A warmer policy for a colder climate:

Can China both reduce poverty and cap carbon emissions?

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31 May 2016

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Abstract

Reducing global carbon dioxide (CO_2) emissions is often thought to be at odds with economic growth and poverty reduction. Using an integrated assessment modeling approach, we find that China can cap CO_2 emissions at 2015 level while sustaining economic growth and reducing the urban-rural income gap by a third by 2030. As a result, the Chinese economy becomes less dependent on exports and investments, as household consumption emerges as a driver behind economic growth, in line with current policy priorities. The resulting accumulated greenhouse gas emissions reduction 2016-2030 is about 60 billion ton (60Mg) CO_2e. A CO_2 tax combined with income re-distribution initially leads to a modest warming due to reduction in sulfur dioxide (SO_2) emissions. However, the net effect is eventually cooling when the effect of reduced CO_2 emissions dominates due to the long-lasting climate response of CO_2. The net reduction in global temperature for the remaining part of this century is about 0.03 ± 0.02 degrees, corresponding in magnitude to the cooling from avoiding one year of global CO_2 emissions.

Keywords: Emissions mitigation; Poverty reduction; Carbon tax; Land subsidy; Integrated assessment modeling; Global warming.

1 Introduction

The Working Group III report from the IPCC 5th assessment on climate mitigation (Edenhofer et al., 2014) was received with dissonant responses by climate experts and policy analysts when it was released in April 2014 (Schiermeier, 2014; Tol, 2014). Although some plainly stated that the analysis is already there, we only need action (The Economist, 2014), there were several critical comments pointing out that the report lacked specific guidance on how countries could lower their emissions.

Some countries are well prepared for a reorientation of their energy policy, with technological, economic and institutional capacity to transform. Other countries face the challenge to develop the economy and reduce poverty at the same time as a fossil energy system needs to be phased out. As argued in the post Working Group III debate (Schiermeier, 2014; Tol, 2014), several policy issues need to be solved together with the climate problem. In this context it was argued that technological progress and poverty reduction might prove to be more efficient in reducing emissions than an international treaty like the Kyoto Protocol.

A ranking of major factors contributing to historic avoided emissions was presented by The Economist (2014) as a guide to the actions that have done the most to slow global warming. The Montreal protocol from 1987 stands out above all policies as the climate mitigator no 1. Well behind follows growth in nuclear and hydro power production, and then comes the one child policy of China. Although merely an illustration, this ranking highlights the relevance of taking factors outside the sphere of dedicated climate policy into account, particularly for developing countries, where the society is in rapid transition along many dimensions. A major issue is therefore to explore the relationship between policy for development and policy for climate mitigation in emerging economies where poverty is still a challenge. Poverty reduction is a stated aim of both poor and rich countries, and the possibility that climate policy will add burdens to the poor is considered unacceptable.

Among emerging economies, China demonstrates will and actions to reduce the climate impact of their rapid growth. In their Intended Nationally Determined Contributions (INDCs) to the COP21 meeting in Paris (UNFCCC, 2015), China pledged to peak CO_2 emissions around 2030 and make their best efforts to peak earlier, reducing CO_2 emission intensity by 60-65 per cent based on reference year 2005. Although China had rapid economic growth over the last three decades, the country is still ridden by huge income differences and serious poverty. It is timely to ask what kind of policies can be successful in achieving both climate mitigation and poverty reduction in China.

In the debate that surfaced after the IPCC AR5 Working Group III report, Victor et al. (2014) called for a return to the early phase of the IPCC when there was pluralism in national climate assessments, allowing better tailoring of climate policies to local circumstances and priorities. While arguing that IPCC still will be needed to merge national assessments into a global approach, he pointed out that national assessments would ensure that developing countries would include their broader policy perspective in projections.

China is now ranked among upper middle income countries (World Bank, 2015), but there is still widespread poverty with 70 million people living below the poverty line of USD 1.25 per day, corresponding to CNY 2800 per year in 2014 (NBSC, 2015b). China is the biggest emitter of CO_2 in the world and has the world’s largest economy when GDP of countries are measured and compared in purchasing power parities (PPP), which better reflect the scale of resource use. During the rapid growth period China has become more unequal and the Gini coefficient for family income was as high as 0.5 in 2010 (Xie and Zhou, 2014). The urban average income is around 3 times higher than that of the rural population (NBSC, 2015a). The Chinese government aims at reducing the rural-urban income gap for at least three reasons. First, there is the urgent need to reduce poverty. Second there is the priority to maintain social stability threatened by the huge income disparities and by the serious urban air pollution generating widespread discontent (BBC, 2015; Munro, 2014; Tollefson, 2016). Third there is the need to strengthen domestic consumption as a driver of economic growth and reduce the dependence on export and large-scale public investment programs.

The need for rebalancing the economy was set on the agenda in 2005 when the consumption share of GDP was as low as 40 per cent (Naughton, 2013; Pettis, 2013) and firmly restated during the National Peoples’ Congress in March 2015 (National People's Congress, 2015). Over this decade the consumption share increased from 40 to about 50 per cent (Ministry of Commerce, 2015), which is still a critically low level, leaving China extremely vulnerable to changes and shocks in foreign demand and domestic investments.

Giving the poor more purchasing power is an effective way of raising consumption. The government has implemented major reforms in terms of better access to health care and education, in particular in rural areas (Cai et al., 2014). The rural population of over 600 million and the rural work migrants of more than 200 million in the cities (NBSC, 2012) are practically without social security and save to compensate for that. Hence, both the poor and the wealthy save and the large financial surplus of the economy tends to flow into less productive, but politically strong industries, e.g. the state owned enterprises (Naughton, 2013). The state owned enterprises dominate the energy intensive industries and a transition from investment and export driven growth to more consumption based growth is expected to affect the industrial structure, with potential large implications for energy use and emissions of CO_2.

Our study considers climate policy separately and in combination with socio-economic reforms. By reducing poverty these reforms might support the transition towards a more consumption driven economic growth. Our study will show if there is synergy or trade-off between climate policy and the preferred socioeconomic development in China. We modify the China module of the global computable general equilibrium (CGE) model named GRACE (Aaheim and Rive, 2005), which has been used for various studies of global and regional climate and energy policy issues (e.g. Glomsrød et al., 2015; Liu and Wei, 2016; Underdal and Wei, 2015; Wei et al., 2015). The urban and rural economies are dealt with separately to trace the effect of the policy on the urban – rural income gap.

We first introduce climate policy in terms of a tax on CO_2 emissions from fossil fuel combustion. The CO_2 tax is endogenous and stabilizes China's CO_2 emissions at 2015 level towards 2030. The accumulated emission reductions from this policy corresponds to one and a half times the current global CO_2 emission level. In another scenario we assess the effect of a similar CO_2 tax and avoided emissions in combination with policy for socioeconomic reforms targeting poverty among rural households. Our results cover the impact on economic growth, urban and rural income distribution, the consumption share of GDP, energy market development and emissions of greenhouse gases (GHG). Further, we assess the effect on the global mean temperature to illustrate the climate contribution of this policy reorientation in China.

Earlier studies have looked at the climate effect of hypothetical reductions in emissions (Aunan et al., 2009; Shindell and Faluvegi, 2010; Unger et al., 2009).To our best knowledge, our approach is the first to study the climate effect of relevant national development policies to see if further growth and poverty reduction can go hand in hand with climate mitigation.

Section 2 below presents and discusses the design and policy relevance of the business as usual and policy scenarios. Section 3 presents the set of economic and climate models used in our analyses, together with major data sources. The main structure and assumptions of the global multiregional CGE model are explained, followed by an overview of climate models used to assess the effect of policies on radiative forcing and the global mean temperature.

Section 4 reports the impacts on the economy and energy use whereas Section 5 assesses the climate effect of stabilizing CO_2 emissions at 2015 level towards 2030. The last section concludes the paper.

2 Scenarios

We develop a baseline or business as usual (BAU) scenario as our starting point and introduce two policy scenarios. One policy scenario (SN1) stabilizes CO_2 emissions at 2015 level onwards by means of an endogenous CO_2 tax on fossil fuels use. The other policy scenario (SN2) considers the effect of a similar reduction of CO_2 emissions achieved through a CO_2 tax on fossil fuel combustion but in this case, the tax revenue is recycled to rural households to reduce poverty and the urban-rural income gap.

SN1: Tax on CO_2 emissions from fossil fuels. The CO_2 tax is introduced as the only policy measure. Total government revenue and associated expenditure is assumed to be a fixed share of GDP. The economy is only affected by the changes in relative prices following the CO_2 tax, in turn influencing energy use, level of economic activity and the income distribution. The CO_2 tax is endogenous and adjusts to stabilize CO_2 emissions at 2015 level onwards. To keep the CO_2 emissions constant, the tax increases from USD 0.4 per ton CO_2 in 2016 to USD 57.3 per ton CO_2 in 2030. So far a CO_2 tax is not formally introduced in China. However, the government regulates the fuel prices and can mimic a CO_2 tax in line with emission characteristics of coal, oil and gas.

A CO_2 tax is appropriate from an environmental point of view, considering the hazardous effect of CO_2 on global and regional climate (IPCC, 2014) and the serious air pollution linked to combustion of fossil fuels and in particular to coal. Recent research indicates that air pollution reduced life expectancy by 5.5 years in Northern China owing to coal based winter heating, increasing the incidence of cardiorespiratory illnesses (Chen et al., 2013).

Acknowledging the large health damage by coal, China is now pursuing a policy for substantial constraints on coal use for electricity production.

In order to control the smog problem, the State Council executive meeting on 2nd December 2015 required the emissions from all coal-fired power plants to comply with emissions standards for gas turbines by 2020 (State Council, 2015). Existing coal-fired power plants must implement the new emissions standards by the end of 2017 in the Eastern provinces and by the end of 2018 in the Central regions. Already in January 2015 the government announced a cap on investments in new coal-fired power plants in the Eastern provinces (National Energy Bureau, 2015) and a five year moratorium on new coal-fired plants in the coal rich province of Shanxi (Shanxi Provincial Government, 2015). These regulations follow up on the *Action Plan for Energy Efficiency and Emission Reduction in coal power production 2014-2020* by the National Development and Reform Commission (NDRC, 2014). Further, the regulations are anchored in the approval by the National People's Congress of the plan for saving energy and reduce emissions as part of the 13th Five Year Plan 2016-2020 (The Chinese Government, 2016). The less developed Central and Western regions are generally facing similar but somewhat less strict regulations than the Eastern provinces. The logical consequence of these regulation would be a phase out of coal for power production and a switch to gas powered and renewable energy sources. Details on implementation will be decided on in the further elaboration of the 13th Five Year Plan 2016-2020.

In our study the tax is imposed on all fossil fuel use and coal is expected to be hit the hardest. The distributional effects are expected to reduce the urban-rural poverty gap. A tax on oil consumption will affect the better-off segments of urban households with a living standard based on high indirect coal use through fossil based electricity and heat consumption. In our context it makes sense that a CO_2 tax shields the poorer rural households who use biomass for heating and cooking (Zhang et al., 2014) and the work migrants in the cities with a very low consumption of fossil energy (Wei et al., 2014). However, indirectly the whole economy will be somewhat affected through a higher cost level, and the rural economy might be affected through increasing costs of transportation and inputs like energy intensive fertilizer.

SN2: CO_2 tax in combination with income redistribution: In SN2 the CO_2 tax revenue is used for active redistribution of income between the urban and rural population. The Government recycles the CO_2 tax revenue as a subsidy to rural households, increasing their income and capacity to consume. These economic transfers may also contain public services in kind, like health care, education and pensions. For technical reasons we implement the transfers to rural households as a subsidy on farmland. The land subsidy represents transfers that neither disturb farmers' incentives for crop production nor consumer demand. Further, it acts as a neutral transfer also with respect to farmland, which is fixed for a single farmer in China and limited on a national scale for resource reasons. A relevant question is if the poorest really will benefit from the additional land subsidy. In China, land is state owned and allocated to farmers according to the family size and land productivity. Hence, Chinese agriculture is based on family farms, and even the poorest have access to land. If land area is the basis for the subsidy, the poor will benefit with the same absolute benefit per unit, but higher in proportion to their income level than the better off. If poor families farm less productive soil, but have larger area per capita, the land subsidy might even favor the poorest families. Further, the low consumption of transportation and manufactured goods of the poor households makes them less exposed to the CO_2 tax on fossil fuels than better off households. A general and direct subsidy to farm-land already exists but is small, only CNY 80 or USD 13 per mu (15 mu = 1ha). The land subsidy rate in SN2 increases from 1.3 per cent of return to land in 2016 to 36.6 per cent in 2035. In principle, the CO_2 tax rate and revenue might differ between SN1 and SN2 because the income transfers change the demand and the industrial structure, which are driving the emissions. However, the difference turns out to be negligible.

BAU: Business as usual: As a background to our policy scenarios we develop an economic baseline scenario (BAU) approximating the regional GDP growth and associated energy market development as depicted in the New Policies Scenario (NPS) of World Energy Outlook 2010 (IEA, 2010). The New Policies Scenario only includes confirmed policy measures, hence the pledges in terms of INDCs at the COP21 in Paris are not included. In the NPS, GDP in China grows annually by 8.7 per cent from 2004 to 2020 and by 3.9 per cent from 2020 to 2030. Meanwhile, coal use increases by 4.9 per cent and 1.2 per cent annually before and after 2020, respectively. Accordingly, the purchaser price of coal in BAU increases annually by 5.7 per cent on average during the whole period, thus taming the coal demand.

In all scenarios the global interactions through trade are taken into account, including the effect on growth and associated emissions worldwide. Other GHG emissions than CO_2 from agriculture are not taxed in SN1 and SN2, although the N_2O emission from fertilizer is a powerful greenhouse gas. A subsidy to farmers might encourage the poorest to use some more of it, in particular if they are cash constrained. On the other hand, the CO_2 tax makes chemical fertilizer more expensive because the production is energy intensive.

3 Data and methods

We have adopted an integrated assessment approach in this study. An economic model was used to simulate the impact of targeted policies on the economy and on particle and gas emissions associated with economic activities. The emissions data serve as inputs for a chemistry transport model, and to climate response metrics, to estimate atmospheric concentrations, radiative forcing, and impact on the global mean temperature of the targeted policies.

3.1 Economic model

To represent the global economy we use the GRACE model developed at CICERO (Aaheim and Rive, 2005; Liu and Wei, 2016). GRACE is a multi-sector, multi-region, recursively dynamic global computable general equilibrium model. An updated version of GRACE is described and applied in a recent application (Liu and Wei, 2016). The model has 7 regions (North America, OECD-Europe[1], Japan, Russia, China, India and Rest of the world). The depiction of each region includes activities of 15 production sectors (Table 3, Glomsrød et al., 2013). All sectors including the electricity sector produce one composite good (or service) by one single technology in this version.

The version of GRACE developed and used for this study is calibrated around the GTAP version 7 database with 2004 as base year (Badri and Walmsley, 2008). The GTAP v7 database is a global database of input-output tables, which has been used for a wide variety of agricultural, trade, and environmental economics analyses. In this study, which has a medium-to-long-term horizon, we assume full employment.

GRACE's parametric values of the elasticities of substitution are from the MIT EPPA model (Paltsev et al., 2005). Detailed description of the structure of the model, calibration of the parameters, and specifications of preferences and technologies in GRACE are reported in Rive and Mideksa (2009).

3.2 Emissions

In this study, emission data include 17 different pollutants. These are the most well-known Kyoto gases (carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O)), as well as additional synthetic Kyoto and greenhouse gases (SF_6, HFC134a, HFC23, CF_4, C_2F_6, C_3F_8, C_4F_8), aerosols and aerosol precursors (black carbon (BC), organic carbon (OC), sulfur

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[1] Eastern Europe except Russia is part of the Rest of the World.

dioxide (SO_2), ammonia (NH_3)), and ozone precursors (NO_x, NMVOC, CO). Most of the emission data for the base year (2004) are from the Emissions Database for Global Atmospheric Research (EDGAR) version 4.1(EC-JRC/PBL, 2010), with the exception of BC and OC which are adopted from Shindell et al. (2012) and adapted to GRACE industry structure.

Three scenarios for future emissions to 2030 are developed using the GRACE model, one corresponding to a business as usual (BAU) pathway and two policy scenarios (SN1 and SN2), see Section 2 for detailed description.

For further input to the chemistry-transport model, the total year 2030 emissions of aerosols and aerosol precursors in each GRACE region was gridded according to emissions intensities in the IPCC Representative Concentration Pathway (RCP) 2.6 (Vuuren et al., 2011). Emissions were distributed according to the fraction of total emission in each grid cell in RCP2.6.

3.3 Climate impact assessment

The global-mean temperature response over time is quantified for each pollutant and scenario using the Absolute Global Temperature change Potential (AGTP) (Shine et al., 2005). The AGTP for pollutant x is given by the radiative forcing (RF) and the temperature response impulse response function (IRF_T) at the time horizon H:

$$AGTP_x(H) = \int_0^t RF_x(t)\ x\ IRF_T(H-t)dt \qquad (1)$$

Hence, the AGTP takes into account both the time evolution of the perturbations to the climate system (and the resulting radiative forcing), and the response of the climate itself.

We use the IRF_T based on the Hadley CM3 climate model (Boucher and Reddy, 2008). The equilibrium climate sensitivity is 1.06 °C/(W/m^2), i.e., a 3.9 °C global-mean temperature increase for a doubling of CO_2, which is in the upper end of the likely range of 1.5-4.5 °C reported by the IPCC (Bindoff et al., 2013).

The temperature response (ΔT) for pollutant x given an emission scenario E_x has been calculated with a convolution:

$$\Delta T_x(H) = \int_0^H E_x(t) \times AGTP_x(H-t)dt \tag{2}$$

The uncertainties in the estimated temperature response were estimated by creating 100 member ensembles of the BAU and SN1 emission scenarios. For each ensemble member, the RF of each short-lived climate forcers was randomly selected within its estimated uncertainty, with a Gaussian probability distribution. The resulting spread in global mean temperature change was subsequently calculated using common radiative forcing metric values (for details on this methodology, see Fuglestvedt et al., 2014). For the aerosols, relative standard deviations of 39%, 33% and 34% were assumed for BC, OC and SO_4 (sulfate) respectively (Boucher et al., 2013). For the greenhouse gases, a 6% uncertainty was assumed (Myhre et al., 2013). No uncertainty was added for the climate sensitivity.

The RF input to Eq. 1 is derived using two different approaches depending on the lifetime of the respective pollutant and is described in the two following sections.

3.3.1 Long-lived greenhouse gases and ozone precursors

A change in the amount of greenhouse gases becomes evenly mixed in the atmosphere on time scales of months to a year due to the long atmospheric residence time of these species. Hence, the consequent climate impact depends little on where the emission originally occurred. For these species we use the radiative efficiencies, i.e., the global-mean radiative forcing per kg emission, from Myhre et al. (2013) as input to Eq. 1. This allows us to estimate the impact of emissions in China without detailed model simulations of changes in atmospheric concentrations.

Once emitted, the pollutants will initially cause a heightened concentration, which then gradually decays on time scales related to the atmospheric residence time of the respective pollutant. To account for the temporal evolution of non-CO_2 species over time we use lifetimes based on atmospheric residence times summarized in Myhre et al. (2013) and Fuglestvedt et al. (2010), and assume standard exponential decay rates. Changes to the CO_2 concentration exhibit a more complex temporal behavior, which can be expressed in a simplified form by an Impulse Response Function (IRF_{CO2}). Here we use the IRF_{CO2} based on the Bern Carbon Cycle Model (Joos et al., 2013). A more detailed description of this approach is found in Aamaas et al. (2013).

In this study we also use global radiative efficiencies to calculate the impact of ozone precursors. In reality, the resulting change in ozone concentrations depends on the location of emissions (Berntsen et al., 2006; Fuglestvedt et al., 1999; Naik et al., 2005). However, this study focuses on CO_2 and aerosols, for which the largest changes in future emissions occur in our scenarios, and using the analytical approach will in practice only have a minor influence on the overall results. Radiative efficiencies are from the global model run of Wild et al. (2001) for NO_x, from Derwent et al. (2001) for CO and from Collins et al. (2002) for VOCs, and are summarized on Fuglestvedt et al. (2010).

3.3.2 Aerosols

Aerosols have atmospheric residence times of days to weeks, and hence do not mix evenly in the atmosphere. The radiative and climatic impact of aerosols is strongly heterogeneous and can depend significantly on where the emissions occur. Estimating the RF from aerosol emissions in China requires a more detailed framework than the simplified analytical approach outlined above.

The distribution of atmospheric aerosol concentrations from emissions in China are quantified using the gridded emissions (Section 3.2) as input to the global 3-dimensional chemistry-transport model OsloCTM2 (Søvde et al., 2008). The OsloCTM2 uses meteorological data generated offline with the Integrated Forecast System (IFS) at the European Center for Medium-range Weather Forecasts (ECMWF) to simulate atmospheric tracer transport, and treats tropospheric chemistry, as well as aerosols. Detailed description of the parameterizations of nitrate, sulfate and carbonaceous aerosols (BC and OC) can be found in Myhre et al. (2006), Berglen et al. (2004), Berntsen et al. (2006), and Skeie et al. (2011).

Three simulations are performed in a T42 horizontal resolution (2.8°x2.8°) with 60 vertical layers; *(i)* a baseline run with emissions for 2004 and *(ii)* two runs for year 2030 with emissions of BC, OC, SO_2, NH_3 and NOx in China following the BAU and SN1 scenarios. Meteorological data for year 2006 is used in all simulations. Hence, the results do not account for the effect of future climate change on meteorology and atmospheric chemistry.

In order to quantify the consequent RF, i.e., the radiative imbalance caused by the changes in concentrations, the atmospheric distribution of aerosols in 2004 and 2030 are fed into an offline radiative-transfer model (Myhre et al., 2009). The model is based on the DISORT radiative-transfer scheme (Stamnes et al., 1988) and uses eight multiple-scattering streams and four shortwave spectral bands for aerosol simulations. We calculate the direct RF of BC, sulfate and nitrate aerosols. The estimate for BC does not include the impact of reduced albedo of snow and ice or semi-direct effects. The first indirect effect of aerosols, i.e., through modification of cloud albedo, is calculated using a parameterization of cloud droplet number concentration versus aerosol optical depth, following a method outlined by Quaas et al. (2006) and Quaas and Boucher (2005).

Radiative efficiencies for input to Eq. 1 are obtained by normalizing the RF by emissions. As for other non-CO_2 species, a single exponential timescale is used to represent the temporal behavior. While OC was also included in the OsloCTM2 runs, the noise in the data due to small emission perturbation lead us to use literature values also here (Fuglestvedt et al., 2010).

4 Impacts on the economy

In both policy scenarios SN1 and SN2, the emission paths of GHG included in the Kyoto Protocol are almost the same (Figure 1a), with accumulated emission reduction towards 2030 of 59.3 gigatons CO_2 equivalents ($GtCO_2e$). This corresponds in magnitude to total global emissions of GHGs in 2030 in the business as usual (BAU) scenario, or 120 per cent of current global emission level (e.g. 2010).

However, the impacts on the economy are highly sensitive to whether the CO_2 tax is accompanied by income redistribution (SN2) or not (SN1). For both scenarios the CO_2 tax rate is low initially, but increases steadily to keep the CO_2 emissions constant at 2015 level. Hence, the effects on the economy are also small initially but rising over time. As the CO_2 tax is rising, the domestic cost level is increasing, exposing China to higher competition in the world market. Overall, the Chinese economy will see some profitable options for trade foregone and suffer loss in income. However, structural changes in production and consumption in the wake of the income redistribution might modify this loss.

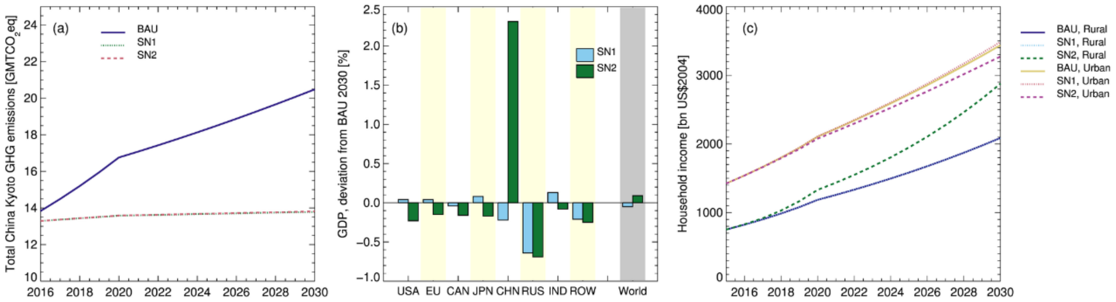

Figure 1: a) The Kyoto GHG emissions in China for the three scenarios for the 2015-2030 period. b) The deviation from BAU for GDP in 2030 for the two policy scenarios of the regions: North America (USA), OECD-Europe (EU) , Japan (JPN), Russia (RUS), China (CHN), India (IND) and Rest of the world (ROW). c) The household income in rural and urban China for the three scenarios.

4.1 GDP growth

It turns out that the CO_2 tax on fossil fuels as a single measure reduces China's GDP only marginally to 0.2 per cent below the BAU level by 2030 (see Figure 1b). When the tax revenue is transferred to rural households (SN2), the GDP pathway slightly shifts upwards and reaches 2.3 per cent above BAU level in 2030. In particular the agriculture responds positively to the income redistribution, increasing output by 6 per cent as food prices increase by 4 per cent. In China's family farming system labour is the main input as land is contracted from the government at a low rate. Hence, the value added contribution from agriculture to GDP is larger for a given increase in output value than in most other production sectors. Further, agriculture is particularly stimulated by the increase in rural income as the income level is low at the outset and food makes up a considerable share of their demand. The CO_2 tax revenue and thus the land subsidy gradually rises to 6.6 per cent of GDP in 2030.

4.2 Effect on the world economy

The world economy is affected by the climate policy of China through trade effects. The largest effect is seen in Russia where GDP is 0.6 per cent lower than in the BAU in 2030 (see Figure 1b), reflecting the falling prices on fossil fuel in the global market and reduced export income for Russia. The CO_2 tax in China tends to reduce the economic activity in the rest of the world (ROW) owing to fewer options for cheap imports of intermediates and consumer goods.

4.3 External trade

External trade is clearly affected by the CO_2 tax. Total exports are reduced by 5.8 per cent (SN1) in 2030, caused by the strong increase in price of energy intensive goods like of steel and other metals products (10-12 per cent). Imports to China only fall slightly in SN1 (0.6 per cent). When combining the CO_2 tax with income redistribution a different consumption pattern adds to these effects, reducing exports as much as 12.6 per cent below BAU in 2030. The shift of expenditure from an urban to a rural consumption pattern requires more resources for domestic production, crowding out some more exports on top of the domestic cost effect. Imports increase by 1.7 per cent, accompanying a similar upwards shift in GDP. The economy has become considerably less dependent on the world market in the SN2 scenario in line with stated policy preferences.

4.4 Income distribution

The effect on household income in rural and urban China is shown in Figure 1c. The wage level is reduced more with a CO_2 tax only (5.7 per cent) than with income redistribution (3.4 per cent). In SN2 laid off workers are absorbed primarily by agriculture and the renewable energy sectors (full employment is assumed in the model). Further, SN2 lowers the rate of return on produced capital by 6.3 per cent versus 5.6 per cent without recycling the tax revenue to rural households (SN1). Hence, SN2 shows less reduction in wages than SN1, and larger reduction in return to capital.

In rural areas the land subsidy from recycled CO_2 tax revenue raises the return to land by 37 per cent. When supported by the substantial increase in agricultural prices of 4 per cent in SN2 versus a decline of 2.9 per cent in SN1, this more than compensates for the rural wage level decline. The improved income distribution is visible in the substantial increase in rural consumption.

4.5 Consumption

In SN1, the CO_2 tax reduces consumption of urban households by 1.3 per cent and of rural households by 1 per cent. Consumption of urban and rural households is reduced more than GDP (0.2 per cent) reflecting the fall in household wage income. Some of the income reduction among the urban population will harm the rural work migrants, living and working in the cities while sending remittances to their families in the villages.

In contrast, the income transfer in SN2 makes a big contribution to rural welfare. Rural households increase consumption by 28.6 per cent, whereas urban households must reduce theirs to 8.8 per cent below BAU in 2030. Still, urban consumption in 2030 increases by 6.5 per cent annually during 2010 – 2030 and reaches a level 3.5 times above 2010 level in 2030.

4.6 Energy markets

In both policy scenarios, the CO_2 tax has a marked effect on the energy prices. The CO_2 tax increases over time to suppress the demand for fossil fuels and particularly coal. Coal is the dominant feedstock for electricity production and the electricity price increases by around 65 per cent by 2030. Total consumption of electricity in SN1 and SN2 is lowered by 13-14 per cent compared with the BAU in 2030, but will still be over 60 per cent above the base year level. The reduced demand for electricity spills over into a similar reduction in demand for coal, which in 2030 is sold at a price nearly one third lower than in BAU.

Purchaser prices on electricity increase markedly and so does the gas price, increasing by about 50 per cent as a demand shift from coal is encouraged by the CO_2 tax hitting coal hardest. The prospects of an increasingly global market for natural gas/liquefied natural gas (LNG) might however ease the upward pressure on the gas price, a factor that is not reflected in this study. The strong increase in the gas price reflects the combination of limited national resources and so far limited access to imports that can compete in price with heavily taxed coal and relatively costly nuclear and new renewables. The future cost of renewables are likely to be overestimated, hence the transition to low-carbon energy might impose less increase in electricity and gas prices than our results indicate.

The cost of energy intensive iron and steel production is increasing by 8-9 per cent. A decline in export of iron and steel of around 30 per cent contributes substantially to the decline in total export volume at 5.8 per cent. Both policy scenarios come out quite similarly with respect to impact on energy prices. Hence, the energy market is mainly affected by the CO_2 tax and less by the change in demand structure and industrial mix in the wake of the income redistribution.

5 Effect on GHG emissions and the global climate

In both policy scenarios CO_2 emissions from fossil fuels combustion in China are stabilized at 2015 level, landing at 39 per cent below the emission level of IEA´s New Policy Scenario in 2030 (IEA, 2010). The climate effect of stabilizing CO_2 emissions by a CO_2 tax on fossil fuels has been assessed. This assessment covers changes not only in CO_2 but a range of other Kyoto and greenhouse gases, aerosols and aerosols precursors, as well as ozone precursors. Among the major greenhouse gases other than CO_2 are CH_4 and N_2O from agricultural production.

The emission differences between the policy scenarios and the BAU scenario are calculated until 2030, while the global temperature response due to these emissions paths are estimated for the entire century to investigate both the short term and long term impacts of the proposed policy during 2016-2030.

CO_2 emissions from fossil fuels generate global warming, however, reduction of fossil fuel combustion also reduces emissions of other components with a more complex impact on climate. Figure 2 shows the radiative forcing for some of the aerosols and aerosol precursors, with both policy scenarios represented by SN1. Coal contains sulfur, which is emitted as SO_2 and transformed to SO_4 in the atmosphere. SO_4 has a cooling effect directly and indirectly. We see that global reduction in fossil fuel use lead to a slight reduction of the cooling effect of SO_2 emissions. However, reduction in emissions of BC tends to lower radiative forcing and thus reduce warming.

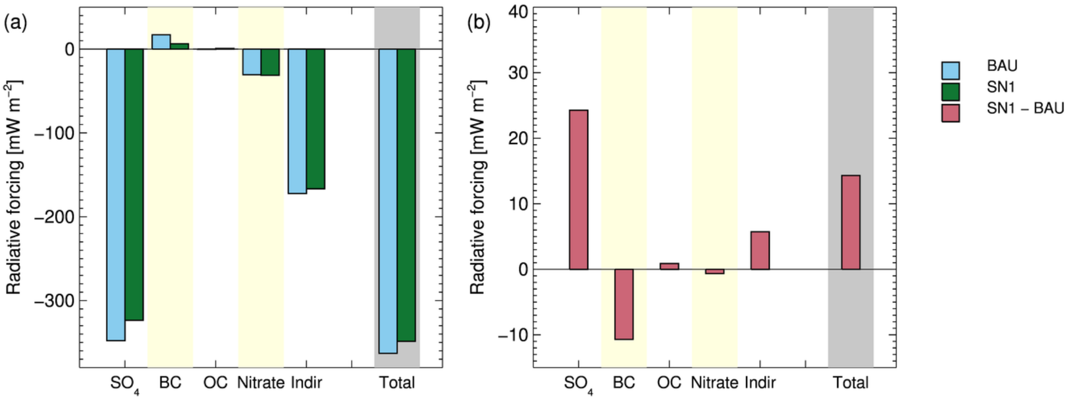

Figure 2: Contribution to radiative forcing by climate emission component calculated with OsloCTM2 for emissions in 2030. All radiative forcings are given with units mW/m2. The effect of BC on snow is not included. a) Radiative forcings in BAU and SN1. b) Difference in radiative forcings between SN1 and BAU.

As the difference in emissions between the policy and BAU scenarios is largest in China, most of the change in radiative forcing occurs over China and downwind of China towards North America, as seen for SO_4 and BC in Figure 3. As the modeling shows, the emission reduction in China leads to slightly increased emissions elsewhere, hence other regions of the world show radiative forcing with opposite sign. This is most clearly seen as reduced RF from increasing coal use and sulfate concentration over India, which is a heavy coal user and increase consumption as the coal price is falling in the global market.

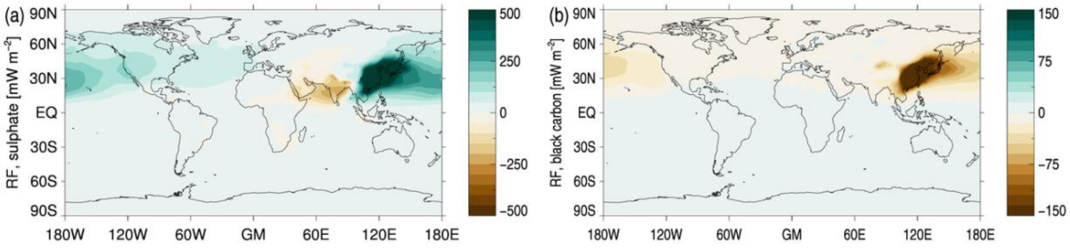

Figure 3: The geographical distribution of the radiative forcing in 2030 between SN1 and BAU for sulfate (a) and BC (b).

Figure 4 panels a) and b) show the climate change induced by China and the rest of the world (ROW) respectively. The reforms in China have spillover effects on the economies of other countries via the world market, in particular via the market for coal. China is the world's largest importer of coal and falling demand from China lowers the world market price on coal. Cheaper coal and higher prices on energy intensive exports from China increase competitiveness of ROW, enhancing their coal use and economic activity.

Figure 4a shows that CO_2 and SO_2 emissions largely determines the effect of avoided coal use in China on the global temperature. Avoided coal use means loss of cooling from SO_2 emissions in the short term. However, due to the long-term response of CO_2, the net warming effect is dwindling from around 2030, as we only consider the influence of the policy for the 2015-2030 emissions. From 2040, the cooling effect of avoided CO_2 emissions in China dominates, an effect that lasts beyond 2100 as avoided CO_2 emissions would benefit the climate for centuries.

The corresponding picture from ROW is shown in Figure 4b. We see that NOx emissions has a more marked effect on the climate development in ROW than in China, initially warming but switching to a modest cooling effect around 2040. The cooling effect of SO_2 emissions in ROW is larger relative to CO_2-induced warming than for China. One reason is that sulfur content of Chinese coal is relatively low.

As illustrated in Figure 4c, the mitigation policy in China initially leads to a negligible warming, a result of removing SO_2 emissions when use of fossil fuels, in particular coal, is lowered by the emission tax. However, around 2030 the cooling effects of lower CO_2 emissions in China takes over, generating a cooling of about 0.03 degree centigrade during the rest of this century and further on, as CO_2 has a very long lasting climate impact. This impact corresponds roughly in magnitude to the cooling effect from avoiding one year of current (2008) global emissions of all the pollutants considered in this study (Aamaas et al., 2013).

Historically, China has contributed a relatively constant share of 10 per cent to global RF, although the use of fossil fuel and in particular coal in China almost tripled during 1980-2010. The SO_2 content of coal and associated concentrations of sulfate particles in the atmosphere has kept the effect on radiative forcing from coal emissions in China roughly constant (Li et al., 2016). A similar lack of impact was found by Shindell and Faluvegi (2010) in the case of growth in global use of coal for electricity production. However, because of the short lifetime of sulfate particles, their cooling can only compensate for the warming from long-lived carbon emissions in the near-term.

Since the uncertainty in the impact of SO_2 and other pollutants with short-lived effect is much larger than for the impact from CO_2, the uncertainty is largest for the first decades. The initial warming due to mainly reduced SO_2 emissions is therefore highly uncertain, while the long term cooling is more certain. Although the change in ROW CO_2 emissions is small, total ROW emissions are larger than China's and the uncertainty of the estimated long term warming by ROW emission increase is higher than for Chinese emission reduction and cooling. The overall uncertainty in our best estimate is in the same order as the estimated cooling, but is gradually reduced towards 0.02 degrees at the end of the century.

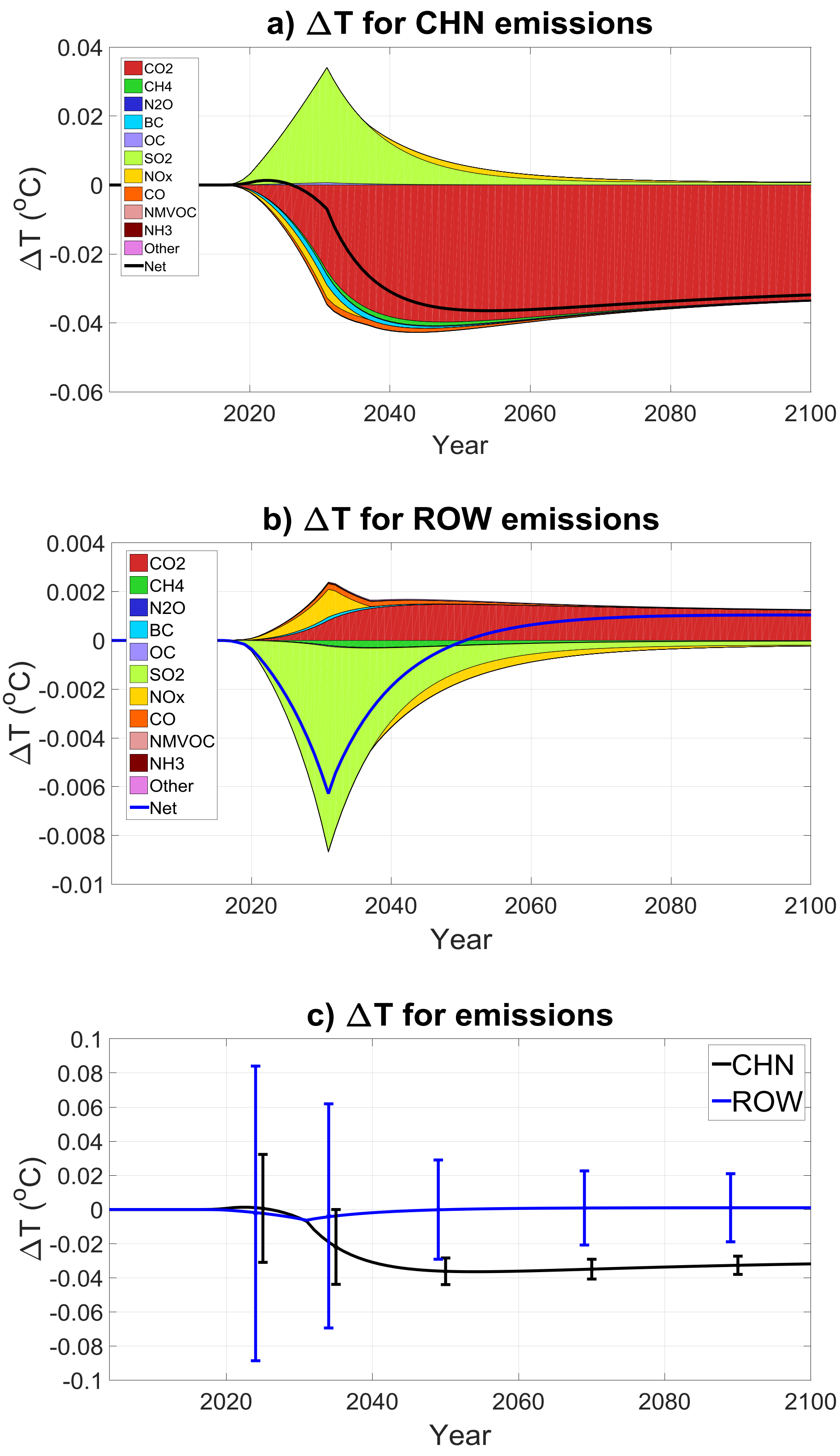

Figure 4: Impact on global mean temperature (T) by Chinese policy reforms and associated change in Chinese emissions (a) and ROW emissions (b), and the net policy impact on T, including uncertainty (c).

6 Conclusions and policy implications

Our study shows that China might make substantial contributions to climate mitigation at the same time as its leadership goes ahead with the national program for social and economic reform that will provide more health services, better education and pensions in rural areas. Reducing the urban-rural income gap by a third is feasible within the limits of domestic resources and the interaction with the world market. The economy becomes less dependent on exports and investments as drivers of economic growth, thus resolving the problem of persistent policy bias towards export subsidies and overinvestments. Avoided greenhouse gas emissions accumulated over the 2016-2030 period are 60 billion ton CO_2e, 120 per cent of the current global emission level, and through this policy the global mean temperature will be reduced by 0.03 ^{o}C, with an uncertainty of 0.02 ^{o}C, for the rest of this century.

This policy is feasible but implementation depends on political will and capacity to overcome barriers, for instance represented by political strongholds like coal based and energy intensive state owned industries. Fortunately, two aspects rank the reform policy high on the to-do list, namely the challenge to social stability from large income differences and further, the deep discontent among urban citizens with the serious air pollution. Combined climate policy and socioeconomic reform will address both the rural and the urban issue. Hence, critical domestic policy issues involving the population at large might be resolved through climate mitigation efforts. For the COP21 meeting in Paris China has pledged to cap CO_2 emissions by 2030 at the latest. Our study shows that Chinese emissions might well be stabilized earlier.

Acknowledgements

We gratefully acknowledge funding from the Research Council of Norway (grants 199491 and 209701). We thank two anonymous reviewers for valuable comments and Zbigniew

Klimont and Glen Peters for providing emission data, Ragnhild B. Skeie for preliminary OsloCTM2 calculations and Gunnar Myhre for essential guidance.

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