CLIMATE AND ENERGY POLICY SOLUTIONS FOR CHINA

QUANTITATIVE ANALYSIS AND POLICY RECOMMENDATIONS FOR THE 13TH FIVE-YEAR PLAN

JULY 2016

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EXECUTIVE SUMMARY

This report represents a joint effort by Energy Innovation LLC, China's National Center for Climate Change Strategy and International Cooperation (NCSC) and China's Energy Research Institute (ERI) to provide insight into which climate and energy policies can most cost-effectively drive down China's emissions.

Together, the three organizations built a system dynamics model, the "Energy Policy Simulator" (EPS), to assess the combined effects of 35 climate, energy, and environmental policies on a variety of metrics, including CO_2 and PM2.5 emissions, use of various fuels, cash flow changes, and monetized social benefits from avoided public health impacts and climate damages. More than 10,000 scenarios were tested using the EPS, seeking policy combinations that could meet China's emissions goals most cost-effectively. Two of those policy scenarios are highlighted in this report (plus a reference scenario and a theoretical scenario based on the strongest internationally observed policies).

Qualitative Policy Design Principles

There are three main approaches to energy and environmental policymaking: regulatory mandates (such as performance standards), economic incentives (such as fuel or carbon taxes), and support for research and development. Deciding which of these approaches to pursue depends on the desired policy outcome as well as local conditions and market considerations. Done well, they complement and reinforce each other, accelerating deployment of new technologies and lowering costs.

The most successful energy and climate policies are designed based on the following nine principles:

1. Require **continuous improvement**, with consistent, predictable increments in performance.
2. Enable innovation by **setting clear goals** and letting the market work out the best solutions.
3. **Reward performance**, not investment, by avoiding unintended consequences. This gives firms—and indeed the whole economy—flexibility in finding the best solution.
4. Be designed to **adapt or repair over time**, with strong programs for measurement, evaluation, and future adjustment.
5. Influence investments in **new infrastructure** when it is designed and constructed in the first place, rather than waiting to retrofit or replace it.
6. Go upstream in the manufacturing process and **capture 100% of the market**.
7. **Cover a wide range of carbon emitters**, to minimize "leakage" and to capture lowest cost carbon reductions where they may be found.

8. **Ensure that the government institutions that implement or enforce the policy are sufficiently funded, staffed and carry the authority necessary to ensure full compliance.**
9. Facilitate **private sector investment** and innovation.

These criteria, properly applied, make for very effective policies. They will reduce costs, accelerate innovation, and deliver the social and economic benefits China requires.

Finally, evaluating policy efficacy is an important part of policy design. Policy evaluation helps ensure that limited resources are used as effectively as possible, allows for the testing of new policy approaches, and helps inform policymakers when adjustments are needed. A detailed description of the best policy evaluation metrics and when to conduct evaluation is included in this report.

Quantitative Model Overview

The Energy Policy Simulator (EPS) is a computer program that assesses the effects and interactions of 35 energy and environmental policies using official Chinese government data. Numerous output metrics are available, including emissions of nine different pollutants; the use of various fuels (coal, natural gas, etc.) by sector; electricity capacity and generation; changes in capital and operation and maintenance expenditures, and many others.

The model is divided into five sectors: electricity, industry, transportation, buildings, and district heat. Using input data provided by NCSC and ERI or obtained from published research, the model builds a Reference Scenario (RS). The **Reference Scenario** reflects the continuation of existing trends and policies without the addition of new policies. It is intended to serve as the baseline to which other policy scenarios are compared. The Reference Scenario includes recent policies that will affect future fuel use and emissions. For example, China's 2015 fuel economy standards for light duty vehicles are incorporated and will cause the fuel efficiency of light duty vehicles to increase throughout the model run.

When model users change policy settings, the model constructs a new scenario in real-time by tracking changes relative to the RS.[1] Therefore, the most meaningful way to interpret the model's findings is to evaluate the *difference* between policy scenario outputs and Reference Scenario outputs, rather than looking at the absolute value of the policy scenario outputs in a given year.

Two policy packages are highlighted in this report, based on examining thousands of model runs and considering policymakers' requirements. A third scenario is included but not highlighted; its purpose is to represent the theoretical minimum level of greenhouse gas emissions achievable in the model. All three of these scenarios, as well as the Reference Scenario, are based on the same underlying assumptions about exogenous inputs, for example GDP growth. The differences stem

[1] The model begins applying policies in 2013 and reports outputs at annual intervals from 2013 through 2030. If policies were to begin in 2016, peak years and other results may occur a few years later than modeled.

from the use of different policies as well as from the use of different settings for the same policy (for example different carbon prices). The two highlighted scenarios are:

- Low Carbon Scenario
- Accelerated Low Carbon Scenario

The **Low Carbon Scenario** (LC) is NCSC's and ERI's scenario that incorporates measures intended to peak CO_2 emissions between 2025 and 2030. The specific policies used in this scenario are discussed below.

The **Accelerated Low Carbon Scenario** (ALC) is Energy Innovation's scenario that incorporates additional measures intended to peak CO_2e (including non-CO_2 greenhouse gases) by 2030 and peak CO_2 as soon as possible while focusing on cost effectiveness.

In addition to these two highlighted scenarios, the **Strongest Internationally Observed Policies Scenario** (SIOP) is a scenario designed by Energy Innovation that is used to represent the theoretical minimum level of greenhouse gas emissions achievable using the policies in the model. This scenario uses international best practice for all policy settings. The SIOP scenario is meant as a lower bound on emissions rather than as recommended policy settings. This scenario is included for context, but is not analyzed alongside other scenarios.

The greenhouse gases included in CO_2e emissions are carbon dioxide, methane, volatile organic compounds, carbon monoxide, f-gases (including HFCs), and nitrous oxide. Emissions of these pollutants are multiplied by their global warming potentials from the IPCC AR5 report to calculate CO_2e emissions. CO_2e emissions include direct emissions from burning fuel in the buildings, transportation, electricity, and industry sectors as well as emissions of the above pollutants generated through industrial processes, for example cement manufacturing. They do not include emissions from land use, land use change, and forestry (LULUCF) nor do they include emissions from other sectors not covered by the EPS (for example, construction). Additionally, while CO_2e includes non-fuel emissions, for example industrial process emissions, CO_2 includes only direct emissions from fuel combustion.

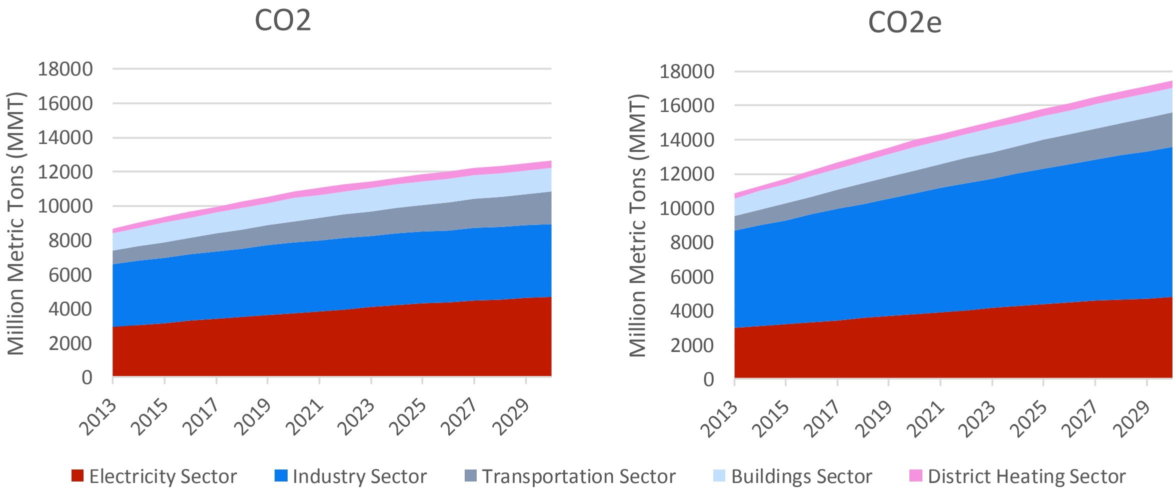
ECONOMY-WIDE RESULTS

Reference Scenario

In the Reference Scenario, CO_2 emissions increase from 8,684 MMT in 2013 to 12,650 MMT in 2030. carbon dioxide equivalent (CO_2e) emissions increase from 10,841 million metric tons (MMT) in 2013 to 17,468 MMT in 2030.

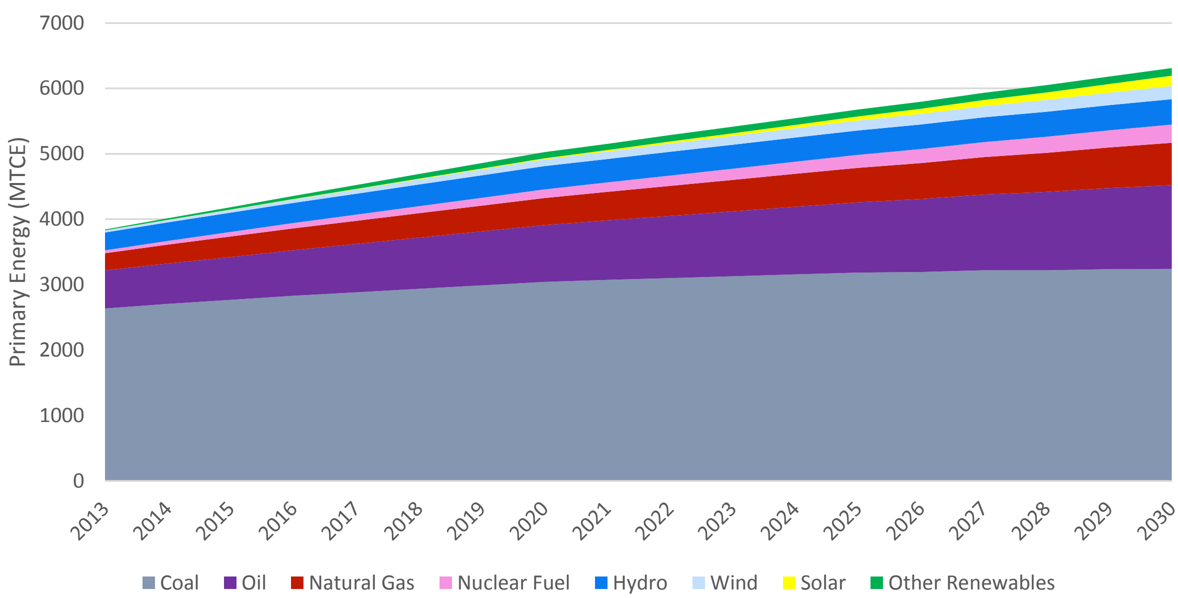
The EPS model attributes emissions to the sectors that directly emit them, so emissions from the electricity and heat sectors are assigned to those sectors, rather than to the sectors that demanded electricity or heat. In CO_2e terms, the industry sector is by far the largest emitter, accounting for 50% of emissions in 2030. In CO_2 terms, the electricity sector is the largest emitter, accounting for 37% of 2030 emissions.

Figure 1. CO_2 and CO_2e emissions by sector



In the Reference Scenario, total primary energy use increases from 3,843 million tons of coal equivalent (MTCE) in 2013 to 6,311 MTCE in 2030. Coal use increases from 2,635 MTCE in 2013 to 3,240 MTCE in 2030, though its share of primary energy use decreases from 69% in 2013 to 51% in 2030. Oil use grows from 581 MTCE in 2013 to 1,281 MTCE in 2030. Natural gas use increases from 263 MTCE in 2013 to 647 MTCE 2030 and makes up 8.2% of all primary energy use in 2020. The remainder of primary energy use comes from nuclear, hydro, wind, solar, and other renewables.

Figure 2. Primary energy use by fuel type in Reference Scenario



Emissions of fine particulate matter ($PM_{2.5}$) increase from 2.6 MMT in 2013 to 3.0 MMT in 2030. Nitrogen oxide (NO_x) emissions increase from 14.9 MMT in 2013 to 22.9 MMT in 2030. Emissions of sulfur oxides (SO_x) continue to increase as well, growing from 15.5 MMT in 2013 to 19.4 MMT in 2030.

Policy Scenarios

CO_2 emissions peak in 2029 in the Low Carbon Scenario at 10,977 million metric tons (MMT) of CO_2 decreasing to 10,973 MMT in 2030. In the Accelerated Low Carbon scenario, CO_2 emissions peak in 2022 at 9,845 MMT and decrease to 9,575 MMT in 2030. In the SIOP scenario, CO_2 emissions peak in 2013 at 8,710 MMT.

Figure 3. CO_2 emissions excluding process emissions

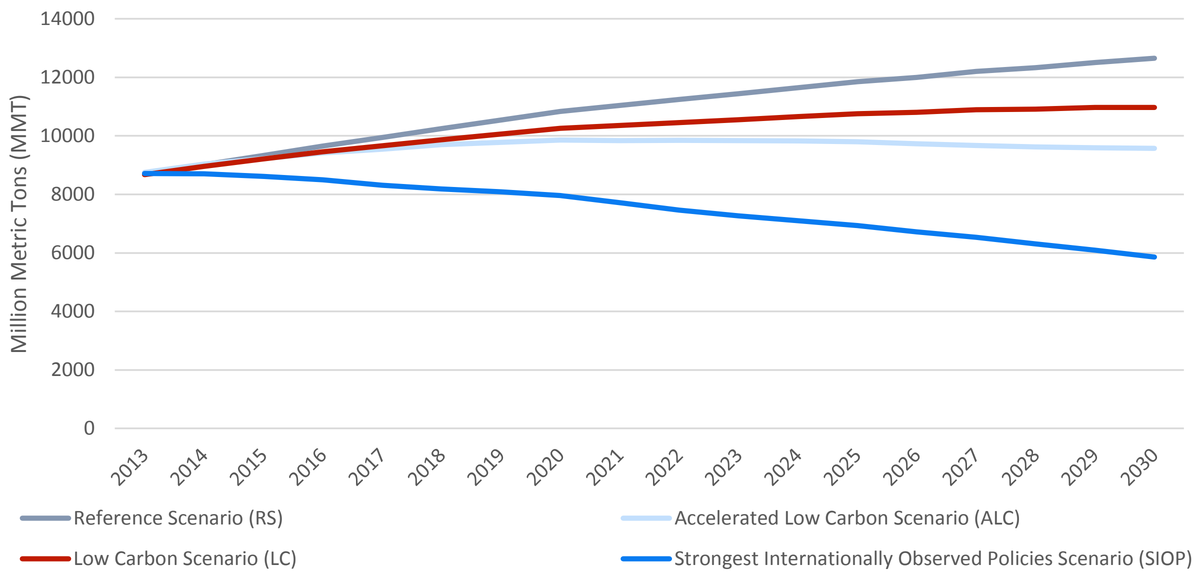
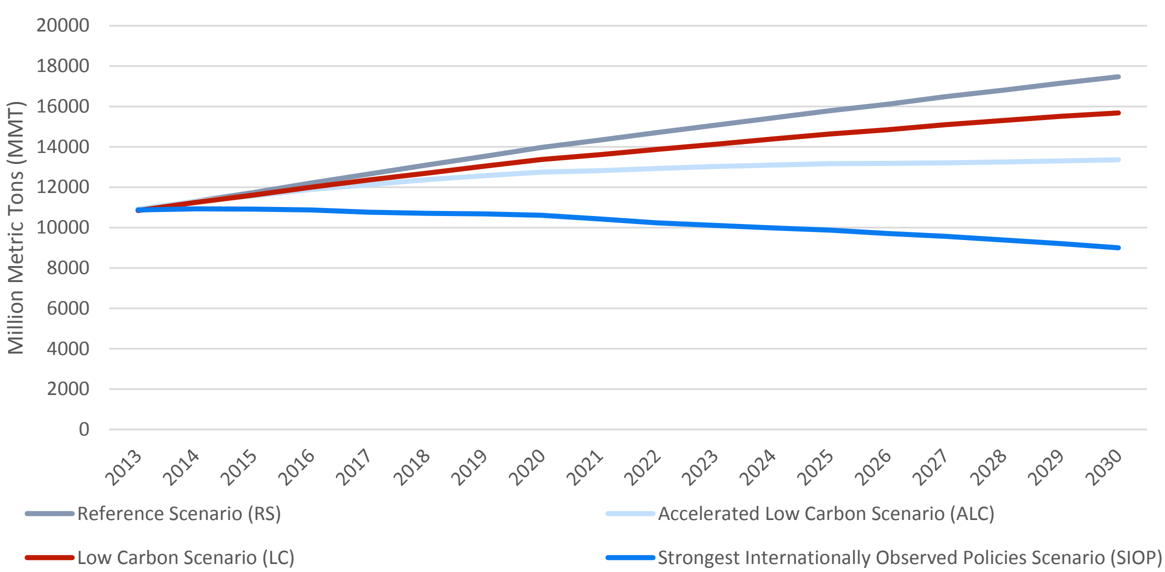
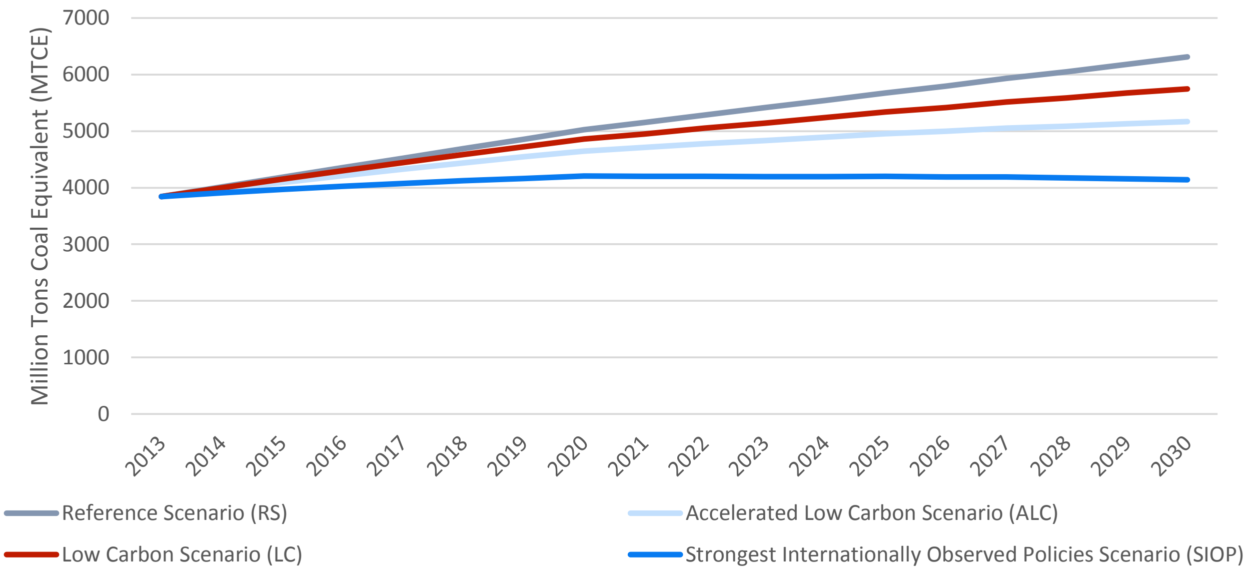


Figure 4. CO_2e emissions including process emissions



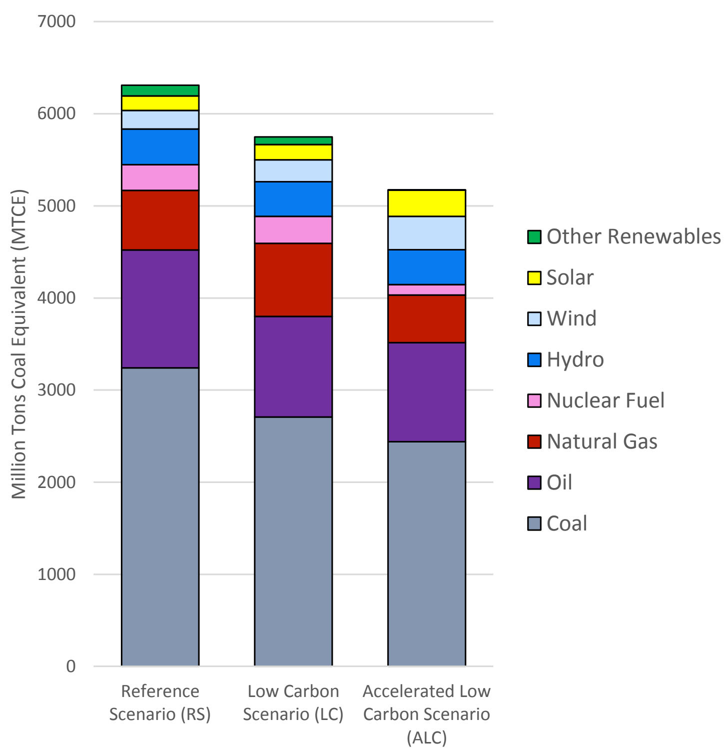
CO_2e emissions increase through 2030 in the Low Carbon scenario, reaching 15,677 MMT. In the Accelerated Low Carbon scenario, CO_2e emissions peak in 2030 at 13,350 MMT. Emissions peak in the SIOP Scenario in 2014 (the first simulated model year) at 10,929 MMT CO_2e.

Figure 5. Primary energy use



Primary energy use under the LC and ALC scenarios continues to increase through 2030, reaching 5,750 and 5,171 MTCE respectively. Coal's share of primary energy use decreases from 51% in 2030 under the RS to 47% in 2030 under both the LC and ALC scenarios. The non-fossil portion of primary energy use increases from 18% in 2030 in the RS to 20% and 22% in the LC and ALC scenarios. Similarly, the non-fossil portion of primary energy in 2020, the year in which China has set a target of around 15% non-fossil primary energy use, is 14% and 13% under the LC and ALC scenarios.

Figure 6. Primary energy use by scenario in 2030



By 2030, natural gas accounts for 13.7% of primary energy use in the LC scenario and 10% in the ALC scenario. In the LC scenario, wind and solar account for 7% of primary energy use in 2030, while in the ALC scenario they account for 12.5%. Nuclear also contributes a much smaller share of primary energy use in the ALC scenario than in the RS and LC scenarios.

Emissions of $PM_{2.5}$ decrease considerably under both the LC and ALC scenarios. In the LC scenario, $PM_{2.5}$ emissions peak at 2.8 MMT in 2020 and decrease to 2.5 in 2030. In the ALC scenario, emissions also peak in 2020 at 2.8 MMT and decrease to 2.4 MMT in 2030. Emissions of NO_x continue to increase in the LC scenario, reaching 19.6 MMT in 2030. In the ALC scenario, NO_x emissions peak in 2025 at 18.0 MMT, decreasing only slightly by 2030. SO_x emissions peak in 2020 in the LC scenario at 16.8 MMT and decrease to 16.2 MMT in 2030. In the ALC scenario, SO_x emissions peak 2018 at 16.7 MMT and decrease to 14.6 MMT in 2030.

Figure 7. PM 2.5 emissions

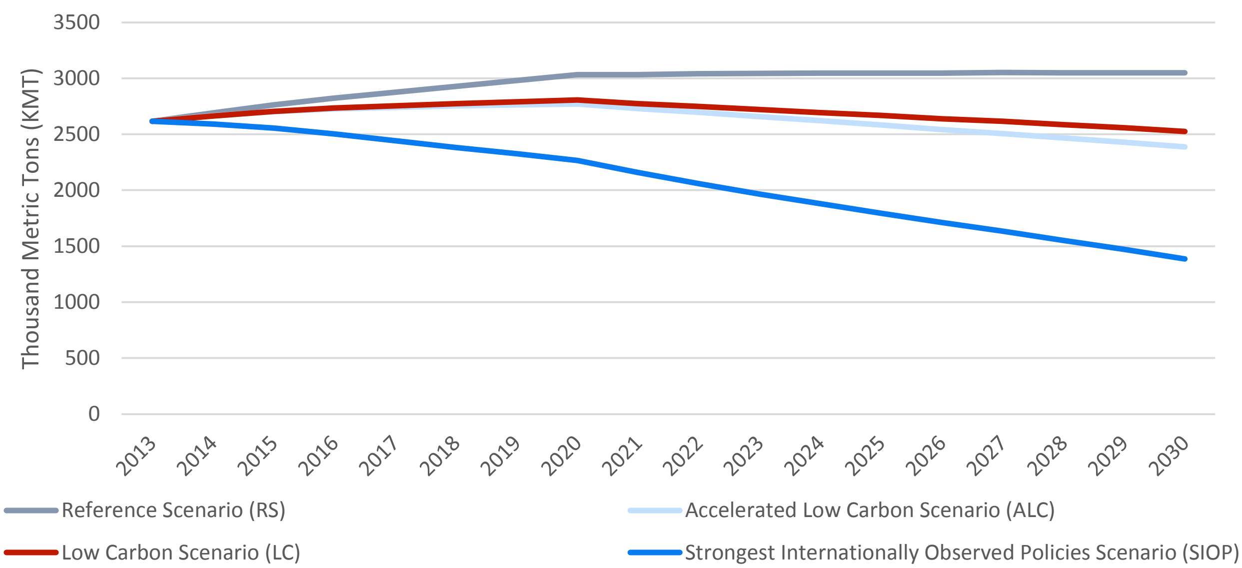
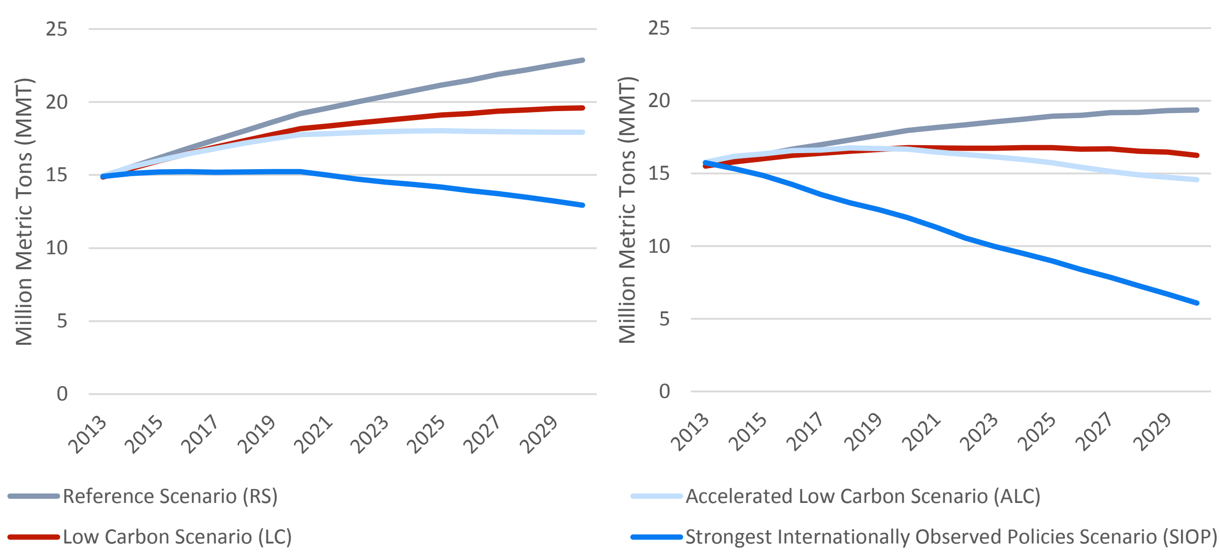


Figure 8. NO_X and SO_X emissions



SECTORAL RESULTS

Cross-Sector

Several cross-sector policies are used in the LC and ALC scenarios. Carbon pricing is by far the strongest cross-sector policy in both scenarios. In the LC scenario, a carbon price of 63 RMB per ton in 2030 contributes 90.65% of cross-sector CO_2e reductions in 2030.[2] In the ALC scenario, a carbon price of 252 RMB per ton in 2030 contributes 96.51% of cross-sector CO_2e emissions reductions in 2030.

The graph below shows the individual policy contributions to the total emissions reductions from all cross-sector policies in each scenario.

Figure 9. Cross-sector policy abatement and cost-effectiveness

Low Carbon Scenario		
Policy	*Abatement in 2030 (CO2e)*	*Cost per Ton (RMB/ton CO2e)*
Carbon Pricing	90.65%	1,274
Transportation Petroleum Fuel Tax	7.73%	5,239
Accelerated Deployment of CCS	1.62%	95
Accelerated Low Carbon Scenario		
Policy	*Abatement in 2030 (CO2e)*	*Cost per Ton (RMB/ton CO2e)*
Carbon Pricing	96.51%	1,609
Elimination of Fossil Fuel Subsidies	3.49%	5,811

The other cross-sector policies are substantially smaller in both the LC and the ALC scenarios. In the LC scenario, petroleum taxes on transportation fuels has a much smaller contribution to cross-sector policy abatement with 7.73% of emissions reductions followed by 1.62% for accelerated deployment of carbon capture and sequestration. In the ALC scenario, elimination of fossil fuel subsidies contributes 3.49% of emissions reductions in 2030.

It is important to note that the abatement of a single policy is dependent on the level the policy is set to, and this varies significantly across scenarios. For example, Figure 9 carbon pricing has very different abatement potential between scenarios because it is set to 63 RMB in the LC scenario and 252 RMB in the ALC scenario. This effect will be observed in the sectoral results below as well. It is important to note that the effectiveness of a certain policy is based both on the policy's ability to drive carbon abatement as well as the stringency of that policy setting within the scenario.

Electricity Sector

The electricity sector was the second largest source of CO_2 and CO_2e emissions in China in 2013.[3] In the RS, CO_2 and CO_2e from the electricity sector increase through 2030, reaching 4,693 and

[2] Emissions reductions reflect the savings from an individual policy within the LC and ALC scenarios rather than reductions from an individual policy with no other policies enabled. For more information, see the sectoral analyses in the full report.

[3] CO_2e emissions in the electricity sector include emissions of non CO_2 gases from fuel combustion at power plants, most notably carbon monoxide (CO) and oxides of nitrogen (NOx), these are very small compared to the amount of CO_2. CO_2 accounts for more than 98% of CO_2e emissions in the electricity sector.

4,782 MMT. Coal continues to dominate the electricity sector, comprising about half of all capacity, or 1.2 terawatts (TW) of the 2.5 TW of installed capacity in 2030. Installed nuclear capacity reaches 111 gigawatts (GW) while solar, wind, and biomass reach 299, 362, and 40 GW, respectively. Hydro and natural gas capacity increase to 387 and 41 GW in 2030.

Under the LC scenario, CO_2e emissions in the electricity sector increase through 2030, reaching 4,110 MMT in 2030. Emissions of CO_2 peak in 2029 at 4,188 MMT. Coal capacity increases more slowly than in the RS, reaching 1,108 GW in 2030. Natural gas increases faster than in the RS, reaching 88 GW in 2030. The installed capacity of nuclear, wind, solar, and biomass reach 117, 420, 329, and 29 GW in 2030. Hydro capacity increases to 377 GW in 2030.

In the ALC scenario, electricity sector CO_2 emissions peak in 2029 at 4,112 MMT. CO_2e emissions from the electricity sector peak in 2018 at 3,340 MMT and then decrease through 2030, reaching 3,140 MMT. Coal capacity remains relatively flat, increasing from 747 GW in the first year of the model run to 803 GW in 2030. Natural gas capacity decreases to 22 GW in 2030 while nuclear increases to 44 GW in 2030. The majority of displaced coal capacity relative to the RS is made up by increased renewable energy sources. Solar PV, solar thermal, and wind increase to 630, 22, and 630 GW in 2030. Hydro increases to 380 GW in 2030.

The LC scenario meets China's 2020 natural gas target of 10% of primary energy use by using mandated capacity construction targets for natural gas in the electricity sector. Under the ALC scenario, natural gas only reaches 8.3% of primary energy use and therefore it does not meet the 2020 natural gas target. This is because the ALC scenario focused on cost-effective emissions reductions, and found that policies to increase natural gas capacity high enough to meet the target actually increased emissions and overall policy costs.

Figure 10. Electricity sector policy abatement and cost-effectiveness

Low Carbon Scenario		
Policy	*Abatement in 2030 (CO2e)*	*Cost per Ton (RMB/ton CO2e)*
Increased Electricity Capacity Targets	89.04%	68
Subsidy for Wind Electricity	5.67%	64
Subsidy for Natural Gas Electricity	3.74%	1,682
Nuclear Power Plant Lifetime Extension	1.52%	-156
Hydro Power Plant Lifetime Extension	0.03%	-136
Accelerated Low Carbon Scenario		
Policy	*Abatement in 2030 (CO2e)*	*Cost per Ton (RMB/ton CO2e)*
Renewable Energy Standard	96.32%	131
Additional Early Retirement of Coal Power Plants	3.68%	278

The graph above shows the individual policy contributions to the total emissions reductions from all electricity policies in each scenario.

The strongest electricity sector policy used in the Low Carbon scenario is increased electricity capacity targets, which contributes 89.04% of CO_2e reductions from electricity sector policies. Subsidies for wind electricity and natural gas electricity also reduce emissions but only provide much smaller abatement with 5.67% and 3.74% contributions in 2030.

In the Accelerated Low Carbon Scenario, the strongest policy is a renewable energy standard, which compriese 96.32% of electricity sector policy emissions abatement in 2030. In practice, the renewable energy standard is not all that different from electricity capacity targets; it just focuses on cost-effectiveness by letting the market decide precise quantitites of non-fossil fuels. Additional early retirement of coal power plants accounts for 3.68% of reductions in 2030. When these and other policies increase the share of renewables in China, policies that provide grid flexibility (for example demand response, transmission, or storage) allow significantly greater emissions reductions and are very cost effective.

Industry Sector

The industry sector is the largest source of CO_2 and CO_2e emissions in China in 2013.[4] In the RS, CO_2 emissions from the industry sector increase from 3,646 to 4,242 MMT in 2030. Emissions of CO_2e increase from 5,677 MMT in the first year of the model run to 8,796 MMT in 2030.

In the LC scenario, industry sector CO_2 emissions peak in 2020 at 3,966 MMT, decreasing to 3,827 MMT in 2030. Emissions of CO_2e increase through 2030, reaching 8,313 MMT. In the ALC scenario industry sector CO_2 emissions peak in 2020 at 3,781 MMT. CO_2e emissions increase to 6,926 MMT in 2030. This is due to the fact that CO_2e emissions in the industry sector grow rapidly between 2013 and 2030 in the RS.

The strongest industry sector policy in the LC scenario is industrial fuel switching, which causes natural gas and electricity to be substituted for coal in the industry sector. Industrial fuel switching contributes 71% of industry sector policy emissions reductions in 2030. Improved industrial equipment efficiency contributes an additional 29%.

The graph below shows the individual policy contributions to the total emissions reductions from all industry sector policies in each scenario.

[4] CO_2e emissions in the industry sector include emissions from direct fuel burning and industrial process emissions. Over 98% of direct fuel burning CO_2e comes from CO_2. Process emissions cover N_2O and methane from natural gas and petroleum systems; N_2O, methane, and f-gases from chemical manufacturing; N_2O and methane emissions from waste treatment and management; and f-gases from other industries including semiconductor, aluminum, magnesium, flat panel display, and photovoltaic manufacturing as well as from electric power systems in the industry sector. Across the entire industry sector, 63% of process emissions (in CO_2e) are from CO_2, 23% are from f-gases, 14% are from methane, and 0.6% are from N_2O.

Figure 11. Industry sector policy abatement and cost-effectiveness

Low Carbon Scenario		
Policy	*Abatement in 2030 (CO2e)*	*Cost per Ton (RMB/ton CO2e)*
Industrial Fuel Switching	71.00%	2,847
Improved Industrial Equipment Efficiency	29.00%	-1,289
Accelerated Low Carbon Scenario		
Policy	*Abatement in 2030 (CO2e)*	*Cost per Ton (RMB/ton CO2e)*
Reduction of Demand for Industrial Products	31.51%	-157
Avoided Non-Methane Non-CO2 GHG Venting	30.32%	68
Improved Industrial Equipment Efficiency	30.30%	-1,202
Early Retirement of Inefficient Industrial Facilities	5.58%	-1,238
Industrial Fuel Switching	2.29%	2,858

In the ALC scenario, three industry sector policies result in large emissions reductions. The largest is reduced demand for industrial products, which contributes 31.51% of industry sector policy emissions in 2030. The next strongest policy is avoided non-methane non-CO_2 greenhouse gas venting, which contributes 30.32% of reductions, followed by improved industrial equipment efficiency, which contributes 30.30%. Increased early retirement of inefficient industrial facilities contributes an additional 5.58% MMT of abatement, followed by industrial fuel switching at 2.29%.

Transportation Sector

Transportation sector CO_2 and CO_2e continue to grow under all scenarios due to the growth of demand for travel.[5] However, aggressive transportation policies in both the LC and ALC scenarios significantly lower emissions relative to the RS by 2030. Emissions of CO_2 in 2030 decrease from the RS value of 1,894 MMT in 2030 to 1,537 MMT for the LC scenario. CO_2e emissions decrease from 2,036 MMT in the RS to 1,651 MMT.

In the ALC scenario, CO_2 emissions reach 1,586 MMT in 2030 while CO_2e emissions reach from 1,704 MMT.

The graph below shows the individual policy contributions to the total emissions reductions from all transportation sector policies in each scenario.

Figure 12: Transportation sector policy abatement and cost-effectiveness

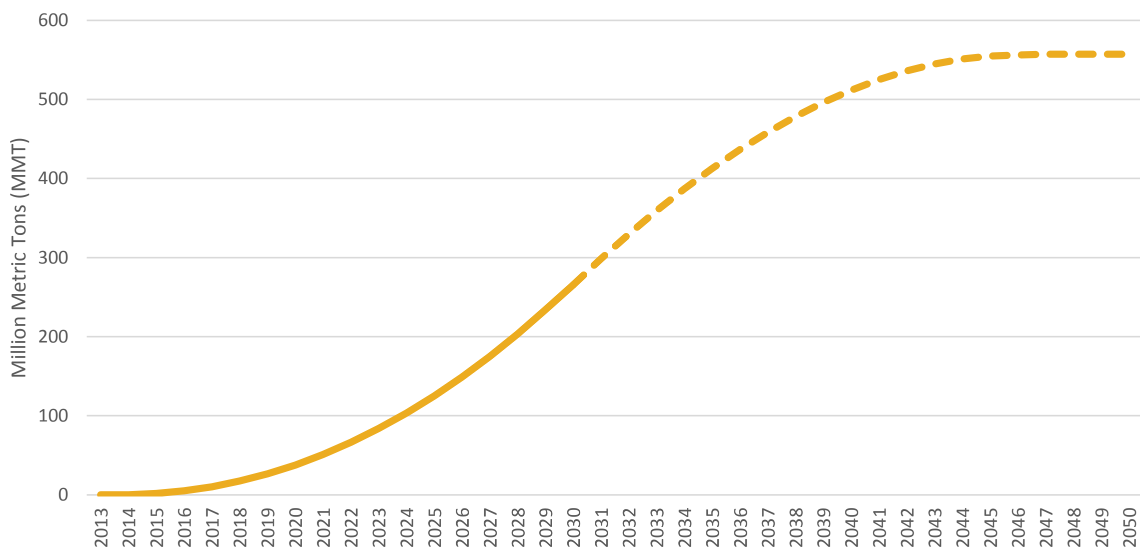
Low Carbon Scenario		
Policy	*Abatement in 2030 (CO2e)*	*Cost per Ton (RMB/ton CO2e)*
Increased Fuel Economy Standards for LDVs and HDVs	83.82%	-2,673
Increased Electrification of LDVs and HDVs	12.76%	873
Transportation Demand Management	3.43%	-2,779
Accelerated Low Carbon Scenario		
Policy	*Abatement in 2030 (CO2e)*	*Cost per Ton (RMB/ton CO2e)*
Increased Fuel Economy Standards for LDVs and HDVs	96.35%	-2,674
Transportation Demand Management	3.65%	-2,781

[5] Transportation sector CO_2e includes direct fuel burning emissions of CO_2, VOCs, carbon monoxide, NO_x, methane, and N_2O. Emissions are dominated by CO_2 which account for 93% of CO_2e emissions, followed by carbon monoxide (2.9%), NO_x (2.8%), VOCs (0.8%), methane (0.2%), and N_2O (0.2%).

The strongest transportation sector policy in the LC scenario is increased fuel economy standards for LDVs and HDVs, which contribute 83.82% of emissions reductions. Increased electrification of LDVs and HDVs contributes an additional 12.76% of reductions in 2030, while transportation demand management adds another 3.43%

In the ALC scenario, increased fuel economy standards for LDVs and HDVS contribute 96.35% of CO_2e reductions, while transportation demand management contributes 3.65%.

Figure 13: Transportation sector CO_2 emissions abated by standards that freeze in 2030



Many of the emissions reductions from transportation policies are not observed by 2030, and in fact the reductions continue long after 2030. This happens because fuel standards are phased in over time, meaning the level prescribed by policy settings is not reached until 2030. Vehicles last for 16 years on average, meaning that even if new cars sold in 2030 meet the standard, the *fleet-wide* average fuel economy does not reach the prescribed policy setting until long after 2030. Therefore, only roughly half of the emissions abatement from fuel economy standards is observed by 2030 when a standard is phased in linearly starting today.

Buildings Sector

Buildings sector CO_2 and CO_2e emissions continue to increase in the RS, reaching 1,385 and 1,410 MMT, respectively.[6] In the LC scenario, buildings sector CO_2 peaks in 2020 at 1,241 MMT. CO_2e emissions also peak in 2020 at 1,244 MMT. The ALC scenario peaks CO_2 and CO_2e in 2020 at 1,283 MMT and 1,307 MMT. Building codes and appliance standards exhibit the same kind of behavior as the vehicle fuel economy standards—because of the slow turnover of the building fleet, the full effect of building codes enacted by 2030 cannot be seen until many years after 2030.

[6] Buildings sector CO_2e includes direct fuel burning emissions of CO_2, carbon monoxide, NO_x, methane, and N_2O. Emissions are dominated by CO_2, which accounts for more than 98% of CO_2e emissions in the buildings sector.

The graph below shows the individual policy contributions to the total emissions reductions from all industry sector policies in each scenario.

Figure 14: Buildings sector policy abatement and cost-effectiveness

Low Carbon Scenario		
Policy	*Abatement in 2030 (CO2e)*	*Cost per Ton (RMB/ton CO2e)*
Enhanced Building Codes	56.01%	-1,076
Accelerated Building Retrofitting	22.31%	-910
Improved Appliance Labeling	10.30%	-1,015
Improved Contractor Education and Training	7.58%	-911
Enhanced Appliance Standards	3.80%	-1,640
Accelerated Low Carbon Scenario		
Policy	*Abatement in 2030 (CO2e)*	*Cost per Ton (RMB/ton CO2e)*
Enhanced Building Codes	66.44%	-1,079
Accelerated Building Retrofitting	22.30%	-929
Enhanced Appliance Standards	11.26%	-1,567

In the LC scenario, the strongest building sector policy is enhanced building codes, which contributes 56.01% of reductions in 2030. Accelerated building retrofitting contributes another 22.31%. Improved appliance labeling, improved contractor education and training, and enhanced appliance standards all contribute smaller amounts of emissions abatement, with 10.30%, 7.58%, and 3.80% respectively.

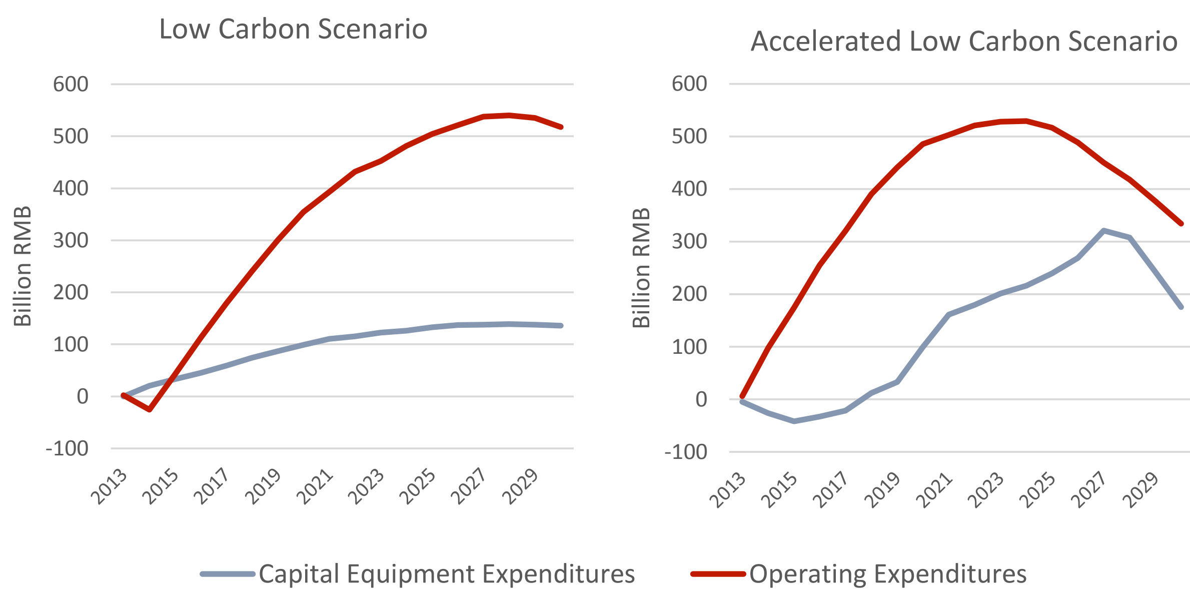
The strongest ALC sector policy is also enhanced building codes, which contribute 66.44% of the buildings sector policy emissions reductions in 2030. Accelerated building retrofitting contributes 22.30% of emissions reductions, and enhanced appliance standards contribute another 11.26%

COST AND BENEFIT RESULTS

In addition to pollution impacts, the Energy Policy Simulator tracks changes in cash flows in each policy scenario. Though there are many different ways to evaluate cash flows, two outputs are of particular interest. The first metric tracks the policy-induced change in expenditures on capital equipment, such as new power plants or building heating systems. The second metric, change in operating expenditures, tracks changes in the amount spent on fuel and labor taxes from policy scenarios. The share of operating expenditures from changes in fuel use greatly outweighs the share from changes in labor taxes. Both the capital and operating metrics include taxes. However, both metrics do not account for government payments in the form of subsidies. This means that subsidy policies tend to reduce operational expenditures because subsidies are only counted as a reduction in payments by industry and consumers, regardless of how much money is being transferred from the government to businesses and consumers. It is important to keep this in mind when evaluating the cost-effectiveness of subsidy policies. All changes in expenditures are relative to the RS scenario as a baseline. They are not indicative of the total cost of all policies but instead reflect the *change* in expenditures between the reference scenario and the scenarios being evaluated.

The LC scenario leads to increased capital equipment expenditures of RMB136 billion in 2030.[7] Operating expenditures increase as well, peaking at RMB540 billion in 2028 before declining to RMB518 billion in 2030. The net increase in capital equipment and operating expenditures is RMB654 billion in 2030, equivalent to 0.48% of projected GDP in 2030.

Figure 15: Change in capital equipment and operating expenditures



In the ALC scenario, capital equipment expenditures peak in 2024 at RMB529 billion before dropping to RMB334 billion in 2030. Operating expenditures increase as well, peaking at RMB321 billion in 2027 before declining to RMB175 billion in 2030. The net change in capital equipment and operations expenditures in 2030 is RMB509 billion, equivalent to 0.38% of projected GDP in 2030. If the policy settings froze in 2030, efficiency improvements would continue to reduce operating expenditures beyond 2030—into the 2040s and 2050s. By the time the efficiency policies have their full effect, net operational expenditures would become negative, ultimately leading to annual savings.

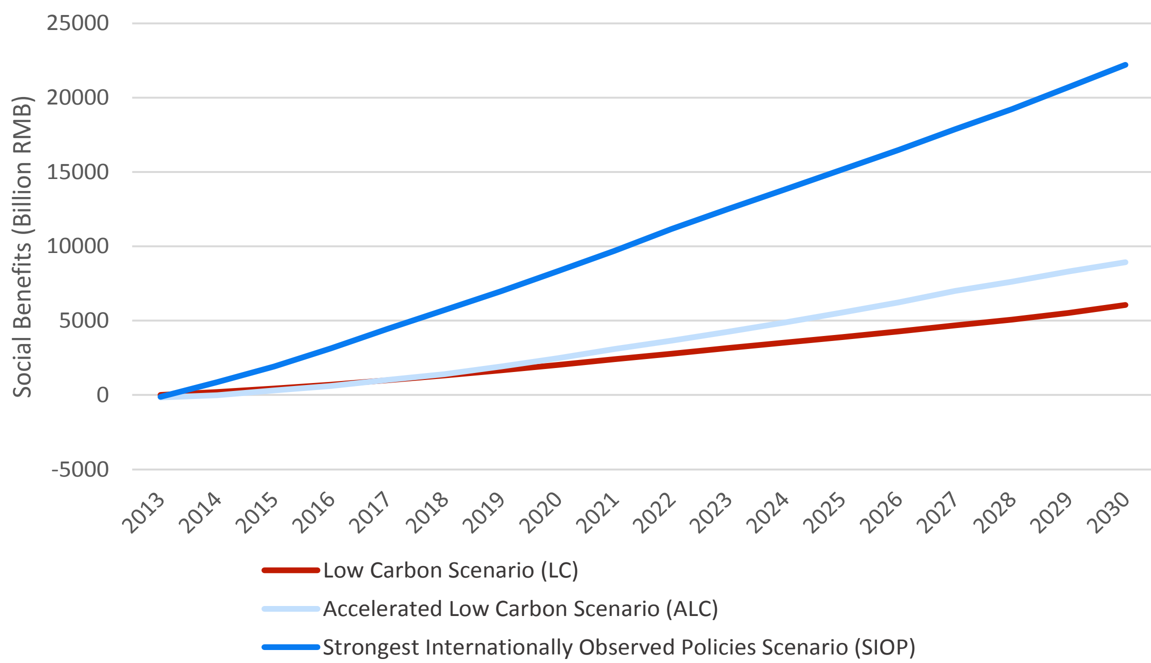
One of the primary differences in expenditures across the three scenarios is the use of fuel taxes and efficiency standards. The LC scenario utilizes fuel taxes for petroleum gasoline and diesel. The ALC scenario does not use fuel taxes, though it does use carbon pricing, which on its own causes increased fuel costs based on their carbon content of RMB2.5 trillion, or about 1.8% of GDP, in 2030. The majority of this increase is offset through the use of aggressive efficiency policies, which reduce fuel expenditures. Given a slightly longer time horizon, the use of several aggressive efficiency standards, including vehicle fuel economy standards, building codes and appliance efficiency standards, and industry efficiency standards, would cause fuel savings to

[7] All monetary values are reported in 2012 RMB.

increase enough over time to more than offset the cost of carbon pricing in the ALC scenario (the trajectory of the curve).

The Energy Policy Simulator also tracks social benefits, which are the monetized value of avoided pollution-induced premature mortality from fine particulates and climate damages from CO_2e. The avoided premature mortality calculations are based on the total reduction in emissions of $PM_{2.5}$ multiplied by a benefit-per-ton factor that relates emissions of particulates to premature deaths and the social cost of a premature death. Pollution-induced morbidity costs are not included here. The climate damages portion of the social benefit calculation is determined by multiplying the total amount of CO_2e abated by the social cost of carbon, a value that captures the monetized avoided damages of increased warming from each ton of CO_2e avoided. The social cost of carbon is set to 244 RMB per ton in 2013 and ramps up to 363 RMB per ton in 2030. More information on these metrics can be found in the full report.

Figure 16: Social benefits



In the LC scenario, social benefits increase to RMB6.1 trillion in 2030, or 4.5% of projected GDP in 2030. Social benefits in the ALC scenario increase to RMB8.9 trillion in 2030, or 6.6% of projected GDP in 2030. The monetized social benefits tend to drastically outweigh any increase in capital equipment or O&M expenditures.

POLICY EVALUATION

Strongest Policies for Reducing Emissions

The graph below shows the individual policy contributions to the total emissions reductions from all policies in each scenario.

Figure 17. Strongest carbon abatement policies

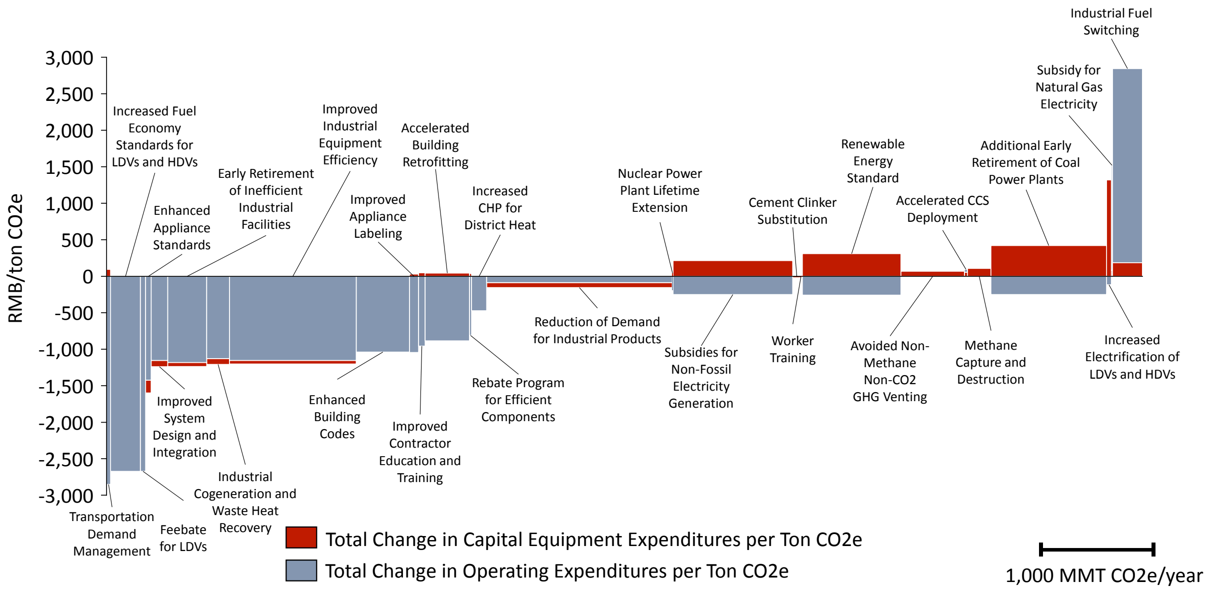
Low Carbon Scenario		
Policy	*Abatement in 2030 (CO2e)*	*Cost per Ton (RMB/ton CO2e)*
Carbon Pricing	27.49%	1274
Increased Electricity Capacity Targets	20.15%	68
Enhanced Building Codes	16.69%	-1076
Increased Fuel Economy Standards for LDVs and HDVs	6.72%	-2673
Accelerated Building Retrofitting	6.65%	-910
Accelerated Low Carbon Scenario		
Policy	*Abatement in 2030 (CO2e)*	*Cost per Ton (RMB/ton CO2e)*
Carbon Pricing	32.46%	1,609
Renewable Energy Standard	16.54%	131
Reduction of Demand for Industrial Products	10.74%	-157
Avoided Non-Methane Non-CO2 GHG Venting	10.34%	68
Improved Industrial Equipment Efficiency	10.33%	-1,202

In both scenarios, carbon pricing is the strongest policy, contributing to approximately 30% of total emissions reductions. Policies targeting increase renewable electricity – increased electricity capacity targets in the LC scenarios and a renewable energy standard in the ALC scenario – are the second strongest policies in the both scenarios. In the LC scenario, enhanced building codes are the third strongest with 16.69% of total emissions reductions, followed by increased fuel economy standards for LDVs and HDVs and accelerated building retrofitting. In the ALC scenario, reduction of demand for industrial products, avoided non-methane non-CO_2 GHG venting, and improved industrial equipment efficiency are the third through fifth strongest policies, which contributing roughly 10% of total emissions reductions.

Cost-Effectiveness

By tracking both changes in emissions and changes in cash flows, the Energy Policy Simulator can be used to estimate which policies have the highest emissions abatement potential as well as the most favorable change in cash flow per unit of avoided emissions. The abatement potential of policies within each sector is detailed above. The graph below presents policies ranked by the lowest change in net capital and operational expenditures per unit of CO_2e abated. Polices with negative values towards the left of the graph reduce net expenditures; these tend to be policies that focus on reducing fuel use and have small implementation costs, such as fuel economy standards or energy efficiency standards. Policies on the right side of the graph are those that have a net increase in capital or O&M expenditures; these tend to be pricing policies such as fuel taxes or carbon pricing. This is because polluters are paying directly for “externalities” that they did not pay for (with money) before. The width of each policy bar reflects the total abatement potential of each policy. Policies are evaluated individually to create this chart, so this particular chart does not reflect interactions between policies. Additionally, taxation policies and elimination of subsidies are excluded because their cost-effectiveness is directly related to how tax revenues (or avoided subsidies) are utilized, which is outside the scope of this model.

Figure 18. Policy abatement potential and cost-effectiveness



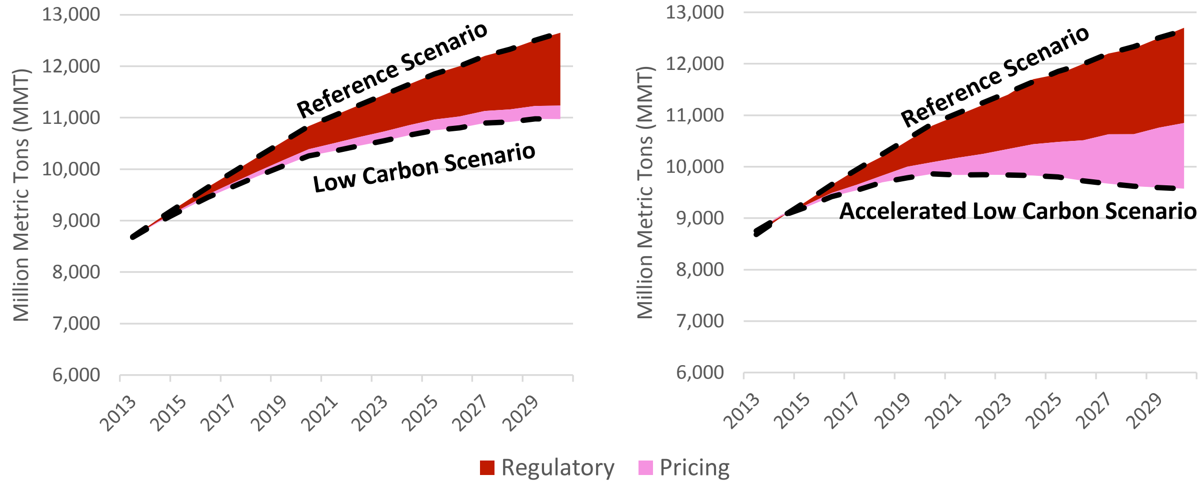
The most cost-effective policies are those with most negative cost per ton reduced but that also have significant abatement potential. Utilizing this approach, the most cost-effective policies include fuel economy standards for LDVs and HDVs, early retirement of industrial sites, industrial energy efficiency standards, building codes, and industrial product demand reduction. Carbon pricing, though not pictured here, has significant abatement potential and is discussed later in this report.

Abatement by Policy Type

Policies used in the LC and ALC scenarios can be broken into two categories for purposes of exploring potential emissions reductions: "regulatory" and "pricing" policies. Regulatory policies set standards or performance requirements and include policies such as building codes, fuel economy standards, and renewable energy standards. Pricing policies reduce emissions through taxes and subsidies, and include policies such as carbon pricing, fuel taxes, and subsidies for non-fossil electricity generation.

In both the LC and ALC scenarios, regulatory policies drive the majority of emissions reductions. However, pricing policies can have a large effect on reducing emissions—especially when demand for emissions-intensive products and services is elastic. In particular, carbon pricing can drive significant carbon reductions, and is the dominant pricing policy in both scenarios. In the ALC scenario, a strong carbon pricing policy contributes 40% of the reductions.

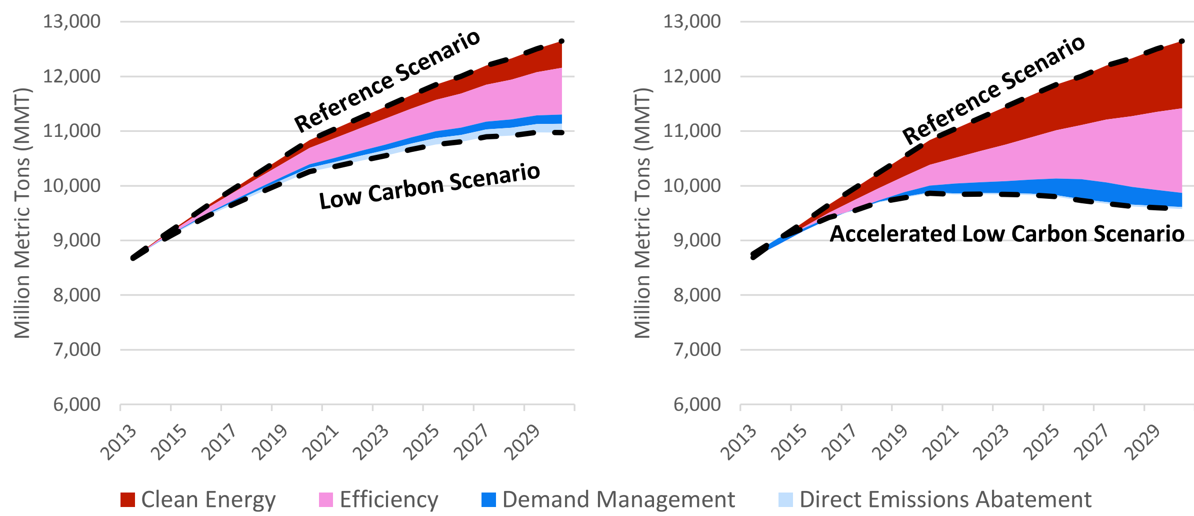
Figure 19: CO_2 abatement potential by policy type



Abatement by Policy Approach

The same policies from the LC and ALC scenarios can also be categorized into four policy approaches: clean energy, efficiency, demand management, and direct emissions abatement. Clean energy policies decrease the carbon intensity of energy use by promoting new, renewable energy sources or promoting a shift away from coal and towards other sources of energy. Policies such as the renewable energy standard, industrial fuel switching, and early retirement of coal power plants are considered clean energy policies.

Figure 20: CO_2 abatement potential by policy approach



Efficiency policies increase the energy efficiency of providing services such as mobility, manufacturing, indoor comfort, and more. These include policies such as fuel economy standards for vehicles, industrial energy efficiency standards, and building codes.

Demand management policies directly reduce the demand for energy or energy intensive products. The primary policy in this category is industrial product demand reduction.

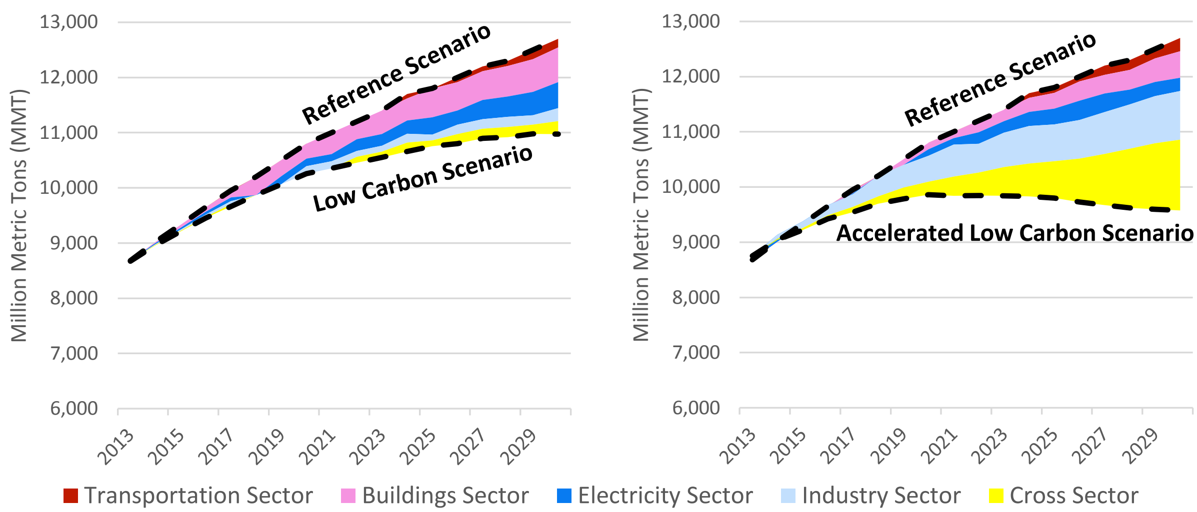
Finally, direct emissions abatement policies reduce emissions through destruction (e.g., burning) or capture. Policies such as carbon capture and sequestration, methane capture, and reduced venting of non-CO_2 greenhouse gases are examples of direct of emissions abatement policies.

In both the LC and ALC scenarios, efficiency policies are the primary driver of emissions reductions, followed by clean energy policies. Demand management and direct emissions abatement policies have a much smaller, though still noticeable, impact on CO_2 (the only greenhouse gas included on these particular figures), but direct emissions abatement policies would appear more significant if all greenhouse gases (e.g., methane, f-gases, etc.) were included in these figures. For example, when including all GHGs, direct emissions abatement policies in the ALC scenario increase to 13% of all emissions reductions in 2030.

Abatement by Sector

For the purposes of further exploring emissions reduction potential, the same policies from the LC and ALC scenarios can also be broken into four sectors (transportation, buildings, electricity, and industry) plus a cross-sector category. In both scenarios, emissions reductions are distributed broadly across policies in all sectors. In the LC scenario, reductions are dominated by buildings sector policies, which is due to strong settings in that scenario for building codes, retrofitting, and appliance standards. The electricity sector policies, primarily via increased electricity capacity targets, drive large reductions in the electricity sector as well. Transportation sector emissions reductions are only a small share of the total by 2030, as are cross-sector emissions reductions, primarily from carbon pricing.

Figure 21: CO_2 abatement potential by sector



In the ALC scenario, the largest share of emissions reductions comes from carbon pricing, which falls into the cross-sector category. Industry sector policies also drive a significant amount of CO_2

abatement due to the use of strong industrial efficiency standards, and a shift away from heavy manufacturing through industrial product demand reduction. Industry sector policies make up an even larger share of reductions when looking at CO_2e instead of just CO_2. Finally, buildings sector and electricity sector policies drive a similar amount of reductions.

POLICY RECOMMENDATIONS

Examining many policy scenarios has helped identify the policies with the highest abatement potential and the greatest cost-effectiveness. The top five policies are highlighted here because of their high marks in terms of abatement potential and cost-effectiveness:

Carbon Pricing

Carbon pricing is the single strongest policy available to reduce carbon emissions. In both the LC and ALC scenarios, carbon pricing resulted in the largest emissions reduction. The impact of carbon pricing on emissions will ultimately depend on the price of a ton of carbon. While carbon pricing tends to be slightly less cost-effective than some other policies, it has far higher abatement potential than others. Additionally, carbon pricing can be made more cost-effective if the revenues are used in part to offset some of the costs of the taxes. This approach is discussed further in the full report.

China is currently in the process of creating a national carbon market which will replace and expand the regional pilot markets. Based on historical trading, the average price of carbon in the regional markets has been between 10 and 40 RMB[8], which is substantially lower than the values used in both the LC and ALC scenario (which used 63 RMB per ton and 252 RMB per ton in 2030, respectively). To increase the emissions reduction from carbon pricing, a higher price-at least as high has 60 RMB per ton--should be used in future years. As China deploys its carbon market, policymakers should focus on regulating upstream resources to minimize administrative costs and capture as much of the market as possible. Another important consideration is how permits are initially allocated. An auction system is highly preferable to giving away allowances, as discussed later in this report. Finally, given the significant potential for reducing non-CO_2 greenhouse gas emissions in China, policymakers should explore the potential for expanding the carbon market to cover non-CO_2 gases.

Increased Electricity Capacity Targets/Renewable Energy Standard

Another strong policy is the use of increased electricity capacity targets or, alternatively, a renewable energy standard in the electricity sector. While electricity capacity targets are effective for increasing the share of non-fossil resources in China's electricity mix, they do not guarantee that these resources will be dispatched. Conversely, a production-based renewable energy standard (based on gigawatt-hours delivered, rather than gigawatts built) can drive both installation and generation from these resources. Both can be used together as well with the

[8] Partnership for Market Readiness, *China Carbon Market Monitor*, February 2016, available at: https://www.thepmr.org/system/files/documents/0203-PMR%20%20China%20Carbon%20Market%20Monitor%20%233%20FINAL%20EN.pdf

capacity targets ensuring capacity is installed and renewable energy standard ensuring those newly-built resources are dispatched.

As China revises its non-fossil capacity targets in the 13^{th} Five Year Plan, it should also consider increasing the renewable energy target beyond 30% by 2030. China may consider setting a target specifically for the electricity sector rather than for the whole economy. A strong 2030 target in the 13^{th} Five Year Plan would help drive more renewables and help decrease emissions.

Another important consideration is the role natural gas will have in China's electricity sector. In the LC scenario, increased natural gas capacity targets and subsidies ultimately resulted in higher costs and increased emissions. It will be important to ensure that natural gas power plants are used to displace coal and are not in direct competition with non-fossil electricity sources.

Building Codes

Buildings codes have a high potential for carbon abatement and are also very cost-effective. To improve building codes, China could make Ministry of Housing and Urban-Rural Development (MOHURD) One Star the new minimum. Recent experience in China shows that MOHURD one-star, and even two-star and three-star buildings, cost almost the same amount as less efficient buildings, but have dramatic long-term savings. Enhanced building codes will continue to provide savings for many years into the future, as buildings last a long time and China will be building quite a lot of them in the coming decades. It is critical that strong building codes are backed by a strong enforcement apparatus. This includes employing enough inspectors in each province and building a strong training program for engineers, builders, and inspectors on energy use in buildings.

Industrial Product Demand Reduction

A restructuring of China's industry sector has the highest potential to reduce emissions from industry. The industry sector is the largest contributor to China's CO_2e emissions and second largest contributor (behind the electricity sector) when looking just at CO_2. Transitioning to a knowledge and service economy—based on quality rather than quantity—will reduce the scale of industrial production, saving energy and reducing carbon emissions. Measures to reduce demand for heavy industrial products can also help prevent leakage so that the manufacturing and associated emissions are not simply exported to other countries.

Reduced Venting of Industrial GHGs

There is significant CO_2e abatement potential by reducing process emissions in industry, and in particular venting of f-gases. The U.S. and China recently agreed to try and phase out f-gases in the coming years. In addition to reducing the venting of f-gases, there is significant abatement potential by reducing other process emissions in industry, such as flared or vented methane, and CO_2 emissions from cement manufacturing. China can make a measurable dent in overall GHGs by targeting these cost-effective opportunities to reduce emissions in the industry sector.