The Energy and CO_2 Emissions Impact of Renewable Energy Development in China

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Xiliang Zhang[*†], Tianyu Qi[*‡], and Valerie J. Karplus[‡]

Abstract

China's recently-adopted targets for developing renewable electricity—wind, solar, and biomass—would require expansion on an unprecedented scale in China and relative to existing global installations. An important question is how far this deployment will go toward achieving China's low carbon development goals, which include a carbon intensity reduction target of 40–45% relative to 2005 and a non-fossil primary energy target of 15% by 2020. During the period from 2010 to 2020, we find that current renewable electricity targets result in significant additional renewable energy installation and a reduction in cumulative CO_2 emissions of 1.2% relative to a no policy baseline. After 2020, the role of renewables is sensitive to both economic growth and technology cost assumptions. Importantly, we find that CO_2 emissions reductions due to increased renewables are offset in each year by emissions increases in non-covered sectors through 2050. By increasing reliance on renewable energy sources in the electricity sector, fossil fuel demand in the power sector falls, resulting in lower fossil fuel prices, which in turn leads to greater demand for these fuels in unconstrained sectors. We consider sensitivity to renewable electricity cost after 2020 and find that if cost falls due to policy or other reasons, renewable electricity share increases and results in slightly higher economic growth through 2050. However, regardless of the cost assumption, projected CO_2 emissions reductions are very modest under a policy that only targets the supply side in the electricity sector. A policy approach that covers all sectors and allows flexibility to reduce CO_2 at lowest cost—such as an emissions trading system—will prevent this emissions leakage and ensure targeted reductions in CO_2 emissions are achieved over the long term.

Contents

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1. INTRODUCTION

China has adopted targets for the deployment of renewable energy through 2020. These targets are sizable both in terms of total installed capacity as well as the anticipated contribution of renewable energy to total electricity generation.[1] An important objective of renewable energy development in China is to reduce CO_2 emissions and reliance on imported energy by decoupling rising fossil energy use from economic growth over the next several decades. This decoupling is expected to have a positive impact on local air and water quality—environmental pollution is estimated to cost over 4% of GDP each year (The World Bank and China Ministry of Environmental Protection, 2007). Emphasis on renewable energy is also designed to promote China's competitiveness as a leading global supplier of clean, low cost renewable energy technologies. In this paper, we quantify the impact of China's renewable energy targets on both renewable and fossil energy use as well as the impact on CO_2 emissions, both of which are of significant interest to policymakers in China.

Targets for renewable energy deployment form part of a broader set of energy and climate policies that China's central government has defined for the period through 2020. National goals have been set through 2020 for energy and carbon intensity[2] reduction, as well as for the contribution from non-fossil sources to total primary energy. These broad goals are then supported by measures that target increases in specific types of generation—targets applied specifically to wind, solar, and biomass electricity generation are the focus of this analysis. As officials begin considering policies for the period beyond 2020, there is a strong need to understand how such supply-side targets for renewable energy could contribute to China's broader energy and climate policy goals. In order to understand what role renewable energy could play in achieving China's low carbon development, we assess the impact of renewable energy targets.

This analysis is organized as follows. First, we discuss in detail recent developments in China's energy and climate policy, the expected contribution of renewable energy and related policies, and the status of renewable energy development in China. Second, we describe the model used in this analysis, the China-in-Global Energy Model or C-GEM. We include a detailed discussion of how renewable energy is represented. Third, we describe the policy scenarios and how they are implemented in the modeling framework. Fourth, we present the results, which explore the impact of China's renewable energy targets on energy use, CO_2 emissions, and consumption under alternative economic growth and technology cost assumptions. Fifth, we discuss the relationship between China's renewable energy targets and the nation's long-term energy and climate policy goals.

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[1] Targets for installed capacity have been specified for all renewable generation types, while generation targets have only been set for wind (290 TWh in 2020).

[2] Carbon intensity is defined as the ratio of carbon dioxide emissions per unit of output. As a measure of output we use gross domestic product (GDP).

2. RENEWABLE ENERGY IN CHINA AND POLICY CONTEXT

2.1 Energy and Climate Policy Goals in China

China's energy and climate policy sets forth a national carbon intensity reduction target of 17% as part of the Twelfth Five-Year Plan (2010–2015). This target is consistent with the nation's commitment at the Copenhagen climate talks of achieving a 40–45% CO_2 intensity reduction by 2020, relative to a 2005 baseline. The Twelfth Five-Year Plan was the first time a CO_2 intensity target was included, as previous Five-Year Plans defined only energy-intensity targets. Looking forward, reducing CO_2 remains an important energy-related policy goal alongside energy security, air quality improvement, and balancing economic development across rural–urban and east–west dimensions.

Alongside carbon and energy intensity goals, China also aims to increase the contribution of non-fossil energy (including renewable sources, hydro, and nuclear) in total primary energy use. In 2010, actual non-fossil energy was 9.1%, and increases to 11.4% in 2015 and 15% in 2020. The non-fossil energy goal is viewed as a way to reinforce the goal of carbon reduction specifically through the deployment of low carbon energy (and especially electricity) sources. While the non-fossil energy goal focuses on expanding the contribution of technology to CO_2 reduction, broad mandates for improving industrial and building energy efficiency have also been strengthened and expanded during the Eleventh and Twelfth Five-Year Plans (Institute for Industrial Productivity, 2012).

2.2 Renewable Electricity Targets

Broad targets for energy and carbon intensity, non-fossil energy, and energy efficiency are typically implemented by assigning responsibility for target implementation at the sectoral, industry, or firm level. One way of assigning this responsibility for renewable energy policy in particular has involved setting renewable energy quotas. China's *National Renewable Energy Law of 2006* provides for renewable energy targets at the national level, a feed-in tariff and a special subsidy to support target achievement, tax relief for developers, and public R&D support (ERI, 2010; Renewable Energy World, 2005).

The expansion of China's renewable energy development in recent years has been substantial. China's renewable energy supply from wind, solar, and non-traditional biomass (including biomass for electricity, biogas, and biofuels) increased threefold between 2000 and 2010, from 95 million tons of coal equivalent (Mtce) to 293 Mtce. The composition of renewable energy in China in 2010 is shown in **Figure 1**.

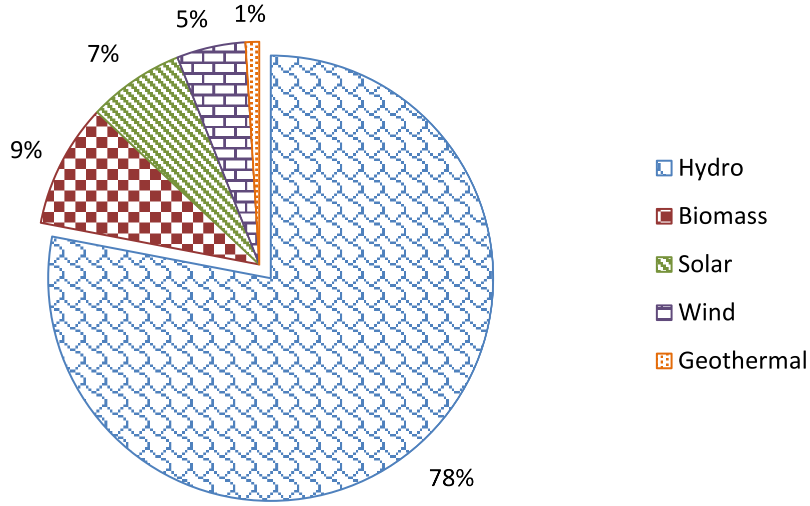

Figure 1. Composition of "new" renewable energy in China in 2010 (excludes traditional biomass).

Current renewable energy targets foresee a six-fold increase in wind power, a 62.5-fold increase in solar power, and a 5.4-fold increase in biomass electricity by 2020 relative to 2010 (for wind, some expect this deployment to occur even faster).Targets for 2015 and 2020 are discussed later on in the Current Policy scenario description.

3. DATA AND THE C-GEM MODEL DESCRIPTION

This paper employs the China-in-Global Energy Model (C-GEM) to evaluate the energy and CO_2 emissions impact of China's renewable energy development. The C-GEM is a multiregional, multi-sector, recursive–dynamic computable general equilibrium (CGE) model of the global economy that separately represents 19 regions and 19 sectors as shown in **Table 1**. In the model, China is represented as a single region.

Table 1. Sectors and regions in the China-in-Global Energy Model (C-GEM).

Sector	Description	Region	Description
Crops	Crops	China (CHN)	Mainland China
Forest	Forest	United States (USA)	United States of America
Livestock	Livestock	Canada (CAN)	Canada
Coal	Mining and agglomeration of hard coal, lignite, and peat	Japan (JPN)	Japan
Oil	Extraction of petroleum	South Korea (KOR)	South Korea
Gas	Extraction of natural gas	Developed Asia (DEA)	Hong Kong, Taiwan, Singapore
Petroleum and Coke	Refined oil and petro chemistry product, coke production	European Union (EUR)	Includes EU-27 plus Countries of the European Free Trade Area (Switzerland, Norway, Iceland)
Electricity	Electricity production, collection and distribution	Australia–New Zealand (ANZ)	Australia, New Zealand, and rest of the world (Antarctica, Bouvet Island, British Indian Ocean Territory, French Southern Territories)
Non-Metallic Minerals Products	Cement, plaster, lime, gravel, concrete	India (IND)	India
Iron and Steel	Manufacture and casting of basic iron and steel	Developing Southeast Asia (SEA)	Indonesia, Malaysia, Philippines, Thailand, Vietnam, Cambodia, Laos, rest of Southeast Asia.
Non-Ferrous Metals Products	Production and casting of copper, aluminum, zinc, lead, gold, and silver	Rest of Asia (ROA)	Rest of Asia countries.
Chemical Rubber Products	Basic chemicals, other chemical products, rubber, and plastics products	Mexico (MEX)	Mexico
Fabricated Metal Products	Sheet metal products (except machinery and equipment)	Middle East (MES)	Iran, United Arab Emirates, Bahrain, Israel, Kuwait, Oman, Qatar, Saudi Arabia
Mining	Mining of metal ores, uranium, gems. other mining and quarrying	South Africa (ZAF)	South Africa
Food and Tobacco	Manufacture of foods and tobacco	Rest of Africa (AFR)	Rest of Africa countries.
Equipment	Electronic equipment, other machinery, and Equipment	Russia (RUS)	Russia
Other industries	Other industries	Rest of Europe (ROE)	Albania, Croatia, Belarus, Ukraine, Armenia, Azerbaijan, Georgia, Turkey, Kazakhstan, Kyrgyzstan, rest of Europe.
Transportation Services	Water, air, and land transport, pipeline transport	Brazil (BRA)	Brazil
Other Service	Communication, finance, public service, dwellings, and other services	Latin America (LAM)	Rest of Latin America Countries.

3.1 Model Data

The China-in-Global Energy Model (C-GEM) is a recursive–dynamic general equilibrium model of the world economy developed collaboratively by the Tsinghua Institute of Energy, Environment, and Economy and the MIT Joint Program on the Science and Policy of Global Change. Energy production and consumption are explicitly represented in the sector detail to reflect its change over time and policy impacts. C-GEM is parameterized and calibrated based on the latest version of the Global Trade Analysis Project Version 8 (GTAP 8) global database and China's official national statistics. The GTAP 8 data set is includes consistent national accounts on production and consumption (input–output tables) together with bilateral trade flows for 57 sectors and 129 regions for the year 2007 (Narayanan, Betina, and Robert, 2012; Narayanan, 2012). C-GEM has replaced the GTAP 8 data with the data from China's official data sources, including the national input–output tables and energy balance tables for 2007 (National Bureau of Statistics of China, 2008). To maintain the consistency between these two data sets, we have rebalanced the revised global database with a least-square recalibration method (Rutherford and Paltsev, 2000).

The model is solved recursively in five-year intervals through 2050. The C-GEM model represents production and consumption sectors as nested constant elasticity of substitution (CES) functions (or the Cobb-Douglas and Leontief special cases of the CES). The model is written in the GAMS software system and solved using MPSGE modeling language, a sub-system of GAMS (Rutherford, 2005).

3.2 Renewable Energy Technology

We represent 11 types of advanced technologies in C-GEM as shown in **Table 2**. Three technologies produce perfect substitutes for conventional fossil fuels (crude oil from shale oil, refined oil from biomass, and natural gas from coal gasification). The remaining eight technologies are electricity generation technologies. Wind, solar, and biomass electricity technologies are treated as imperfect substitutes for other sources of electricity due to their intermittency. The final five technologies—NGCC, NGCC with CCS, IGCC, IGCC with CCS, and advanced nuclear—all produce perfect substitutes for electricity output.

Table 2. Advanced technologies in the C-GEM model.

Technology	Description
Wind	Converts intermittent wind energy into electricity
Solar	Converts intermittent solar energy into electricity
Biomass electricity	Converts biomass into electricity
IGCC	Integrated gasification combined cycle (coal) to produce electricity
IGCC-CCS	Integrated gasification combined cycle (coal) with carbon capture and storage to produce electricity
NGCC	Natural gas combined cycle to produce electricity
NGCC-CCS	Natural gas combined cycle with carbon capture and storage to produce electricity
Advanced nuclear	Nuclear power beyond existing installed plants
Biofuels	Converts biomass into refined oil
Shale oil	Extracts and produces crude oil from oil shale
Coal gasification	Converts coal into a perfect substitute for natural gas

Wind, solar, and biomass electricity have similar production structures as shown in **Figure 2**. As they produce imperfect substitutes for electricity, a fixed factor is introduced on the top level of CES layers to control the penetration of the technologies (McFarland et at., 2004). Like biofuels, biomass electricity also needs land as a resource input and competes with the agricultural sectors for this resource. Other inputs, including labor, capital, and equipment are intermediate inputs and are similar to shale oil and biofuels.

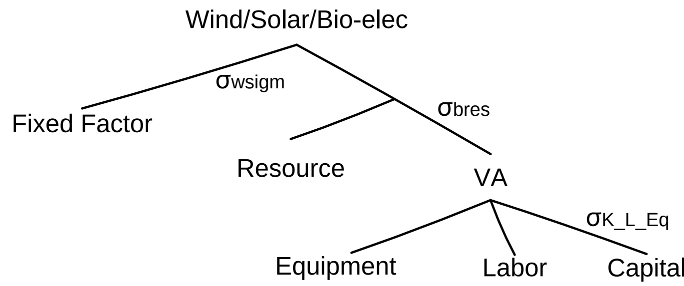

Figure 2. CES production structure for wind and solar power.

To specify the production cost of these new technologies, we set input shares for each technology for each region. This evaluation is based on outside cost estimates, demonstration project information, and expert elicitations (Babiker et al., 2001; Deutch and Moniz, 2007; Moniz, Jacoby, and Meggs, 2011; Paltsev et al., 2005). A markup factor captures how the incremental cost of new technologies compared to traditional fossil generation technologies. All inputs to advanced technologies are multiplied by this markup factor. For electricity technologies and biofuels, shown in **Table 2**, we estimate the markups for each technology based on a recent report by the Electric Power Research Institute that compares the technologies on a consistent basis (Electric Power Research Institute, 2011).

4. SCENARIO DESCRIPTION

We design scenarios to assess the impact of China's renewable energy policy under several economic growth assumptions. We first simulate energy use and CO_2 emissions under three growth trajectories in the absence of policy. These scenarios provide a basis for comparing three corresponding "Current Policy" scenarios in which existing renewable energy targets through 2020 are implemented. The goal is to understand the interaction between baseline economic growth and the requirement of current policies. We treat economic growth through 2050 as an important source of uncertainty, as it will influence the level of energy use, which will in turn impact energy prices and the relative prices of various electricity generation types (including the competitiveness of renewable electricity). The six main scenarios considered in this analysis are shown in **Table 3**.

Table 3. Scenario description

Economic Growth	Renewable Energy Policy	
	No Policy (NP)	Current Policy (CP)
High	No Policy-H	Current-H
Middle	No Policy-M	Current-M
Low	No Policy-L	Current-L

4.1 Economic Growth Assumptions

We design high, low, and medium economic growth trajectories that diverge after 2015, assuming that the Twelfth Five-Year Plan growth rate of 7.5% is achieved in all scenarios. After 2015, we design the scenarios to include three potential trajectories. The high and low growth scenarios represent roughly 25% above and below the medium growth trajectory through 2035, and the detailed growth rates assumed in each period are shown in **Table 4**. After 2035, we adjust the growth rate downward, consistent with the developed state of the Chinese economy by that point. Using these growth rate assumptions produces the GDP trajectories and energy consumption patterns in the High, Medium, and Low cases as shown in **Figure 3** and **Figure 4**.

Table 4. Annualized growth rate assumptions for the low, medium, and high growth scenarios.

	2007–2010	2010–2015	2015–2020	2020–2025	2025–2030	2030–2035	2035–2040	2040–2045	2045–2050
Low	9.3%	7.5%	5.7%	4.4%	4.0%	2.9%	2.7%	2.4%	2.4%
Medium	9.3%	7.5%	7.3%	5.7%	5.2%	3.9%	3.4%	3.2%	2.9%
High	9.3%	7.5%	9.0%	7.4%	6.8%	4.7%	2.8%	1.8%	1.2%

Note: Annualized growth rate assumptions are set for the specified five-year interval.

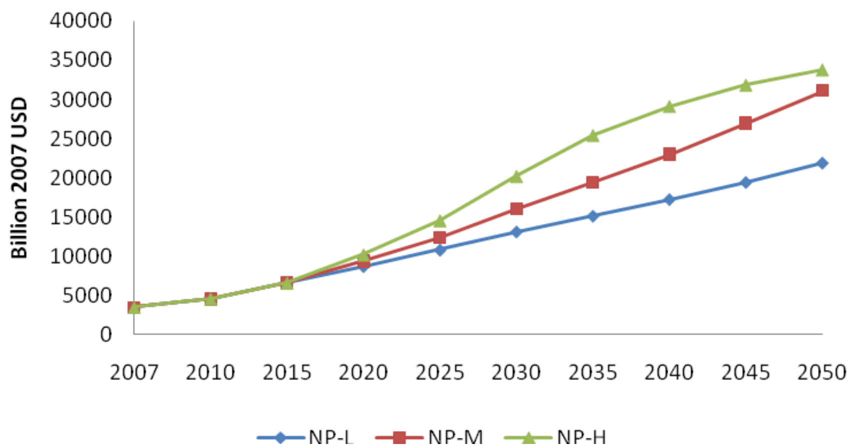

Figure 3. Economic growth trajectories in high, medium, and low growth scenarios.

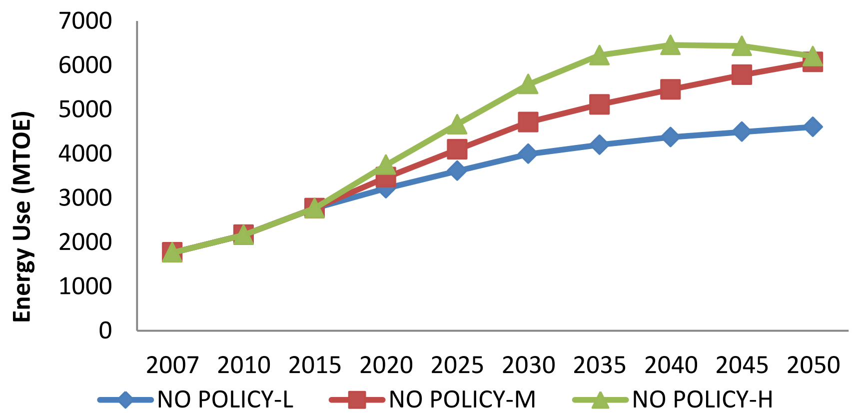

Figure 4. Energy use under high, medium, and low growth in the No Policy scenario.

4.2 Current Policy Assumptions

We then run the low, medium, and high growth scenarios assuming “Current Policy” for renewable energy through 2020 in China, which is described in section 2. Current policy includes targets specified for wind, solar, and biomass generation. The policy targets are stated in terms of installed capacity with the exception of wind, which also has a target for generation. We convert capacity targets to generation targets as shown in the following table. To obtain generation targets, we assume that the ratio of kilowatt-hours generated per unit of installed capacity remains constant as installed capacity is scaled up to meet the target. We use values for

2010 to compute this ratio.[3] The assumptions for installed capacity and generation from 2010 to 2020 are shown in **Table 5**. After 2020, no capacity or generation target has yet been proposed for renewable energy in China, and so the contribution of renewable sources to electricity generation is based on their cost competitiveness.

Table 5. Published targets for installed capacity and conversion to generation target through 2020.

Renewable energy targets	**Installed Capacity (GW)**			**Generation Target (TWh)** (2010 – actual / 2015, 2020 – authors' projection)		
	Year			Year		
	2010	2015	2020	2010	2015	2020
Wind	31	100	200	58.9	190	390
Solar	0.8	21	50	0.95	25	59.5
Biomass	5.5	13	30	33	78	180

To model the implementation of targets, we apply an endogenous subsidy to the production of renewable energy from each type until the generation target is achieved. The subsidy is assumed to be financed out of household income through tax payments. Current feed-in tariffs for renewable energy are financed by electricity tariff surcharges. In our modeling strategy, the generation target does not depend on the economic growth assumption. After 2020, we assume that the subsidies are phased out linearly through 2030, and that no subsidies remain in place after 2030.

4.3 Cost and Availability Assumptions for Energy Technologies

We assume that all three renewable energy technologies are available in the base year 2007 at a higher cost relative to fossil generation sources. Each generation type has an associated cost markup (shown in **Table 6**), which captures the incremental cost relative to the levelized cost of conventional fossil fuel generation. Renewable energy can enter the market when its cost falls relative to fossil fuel electricity, which can occur either as the fossil fuel price rises (due to policy or market forces) or if renewable energy is subsidized. To simulate realistic rates of adoption once renewable electricity becomes cost competitive, we included an additional resource input in the production function of each renewable electricity type. This resource input simulates limits on early adoption due to the need to repurpose production facilities, train the labor force, and incur other startup costs. The basic representation of the resources factor evolution is a function of the renewable energy output and the total electricity sector output, as shown in Equation 1 below. This resource input, which is parameterized for each renewable energy type, is treated identically in all scenarios (Paltsev et al., 2005; Karplus et al., 2010).

$$F_{res,t} = F_{res,t-1} + f(Y_{renew}, Y_{elec}) \tag{1}$$

[3] In 2010 it is widely acknowledged that a fraction of installed capacity was not yet connected to the grid, and so our assumption may underestimate the ratio of generation to installed capacity in the future.

where $F_{res,t}$ is the resources factor at time t, $f(Y_{renew}, Y_{elec})$ is the incremental resource supply in the new period, which is a function of renewable energy output Y_{renew} and total electricity output Y_{elec}.

Renewable energy subsidies are often justified as supporting the technology in its early stages, allowing developers to gain experience and scale up production in ways that effectively reduce the future cost of each renewable energy type. In our six main scenarios we assume that the markup on renewable energy relative to conventional fossil generation stays constant over time. However, we also include a scenario in which the subsidized development of renewable energy leads to lower costs in 2020. In this scenario, the wind markup is 10% (compared to 20%), solar is 50% (compared to 200%), and biomass markup is 30% (compared to 60%).

Table 6. Markups expressed in percentage terms as the additional cost for each renewable electricity type relative to fossil fuel electricity.

Type	**2010–2020**	**2020–2050**	
	All scenarios	Six main scenarios	Low cost scenario
Wind	20%	20%	10%
Solar	200%	200%	50%
Biomass	60%	60%	30%

Both No Policy and Current Policy cases include growth assumptions for nuclear and hydro which are currently set forth by government plans. The government plan for the installed capacity of nuclear is 40GW in 2015 and 70GW in 2020; for hydro it is 290GW in 2015 and 420GW in 2020 (China electricity council, 2012; State Council of China, 2013). As we are interested in the impact of supporting renewable energy specifically, we do not explore alternative cost or availability assumptions for nuclear, hydro, and conventional fossil generation.

5. RESULTS

We now consider the impact of the renewable energy targets against the background of the three alternative GDP growth trajectories. As expected, we find that the level of GDP growth results in different renewable energy requirements. The share of generation from renewable electricity sources in the current policy scenarios for each of the growth trajectories assumed is shown in **Table 7**.

Table 7. The share of renewable electricity in total power generation in current policy scenarios by high, middle and low growth trajectories.

	2010	**2015**	**2020**	**2030**	**2050**
High growth rate	1.9%	4.5%	6.6%	7.9%	23.7%
Mid growth rate	1.9%	4.5%	7.3%	4.7%	16.7%
Low growth rate	1.9%	4.5%	7.7%	3.3%	7.4%

For each scenario, we consider the impact of renewable subsidies on energy use, CO_2 emissions, and economic growth. We find that while renewable energy subsidies result in an increase in renewable energy, the impact on CO_2 emissions is relatively modest. This is because renewable energy displaces some fossil fuel use in the electricity sector and puts downward pressure on fossil fuel prices, leading to increased use in other sectors. We further find that if the cost of renewable energy is successfully reduced during the subsidy period renewable sources will compete successfully without subsidies through 2050 and supply a much larger share of the primary energy mix in China. However, our analysis suggests that subsidies alone will not be sufficient to realize the emissions reduction potential available from renewable energy. This analysis demonstrates that it is important to consider impacts on the integrated energy–economic system when designing renewable energy policy.

5.1 Renewable Energy Growth under Policy

Current policies result in significant growth in renewable energy under all three growth scenarios. In all scenarios renewable energy growth follows the target trajectory through 2020, significantly above the level of renewable energy generation under the No Policy scenario (**Figure 5**). After 2020, the differences between the No Policy and Current Policy scenarios are less pronounced. In both the No Policy and Current Policy, the renewable growth trajectories diverge under different growth assumptions and affects both energy demand and the relative prices of energy types. In the Current Policy case, as subsides are phased out between 2020 and 2030, the total generation from renewable energy begins to fall, and its contribution into the future depends on its cost competitiveness relative to other generation types.

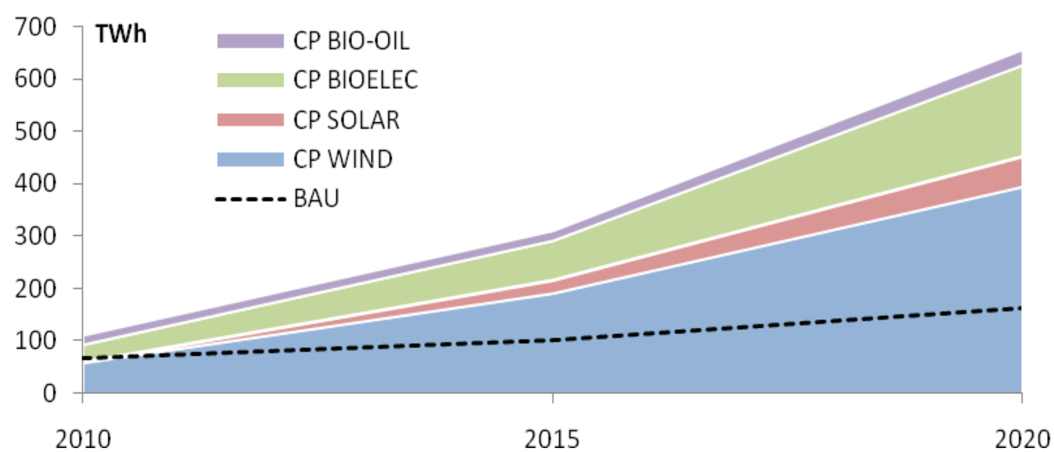

Figure 5. Renewable energy generation target by type and relative to total renewable generation in the No Policy scenario (dashed black line).

Figure 6 compares the renewable electricity generation and its share of total electricity use in 2010, 2020, 2030, and 2050. The target is met in both cases through 2020. After 2020, under slower economic growth, fossil energy prices increase more slowly, and so renewable energy is less competitive relative to fossil sources. However, if large demand pressure causes energy prices to increase more rapidly in the high growth scenario, renewable energy will be more cost competitive and by 2050 may make a significant contribution to overall generation, at almost three times as large as in the low growth scenario. These results demonstrate how GDP growth can strongly influence the prospects for renewable energy through its impact on fuel demand and competition among fuels—higher growth puts more pressure on fossil fuel resources, and so there is more market pressure to increase renewable energy. While renewable energy gets a slower start without current policies, its eventual contribution by 2050 is about the same under the No Policy and Current Policy scenarios.

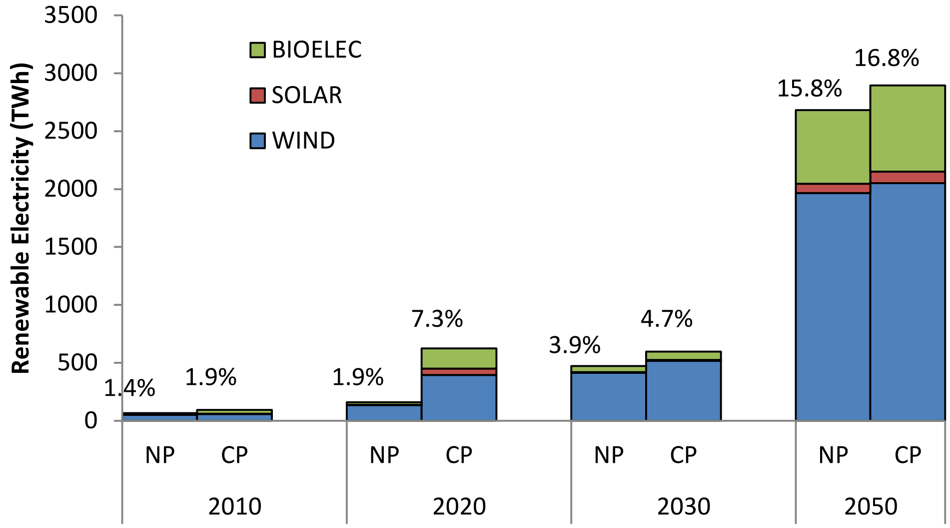

Figure 6. Renewable energy output and percent of total generation in the NP and CP scenarios under middle economic growth assumption.

5.2 Impact of Renewable Energy Subsidies on CO_2 Emissions Reductions

Our modeling framework allows us to assess the impact that current renewable energy subsidies will have on total CO_2 emissions from China's energy system. We consider two periods, 2010 to 2020, and 2020 to 2050 and compute the total reduction achieved, focusing on the medium growth case only for simplicity.[4] We compare this to an "idealized" reduction that assumes that all new renewable energy generation displaces fossil fuel generation and that there is no incentive to increase use of carbon-intensive fuels in other sectors as a result of displacing them from electricity.

We compute the CO_2 emissions reduction achieved in the medium growth case by comparing the No Policy and Current Policy scenarios. We find that the renewable electricity target has the effect of lowering emissions intensity by 2% in 2015 and by 3.5% in 2020 compared to No Policy scenario. From 2020 to 2050, we find an average 1.5% reduction in CO_2 emission intensity after 2020 in the Current Policy scenario (although no targets are being imposed in this period).

[4] Using instead the low or high growth assumption does not change the policy results significantly.

In terms of the total CO_2 emissions reduction, the model predicts cumulative CO_2 emissions will be lower by 1173 million metric tons (mmt) (1.2%) over the period 2010 to 2020. After 2020 we find that the impact of a target from 2010 to 2020 on future CO_2 emissions is more complex. Cumulative emissions from 2020 to 2050 are slightly higher with early renewable deployment (Current Policy scenario) relative to a No Policy scenario by 8628 mmt (1.8%). Comparing the total cumulative reduction over the period 2010 to 2050, we find a net increase of 7455 mmt (1.3%) under the Current Policy scenario. We note that economic growth is slightly higher after 2020 in the Current Policy scenario, so despite a slight increase in CO_2 emissions under policy, emissions intensity is reduced relative to the No Policy scenario.

Sectoral leakage is another factor causing lower than expected CO_2 emissions reductions. For this analysis we use a CGE model with energy system detail in order to capture how the renewable subsidy policy interacts with fuel prices, fuel demand, and the broader evolution of the energy-economic system and its associated CO_2 emissions. The total CO_2 emissions reductions measured using this model will reflect how the policy affects underlying energy prices, and how these effects are transmitted across markets through economic activity and trade linkages in China and on a global scale. The objective is to capture all of the real-world factors that will affect the impact of renewable energy on CO_2 emissions outcomes, but are omitted from many models. It is instructive to compare the results of this model to a calculation that focuses on renewable energy only and assumes that renewable energy directly displaces fossil energy use and associated CO_2 emissions, which can be taken as an "ideal" upper bound on emissions reductions. **Table 8** compares the actual simulated emissions reductions with the ideal calculation. The simulated "actual" reduction is the reduction we expect given the interactions of the renewable target with the broader economy, including relative energy prices. The simulated reduction is sizable in 2015 and 2020 (although still smaller than ideal). After the subsidies are phased out in 2020, we find a slight increase in total CO_2 emissions in every future period as a result of higher-than-baseline economic growth and sectoral leakage. In the model, we further observe that the prices for fossil generation types remain lower under the Current Policy scenario for much of the next half century, which provides an incentive to increase their use. This result suggests that once dynamics in the broader economic and energy system are taken into account, the total CO_2 reduction predicted due to the deployment of renewable electricity is significantly smaller than the so-called ideal reduction.

Table 8. Reduction in CO_2 emissions due to Current Policy, relative to the No Policy scenario (mmt).

	2015	2020	2025	2030	2035	2040	2045	2050
Simulated ("Actual") Reduction	150	141	-305	-542	-396	-302	-213	-76
Ideal Reduction	173	454	411	204	207	205	194	199

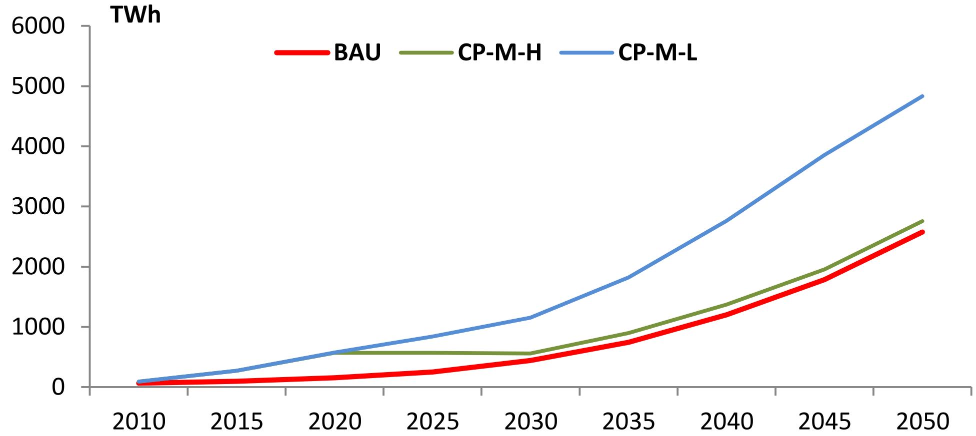

Figure 7. Growth in renewable energy in the No Policy, Current Policy, and Current Policy + Low Cost scenario under the medium growth assumption.

5.3 Impact of a Cost Reduction for Renewable Energy After 2020

Earlier scenarios assumed that the markup for renewable energy remains constant after 2020. If we instead assume that the nth plant cost for each renewable energy type will drop significantly after 2020 (by adopting the low cost technology assumptions described above), we find that renewable electricity generation increases significantly by 2050 as the cost of renewable electricity falls (as shown in **Figure 7**). This increase could be dramatic: under the Current Policy + Low Cost scenario, we find that renewable generation increases to 30% of the total compared to 17% under the Current Policies only and 16% under the No Policy scenario.

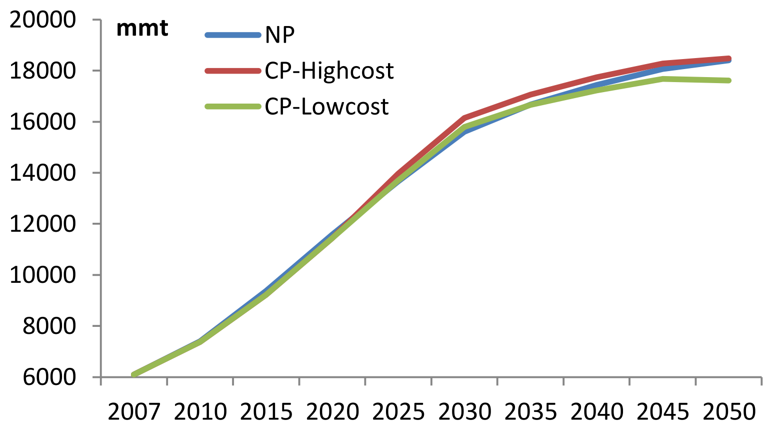

Figure 8. Total CO_2 emissions in the No Policy, Current Policy, and Current Policy + Low Cost scenario under the medium growth assumption (mmt coal equivalent).

Table 9. Impact on renewable energy generation and CO_2 emissions intensity reductions (No Policy, Current Policy, and Current Policy + Low Cost, broken down by type).

Scenario	**Renewable Electricity Type**	**Electricity Generation (mtoe)***			
		2015	2020	2030	2050
No Policy	Wind	81	136	414	1971
	Solar	1	2	6	81
	Biomass	17	23	54	638
Current Policy	Wind	191	394	518	2052
	Solar	24	57	8	98
	Biomass	74	173	71	745
	CO_2 emission intensity reduction (%)	2.0%	3.5%	1.8%	0.8%
Current Policy + Low Cost	Wind	191	394	735	2288
	Solar	24	57	334	2110
	Biomass	75	173	203	932
	CO_2 emission intensity reduction (%)	2.0%	3.5%	5.4%	8.6%

* Electricity generation is measured in terms of million tons of oil equivalent (mtoe).

We also study the impact of the assumed cost reduction on renewable generation by type and on total CO_2 emissions relative to the Current Policy case with no cost reduction. Focusing on the period 2010 to 2050, we find that the cumulative CO_2 reduction is significantly larger, reaching 5385 mmt or 1% relative to the No Policy scenario. As shown in **Table 9**, an average 5.4% emission intensity reduction is observed in the Current Policy + Low Cost scenario, compared to 1.8% in Current Policy only scenario. The difference in CO_2 emissions in the Current Policy and Current Policy + Low Cost (medium growth) scenarios are shown in **Figure 8**.

In the low cost scenario, it is important to realize that the leakage effects associated with the supply-side cost shock are also more pronounced. This result is consistent with the fact that in the Current Policy + Low Cost scenario we find that in 2050 the electricity price is 4% lower and the coal price is 10% lower relative to the Current Policy scenario.

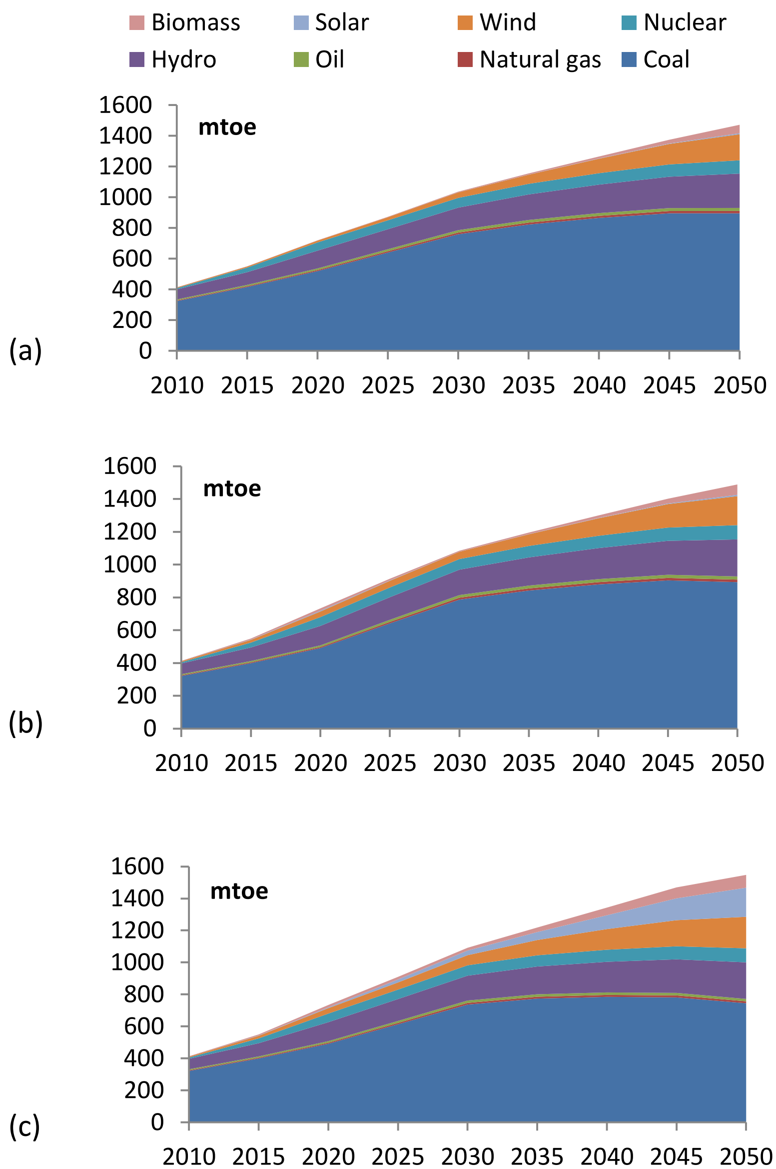

Figure 9. The evolution of the electricity generation mix through 2050 in the (a) No Policy reference case, (b) Current Policy case, and (c) Current Policy + Low Cost scenario.

6. CONCLUSION

China's renewable energy policy is currently focused on increasing the installed capacity of wind, solar, and biomass electricity as well as boosting its contribution to total generation. When the current policy is simulated in the C-GEM model, we find that the policy does have the effect of increasing the renewable electricity generation from 2010 to 2020 in both absolute (from 92 TWh to 629 TWh) and relative terms (from 1.9% to 7.3% of total generation). Due to the introduction of renewable energy over the period 2010 to 2020, overall CO_2 emissions intensity falls by a modest 2%.

After 2020 the impact of renewable energy largely depends on the economic growth and cost assumption. We find that high economic growth results in higher energy demand and prices, which create more favorable conditions for renewable adoption. The low economic growth assumption, by contrast, alleviates the price pressure of fossil fuels and so renewable sources are less competitive—but total energy use and CO_2 emissions are also lower overall. In this respect, renewable energy may be expected to respond automatically to price signals, delivering a low cost substitute when fossil demand is high, but playing a less prominent role when fossil fuel demand is lower. If renewable energy is to respond in this way, it will be important to allow the prices of fossil fuels to reflect their true cost of production. In our model we assume that energy prices are determined by the market. If we assume instead that end-user fuel or electricity prices are managed by the government (which is currently the case in China), we expect that growth in renewable energy will decrease over the time period we consider.

Subsidies for renewable energy in China impose a cost to the government (ultimately borne by the household through taxes and electricity tariffs). Some point out that these early investments could result in learning-by-doing that reduces the cost of renewable electricity in future periods. Here we capture this possibility by simulating a case in which costs fall after 2020, for instance through materials substitution, manufacturing advances, and additional reductions in installation costs. We explore a scenario that reduces the markup for renewable generation after 2020, which we assume has occurred as a result of renewable generation expansion under the policy from 2010 to 2020. After 2020, the cost reduction has a large impact on the level of renewable energy adoption. With higher levels of renewable energy adoption, the impact of CO_2 emissions is also larger, while electricity prices do not rise as much as they would have in the absence of a cost reduction. This is because less expensive renewable electricity becomes competitive sooner as the cost of fossil fuel generation increases with rising demand over time.

When it comes to reducing CO_2 emissions, we find that supply-side policies such as the current renewable electricity target may have a more modest impact on total emissions than many expect, due to offsetting leakage effects. In both the Current Policy scenario and the Current Policy + Low Cost scenario, we find that ideal reductions delivered by additional renewable capacity are partially (or even totally) offset in future years by increases in the use of fossil fuels in other sectors of the economy. Adding renewable generation in the electricity sector reduces the need to build more fossil-fired generation capacity, placing downward pressure on fossil fuels, and thereby encouraging increases in their use in other sectors. The greater the contribution of renewables to generation, the greater the downward pressure on fossil fuel prices, and the greater the leakage effects. Policymakers would be well served to consider the impact of these offsetting effects as they design complementary or alternative policies to bring renewable energy into the generation mix. One such approach would be to include electricity and other sectors under a cap-and-trade system for CO_2 emissions, an approach that is already being piloted on a limited basis in some Chinese provinces.

Finally, we consider the contribution of the renewable electricity target to China's national carbon and non-fossil energy goals. Our model results suggest that the renewable electricity targets will make a relatively modest contribution to the Twelfth Five-Year Plan carbon intensity reduction goal of 17%, accounting for about 12% of the total reduction in 2015 (or a total of 2%). We further find that the targets contribute about 11% to China's Copenhagen commitment of a 45% CO_2 intensity reduction by 2020, relative to CO_2 intensity in 2005. We point out that if the ideal reduction numbers are used instead, this reduction looks much larger. This analysis cautions against the use of sector-by-sector calculations of CO_2 reduction impacts that ignore broader economy-wide interactions. A policy approach that covers all sectors and allows substantial flexibility to reduce CO_2 at lowest cost—such as an emissions trading system—would do more to prevent emissions leakage and ensure targeted reductions in CO_2 emissions are achieved over the long term. However, it would provide less certainty for renewable electricity developers and may instead achieve CO_2 emissions reductions largely through other sectors of the economy with lower associated marginal abatement cost.

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