The Role of China in Mitigating Climate Change

Sergey Paltsev, Jennifer Morris, Yongxia Cai,
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Sergey Paltsev*†, Jennifer Morris*, Yongxia Cai*, Valerie Karplus* and Henry Jacoby*

Abstract

We explore short- and long-term implications of several energy scenarios of China's role in efforts to mitigate global climate risk. The focus is on the impacts on China's energy system and GDP growth, and on global climate indicators such as greenhouse gas concentrations, radiative forcing, and global temperature change. We employ the MIT Integrated Global System Model (IGSM) framework and its economic component, the MIT Emissions Prediction and Policy Analysis (EPPA) model. We demonstrate that China's commitments for 2020, made during the UN climate meetings in Copenhagen and Cancun, are reachable at very modest cost. Alternative actions by China in the next 10 years do not yield any substantial changes in GHG concentrations or temperature due to inertia in the climate system. Consideration of the longer-term climate implications of the Copenhagen-type of commitments requires an assumption about policies after 2020, and the effects differ drastically depending on the case. Meeting a 2°C target is problematic unless radical GHG emission reductions are assumed in the short-term. Participation or non-participation of China in global climate architecture can lead by 2100 to a 200–280 ppm difference in atmospheric GHG concentration, which can result in a 1.1°C to 1.3°C change by the end of the century. We conclude that it is essential to engage China in GHG emissions mitigation policies, and alternative actions lead to substantial differences in climate, energy, and economic outcomes. Potential channels for engaging China can be air pollution control and involvement in sectoral trading with established emissions trading systems in developed countries.

Contents

1. INTRODUCTION

China is a major economy, energy user and emitter of greenhouse gases (GHGs). Its share of the global economy and energy use has increased substantially in the past 30 years and is likely to continue to grow. In this paper, we explore short- and long-term implications of several scenarios of energy and climate policy in China. We focus on the impacts on global energy markets, GDP growth and welfare in China, and on global climate indicators such as atmospheric GHG concentrations, radiative forcing, and global temperature change. To investigate these alternative pictures of economic development and energy use, we employ the MIT Emissions Prediction and Policy Analysis (EPPA) model, a computable general equilibrium model of the world economy.

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Many analysts and policymakers have emphasized the importance of China to climate stabilization. Indeed, the refusal by the U.S. to ratify the Kyoto Protocol was strongly influenced by a concern that developing countries like China and India were not taking similar commitments (Bush, 2001). The main contribution of this paper is a quantification of the impacts of China's participation in global climate policy based on a modeling system that considers linkages among all economic sectors and all regions of the world. We consider both the impacts of the short-term commitments that China proposed during the UN climate meetings in Copenhagen and Cancun (Copenhagen Accord, 2010), and longer-term implications of an accelerated deployment in China of natural gas, nuclear energy, bioenergy, renewable electricity, electric cars, and improvements in energy and fuel efficiencies.

The paper is organized in the following manner. In Section 2 we briefly describe historic trends in China's energy use and emissions in the last 30 years. Section 3 focuses on short-term plans (for the next decade) regarding China's emissions. In Section 4 we consider potential long-term trajectories for China's emissions, and the resulting contributions to control of global climate risk. Section 5 elucidates our conclusions.

2. HISTORIC TRENDS IN CHINA'S ENERGY USE AND EMISSIONS

In a relatively short period of time China has become a major economic force. As China moved to greater openness and economic restructuring, its eagerness to engage in numerous fast-developed projects and its relatively cheap labor force have attracted many manufacturing enterprises. Companies and entrepreneurs of different incomes and sizes have moved to China to capitalize on its comparative advantage, make products more cheaply, and export them to other regions of the globe. "Made in China" has been transformed from a rarity in developed markets in the 1980s to the dominant label in the 1990s and 2000s. The resulting increase in the earnings of exporters—and in the income of workers, domestic entrepreneurs and government entities—has allowed China to move forward on substantial domestic infrastructure projects. Energy and cement needs have increased even further in the 2000s, making China the world's largest energy consumer (IEA, 2011; BP, 2011) and greenhouse gas (GHG) source in 2010 (Reuters, 2010).

At the same time, the 1990s and 2000s have seen an increased awareness of the impact of anthropogenic emissions of GHGs. Fossil fuel emissions are a major component of anthropogenic emissions (IPCC, 2007). Coal is relatively more carbon-intensive compared to oil and natural gas[1]. As China relies on coal for its energy needs, consuming about 50 percent of the total world coal (BP, 2011), it has become clear that any meaningful climate stabilization will not be possible without China. The country would need to transform its energy system from being coal- and oil-based to relying, instead, on lower carbon-emitting technologies.

Looking at total energy use in China (**Figure 1**), from 1980 to 1990, the increase was about 60%; from 1990 to 2000 it was around 50%, and from 2000 to 2010 energy use grew by 130%. Most of the increase in the 2000s was associated with a decision to begin to reorient the economy from exports toward domestic consumption, a shift that required large infrastructure projects and substantial energy inputs. As previously mentioned, coal is the primary energy source in China with a share of about 70%, with oil consumption representing another 20%. As the population of China gets wealthier, the number of automobiles and oil consumption are increasing. Recently, use of natural gas and hydropower has also increased, but this still comprises a small share of China's energy needs.

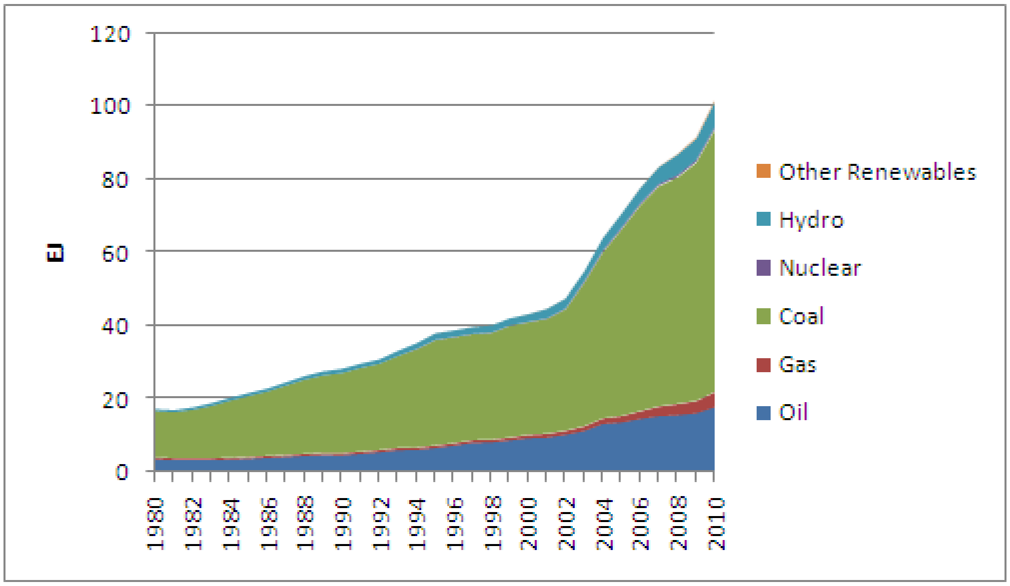

Figure 1. Energy use in China by fuel type in 1980-2010. Source: BP (2011)

Because of the relatively higher carbon content of coal relative to other fossil fuels, the proportion of coal in total energy CO_2 emissions is even larger than its share of energy use. According to Carbon Dioxide Information Analysis Center (CDIAC) data, (**Figure 2**), in 2008

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[1] According to BP (2011), coal emits 3.96 tCO_2 per tonne of oil equivalent (toe), oil emits 3.07 tCO_2/toe, and natural gas emits 2.35 tCO_2/toe.

coal contributed more than 80% to the total energy-related CO_2 emissions in China. The figure also shows CO_2 emissions from cement production. These grew at an even higher rate than energy-related emissions—the proportion of cement in total CO_2 was about 3–4% in the 1980s and 1990s, and then grew to about 9–10% in the 2000s. Figure 2 also shows a small decrease in emissions from coal at the end of the 1990s, while coal use was roughly constant during that time. That decrease is attributed to switching to more efficient coal power plants and the replacement of old, inefficient industrial facilities. Coal use and emissions started to grow rapidly again in the 2000s. Total CO_2 emissions in China increased from 3.4 Gt CO_2 in 2000 to 7 Gt CO_2 in 2008. In comparison, the U.S. fossil fuel CO_2 emissions were around 5.7 Gt CO_2 both in 2000 and 2008. China's share of global energy-related CO_2 emissions has increased in just eight years from 14% in 2000 to 22% in 2008.

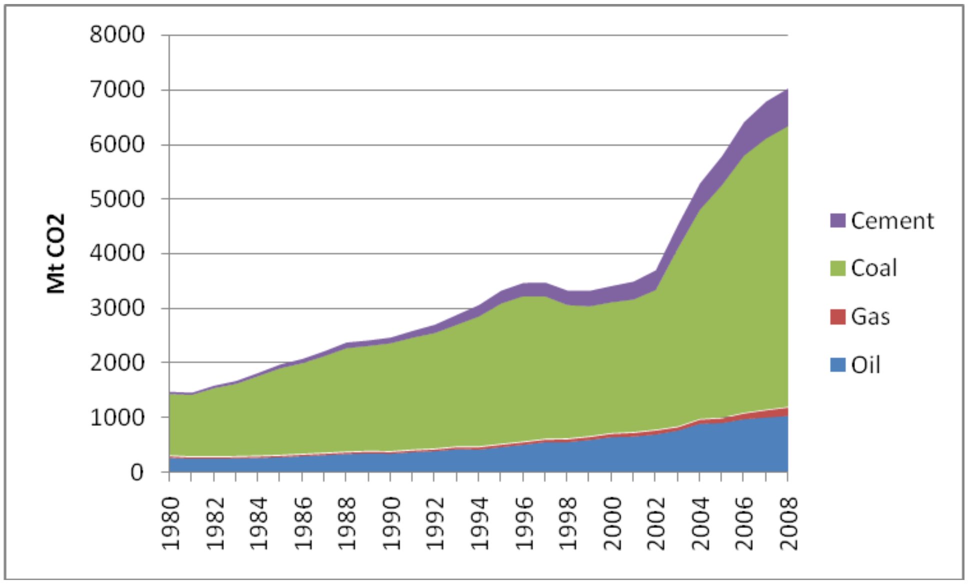

Figure 2. Carbon dioxide emissions in China in 1980–2010. Source: CDIAC (2011)

In the last 30 years, China has experienced a remarkable increase in economic activity. Its real GDP growth between 1980 and 2010 was (on average) 10% per year. **Figure 3** shows real GDP in China as compared to total population. As a result of GDP growth, GDP per capita improved in real terms (measured in 1990 *yuan*) from about 800 *yuan* in 1980 to 10,500 *yuan* in 2010—a 13-fold increase for an average Chinese citizen.

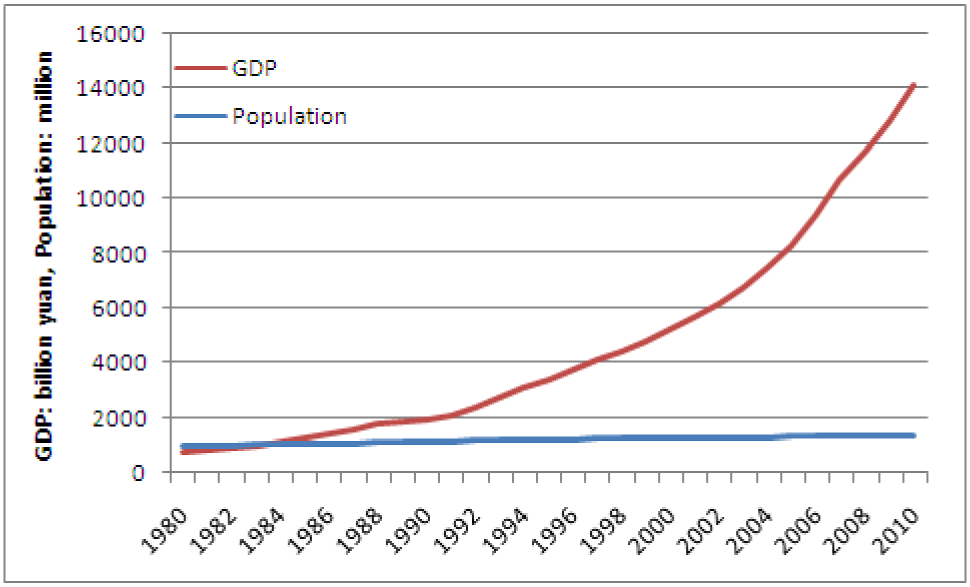

Figure 3. Real GDP and population in China in 1980–2010. Source: International Monetary Fund (IMF) (2011)

As GDP grew at a faster rate than energy use, energy intensity (*i.e.*, energy use per unit of GDP) has been falling (a trend that is depicted for China in **Figure 4**). Paltsev and Reilly (2009) discuss the trends for energy intensity in China, and compare them with the trends for other major Asian countries. China's energy intensity fell by about 45% in 1970–2000; however, in India, Indonesia, and Korea energy intensity rose. For China, a decrease in energy intensity from more than 20EJ/trillion *yuan* in 1980 to about 8EJ/trillion *yuan* in 2000 can be attributed to structural and technological changes. This decrease in energy intensity accompanied shifts in the organization of the economy, as China moved from a planned economy to one more driven by market forces (Paltsev and Reilly, 2009). This trend reversed in the early 2000s, with an increase in energy intensity between 2000 and 2004, a period when a number of steel mills and coal-based electric generation were brought online at a very rapid pace. A pattern of decreasing energy intensity resumed in 2005, but at a modest rate and with a slight increase yet again between 2009 and 2010.

Emissions intensity per unit of GDP reveals a similar trend, with a rapid decline from 1980 to 2000 and leveling off in 2000s. CO_2 emissions per unit of energy have been relatively stable in China with about 80–85 $MtCO_2/EJ$ in the 1980s and 1990s and about 70–75 $MtCO_2/EJ$ in the 2000s. This relative stability is attributable to continuing reliance on coal in the energy system.

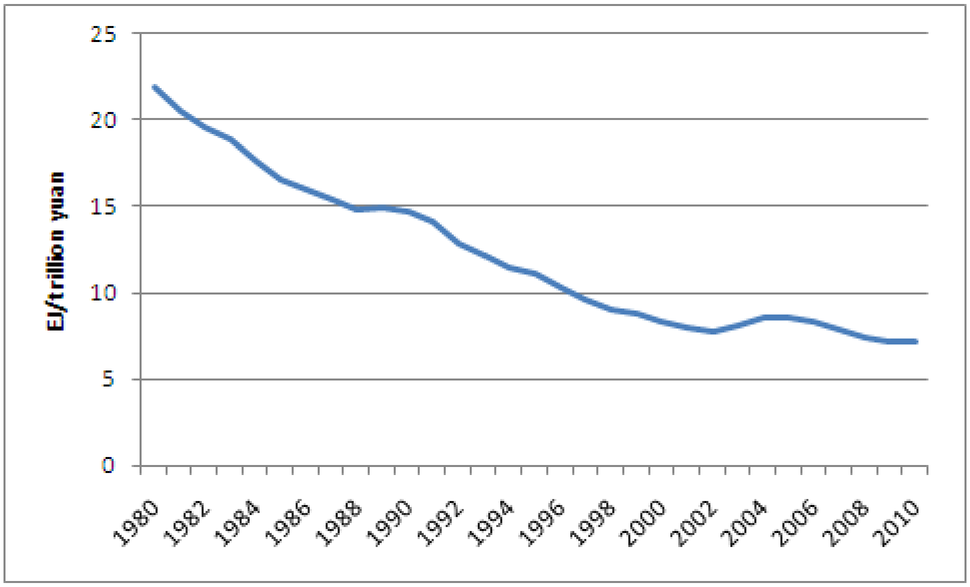

Figure 4. Energy intensity of real GDP in China in 1980–2010.

Future paths of energy and carbon intensities depend on the introduction of lower carbon-emitting (or even carbon-free) technologies, further increases in efficiency due to rising energy prices (and potentially the imposition of carbon prices), and potential structural changes in the economy that move from heavy manufacturing toward the services sector. In the next section, we describe plans by China that address these possibilities.

3. SHORT-TERM PLANS

China recognizes the challenges in energy system transformation, putting energy targets into its five-year plans. For example, in its 11th Five-Year Plan the goal of a 20% reduction in energy intensity for 2006–2010 was combined with a target of a 10% share of non-fossil fuels (hydro, nuclear, solar, wind, biomass, etc.) in primary energy consumption. The second target is hard to assess with publicly available data because China puts traditional biomass use into the target, and this number is difficult to get from independent sources.

The reduction in energy intensity is easier to verify, but there is some discrepancy between the data released by China's National Development and Reform Commission (NDRC)[2] and the data for energy from BP (2011) and for GDP from the IMF (2011). The numbers align very well for 2005–2009 (when a reduction of 16% was achieved), but NDRC reports a further reduction of about 3% in 2010, while BP and IMF data show an increase in energy intensity over that final

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[2] As reported by Deutsche Bank (2011).

Plan year of 0.5%. As a result, according to NDRC about a 19% reduction was achieved, while alternative estimates from well-established sources reveal approximately a 15% reduction. Considering the increasing trend in the early 2000s, even a 15% reduction in energy intensity is a remarkable achievement.

In its current 12th Five-Year Plan (2011–2015), China has declared even more ambitious goals[3]. It plans for 11.4% share of non-fossil fuels in primary energy consumption by 2015, rising to 15% by 2020. (See **Table 1** for a list of major energy and emission goals.) Initial reports also mention a 16% reduction in energy intensity (*i.e.*, energy use per unit of GDP) for 2011–2015 and a 17% reduction in carbon intensity (*i.e.*, carbon emissions per unit of GDP) for the same period. Deutsche Bank (2011) refers to China's Ministry of Industry and Information Technology where it cites 18% reduction targets (approximately) both for energy and carbon intensity for the period.

Table 1. Major energy and emissions goals in China for 2015 and 2020.

	12th 5-year Plan goals for 2015	Copenhagen Targets for 2020
Energy Intensity	18% reduction relative to 2010	
Carbon Intensity	18% reduction relative to 2010	40-45% reduction relative to 2005
Non-Fossil Fuels in Total Energy	11.4%	15%
Nuclear Power Capacity	40GW	
Wind Power Capacity	additional 70GW	
Solar Power Capacity	additional 5GW	
Hydro Power Capacity	additional 120GW	

The plan also calls for capacity targets for non-fossil electricity by 2015: 40 GW of nuclear, an additional 70 GW of wind, an additional 5 GW of solar, and an additional 120 GW of hydro (although a target for hydro does not specify the exact date). Considering that current (2010) nuclear electricity generation capacity is about 10 GW, wind generation capacity is 45 GW, solar generation capacity is 0.9 GW, and hydro is 120 GW, the targets for 2015 are very ambitious. At the same time, the total electrical capacity in 2008 was about 800 GW[4]. Therefore, even if all these additions materialize, fossil fuels (primarily coal) will remain by far the major source of electricity.

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[3] A summary of goals is available in English in a paper by the U.S.-China Economic and Security Review Commission (Casey and Koleski, 2011). See also Deutsche Bank (2011).

[4] IEA (2010) reports 780 GW for 2008 and Deutsche Bank (2011) reports 970 GW for the end of 2010.

There also are plans for pilot cap-and-trade systems and feed-in tariffs for wind and biomass for some provinces. In the transportation sector, rebates for electric cars and small cars are envisioned. Natural gas production (and use) has also received special attention. In the 11th Five-Year Plan there was a goal for natural gas to have a 10% share of energy use by 2020, which—depending on the total energy use—could be translated to about 10–13 trillion cubic feet (Tcf) of natural gas consumption. The 12th Five-Year Plan calls for an increase in natural gas use from the current (year 2010) consumption of about 4 Tcf to more than 9 Tcf by 2015.[5]

China submitted its plans for 2020 to the United Nations Framework Convention on Climate Change (UNFCCC) where it declared a 40–45% target reduction in carbon intensity in 2020 (relative to 2005) and an increase in the share of non-fossil fuels in primary energy consumption to around 15% by 2020 (Copenhagen Accord, 2010).

As discussed in Section 2, in the 2000s improvement in energy intensity and carbon intensity in China slowed in comparison to the 1980s–1990s; the reduction from 1985 to 2000 was about 50%, while in 1995–2010, it was only about 35%. Still, the target of 40–45% by 2020 is well within reach with the planned development of nuclear, natural gas, hydro and other renewables. Assuming annual GDP growth of 7–8%, to satisfy an 18% energy intensity reduction requirement in 2015, the total energy use in China should be 117–123 EJ. To meet the Copenhagen carbon intensity target of 40% reduction, the total 2020 CO_2 emissions in China should be 11.6–12.7 Gt CO_2; for a 45% reduction total emissions should be around 10.6–11.7 Gt CO_2. We will return to these targets in the next section (Section 4) where we discuss the simulation results.

In terms of the immediate climate implications of China's short-term goals, we find that—in 2020—actions by China would reduce atmospheric concentrations by less than 10 ppm CO_2-eq, which translates to a difference in global temperature of about 0.1 degree C in 2020[6]. This result is consistent with previous work (*e.g.,* Prinn *et al.,* 2011) that shows that inertia in the climate system leads to very small differences in climate results in the next 10 to 20 years, regardless of mitigation effort. For a meaningful climate policy there is a need for a sustained reduction in emissions for an extended period of time. We discuss such trajectories in the following section.

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[5] For a discussion about natural gas use in Asia, see Paltsev (2011).

[6] The results for concentrations and temperature are from the MIT IGSM model discussed in Section 4.

4. POTENTIAL LONG-TERM TRAJECTORIES

To consider long-term implications of different emissions trajectories, we apply scenarios developed by the Asian Modeling Exercise (Calvin *et al.*, 2012) as follows:

- *Scenario 1a* = "Reference", where we assume no climate policy and do not explicitly impose the energy and emissions targets discussed in Section 3;
- *Scenario 2a* = "CO_2 Price \$10 (5% p.a.)", where all regions of the world impose a \$10/tCO_2 price starting in 2020 which grows at 5% per year;
- *Scenario 2b* = "CO_2 Price \$30 (5% p.a.)", which is similar to Scenario 2a but starts at \$30/tCO_2 in 2020;
- *Scenario 2c* = "CO_2 Price \$50 (5% p.a.)", which is similar to Scenario 2a, but starts at \$50/tCO_2 in 2020; and
- *Scenario 3a* = "3.7 W/m^2 NTE", where a carbon price is imposed to reach the specified radiative forcing stabilization by 2100.

For climate simulations, we use the MIT Integrated Global System Model (IGSM),which couples sub-models of human activity and emissions, the Emissions Prediction and Policy Analysis (EPPA) model, atmospheric dynamics, physics and chemistry (including separate treatment of urban regions), oceanic heat uptake, sea ice and carbon cycling, and land system processes described by the coupled Terrestrial Ecosystem Model (TEM), Natural Emissions Model (NEM), and Community Land Model (CLM), as described in detail in Sokolov *et al*. (2005).

Calvin *et al.* (2012) provide an overview of the results for the different scenarios of the Asia Modeling Exercise described above, so we focus herein only on the major findings. Scenario 3a is the most stringent of the four core policy scenarios (it requires carbon prices three times higher than Scenario 2c), so we provide more detailed results for Reference and Scenario 3a. In all climate policy scenarios, carbon revenues are recycled to representative consumers in a lump-sum fashion. Projections for energy use in China in the Reference scenario are presented in **Figure 5**. Without policy intervention, coal and oil usage continues to grow with their combined consumption by 2050 exceeding 200 EJ, while the total energy use in 2010 is about 100 EJ. The total energy use is expected to grow to more than 250 EJ by 2050.

As presented in the previous section, in order to satisfy an 18% energy intensity reduction target, China's total energy in 2015 should be in the range of 117–123 EJ. In the EPPA model annual GDP growth is an endogenous variable, equal to 7.6% for 2011–2015 and 6.9% for 2016–2020. The projected energy use for 2015 is about 120 EJ, so the Plan target is, in effect, achieved under no-policy Reference conditions.

To reach the Copenhagen commitment of 40% reduction in carbon intensity by 2020, total CO_2 emissions should be in the range of 11.9 Gt CO_2 (10.9 Gt for a 45% reduction). In the Reference scenario, 2020 CO_2 emissions are about 1 Gt higher than that range. Also in the Reference scenario targets for electricity are roughly equal to the planned capacity increases. The channels for additional energy and emissions reduction are improvements in transportation fuel efficiency and residential and industrial energy efficiency; yet, the impact of this CO_2 intensity commitment is less than a 1% reduction in GDP in 2020 in comparison to the no-policy Reference scenario.

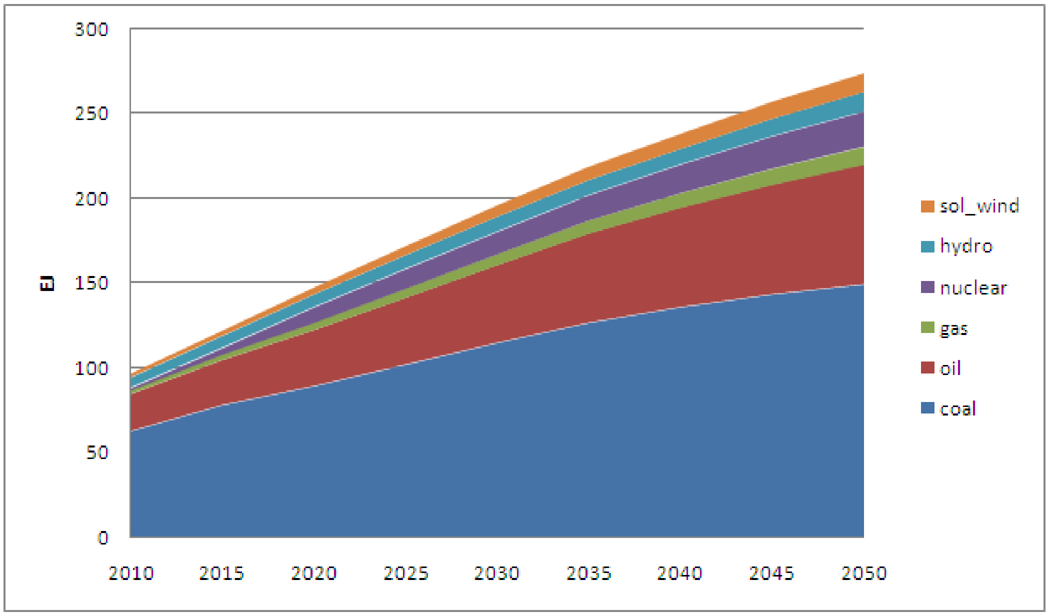

Figure 5. Energy use in China in 2010–2050 in the Reference scenario.

Figure 6 shows a projection of energy use for an alternative scenario where global carbon emissions are limited to meet a long-term radiative forcing target of Scenario 3a. This emissions path is consistent with 550 ppm CO_2-eq stabilization for all Kyoto GHGs, or roughly 450 ppm for CO_2. To simulate this case, a common GHG price is applied in all countries, rising at 4% per year, at a level that attains the global concentration goal. In this scenario, coal without carbon capture and storage (CCS) is driven out of the Chinese energy system; oil usage is substantially reduced (higher oil prices induce significantly more efficient cars with internal combustion engines and introduction of electric cars), and natural gas fills the gap. CCS technology is still too expensive and at the beginning of its learning curve. Increased energy prices due to the carbon charge reduce energy use substantially, with total use less than 200 EJ in 2050. Nuclear generation and renewables have a larger share of energy, while hydroelectricity does not grow in comparison to the Reference scenario.

An aspect of this concentration stabilization scenario is that the required changes in the energy system are dramatic in comparison to China's goals for 2020 discussed earlier. The total energy use in China in 2020 would need to be reduced to about 107 EJ, with almost doubled use of solar and wind electricity, increased fuel efficiency in transportation and the use of biofuels[7]. The use of natural gas in 2020 approaches 20 EJ, a number comparable to the natural gas use by the European Union. Nuclear electricity continues to grow (reaching about 40 EJ), which corresponds to about 400 GW of capacity by 2050. A comparison of the Reference and Policy scenarios, in Figures 5 and 6, highlight the much more aggressive actions that would be required.

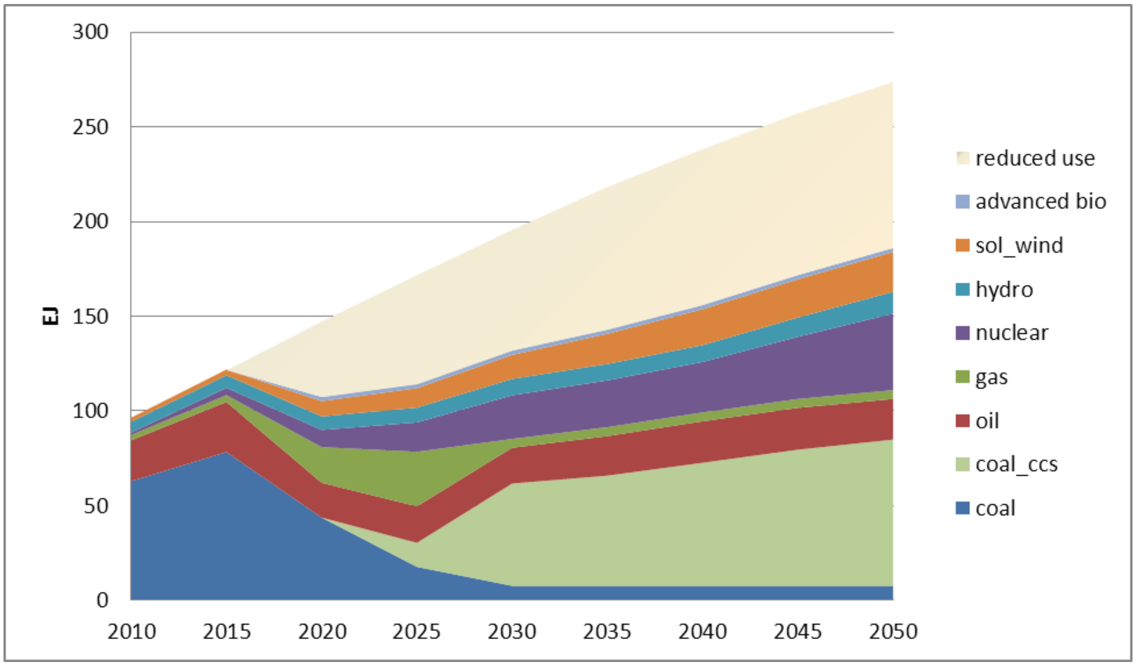

Figure 6. Energy use in China in 2010–2050 in 550 ppm stabilization.

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[7] In the scenario considered here, international trade in biofuels is limited, and China does not produce substantial amount of biofuels domestically due to a competition for land with agriculture. Current generation biofuels are reported in the oil category. Advanced biofuel production does not grow substantially due to high costs.

The drastic transformation would require substantial investments in new energy infrastructure. Also—in the simulation—the economic system is responding to increased energy prices that are driven by carbon charges. The cost of this transformation can be significant, with a reduction of GDP in 2050 at about 10–20% below the Reference projection. This estimate reflects mitigation costs only and does not consider climate benefits and potential ancillary non-climate benefits of GHG mitigation (*e.g.,* through reduced urban air pollution). Matus *et al.* (2012) estimated that welfare impacts of air pollution in China can be in the range of 5–10% of total macroeconomic consumption.

We now turn to the climate implications of these alternative scenarios. To project climate results we extend the simulation horizon even further, to 2100. The emissions and climate implications of alternative scenarios are presented in **Figure 7**. Figure 7a shows that, in the absence of any climate policy, GHG emissions are projected to grow from the current 45 Gt CO_2-eq to about 100 Gt CO_2-eq by the end of the century. In the control scenarios considered here, carbon prices are rising over time, so the reductions are also increasing over time.

Figure 7b shows the resulting GHG concentrations in CO_2 equivalent terms considering all Kyoto gases. In the Reference scenario, concentrations reach above 1,300 ppm and continue to grow, while Scenario 3a results in stabilization at around 550 ppm. Scenarios 2a, 2b, and 2c result in 950, 750, and 650 ppm concentrations by 2100, respectively.

Figure 7c shows the resulting increase in global average surface temperature relative to 2000. In the Reference scenario, temperature increases by about 5.5°C, while stabilization scenarios 2a, 2b, 2c and 3a limit the increase to 3.5°, 2.4°, 2.0°, and 1.2°C respectively. As the increase in temperature from the pre-industrial level to the year 2000 was about 0.8°C, Scenario 3a puts the world on track to the often-stated target of limiting the global temperature increase to 2°C.

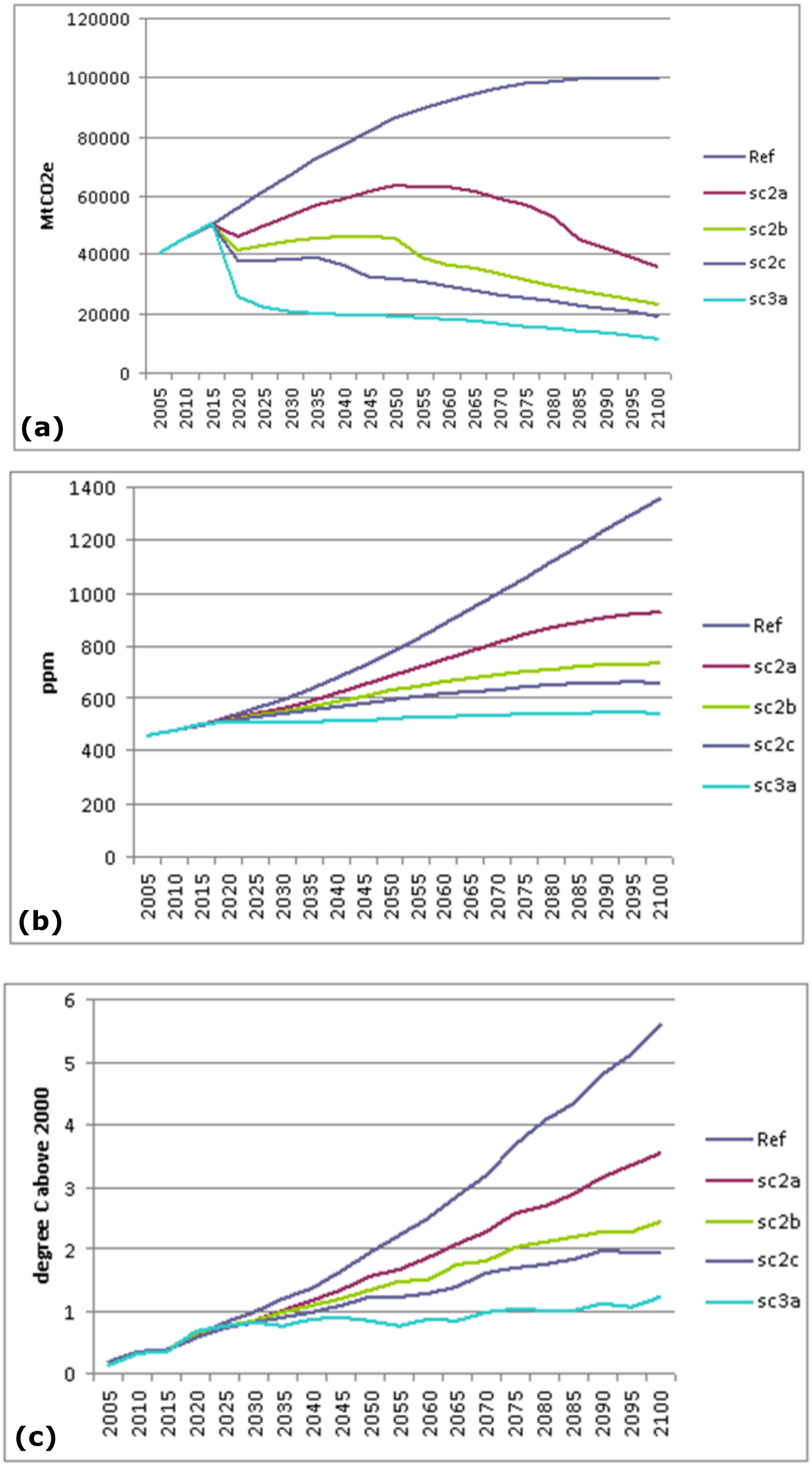

Figure 7. Emissions and climate implications of alternative scenarios: (top panel) Global GHG Emissions; (middle panel) GHG concentrations; (bottom panel) Average temperature increase relative to 2000.

To explore the role of China in climate stabilization pathways, we consider two additional scenarios. One scenario, called “3a scenario without China (3a_no_China)”, is constructed in such a way that China does not participate in climate policy while other countries follow their paths from Scenario 3a. Another, called “China only”, has only China taking on emissions reduction, following its path from Scenario 3a, while all other regions continue on their no-policy trajectory. The “China only” scenario is constructed to illustrate the climate impacts when even the largest world GHG emitter acts alone, and it is not intended to represent any real-world outcome. The resulting global GHG emissions and their climate implications are presented in **Figure 8**.

Figure 8a shows that if only China is engaged in the policy, the resulting global emissions for the second part of the century are lower by about 25 Gt CO_2-e per year, compared to Reference scenario emissions. Conversely, if China does not join the global effort, for the most part of the century global GHG emissions more than double those under Scenario 3a. One contribution to global emissions with partial compliance is leakage, in this case from the rest of the world to China.

The results for GHG concentrations in Figure 8b suggest that non-participation of China in global climate architecture can lead by 2100 to a 200 ppm difference in the total GHG concentrations. Instead of stabilization at 550 ppm, without China the world arrives at about 750 ppm concentrations by 2100. On the other hand, China’s actions alone can lower GHG concentrations from around 1,360 ppm in the no-policy scenario to about 1,080 ppm—a 280 ppm reduction. Figure 8c shows the results for temperature increase where instead of an increase by 1.2°C relative to 2000 levels in Scenario 3a, the resulting temperature is 2.3°C higher, if China does not participate. These scenarios illustrate that without China’s involvement, ambitious global climate goals are vastly more difficult (if not impossible) to achieve. Beyond the calculation shown here is another effect: without China, other countries also have reduced incentives to impose substantial emissions reductions because the climate effectiveness of such action is diminished.

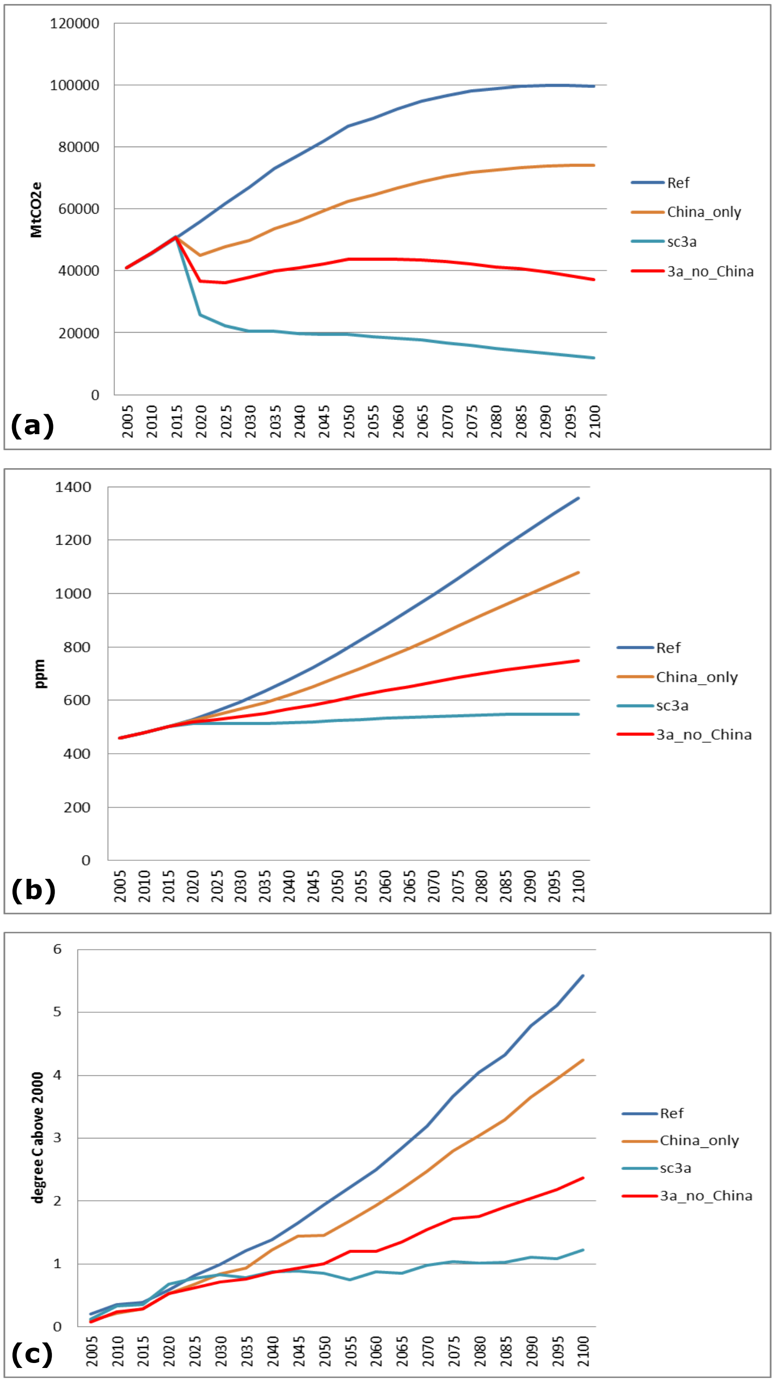

Figure 8. Emissions and climate implications of alternative scenarios about China's participation: (a) Global GHG emissions; (b) GHG concentrations; (c) Average temperature increase relative to 2000.

On the other hand, if China decides to re-structure its energy system for energy security, export potential of carbon-free technologies, or air pollution reasons, the risks of negative climate impact are reduced substantially. Webster *et al.* (2012) show that even limited actions towards reducing GHG concentrations result in a substantial reduction in risk of exceeding a certain temperature threshold. For example, stabilization at 800 ppm reduces the probability of exceeding 4°C in 2100 to 7% from 85% in the no-policy scenario. Therefore, even some action directed at GHG reductions by a subset of regions will appreciably reduce the probability of more extreme levels of temperature increase.

As previously mentioned, GDP and welfare impacts of stabilization policies are significant. Even in the carbon pricing scenarios considered here, GDP losses in China could be in the range of 10–20% in 2020–2050, and up to 40% by the end of the century in the most stringent scenario in comparison to a non-policy scenario. The suggested GDP losses are driven by higher energy prices leading to a relative reduction of domestic consumption, a decrease in exports and an increase in imports. When policy instruments deviate from an idealized economy-wide GHG tax or pricing, the costs of meeting a target increases further. (For a discussion of impacts when GHG pricing or a cap-and-trade system is replaced with renewable energy requirements, see, for example, Morris *et al.*, 2010). It should be noted that estimates of GDP losses depend on many assumptions, such as the costs of advanced technologies; potential for a re-location of heavy-industry and manufacturing to relatively lower-cost regions; availability of energy resources, and other factors. For example, we do not consider here the scenarios with relatively cheap and substantial natural gas reserves in China. The U.S. Energy Information Administration (EIA, 2011) reports large shale gas resources in China, but their volumetric estimates are highly uncertain and cost estimates are not yet available. Relying on inexpensive natural gas as opposed to coal (that faces larger carbon penalties) would reduce energy costs and lead to higher domestic consumption and lower production costs; this in turn would affect net exports from China. Another aspect not considered here is related to China's potential leadership in development of advanced energy technologies and their exports to other countries that would positively affect GDP calculations and reduce losses.

Absent near universal participation of major GHG emitters, stringent climate stabilization goals are very costly (or not achievable) because economic activity and emissions would shift to nations that are not signatories to the agreement. Even with all nations taking on commitments, the policies would require a complex system of financial transfers to simultaneously satisfy widely-discussed burden-sharing goals. Ultimately, differences in the costs of abatement between countries will depend on their energy, industrial and agricultural systems (which determine marginal costs of abatement in the sectors), emissions allocations, policy instruments, and financial transfers.

One way to engage China and other developing countries in mitigation actions and spur investment in low-carbon technologies might be by sectoral trading, which involves including a sector from one or more nations in an international cap-and-trade system. Gavard *et al.* (2011) explored the issue and found that a sectoral policy induces significant financial transfers between countries, but for China it might lead to only small increases in electricity generation from nuclear and renewables.

Another way to facilitate the involvement of developing countries would be through compensation of mitigation costs. For example, for 50% global emissions reductions by 2050 relative to 2000, Jacoby *et al.* (2009) show that if developing countries are fully compensated for the costs of mitigation in the period up to 2050, then the average welfare cost to developed countries is around 2% of GDP in 2020 (relative to reference level), rising to 10% in 2050. The implied financial transfers are large—over $400 billion per year in 2020 and rising to around $3 trillion in 2050. Successful climate negotiations will need to be grounded in a full understanding of the substantial amounts at stake. As shown, China's involvement in substantial GHG emissions reduction is a key to a successful climate policy. Recent attention by China to its energy and emissions problems offers an encouraging sign that a successful climate policy still can be a reality.

5. CONCLUSION

China is a major economy, energy-user and emitter of GHGs. Its share of the global economy and energy use has increased substantially in the past 30 years and is likely to continue to grow. Our analysis of the short-term commitments that China proposed during the UN climate meetings in Copenhagen and Cancun show that they might be reached at a very modest cost. In terms of climate results, in the next 20 years China's alternative actions do not contribute to any substantial changes due to inertia in the climate system. To consider the long-term climate implications of the Copenhagen-type of commitments (which establish the pledges for the next 10 years only), one has to assume the policies after 2020; the effects differ drastically based on the assumptions about actions in the post-2020 period. Meeting a 2°C target is problematic unless radical GHG emissions reductions are assumed in the short-term.

In terms of climate results over the next 10–20 years, China's intended actions over the next decade do not contribute to any substantial changes due to inertia in the climate system. In terms of the long-term impacts on climate, the participation or non-participation of China in global climate architecture can lead by 2100 to a 200–280 ppm difference in the total GHG concentrations, which results in a 1.1–1.3°C of temperature change by the end of the century. A meaningful participation by China in long-term climate stabilization will require more ambitious plans and targets than China is currently envisaging. We conclude that it is essential to engage China in GHG emissions mitigation policies, and alternative actions lead to substantial differences in climate, energy, and economic outcomes. Potential channels for engaging China can be air pollution considerations and involvement in sectoral trading with established emissions trading systems in developed countries.

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