat exchangers, condensers, pumps, etc.) in chemical and other industries

Sectoral Outlook and Findings

Residential Sector

Residential energy demand is driven simultaneously by urbanization and growth in household incomes. Urban households tend to consume more energy than rural households, particularly in non-biofuels; increase in household income affects the size of housing units and subsequent heating and cooling loads, as well as increases in ownership and usage of energy-consuming equipment such as appliances, lighting and electronics.

As a result, under E3, residential primary energy demand will continue growth at 2.7% per year to 2020 and beyond continued urbanization and rising appliance ownership persist until ~2030. The impact of the aggressive efficiency improvements under Max Tech is to cap demand growth in the residential sector, with growth of 1.6% per year; total residential energy demand is 12% lower than E3 by 2020. Cumulatively, the efficiency improvements and technology switching under Max Tech will lead to a reduction of 430 Mtce between 2010 and 2020 compared to E3. The energy savings opportunity in the residential sector varies across end-uses, with appliances having the largest savings potential followed by space heating and lighting, as shown in Figure 1. Substantial savings potential for appliances in 2020 is found in major residential energy consuming end-uses including refrigerators and air conditioners, as well as large efficiency improvements such as in OLED televisions and reduction in standby power. Figure 2 illustrates that if policies such as more stringent appliance efficiency standards and financial incentives and subsidies for new technologies like OLED TVs, LED lighting and efficient heating and cooling equipment are adopted under Max Tech scenario, China can achieve cumulative reduction of 1354 Mt of CO_2 (relative to E3) in the residential sector alone over the next ten years.

Figure 1. 2020 Residential Energy Savings by End-Use

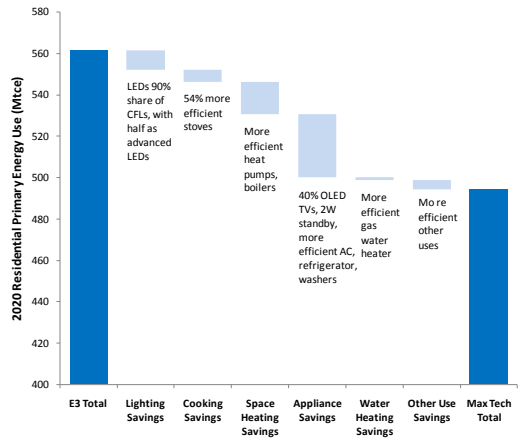
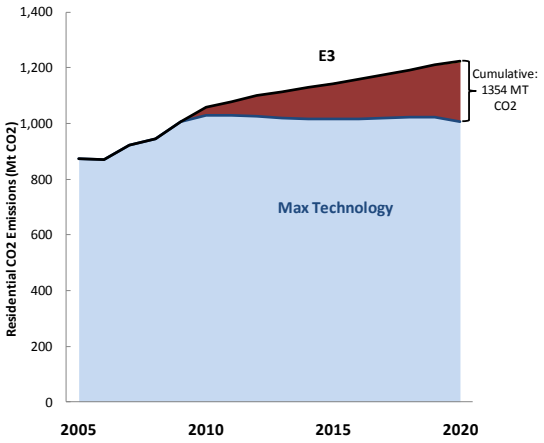


Figure 2. Residential CO_2 Emissions by Scenario



Note: Y-axis not scaled to zero.

Commercial Sector

As China's economic development and the structural shift away from heavy industry towards a service-oriented economy quickens, the commercial sector will become an increasingly important sector and a larger energy consumer than today. Under the E3 scenario, energy demand in this sector is still growing rapidly at annual average rate of 5.6% between 2010 and 2020 while growth slows to 4% annually under the Max Tech scenario. The main driver of energy consumption in commercial sector buildings is rising energy consumption per m^2 rather than overall increases in commercial floor area; we project growth in total commercial building floor space to slow in the short term while energy end use equipment grows rapidly until reaching current levels in industrialized countries. In particular, lighting, office equipment and other end uses in commercial buildings are expected to grow dramatically through 2020 with lighting intensity per m^2 doubling from current levels. Growth in office equipment energy consumption is even greater with tripling and doubling of 2010 levels by 2020 under the E3 and Max Tech scenarios, respectively. The greatest energy savings and emission reduction potential are thus from efficiency improvements in equipment and lighting, which together

comprise 55% of the Max Tech energy savings as compared with E3 in 2020. These efficiency gains along with fuel switching in electricity production can achieve cumulative energy savings of 224 Mtce or 407 TWh by 2020, with additional 121 Mtce from building shell and efficiency improvements in cooling and 49 Mtce from heating improvements. (Since both lighting and equipment use electricity exclusively, the CO_2 emissions reduction associated with Max Tech electricity savings will depend on the fuel mix of the electricity generation and its carbon intensity.) Overall maximum technical improvements in 2020 can reduce commercial sector CO_2 emissions by 1200 Mt CO_2 cumulatively by 2020.

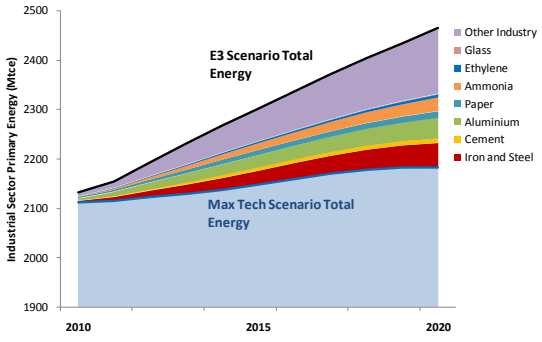
Industrial Sector

The industrial sector has been a major driver of China's economic boom and related energy consumption over the last decade; although its share of energy demand will likely decrease with continued economic development and change in industry structure, production by major industries will continue to have important energy and CO_2 implications. To analyze the energy savings and emission reduction potential of the industrial sector, seven of the largest energy-consuming industrial subsectors are singled out for in-depth study. These seven industrial subsectors are cement, iron and steel, aluminum, paper, ammonia and ethylene, and glass in addition to an "other industry" subsector that captures industries such as the various manufacturing, processing and other chemical industries.

Over the next decade, there are still significant opportunities for efficiency improvements and technology switching in the industrial sector. For the same level of industrial output, the two scenarios of industrial development can result in very different rates of growth in industrial energy demand, with an annual growth of 0.3% under Max Tech and a higher 1.5% annual growth under E3. Under Max Tech, total annual energy demand in 2020 will reach 2182 Mtce, 12% lower than the 2466 Mtce consumed by industry under E3. Most of the savings under the Max Tech is in the form of coal. This is strongly weighted toward coal used to generate electricity and steam, which declines by 260 Mtce per year in 2020. Figure 3 shows that with regard to industrial subsectors, the largest single potential for energy savings under Max Tech is from "other industry" (a conglomeration of many industries of varying energy intensities). The category "other industry" accounts for more than half of total annual energy savings in Max Tech compared with E3. This is followed by iron and steel and aluminum subsectors, which together account for 33% of energy savings in 2020. The aluminum industry, for instance, achieves significant energy savings as a result of the very aggressive shift to 52% secondary production under Max Tech. In contrast, ethylene and glass have the two lowest savings potential in 2020.

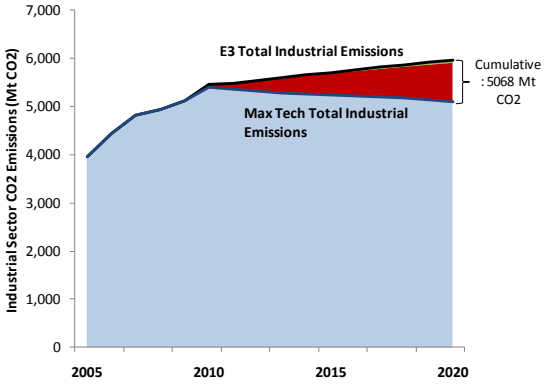
In terms of CO_2 emissions, efficiency improvements as well as power sector decarbonization under the Max Tech scenario have a notable effect on steadily reducing CO_2 emissions by 0.6% annually after 2010 compared with E3. Figure 4 shows that CO_2 emissions from industry have already peaked if the Max Tech policies and fuel switching for power generation are implemented over the next decade. This is compared with a 1% per year growth in industrial CO_2 emissions to 2020 in the E3 case.

Figure 3. Industrial Energy Savings by Subsector



Note: Y-axis not scaled to zero.

Figure 4. Industrial CO_2 Emissions by Scenario



Transport Sector

In China, demand for freight and passenger transport across various modes (road, rail, air, water) is closely linked to economic growth. For example, freight transport is directly related to economic activity with the export of finished products abroad and domestic transport of raw materials and fuels. Likewise, growing vehicle kilometers travelled is driven by population growth as well as growing demand for personal transport with rising income levels, particularly in the form of rising car ownership and use. As a result, the total transport final energy use will grow rapidly from 342 Mtce in 2010 to 626 Mtce under E3 and to 585 Mtce under Max Tech in 2020. Under both scenarios, diesel remains the largest share of fuel consumed, followed by gasoline, heavy oil and jet kerosene. The lower transport final energy demand in Max Tech can mostly be attributed to savings from policies mandating more stringent fuel economy improvements in all internal combustion engine (ICE) vehicles and fostering greater EV penetration, with annual savings of 39 Mtce and 9 Mtce in 2020, respectively. The non-diesel savings of the Max Tech relative to E3 scenario for transport are from reduction in gasoline demand due to improved fuel economy and vehicle electrification and a much smaller reduction in jet kerosene arising from airplane fuel economy improvements. Greater transport electricity use under the Max Tech scenario results in net CO_2 reduction on the order of 2 to 12 Mt CO_2 per year because of the lower carbon intensity of electricity production. Without decarbonization in the power sector, the EV impact on carbon mitigation is negligible.

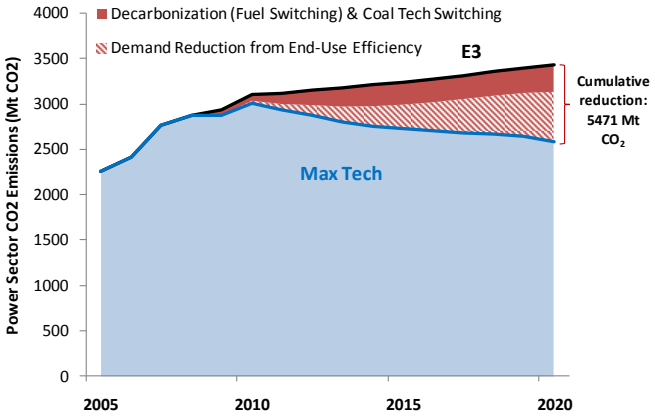
Power Sector

As an increasingly versatile source for China's growing demand for energy services, electricity will account for a growing share of total energy use and related CO_2 emissions. On the demand side, the end use efficiency improvements and technology switching under Max Tech scenario leads to 10% lower annual electricity demand with 5288 TWh generated in 2020 instead of 5928 TWh under the E3 scenario. This amounts to a cumulative reduction of nearly 3300 TWh between 2010 and 2020, or more than half of the annual electricity growth in 2020. Table 2 shows that on the supply side, meeting 2020 renewable capacity targets (which include not only renewable supply but also access to the grid—presently a difficult policy problem) will result in a 35% share of non-fossil fuels (including renewables, hydro and nuclear power) in total installed capacity under E3 in 2020, with a higher share of 38% under Max Tech.[2] Under these circumstances, the coal share of total electricity generation will drop to 65% in the E3 scenario and further to 54% in the Max Tech scenario. Consequently, the average carbon intensity per kWh generated will be reduced to 0.58 kg CO_2 and 0.488 kg CO_2 under the E3 and Max Tech scenarios, respectively.

Table 2. 2010 and 2020 Installed Power Generation Capacity by Type

% of Installed Capacity	2010	2020	
		E3	Max Tech
Wind Power	2%	6%	8%
Nuclear Power	2%	4%	5%
NG Fired CC	2%	4%	5%
Hydropower	19%	19%	18%
Oil Fired Units	0%	0%	0%
Biomass and other Renew	0%	0%	1%
Solar	0%	0%	1%
Coal <100MW	15%	3%	0%
Coal 100-200 MW	8%	3%	0%
Coal 200-300 MW Subcritical Units	7%	3%	2%
Coal 300-600 MW Subcritical Units	32%	20%	12%
Coal 600-1000 MW Supercritical Units	9%	23%	28%
Coal >1000MW Ultra Supercritical Units	5%	13%	20%

Figure 5. Power Sector CO2 Emissions by Scenario



[2] The China End-Use Energy Model's energy transformation sector includes a power sector module which can be adapted to reflect changes in generation dispatch algorithms, efficiency levels, generation mix, installation of carbon capture and sequestration technology and demand side management. For electricity generation, this model uses environmental dispatch order in which low-carbon and renewable fuels are dispatched first to meet demand, with coal capacity dispatched to meet the gap between electricity demand and non-fossil electricity supply.

Under Max Tech, greater CO_2 emissions reduction in electricity production and use result from more aggressive policy-driven end-use efficiency improvements (2/3 of the total) than in power sector decarbonization (1/3) (Figure 5). As a result of both demand reduction and decarbonization, in Max Tech CO_2 emissions from the power sector will peak by 2010 and decline through 2020 but will continue growing at 1% annually under the E3 scenario. These results emphasize the significant role that energy efficiency improvements will continue to play in carbon mitigation in the power sector (vis-à-vis lowering electricity demand), as efficiency improvements can actually outweigh CO_2 savings from decarbonized power supply.

Overall Implications and Findings

Total primary energy demand in China will rise from current levels under both scenarios, but at different paces over the next decade with annual average growth of 2.6% under the E3 scenario and 1.5% under the Max Tech scenario. This translates into annual savings of 466 Mtce in 2020 and cumulative savings of 2700 Mtce between 2010 and 2020 for Max Tech as compared to the E3 scenario. Figure 6 illustrates that most of the savings potential lies in the industrial sector, which in turn is dominated by savings in mining, manufacturing, processing and other sectors rather than for the seven heavy industries.

For end-use technologies, lighting has much greater room for improvement in commercial buildings than in residential, with its savings potential similar to the combined savings from major appliances. Improving residential and commercial buildings shells and raising the efficiency of space heating and cooling technologies can also result in important savings that rival or surpass savings from several of China's leading industries, including glass, ethylene, cement and paper. In the transport sector, most of the energy savings will be from improving the fuel economy of buses and heavy-duty trucks, rather than the fast-growing car population, because cars are already relatively efficient under the E3 scenario.

In terms of emissions, the 2020 CO_2 emissions intensity reduction target goal of 40% to 45% can be achieved under both scenarios, with as much as 60% reduction from the 2005 level possible by 2020 under the Max Tech scenario. Specifically, emissions grow much slower at 0.4% per year under the Max Tech scenario, peaking in 2019 with 8500 Mt CO_2. Emissions continue growing at 1.9% per year throughout the period under E3. The cumulative reduction of 8170 Mt CO_2 emissions between 2010 and 2020 under the Max Tech scenario is mostly from efficiency improvements and technology switching in the industrial sector, as well as decarbonization of power supply.

Figure 6. 2020 Primary Energy Savings by End-Use (E3 Minus Max Tech Scenarios)

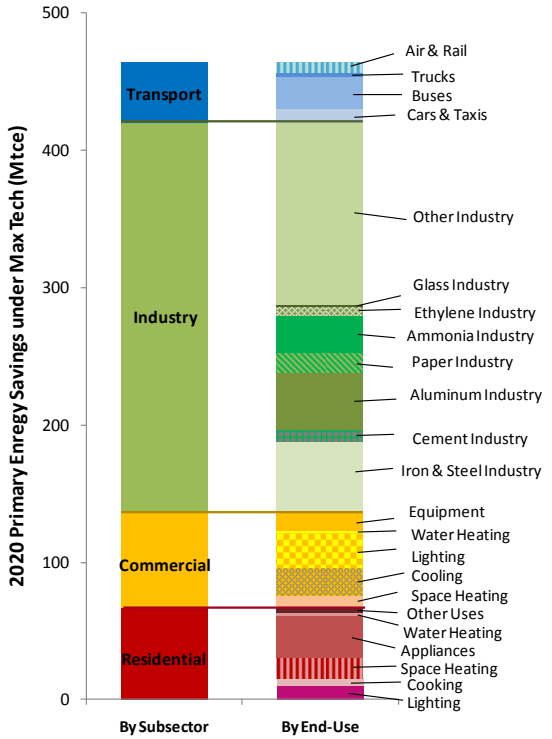
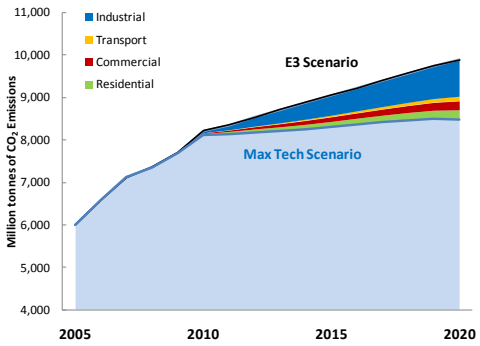
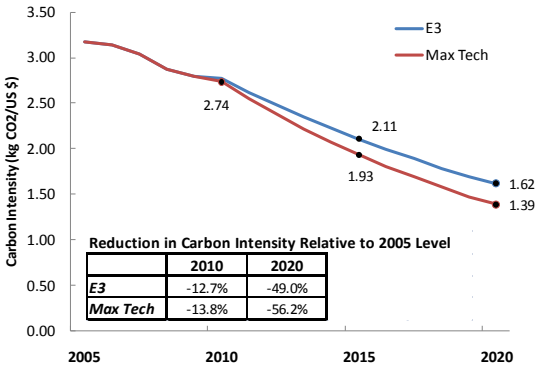


Figure 7. Total CO_2 Emissions and Reduction by Sector



Note: Y-axis not scaled to zero.

Figure 8. CO_2 Emissions per Unit GDP by Scenario



These findings highlight that China can achieve greater than 45% reduction in its carbon intensity by 2020 if it undertakes very strong policies and programs that promote energy efficiency efforts across all sectors including mandatory residential and commercial equipment, buildings, industrial and transport efficiency standards as well as financial incentives for energy efficient technologies and decarbonization of the power sector. Even greater energy savings and CO_2 emission reduction can be realized through a path of more aggressive efficiency and technological improvements if more significant policy actions beyond those already undertaken in the E3 scenario are adopted. Energy savings and CO_2 mitigation potential will vary by sector but most of the energy savings potential remain in the industrial sector. At the same time, electricity savings and the associated emission reduction are magnified by increasing renewable generation and improving coal generation efficiency, underscoring the dual importance of end-use efficiency improvements and power sector decarbonization.

Acknowledgments

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