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ORIGINAL ARTICLE

Disentangling the ranges: climate policy scenarios for China and India

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Abstract Greenhouse gas emissions in China and India have been increasing rapidly over the last decade. Scenario studies can provide insight into expected future trends and the emission reduction potential in these regions. The scenarios show that growing population, gross domestic product, and energy demand are likely to lead to a further increase in emissions. At the same time, a decreasing emission intensity would still allow to create decarbonization scenarios in line with the requirements for reaching a maximal warming of 2 °C. There is, however, a wide range of assumptions across these studies. Based on the literature review, this paper observes that key assumptions in scenarios developed by national institutes in China and India differ from those presented by international studies or modeling teams. We explore how this—and other factors like data availability—may influence the interpretation of the scenarios and how international and national modeling groups could learn from each other. Our main recommendation is for more extensive collaboration between national and international research groups, so that national and international scenario studies can be compared in more detail in order to support international negotiations.

Keywords Climate change · Climate scenarios · Mitigation · China · India

Introduction

Several studies have emphasized the critical importance of China and India in international climate policy (Blanford et al. 2012; Calvin et al. 2012; van Ruijven et al. 2012; van Vuuren et al. 2003). The main reason is the sheer size of these countries: China and India are home to 37 % of global population (2012 numbers), consuming 27 % of global energy (2011), and emitting more than 30 % of global CO_2 emissions (2010; Table 1). Although the countries are often mentioned together, there are large differences between China and India: China's national income is more than 2.5 times the level of India, which is also reflected in the total energy use and CO_2 emissions. For instance, China became the largest contributor to global CO_2 emissions in 2007 (Zhou et al. 2011) and globally became the largest energy consumer in 2010 (BP 2014). In fact, China's CO_2 emissions per capita are already above the world average, while those of India are still far below that level.

China's and India's CO_2 emissions have increased rapidly during the last two decades, and several papers have shown that this trend is expected to continue (Calvin et al.

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Table 1 Key socioeconomic and energy indicators for China and India

	China	India	Global	Survey year
Population (billion persons)	1.35	1.24	7.04	2012
Gross National Income, PPP[a] (billion current US$)	12,206	4,730	85,987	2012
Gross National Income per capita, PPP (current US$)	9,040	3,820	12,207	2012
Energy use (thousand tons oil equivalent)	2,728	749	12,716	2011
Energy use per capita (kgs oil equivalent)	2,029	614	1,890	2011
CO_2 emissions ($GtCO_2$)	8.29	2.01	33.62	2010
CO_2 emission intensity (kg CO_2/PPP US$ of GDP)	0.7	0.4	0.4	2010
CO_2 emissions per capita (tCO_2/capita/yr)	6.2	1.7	4.9	2010

Source: World Bank (2014)

[a] Purchasing power parity

2012). As a result, the importance of these countries for international climate strategies will increase even further. This expectation has led to a multitude of climate change mitigation scenarios for these key countries, developed by both national and international institutes. These scenarios cover a whole range of possible outcomes. Some of the scenarios explicitly look into the required changes under the target to limit global warming to a maximum of 2 °C above pre-industrial levels.

Clearly, the feasibility of global ambitious mitigation scenarios depends on what will happen in major economies, including China and India. There are various ways to test the feasibility of these scenarios. One way is through international model comparison projects, such as EMF (Clarke et al. 2009; Kriegler et al. 2014), LIMITS (Tavoni et al. 2013), and AME (Calvin et al. 2012). However, the assumptions and results of scenarios developed by knowledge centers in China and India are not often taken into account in such studies. It is therefore useful to explore whether the ambitious emission reduction trajectories for China and India resulting from international studies are somehow mirrored in local studies. In fact, there is some evidence that national studies make different assumptions than international studies, both for India and China (Kumar et al. 2011; Yang et al. 2011).

This study compares projections of international studies to those of national (i.e., Chinese or Indian) research groups in order to gain insight into their possible differences and to suggest improvements for both national and international modeling groups. More specifically, we look at the question whether the rapid emission reduction trajectories for China and India resulting from international studies are matched in national studies. If this would be the case, this would give some additional confidence in the feasibility of ambitious global mitigation scenarios. It should thus be noted that this paper does not elaborate on the required emission reductions from developing countries (for this, see Den Elzen et al. 2013), nor on the implications of different fairness principles or effort-sharing regimes for China and India (for this, see van Ruijven et al. 2012).

Section 2 explains which studies have been included in our assessment, how we defined international and national studies, and how mitigation scenarios should be interpreted. Section 3 compares baseline projections of CO_2 emissions and the underlying drivers between national and international studies. Section 4 describes the implications for mitigation scenarios. Section 5 shortly discusses the importance of historical data and technology, followed by general conclusions.

Studies included in the assessment

Over the last few years, scenario studies that provide details on the possible developments in both India and China have regularly been published. Important examples include the scenarios published in the context of the EMF-22 model comparison (Clarke et al. 2009), the AME model comparison (Calvin et al. 2012), and projections published by the IEA World Energy Outlook (2012) and the OECD Environmental Outlook (2012). We use these studies here as input for our comparison. For model studies that both participated in the EMF-22 and AME model comparison exercise, we included only results for the latter, more recent, exercise. In addition, we have looked for scenario studies published by domestic Indian and Chinese organizations. Most of these studies were developed by academic research organizations and/or governmental research institutes.

In the comparison, we only included so-called scenario studies, i.e., studies that provide sufficient detail on the energy system and emissions based on a consistent set of assumptions (thus excluding, for instance, so-called pathways directly derived from fairness principles). Another important selection criterion was the type of scenarios. In the comparison, we included only baseline projections (projections without climate policy) and scenarios that aim for deep emission reductions (mostly 450 ppm or 2.6 W/m^2 forcing scenarios, comparable to the RCP2.6 (van Vuuren et al. 2011).

Table 2 gives an overview of all studies included in our comparison. All studies selected from international modeling groups have a global focus, in which China and India are modeled as two separate regions. The vast majority of the scenarios have been selected from the AME model

Table 2 Overview of studies included in the assessment

Study/model	Data until	Baseline/ mitigation
National studies on China		
ERI (2009), as cited by Li and Qi (2011)	2050	B + M
Kejun (2011)	2050	B + M
McKinsey & Company (2009a)	2030	B + M
UNDP (2010)	2050	B + M
Zheng et al. (2009)	2050	B + M
Zhou et al. (2011)	2050	B + M
Zhou and Mi (2010)	2050	B + M
National studies on India		
IRADe AAs (MoEF 2009)	2030	B
McKinsey & Company (2009b)	2030	B + M
NCAER–CGE (MoEF 2009)	2030	B
Parikh et al. (2009)	2030	B + M
Shukla et al. (2008)	2050	B + M
Srivastava et al. (2010)	2050	B + M
TERI (2008)	2030	B + M
TERI–MoEF (MoEF 2009)	2030	B
World Bank (2009)	2030	B + M
International studies on both China and India		
IEA (2012)	2035	B + M
OECD (2012)	2050	B + M
FUND (only China; Clarke et al. 2009)	2100	B + M
MiniCAM (Clarke et al. 2009)	2100	B + M
POLES (Clarke et al. 2009)	2100	B
SGM (Clarke et al. 2009)	2100	B
AIM-CGE (Calvin et al. 2012)	2100	B + M
AIM-Enduse (Calvin et al. 2012)	2050	B + M
DNE21 (Calvin et al. 2012)	2050	B + M
EPPA (Calvin et al. 2012)	2100	B
GCAM (Calvin et al. 2012)	2100	B + M
GEM-E3 (Calvin et al. 2012)	2100	B
GRAPE (Calvin et al. 2012)	2100	B
GTEM (Calvin et al. 2012)	2100	B
IMAGE (Calvin et al. 2012)	2100	B + M
KEI-Linkages (Calvin et al. 2012)	2050	B
MARIA-23 (Calvin et al. 2012)	2100	B
MERGE (Calvin et al. 2012)	2100	B
MESSAGE (Calvin et al. 2012)	2100	B + M
PECE (Calvin et al. 2012)	2100	B
Phoenix (Calvin et al. 2012)	2100	B
REMIND (Calvin et al. 2012)	2100	B + M
TIAM_WORLD (Calvin et al. 2012)	2100	B + M
TIMES-VTT (Calvin et al. 2012)	2100	B + M
WITCH (Calvin et al. 2012)	2100	B

comparison exercise. In contrast, all domestic scenarios focus specifically at the relevant country (China or India).

As shown in Table 2, more than 30 studies were included in our assessment, of which eight domestic studies on India and seven on China. Not all studies have both a baseline and mitigation scenario. For instance, about half of the AME models did not report deep emission reduction scenarios. Furthermore, the scenarios have different time horizons. Most studies had a horizon to at least 2050 (no data were collected after 2050 for this assessment). For some studies, however, the time horizon was limited to 2030.

Comparison of baseline scenarios

The factors that determine CO_2 emissions can be summarized by the Kaya identity. This identity states that the total emission level can be expressed as the product of population, GDP per capita, energy use per unit of GDP, and carbon emissions per unit of energy consumed. As all scenarios provide information about future population, GDP levels, and carbon emissions, we especially focus on these drivers. For the national studies, data on energy use are limited, preventing a good comparison between national and international studies. We will analyze how far differences in primary energy use could explain differences in CO_2 emissions in Sect. 3.3.

Population projections

Population projections are an important driver of energy use and therefore indirectly of CO_2 emissions. Figure 1 shows that population projections of the national studies are very similar to the international studies, the main difference being that international studies show a wider range of population estimates for India by 2030. The lower range in population estimates by national studies originates from that fact that population numbers of almost all national studies are based on the same source (Office of the Registrar General 2006). For 2050, population numbers were not available for India from national emission scenario studies.

Assumptions regarding the future urbanization rate are also key parameters for emission scenario studies, as strong urbanization will increase the demand for steel, cement, and other materials for the construction of urban infrastructure and houses. As the international scenario studies do not report urbanization rates, with the exception of IEA, a comparison between national and international studies is not possible. However, six of the seven national studies for

China do provide such information. Their projected urbanization rates range from 62 % (UNDP 2010) to 70 % (ERI 2009 and Zhou et al. 2011) for 2030 and from 70 % (UNDP) to 79 % (ERI and Zhou et al.) for 2050. As a comparison, the IEA projects an urbanization rate for China of 62 % by 2030 and 73 % by 2050. For India, the national studies do not report urbanization rates, while the IEA assumes an urbanization rate of 43 % by 2035.

Economic projections

Economic projections also form a key driver of future CO_2 emissions. Both future GDP and the sectoral composition of the economy strongly influence future CO_2 projections.

With regard to the first, Fig. 2 compares future GDP assumptions between national and international studies, for both India and China. For China, national studies on average project about 0.8 % higher GDP growth rates than international studies: The average GDP growth rate of national studies is 6.8 % between 2010 and 2030, while the average of international studies is 6 %. The assumed growth rates between 2030 and 2050 converge somewhat between international and national studies—although the difference in the mean GDP growth rates between national and international studies is still statistically significant (according to Welch's t test, $p < 0.01$). For India, the difference in assumed GDP growth rates between national (8 % on average between 2010 and 2030) and international studies (average of 6.3 % in the same period) is larger. For both India and China, the GDP growth rate is assumed to decline. The decline is stronger for China and occurs in both national and international studies. An important reason for this decline in GDP growth is the demographic development from 2030 onwards (Fig. 1). Overall, it can be concluded that for both China and India, domestic studies use considerably higher growth rates than international studies.

The structure of the economy can play an important role in understanding differences between scenarios. For instance, a relatively strong increase in service-oriented sectors at the cost of heavy industries will lead to lower emission projections compared to scenarios in which the share of the service sector is growing less rapidly. The international scenario studies, however, do not provide information about the (assumed) changes in the structure of the economy (only total GDP is reported), so a comparison between national and international studies is not possible. Only two national studies for China provide sectoral data (Kejun 2011; UNDP 2010), both showing that the share of the primary and secondary sector in total GDP will

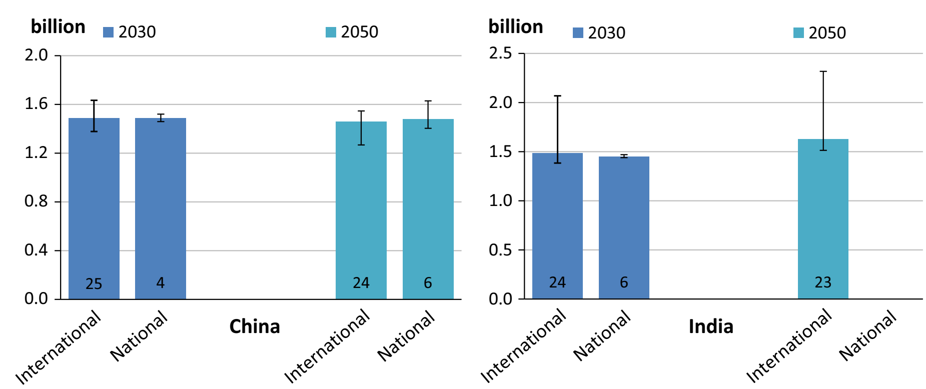

Fig. 1 Average population projections for India and China, national versus international studies. The *error bars* indicate the total range; the numbers in the *bars* the number of studies on which the average and ranges are based

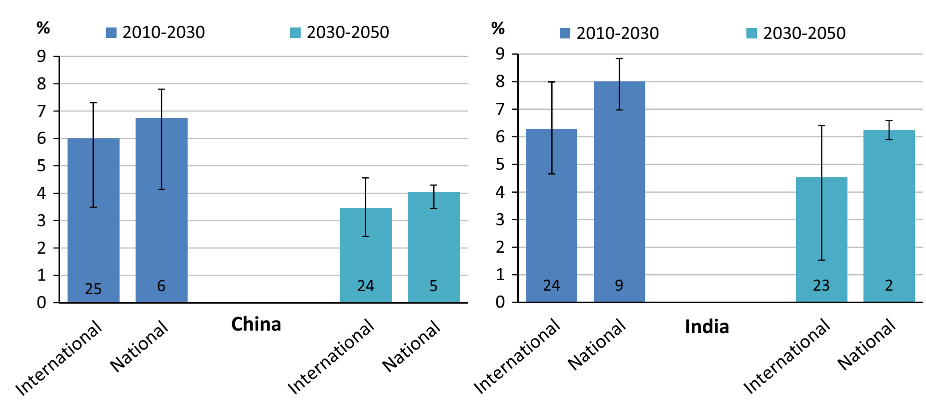

Fig. 2 Average annual GDP growth projections for India and China, national versus international studies. The *error bars* indicate the total range; the numbers in the *bars* the number of studies on which the average and ranges are based. *Note* the time period of GDP growth rates for Indian national studies differs slightly (range is from 2001–2031 to 2010–2030)

decrease strongly: from 10 % (primary) and 49 % (secondary) in 2010 to, respectively, 3–4 and 33–38 % in 2050. The projected share of the tertiary sector increases from 41 % in 2010 to 58–64 % in 2050.

CO_2 emissions projections

The range in CO_2 emissions projected in the no-policy scenarios (baselines) is very large, especially for China (Fig. 3). On average, international and national studies project similar baseline emissions for China by 2030. For 2050, international studies project statistically significant higher baseline emissions. As income growth is assumed to be larger in national studies, these results are remarkable.

For India, national studies project significantly higher baseline emissions than international studies for 2030 (a comparison for 2050 is not possible, as there are only two national studies with data for that year).

To look further into the relationship between income and CO_2 emissions projections, Fig. 4 plots GDP growth rates of individual studies against their CO_2 emission growth rates. Indeed, for India, the CO_2 emissions growth rate between 2010 and 2030 (and to a lesser degree between 2030 and 2050) is positively correlated with the GDP growth rate in the same period (the Pearson correlation coefficient being 0.61 for the period 2010–2030 and 0.5 for the period 2030–2050, with the national and international studies taken together). For China, no correlation between GDP growth and CO_2 growth was found. Here, rapid decarbonization rates, in particular in national studies, obscure the relationship.

GDP versus emission intensity

Studies have shown that in the baseline scenarios, energy intensity is the most important determinant of the variation in energy consumption and emissions (Blanford et al. 2012). We have tested whether, in the scenarios evaluated here, faster income growth assumptions also assume a faster decline in emission intensity per unit of GDP, i.e., the combination of energy intensity of GDP and the carbon intensity of energy. If this would be the case, differences in the assumed income levels would be (partly) offset by the higher intensity improvement rates. Indeed, Fig. 5 shows that emission intensity improvement positively correlates with GDP growth rates in China, both for the period 2010–2030 (correlation coefficient of 0.73) and 2030–2050 (coefficient of 0.51). This explains why there is no relation between GDP growth projections and CO_2 emissions: The improvement in emission intensity exactly compensates the higher GDP growth projections. The improvement in emission intensity can result from an improvement in energy intensity and/or the carbon intensity of energy. Although a good comparison is not possible, as only three of the national studies provide data on total primary energy demand, the studies that do report energy demand show similar projections as the international studies. Total average primary energy consumption of the 19 international studies that participated in the AME exercise (see Table 2) is 160 EJ (range 102–250 EJ) by 2030 and 219 EJ (range 150–336) by 2050. For the national studies, the ranges are 152–243 by 2030 and 161–276 by 2050—well within the ranges of the international studies, even though GDP growth was higher in the national studies. This provides some evidence that the positive correlation between GDP growth and improvement in emission intensity mainly results from a strong correlation between GDP growth and improvement in energy intensity (and less from a correlation between GDP growth and a decline in the carbon intensity of energy).

For India, the picture is less clear. Between 2010 and 2030, hardly any correlation is found between GDP growth and the improvement in emission intensity. In fact, this is consistent with the strong positive correlation between GDP growth and emissions growth, shown in Fig. 4. For the period 2030–2050, however, there is a strong relationship between GDP growth and the improvement in emission intensity (correlation coefficient of 0.72).

Comparison of mitigation scenarios

So far, we concentrated on scenarios without climate policy. We now concentrate on emissions in mitigation scenarios. As indicated, we have selected deep emission reduction scenarios from international and domestic studies. Especially for the latter group, we have aimed to identify the lowest scenarios that were available.

Figure 6 shows that, on average, national studies have much higher emissions than international studies, for both China and India (the differences in average emission levels are significant, apart from 2050 emission levels for India, for which only two national studies were available). It should be noted, however, that the results need to be interpreted carefully. The international studies aim to reduce greenhouse gas emissions consistent with the 2 °C target and assume a cost-optimal reduction in greenhouse gas emissions worldwide (emission reductions take place wherever it is cheapest to do so). This implies that differences in emission levels between international studies can be attributed to differences in baseline emissions and differences in the assumed mitigation potential of China and India as compared to the rest of the world. Many models expect considerable reduction potential in China and India, based on high coal use in the baseline scenario and relatively low current efficiency levels. This, however, does

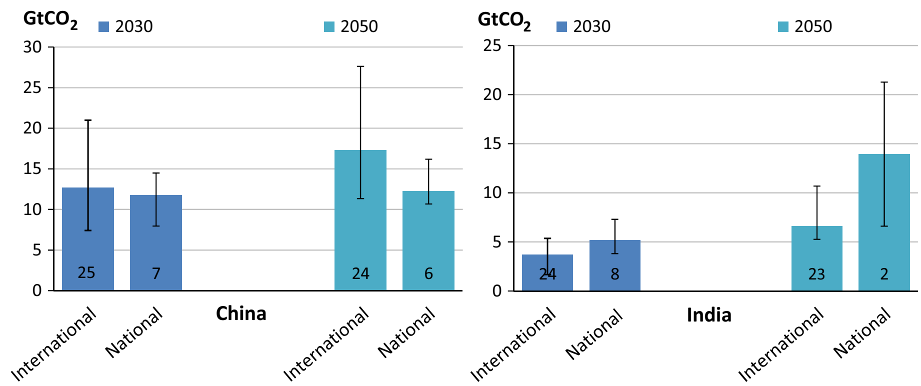

Fig. 3 Average CO_2 emission projections for India and China, national versus international studies. The *error bars* indicate the total range; the numbers in the *bars* the number of studies on which the average and ranges are based

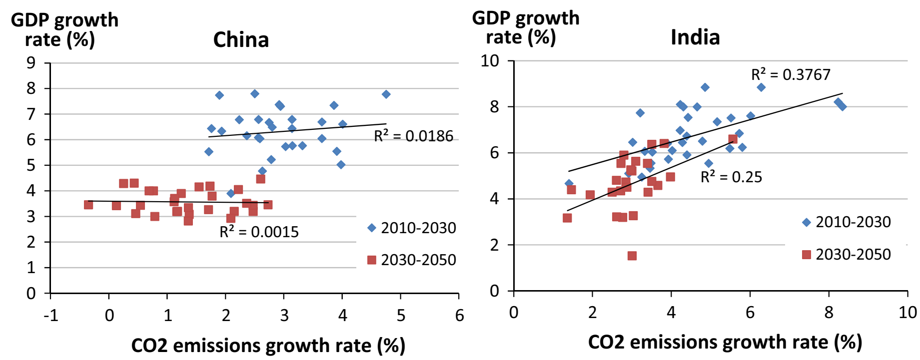

Fig. 4 Relation between GDP growth rates and CO_2 emissions growth rates

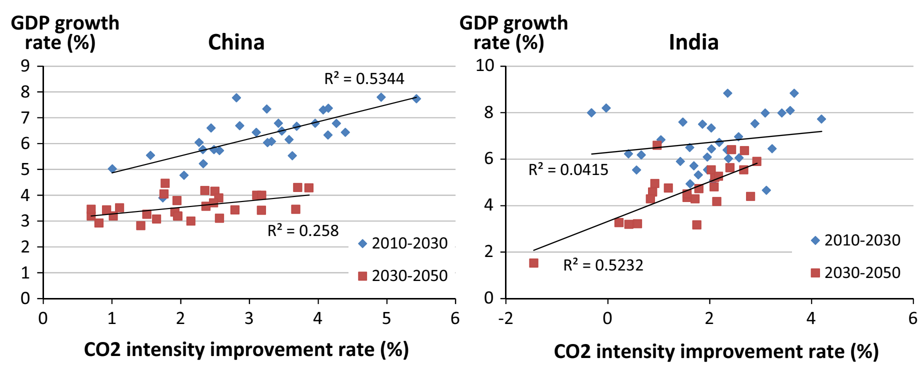

Fig. 5 Relation between GDP growth rates and CO_2 emission intensity improvement rates

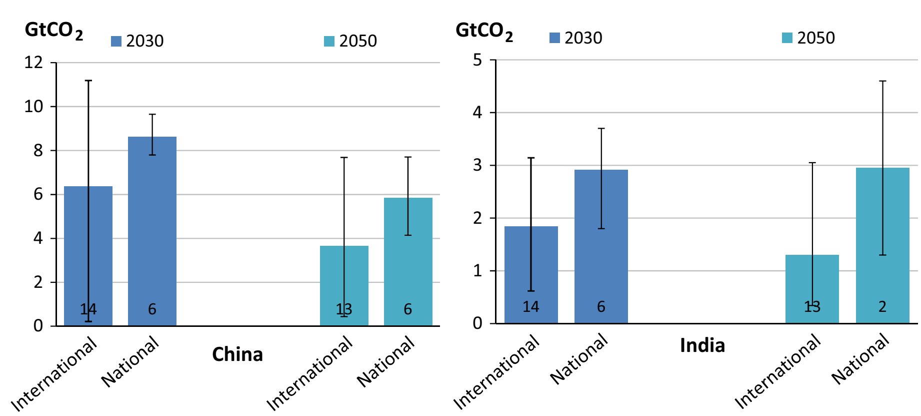

Fig. 6 Average CO2 emission levels in 2 °C scenarios for India and China, national versus international studies. The *error bars* indicate the total range; the numbers in the *bars* the number of studies on which the average and ranges are based

not answer the question how these reductions are implemented (cap-and-trade, domestic measures, and carbon tax) nor who will be paying for these reductions. The domestic studies, in contrast, focus more on the question what are reasonable emission reductions based on the domestic action (exceptions being Zheng et al. (2009) and Srivastava et al. (2010), who analyze the consequences of different burden-sharing principles on the emission allocation of, respectively, China and India). For instance, current measures to reduce emissions in China focus on (1) increasing energy efficiency and energy savings, (2) creating renewable energy production, and (3) increasing the forest carbon sink (Yang et al. 2011). If domestic studies focus especially on such measures, this may very well lead to lower reductions than a worldwide cost-optimal reduction in greenhouse gases assumed by international studies. As higher emissions in domestic studies can be caused either by different assessment of the reduction potential or by different assumptions on burden sharing, emission trading, and even the ambition of international climate policy, the studies can mostly be used as a positive reality check for the international studies.

For India, we found that baseline emissions are higher in the domestic studies than in the international studies (Fig. 3). Apart from the different approaches between national and international studies discussed above, this could be a possible explanation for the higher emissions for ambitious climate policy scenarios by national studies. Figure 7 plots baseline emissions of individual studies against emission levels of 2 °C scenarios. For India, only a weak correlation between baseline and 2 °C studies is found, at least for 2030 (correlation coefficient of 0.31). This suggests that the higher emissions in 2 °C scenarios by national studies cannot be explained by higher baseline emissions. For China, the correlation between baseline and 2 °C scenarios is only slightly higher in 2030, but practically nonexistent in 2050. This implies that for both China and India, different assumptions on the contribution of China and India to international emission reductions are a more likely cause for the differences found in mitigation scenarios between national and international studies. Still, the various national studies present ambitious mitigation scenarios that are useful to take into account in the international studies. One reason is that domestic institutes are better informed on national data, plans, and implementation issues. Studies from these institutes could therefore give a more realistic picture of the mitigation potential than international studies.

Discussion and conclusions

International models need a vast amount of historical data in order to calibrate the model (van Ruijven et al. 2010). Moreover, ideally, these models would take into account current plans in each region in order to construct their scenarios. Due to practical constraints, however, many IAMs do not calibrate their models to historic data each year. A lag in model calibration could be the reason for conservative estimates of installed capacity for onshore wind and solar electricity generation (Greenpeace 2012). India and China are major determining countries in the uncertainties of historic data as their rapid economic growth and large investments in renewable energy lead to major changes to the energy system. For wind power, Asia was the largest contributor to additional installed capacity in 2011, with China being the largest contributor to that growth, followed by India (WWEA 2012). The IEA (2011) showed a fivefold increase in total installed capacity of solar PV application in China between 2010 and 2011. It is therefore important to track changes in historical data.

A complicating factor for calibrating against historical data is that these data are quite uncertain for China and India. Guan et al. (2012) indicated that data discrepancies between national and sub-national reporting in China show over 1 $GtCO_2$ difference. For India, no comprehensive national database on historical greenhouse gas emissions is available, which makes the gathering of data a lengthy

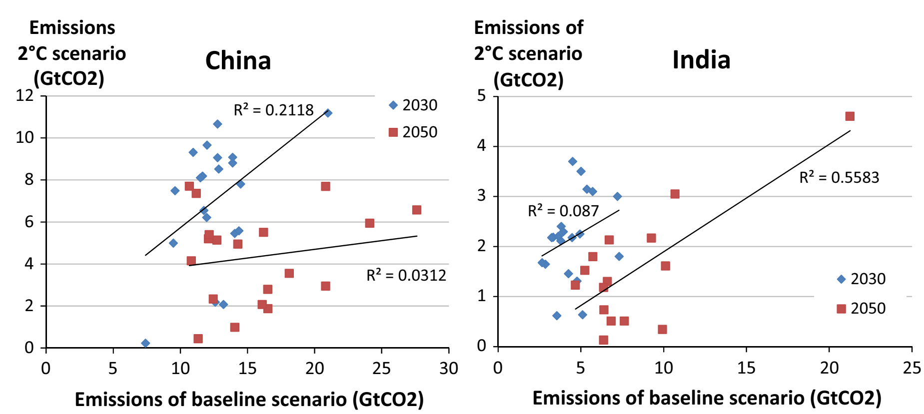

Fig. 7 Relation between baseline emission levels and emission levels in 2 °C scenarios

process based on governmental documents and reporting of industrial associations and changing methodologies (Sharma et al. 2011). These national inventories may sometimes be contradictory or lagging; however, they are a very important data source for both national and international modeling exercises. We argue that especially for rapidly developing countries like China and India, national inventories for energy use and greenhouse gas emissions are of crucial importance to properly model recent history. When national research institutes are able to combine this with local insights in energy trends and policy ambitions, they can become key brokers of data and information that could contribute to more accurate climate policy scenarios internationally.

Within this context, the main conclusions can be formulated as follows:

- *There is evidence that domestic projections for India show higher emission levels than the projections of international studies. This seems to be related to higher GDP projections by national studies. For China, such discrepancy is not observed*. Even though the differences in projections for especially GDP and CO_2 emissions are large between studies, for India, national studies show significantly higher growth projections for GDP and baseline emissions than those used by international modeling groups. The lower projections of international organizations could be caused by their assumptions that the long-term growth rates of low-income countries converge to the much lower level of high-income countries. In contrast, Indian institutes are mostly confronted by currently high growth rates. For China, no difference in baseline CO_2 emissions by 2030 can be observed, and for 2050, international studies even use higher baseline emissions, despite lower GDP projections.
- *Most of the domestic Indian and Chinese studies do not consider the emissions reduction rates that are shown to be consistent with* 2 °C *target by international studies. This cannot be explained by higher baseline emissions used in national studies*. The scenarios from international modeling groups included in this study start from the 2 °C target, and global emissions are thus bounded by this target. Regional emissions reductions are subsequently derived in the models by assuming a cost-effective implementation (top–down). The domestic studies, in contrast, often start from bottom-up considerations such as the (both technological and political) potential for domestic action. The difference in ambition should therefore be carefully interpreted, as it may be caused by different insights in technological emission reduction potential, but also by differences in assumed climate policies both at national and international level. At the same time, it also means that current domestic studies cannot be used as examples of how the projections of international studies can be implemented.
- *More extensive collaboration between national and international research groups is required to further understand the differences in projections.* Domestic information on mitigation potential, policies, and domestic modeling studies could help international studies to improve historic data assumptions, as well as to define more realistic scenarios. However, currently, many of the national studies do not provide sufficient (technological) detail about the key drivers of emissions and emissions reductions. More extensive collaboration between national and international research groups seems a prerequisite for comparing the national and international scenarios in more detail and by this, to develop more realistic (mitigation) scenarios.

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