THE ECONOMICS OF GREENHOUSE GAS MITIGATION IN DEVELOPING ASIA

Lara Aleluia Reis, Johannes Emmerling, Massimo Tavoni, and David Raitzer

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ABSTRACT

Developing Asia has the world's fastest greenhouse gas emissions growth. This study uses an economy–energy–climate model to assess the effects of Paris Agreement pledges on Asia, in comparison with business as usual (BAU) and more ambitious scenarios.

Results confirm that pledges must be strongly increased in ambition to achieve the Paris Agreement's goal of less than 2 degrees Celsius (2°C) warming. The policy costs of Asia's pledges are found to be less than 1% of gross domestic product (GDP) through 2050, while 2°C scenarios may cost less than 2% of GDP. However, costs are sensitive to assumptions about international carbon markets and mitigation timing, with costs for 2°C scenarios doubling in the absence of carbon trade, and increasing the later that mitigation is initiated. Under the 2°C scenarios, annual average energy supply investments are about $300 billion above the BAU levels through 2050.

Mitigation policy may substantially reduce air pollution mortality, with up to 600,000 fewer deaths in Asia annually by 2050. When costs, benefits of avoided climate change, and cobenefits are considered together, investment in mitigation policy is found to have substantial economic returns for the region—if action is taken rapidly and international carbon market mechanisms are implemented.

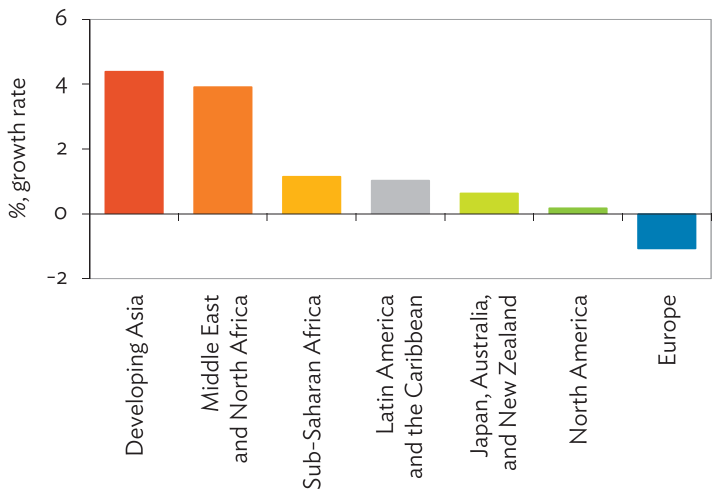
Keywords: climate change, energy, greenhouse gas, mitigation, Paris Agreement

JEL codes: C61, D58, Q52, Q53, Q54

I. BACKGROUND AND OBJECTIVES

Among world regions, developing Asia has had the most rapid greenhouse gas (GHG) emissions growth globally (Figure 1). Between 1990 and 2012, emissions grew at more than 4% annually, whereas no other region had growth above 4% for the period. Much of this emissions growth has been driven by the energy system that is becoming more carbon intensive, even as economies in the region have grown quickly.

Figure 1: Average Annual Growth Rate of Carbon Dioxide Equivalent Greenhouse Gas Emissions, 1990–2012



Source: CAIT Climate Data Explorer. 2015. Washington, DC: World Resources Institute. http://cait.wri.org (accessed August 3, 2016).

Despite substantial GHG emissions of 20 gigatons of carbon dioxide equivalent ($GtCO_2e$) in 2012, per capita income in developing Asia remained below the world average, as did many aspects of energy access (Table 1). With large natural resource-dependent poor populations living in volatile climates, it is also a region with high vulnerability to climate change. This means that the region has a large stake in climate change policy, both in terms of the transformation that emissions reduction may entail and the costs that the region may bear if climate change is not contained.

Table 1: Kaya Emissions and Drivers for 2011

	Emissions ($GtCO_2e$)	Population (billion)	Income ($ ’000 per capita, PPP)	Energy Intensity (MJ/$ PPP)	Carbon Intensity (kg CO_2/kg Oil equivalent)
South Asia, including India	3.5	1.7	4.4	5.1	2.7
Rest of East Asia, Southeast Asia, and the Pacific (ESEAP), including Indonesia and the People’s Republic of China	14.9	2.0	9.5	7.6	3.3
World	52.0	7.0	13.4	5.9	2.6

CO_2 = carbon dioxide, $GtCO_2e$ = gigaton of carbon dioxide equivalent, kg = kilogram, MJ = megajoule, PPP = purchasing power parity.
Source: World Bank. 2015. “World Development Indicators.” http://data.worldbank.org/data-catalog/world-development-indicators

The 2015 Paris Agreement on climate change has revitalized international climate policy, while at the same time leaving contentious issues to be decided in the future. The Paris Agreement is a landmark achievement in many respects. Its most important departure from previous agreements is in terms of broad representation of countries: almost all (98.8% as of July 2016) global GHG emissions are covered, compared to, for example, only 14% within the Kyoto Protocol. This creates the possibility for a comprehensive global mitigation approach once the agreement enters into force. The policy architecture is based on bottom–up actions based on national policies, called “intended nationally determined contributions” (INDCs). As the name suggests, these are intended pledges and do not represent binding commitments until formalized when countries ratify the Paris Agreement. This raises issues about the extent to which the proposed emissions reductions will actually be implemented. One important element of the Paris Agreement is the top–down oversight and guidance provision: the formalized nationally determined contributions will be verified and adjusted every 5 years.[1] This stock-taking process will allow tracking progress and increasing the level of ambition of the currently proposed INDCs.

The diplomatic breakthrough of the Paris Agreement opens up a number of research questions. Perhaps the most important issue is the extent to which the INDCs are compatible with the long-term climate objectives agreed upon in Paris, notably the need to limit the global temperature increase to well below 2 degrees Celsius (2°C). Initial assessments of the ambition of the INDCs, which are based on simple extrapolation, reveal that the INDCs fall short of the ambition required to achieve stringent climate stabilization (Rogelj et al. 2016). However, in order to properly evaluate the climate impacts of INDCs, robust methodological tools are needed to connect short-term emissions reduction strategies with long-term climate objectives. These often include multiple policy objectives, in many cases contingent on the development of the economic and energy system, such as in the case of intensity targets or of emissions reductions over the business-as-usual (BAU) case. Moreover, if an intention is to increase the ambition of the pledges over time, the fundamental question will be how quickly this can be achieved with specific actions.

Existing analysis has been mostly on the basis of effectiveness, when efficiency should also be analyzed. The current Agreement is based on a fragmented approach with limited international coordination, which creates inefficiency. A more efficient alternative arrangement could be exploited to achieve a greater reduction in emissions without increasing the overall compliance costs. The Paris Agreement contains an explicit provision for linking national pledges, including international carbon markets through internationally transferred mitigation outcomes (ITMOs) described in Article 6. Little is known about the potential of ITMOs or similar provisions to improve the economic efficiency of the Paris Agreement. Similarly, the Paris Agreement creates provisions for the development of the Sustainable Development Mechanism as a global emissions offset market, but all details of this will only be resolved in the future. Trading will also have important repercussions for equity considerations, including the politically sensitive issue of the distribution of mitigation costs.

The overall objective of this paper is thus to provide an evaluation of the potential evolution of the Paris Agreement and its effects on developing Asia. The study uses an integrated economy–energy–climate model to help evaluate the different strategies put forward following the INDCs until 2030 and beyond, while taking into account the uncertainties about the future of policy architecture. This approach allows connecting short-term emissions reduction policies with long-term climate objectives and taking into account the interrelations between different major economies. The paper

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[1] Once the agreement enters into force, the nationally determined contributions will replace the INDCs.

takes as a starting point a recent assessment conducted with the same methodology for the case of Southeast Asia by Raitzer et al. (2016), expanding the geographical scope, and explicitly modeling the outcome of the 21st Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change. The focus is on three main outcomes: effectiveness, efficiency, and equity. These are key factors influencing the success and feasibility of future climate policies.

The paper is organized as follows. The methods and study design are described in section II. Sections III and IV will address the issues of effectiveness and action by assessing emissions outcome and mitigation measures of the considered policy scenarios. Section V discusses the INDCs in the light of their direct macroeconomic repercussions. Section VI discusses cobenefits of air pollution. Section VII assesses benefits from less climate change and reductions in air pollution mortality relative to policy costs. Section VIII concludes.

II. METHODOLOGY AND STUDY DESIGN

The outcome of the 2015 Paris Agreement, most notably the INDCs proposed by almost all countries, represents a challenge for policy evaluation given the diversity of policy objectives, but it is also an opportunity for the use of integrated assessment tools to assess climate and economic outcomes. In this paper, the integrated assessment model WITCH (World Induced Technical Change Hybrid) is used to explore the INDCs from three main perspectives: effectiveness, efficiency, and equity. The WITCH model is designed to assess climate policies. It has been developed and is maintained at Fondazione Eni Enrico Mattei (FEEM) and the Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC) (see Emmerling et al. 2016).[2]

The WITCH model consists of a dynamic global model that integrates in a unified framework the most important elements of climate change. It basically consists of a macroeconomy, which is modeled through an intertemporal optimal growth model, a bottom–up representation of the energy sector, and a soft-linked land-use and forestry model (GLOBIOM; Havlík et al. 2011). "Soft-linking" refers to the fact that the models are linked through convergence on central parameters, rather than simultaneous solution. Emissions from peatlands are important in Indonesia (Page, Rieley, and Banks 2011) and this model adds a baseline emissions trajectory disaggregated for peat and other land-use emissions (Strack 2008). A climate model (MAGICC; Meinshausen, Raper, and Wigley 2011) is used to compute the future climate based, among others, on GHG emissions and other air pollutants.

WITCH represents the world in a number of representative regions, or coalitions of regions. For developing Asia, the regions are the People's Republic of China (PRC), India, Indonesia, South Asia, and Southeast Asia. For each region, it generates optimal mitigation and adaptation strategies for the long term (2005–2100), as a result of a maximization process in which the welfare of each region (or coalition of regions) is chosen strategically and simultaneously to other regions. This makes it possible to capture regional free-riding behaviors and strategic interaction induced by the presence of global externalities.

Endogenous representation of research and development (R&D), diffusion and innovation processes constitutes a distinguishing feature of WITCH, allowing to describe how R&D investments in energy efficiency and carbon-free technologies integrate with currently available mitigation options. The model features multiple externalities, both on the climate and the innovation side. The technology

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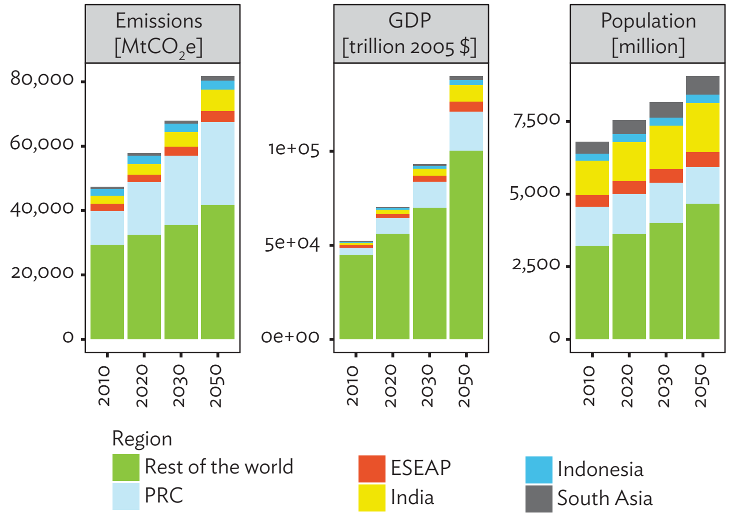
[2] See witchmodel.org for more information and Emmerling et al. (2016) for the main equations and variables of the model.

externalities are modeled via international spillovers of knowledge and experience across countries and time. In each country, the productivity of low-carbon mitigation technologies as well as the overall energy efficiency depend on the region stock of energy R&D and on the global cumulative installed capacity—two proxies for knowledge and experience, respectively. The R&D stock depends on domestic investments, domestic knowledge stock, and foreign knowledge stock through international spillovers. The spillovers moreover depend on the interaction between the countries' absorptive capacity and the distance of each region from the technology frontier. More information about the model can be found in Appendix 1.

A. The Business-as-Usual Scenario

All mitigation scenarios are assessed against a BAU scenario. This is based on the middle-of-the-road scenario SSP2 of the Shared Socioeconomic Pathways (SSPs), which is a scenario without any future climate change mitigation driven actions (van Vuuren et al. 2014). The SSP2–BAU scenario drivers, such as population and gross domestic product (GDP) are presented in Figure 2 for 2005 until 2050. Likewise, GHG emissions are shown for the BAU scenario.

Figure 2: SSP2–BAU Characterization of GHG Emissions, GDP, and Population across WITCH Regions



BAU = business as usual; CO$_2$ = carbon dioxide; ESEAP = East Asia, Southeast Asia, and the Pacific; GDP = gross domestic product; MtCO$_2$e = megaton of carbon dioxide equivalent; PRC = People's Republic of China; SSP = Shared Socioeconomic Pathway; WITCH = World Induced Technical Change Hybrid.
Source: Authors' estimates.

B. Scenario Matrix

Based on this BAU scenario, the study considers six scenarios of different climate policies. First, INDCs reflect unconditional pledges through 2030. Despite the importance of short-term policies, long-term assumptions will be key to assessing climate goals. In order to consider both short- and long-term objectives and assess their effectiveness, efficiency, and equity implications, this study uses a 2 x 2 scenario design (in addition to the BAU scenario and an optimal 2°C scenario). The two axes focus on the extrapolation of the INDCs beyond 2030, and on the level of international integration through carbon trading. The analysis also considers the case of an optimal 2°C scenario, which serves as a point of comparison were mitigation to occur optimally. Table 2 describes the resulting scenario matrix used throughout this study.

Table 2: Scenario Matrix Description

Scenario Name	No Trade in Emissions	Global Trade in Emissions
Business as usual	Reference scenario following the middle-of-the-road "Shared Socioeconomic Pathway" SSP2, the scenario agreed by the Integrated Assessment Modeling Consortium in which current trends continue (Moss et al. 2010)	
INDC	Regions meet their emissions targets until 2030, including the Cancùn 2020 pledges and the INDCs 2030; post-2030 carbon prices extrapolated increasing at an annual 3% rate	The same no-trade emissions profile is reached, but regions are allowed to trade emissions permits immediately.
INDC to 2°C	Global tax from 2030 leading to a global average temperature increase at the end of the century of 2°C	The no-trade emissions profile is reached, but regions are allowed to trade emissions permits after 2030. Permits are allocated based on contraction and convergence.[a]
Optimal 2°C		Global cap and trade leading to global average temperature rise of less than 2°C by the end of the century. Permits are allocated based on contraction and convergence.

°C = degree Celsius, INDC = intended nationally determined contribution.

[a] Contraction and convergence refer to the allocation of emissions allowances that gradually progresses from initial historical emissions shares to national allocations on an equal per capita basis over a span of 30 years (Meyer 2000).

Source: Authors.

The INDC scenario assumes implementation of the Cancùn pledges (until 2020) and INDC (until 2030) emissions pledges. The first two periods (2005–2010) are fixed and calibrated to the data from the International Energy Agency for the energy system database and from the Food and Agriculture Organization of the United Nations for the land use emissions. From 2015 onward, the model chooses the most cost-effective mitigation solution which complies with 2020 and 2030 goals. The INDC scenario has been developed extrapolating INDCs beyond 2030. This is done by applying the marginal abatement costs in 2030 as indicators of effort, which are extrapolated over time at a constant 3% annual growth (the same growth rate as is found up to 2030). For those countries with an INDC that leads to no emissions reduction (a zero implicit carbon price) in 2030, a linear convergence rule is applied to attain the minimum price faced by all developing economies by 2050. The INDC in the 2°C scenario assumes a global carbon tax after 2030 consistent with attaining the 2°C climate goal. The design also includes an optimal 2°C scenario which attains 2°C optimally, that is by allowing more stringent emissions reductions prior to 2030. The definition of the 2°C target in this study follows the mean value of the MAGICC climate model, so that, on average, the global mean temperature increase in 2100 is equal to 2°C of warming over the preindustrial level, which corresponds to a range between 515 and 520 parts per million CO_2 equivalent concentration, including air pollution emissions.

The INDC and INDC 2°C scenarios have also been simulated assuming the existence of a global emissions trading market (denominated TRADE scenarios). In such a market, countries can freely buy and sell carbon dioxide (CO_2) permits, at no transaction costs. In the INDC TRADE case, emissions permits have been allocated on the basis of the emissions foreseen by the INDC. In the INDC to 2°C TRADE case, emissions permits have been allocated based on convergence to equal per capita emissions rights by 2050, thereby reflecting a Rawlsian equity principle.

C. Implementation

To model the INDCs, all 161 INDC submissions as of 16 February 2016 were reviewed. This is carried out via the calculated absolute emissions in 2030 of the unconditional pledges. Some INDCs refer to a relative reduction to the BAU scenario, but do not explicitly refer to the reference values used. For these countries, available emission projections were used. When no value was given and no projection was available, the WITCH BAU projections were applied with country weights based on historical emissions within the WITCH regions. These weights are calculated based on the 2010 GHG emissions reported by the World Resources Institute. The country data were then mapped to the WITCH model regions. Some INDCs require specific assumptions apart from pure emissions trajectories, such as the case of the PRC and the United States (US). The emissions peak in the PRC is modeled by keeping the 2030 emissions as the upper bound throughout the rest of the century. In the case of the US, which has pledges for 2025 instead of 2030, emissions are capped at the 2025 value thereafter.

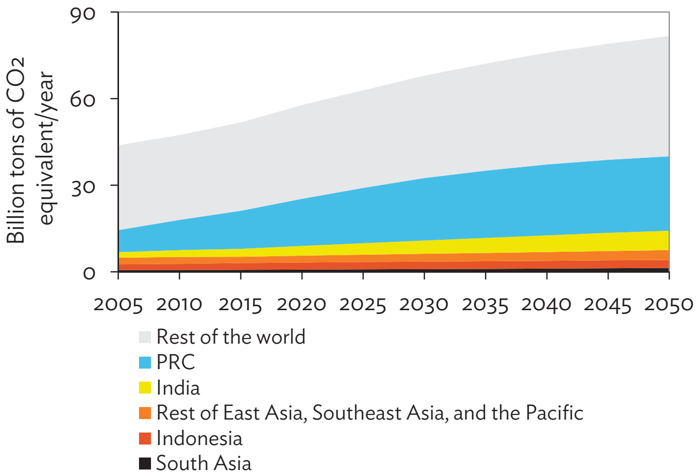
The WITCH model features detailed modeling of air pollutant emissions. These emissions are computed based on the energy sector activity levels of electricity generation and nonelectric energy sectors. The emissions factors are defined by the air pollution scenario, which captures different levels and degrees of implementation of so-called end-of-pipe measures. To account for existing and future air pollution policies, different air pollution policies are considered. The default BAU is legislation implementation, which contrasts with failed legislation (BAU–FLE), in which end-of-pipe measures are held constant (Rao et al. 2016). The BAU scenario corresponds to the implementation until 2030 of all the legislation already (in 2013) foreseen for that period. The air pollutants considered are carbon monoxide, methane, black carbon, organic carbon, sulfur dioxide, nitrogen oxides, ammonia, and volatile organic compounds. The projected emissions are fed into the model FASSTR (the R version of the FASST model; Leitao, Van Dingenen, and Rao 2013), which is a source–receptor matrix reduced model based on the TM5 model (Huijnen et al. 2010), which describes well the relationship between pollutants and pollutant precursors. It calculates population exposure to the main pollutants, in this case particulate matter (PM) and ozone (O_3) distinguishing rural and urban concentrations. The estimation of worldwide population exposure allows the calculation of premature deaths due to PM and O_3 using exposure functions by Lim et al. (2012), Burnett et al. (2013), and Anenberg et al. (2010). The mortality estimation includes ischemic heart disease, cerebrovascular disease, chronic obstructive pulmonary disease, and lung cancer for the population over 30 years old exposed to PM. Additionally, the model includes lower respiratory infection which affects the fraction of the population that is younger than 5 years old. Only mortality from respiratory disease is considered from the exposure to tropospheric O_3.

The FASST model is also used to assess the crop loss associated with a given future emissions scenario. Ozone is one of the major pollutants responsible for the significant yield losses in crops such as maize, rice, and wheat (UNEP 2011). The model uses impact functions from Van Dingenen et al. (2009) for wheat, maize, rice, and soybean, based on a metric called AOT40 which is the accumulated O_3 concentration above the concentration threshold of 40 parts per billion by volume and mean seasonal daytime O_3 estimations, crop suitability, and growing season world maps. Crop loss is assessed on the basis of the average of two O_3 concentration metrics, i.e., AOT40 and seasonal daytime O_3 concentrations.

III. CLIMATE EFFECTIVENESS AND REGIONAL EMISSIONS GAPS

In the absence of new climate change mitigation actions driven by climate policy, developing Asia will continue to have faster growth of GHG emissions than the rest of the world (Figure 3). Although in 2005 developing Asia only accounted for about a third of global GHG emissions, by 2030 the region will account for nearly 50% of global emissions, of which a majority will be from the PRC.

Figure 3: Greenhouse Gas Emissions from Asia and the Rest of the World under the Business-as-Usual Scenario

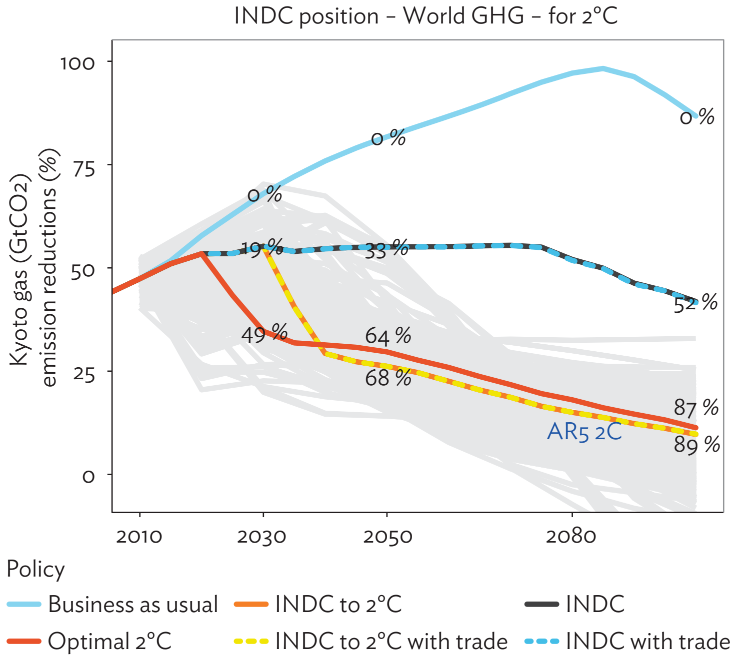


CO_2 = carbon dioxide, PRC = People's Republic of China.
Source: Authors' estimates.

To explore the effects of recent mitigation pledges on this outcome, the scenario results of the climate effectiveness of INDCs can be contrasted with climate policies that are compatible with the 2°C target. Two scenarios reach the 2°C goal by definition. This is contrasted with whether the INDCs can bring emissions levels to pathways which are consistent with the 2°C global average temperature increase in 2100. Figure 4 compares the six scenarios with a subset of the possible pathways that are consistent with the 2°C scenario in the database of the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC 2014).

The INDC pledges stand at the upper end of the emission corridors, in line with delayed action 2°C scenarios in 2030. The implementation of the INDCs implies a level of approximately 55 $GtCO_2$ global GHG emissions, which is consistent with estimates of the United Nations Framework Convention on Climate Change that the INDCs will fall between 52 and 59 $GtCO_2$ equivalent by 2030. This value can be compared with the value of 50 $GtCO_2$ the IPCC AR5 has indeed identified as the critical limit for being able to attain 2°C in the long run, with values above being still possible but raising significant extra costs and higher transitional challenges. Compared to the BAU scenario the INDC scenario represents a reduction of emissions by around 19%. The optimal 2°C scenario, starting immediately, on the other hand, finds an emissions reduction of nearly 50% is necessary by 2030. Therefore, the INDCs appear to cover less than half of the optimal mitigation requirement for staying below 2°C.

Figure 4: Emissions Trajectories of the INDC Scenarios and of the IPCC AR5 Scenarios Consistent with 2°C at the End of the Century

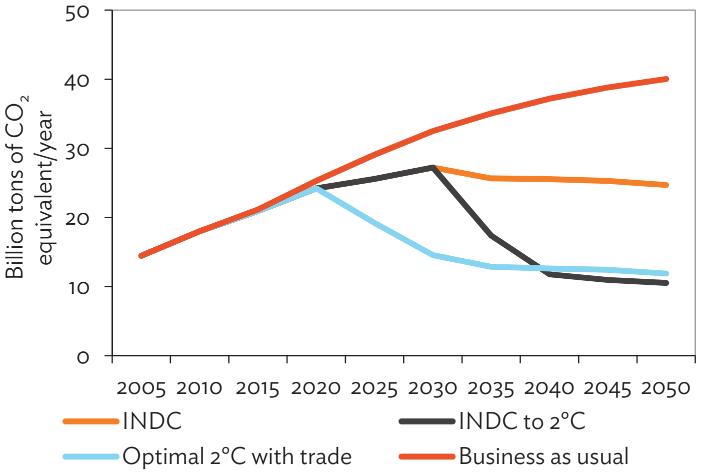


°C = degree Celsius, AR5 = Fifth Assessment Report, GHG = greenhouse gas, $GtCO_2$ = gigaton of carbon dioxide, INDC = intended nationally determined contribution, IPCC = Intergovernmental Panel on Climate Change.
Source: Authors' estimates.

This ratio appears to be relatively constant over time which means that emissions gaps grow in absolute values during the period analyzed. Based on these results, the INDCs reduce emissions by 33% in 2050 (compared to almost 64% in the 2°C scenario) and 52% by 2100 (compared to a required 87% reduction in the 2°C scenario). In order to get a sense of how likely the INDC scenarios are compatible with the 2°C target, the percentage of IPCC AR5 2°C scenarios that fall at or above the INDC pathway are considered. For 2030, only about 15% of the IPCC scenarios show emissions equal or greater than those consistent with INDCs. By the middle of the century, this number is further reduced to around 0.5%.

Patterns evident at the global scale are repeated within the region. Asia's INDCs are a substantial indication of a potential commitment from the region to curtail GHG emissions. However, like the INDCs of other regions, they are insufficient to put the world on a pathway to a maximum of 2°C warming or to ensure that Asian emissions peak in the 2020s as the 2°C path demands. INDCs lead to emissions mitigation of less than half by 2050, which falls short of the 70% reduction or more that is necessary under the scenarios to limit temperature rise to 2°C (Figure 5). An economically optimal pathway to keep warming below 2°C would start action more quickly than the INDCs, as mitigation in 2030 needs to be more than double what the INDCs specify.

Figure 5: Developing Asia Emissions by Scenario



°C = degree Celsius, CO_2 = carbon dioxide, INDC = intended nationally determined contribution.
Source: Authors' estimates.

The MAGICC climate model is applied to estimate the global average temperature increase in 2100. This estimation takes into account the air pollution emissions pathways foreseen in the SSP2 scenario.[3] The emissions pathways of the air pollutants will be discussed in more detail in section VI. Nevertheless, it is important to note that a decreasing pollution emissions pathway leads to higher efforts for mitigation in the 2°C scenarios, because the reduction of aerosols with negative radiative forcing provokes an increase in temperature. Therefore, the 2°C scenarios correspond to a range of GHG concentrations of 515–520 parts per million. The temperature patterns shown in Figure 6 indicate that the BAU baseline would lead to an end-of-century temperature increase of approximately 3.9°C. The INDC continuation scenarios reduce average global temperature by around 1°C to around 2.9°C, which is still far from the 2°C goal of the Paris Agreement.

There is much heterogeneity in the magnitude of the reductions for countries in developing Asia. Figure 7 shows the regional emissions reductions in the different scenarios. India and East Asia, Southeast Asia, and the Pacific are the regions that have lower reductions from INDCs. On the other side of the spectrum is Indonesia, which has 2030 pledges that are closest to what would be optimal under the 2°C scenario.

Overall, this analysis shows that the INDCs represent a significant effort in terms of short-term emissions reductions, but that the continuation of similar efforts post-2030 is not sufficient for the 2°C goal. A ramping up of efforts beyond the submitted INDCs is needed to keep global warming below 2°C.

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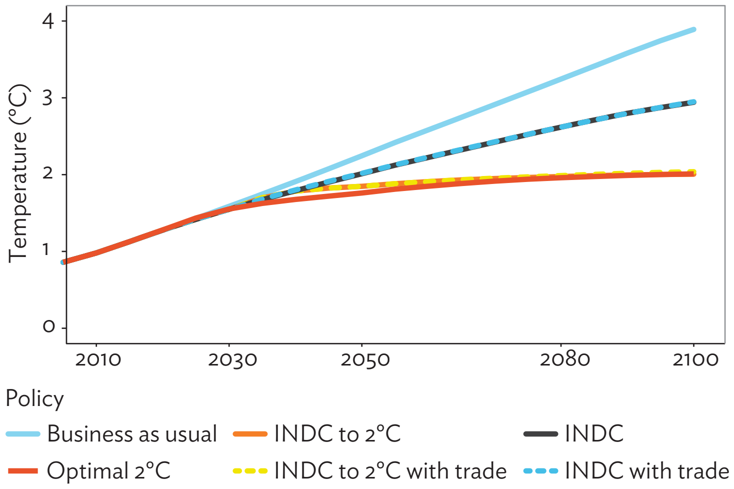
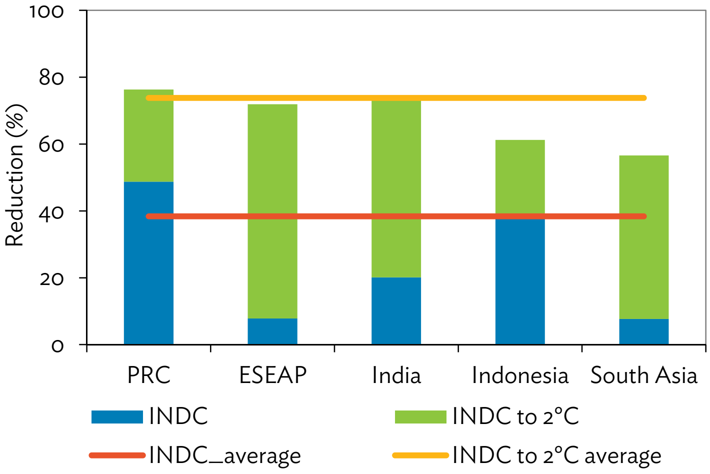
[3] For further information on the air pollutant emissions, please refer to Rao et al. (2016).

Figure 6: Global Mean Temperature Increase across the Scenarios



°C = degree Celsius.
Source: Authors' estimates.

Figure 7: Regional Emissions Reductions with Respect to the Business-as-Usual Baseline

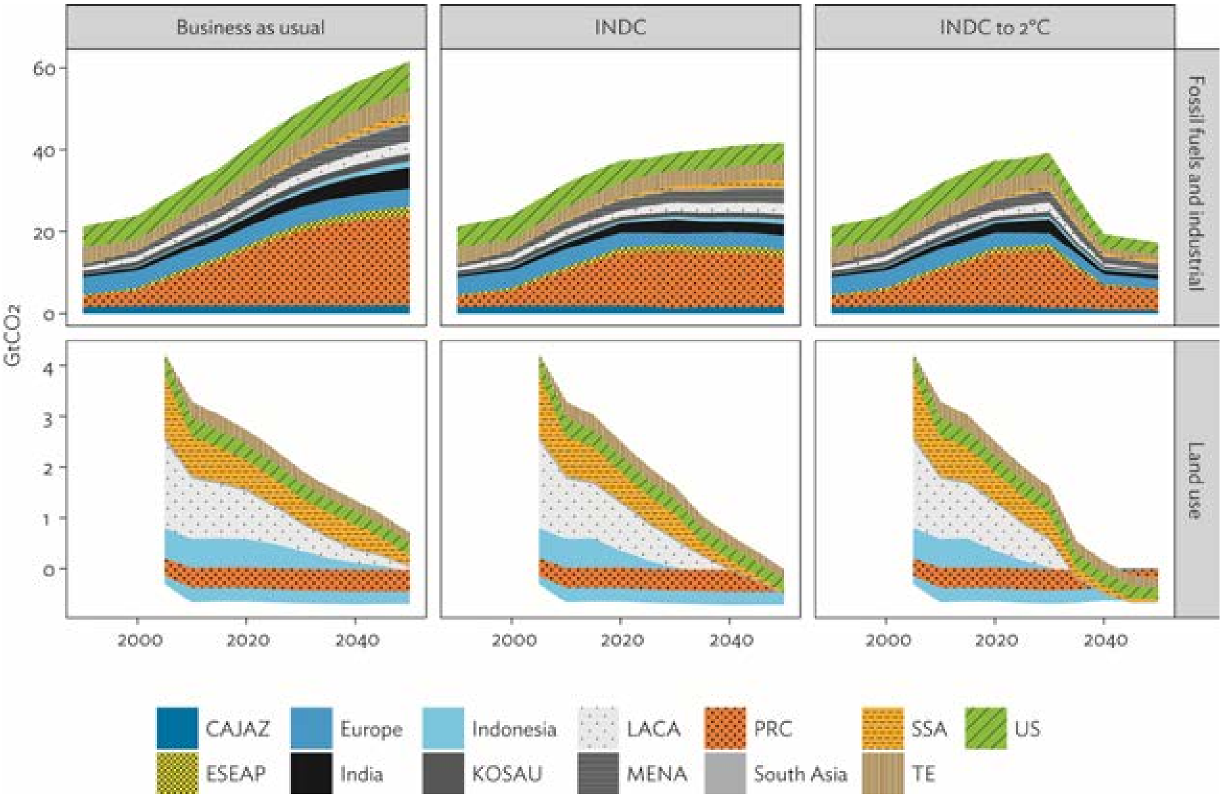


°C = degree Celsius; ESEAP = East Asia, Southeast Asia, and the Pacific; INDC = intended nationally determined contribution; PRC = People's Republic of China.
Source: Authors.

IV. THE TRANSFORMATION CHALLENGE: ENERGY SYSTEM AND LAND-USE CHANGE

Globally, the BAU scenario finds an expected doubling of emissions by 2050. As discussed, aiming at a long-term stabilization of global warming at or below 2°C will therefore require rapid deceleration of this increase, a decrease of emissions in the medium term, and ultimately (almost) full decarbonization of the economy. The energy and industry sectors (fossil fuels and industry) bear the highest mitigation share in absolute terms, even though land use and land-use change and agricultural emissions will contribute negative emissions after 2040 (Figure 8).

Figure 8: Global CO_2 Emissions from LULUC and Fossil Fuels and Industrial Processes across WITCH Regions

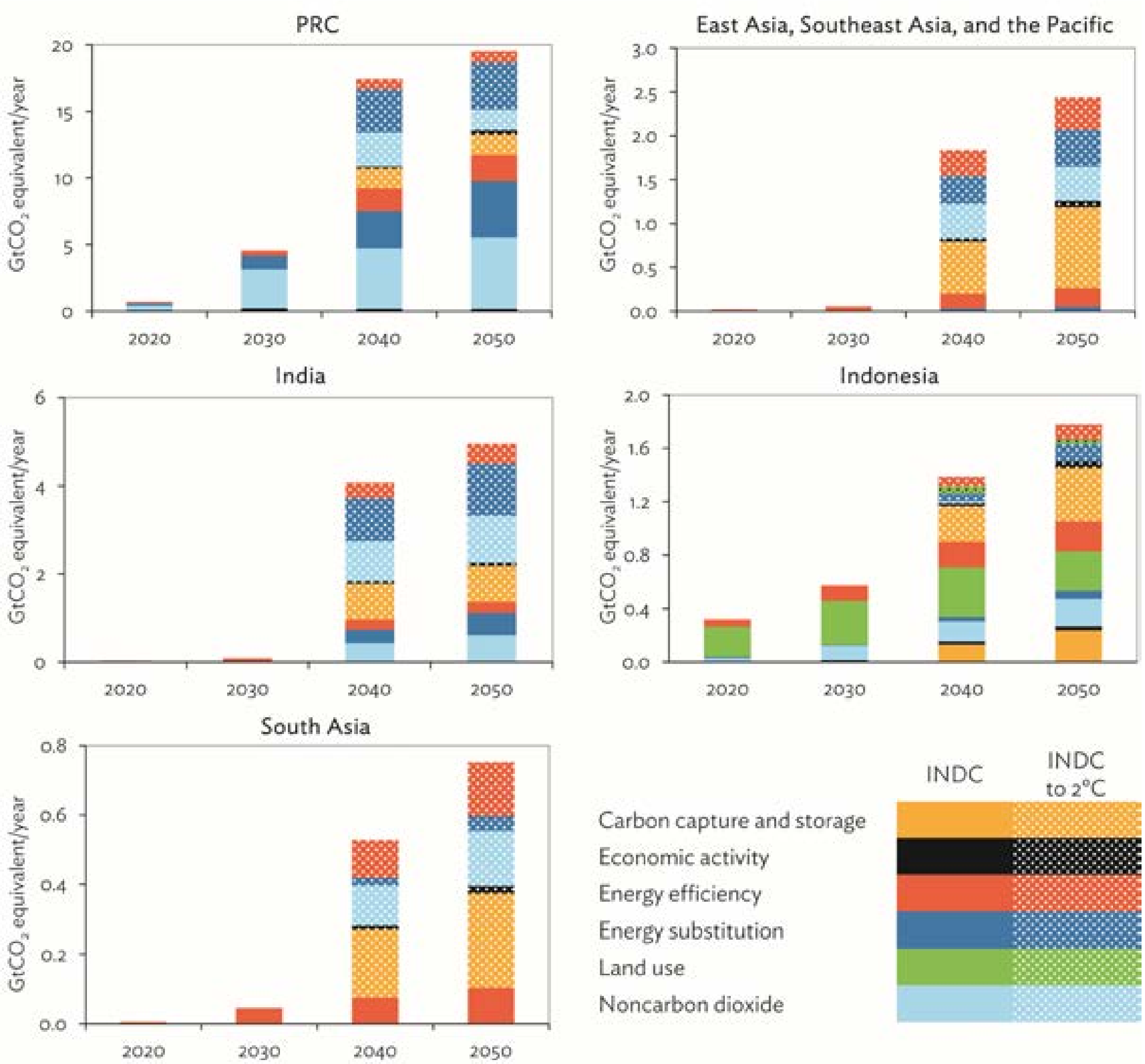


°C = degree Celsius; CAJAZ = Canada, Japan, and New Zealand; CO_2 = carbon dioxide; $GtCO_2$ = gigaton of carbon dioxide; ESEAP = East Asia, Southeast Asia, and the Pacific; INDC = intended nationally determined contribution; LACA = Latin America, Mexico, and the Caribbean; LULUC = land use and land-use change; MENA = Middle East and North America; PRC = People's Republic of China; SSA = Sub-Saharan Africa; TE = transition economies; US = United States; KOSAU = Republic of Korea, South Africa, and Australia; WITCH = World Induced Technical Change Hybrid.
Source: Authors' estimates.

The distribution of mitigation efforts between the different sectors is very region specific: several regions including Europe, India, and the PRC show negative emissions from land-use change today and in the future. In other regions, including many Asian economies, land-use change contributes significantly to GHG emissions: in 2005, land use and land-use change contributed about 74% of CO_2 emissions in Indonesia, about 19% in the rest of East Asia, and 18% in South Asia excluding India.

The specific means of mitigation for the INDC scenario and the additional effort to comply with 2°C can be seen in Figure 9, as derived from the decomposition using an additive mean Divisia index. Energy efficiency improvements contribute around a third to overall mitigation in both scenarios, while non-CO_2 gases can yield emissions reductions especially in the shorter term. Land-use emissions reductions are an important abatement option, especially in Indonesia. The reduction of fossil fuel and industrial emissions and the use of carbon capture and storage, however, provide the largest potential under the 2°C scenario. Under the INDC to 2°C scenario, fuel substitution generates about a third of developing Asian 2050 mitigation, and carbon capture and storage (CCS) contributes about 14%.

Figure 9: Decomposition of Mitigation Sources in the INDC Scenario versus the INDC to 2°C Scenario



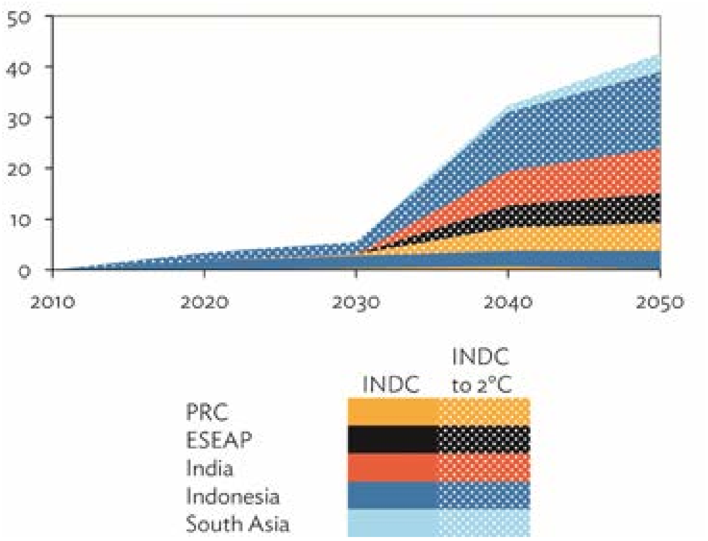
°C = degree Celsius, $GtCO_2$ = gigaton of carbon dioxide, INDC = intended nationally determined contribution, PRC = People's Republic of China.

Notes: Emissions reductions from business as usual to the INDC (dark colors) and additionally the INDC to 2°C scenario (shaded colors). INDC to 2°C values are additional to those of INDC, such that they sum to total INDC to 2°C mitigation when considered together.

Source: Authors' estimates.

Patterns of mitigation are similarly reflected in changes in forest cover outcomes, where changes are concentrated in a few regions. By 2050, the INDC to 2°C scenario produces 45 million additional hectares of forest, most of it in Indonesia and the rest of Southeast Asia. The INDC scenario produces a much smaller addition of 5 million hectares of forest by that time (Figure 10).

Figure 10: Forest Cover in Developing Asia
(million hectare)



°C = degree Celsius; ESEAP = East Asia, Southeast Asia, and the Pacific; INDC = intended nationally determined contribution; PRC = People's Republic of China.

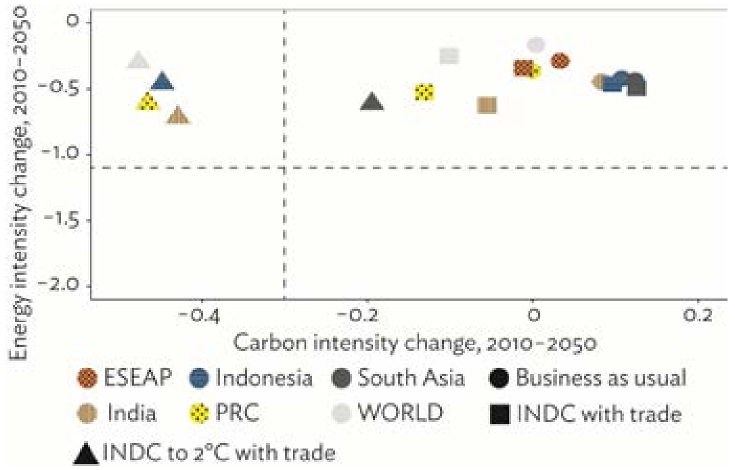
Notes: Forest cover changes under modeled mitigation scenarios relative to business as usual. Values are additive between the INDC scenario and the INDC to 2°C scenario.

Source: Authors' estimates.

Expected energy intensity improvements in Asia under BAU are expected to be around half a percentage point per year (compared to a global historical average of about 1.1% per year), reflecting a comparably higher level of economic growth. Under the INDC and 2°C scenarios, this improvement is increased. Similar to the decarbonization in the energy sector, the carbon intensity improvement reaches around 0.4% per year in this scenario across regions (Figure 11).

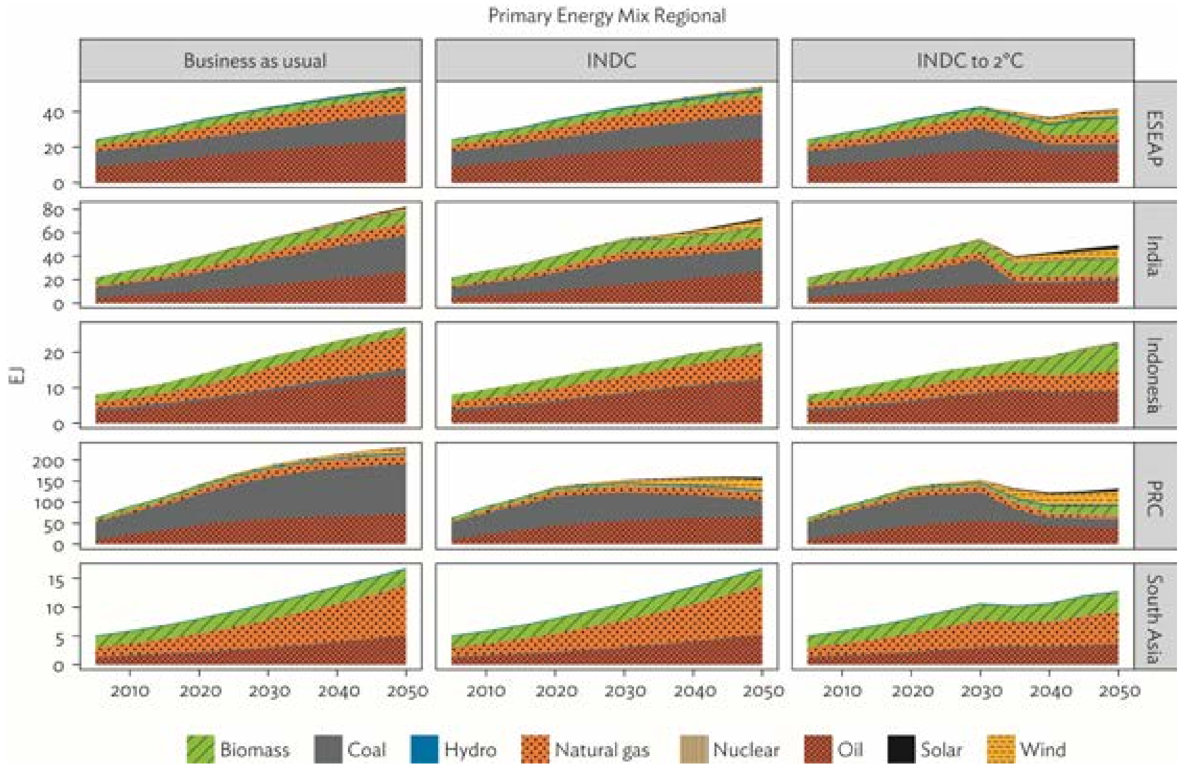
Structural change in the energy system is pivotal for achieving climate goals. Figure 12 shows the primary energy mix in the Asian regions. Historically, there is variability across regions, which persists over time. However, in the INDC, and even more so in the INDC to 2°C scenarios, renewable energy sources are increasingly phased in. In the PRC and India, a substantial reduction in coal consumption will be required starting by 2020 and all mitigation scenarios show a declining share of coal after 2030. The substitute in these countries is mostly renewable energy sources, notably wind and solar energy. In the PRC, the high availability of wind potential and its low investment cost make onshore and (later) offshore wind gain a significant share by 2030. In East Asia and South Asia, higher use of bioenergy and natural gas allows a somewhat slower restructuring of the energy system with expanded use of both energy sources. All scenarios still find continued use of oil, mainly in the transportation sector, where demand is projected to rise significantly and cost-effective substitutes are most likely to penetrate the market only later in the century.

Figure 11: Yearly Energy and Carbon Intensity Improvements, 2010–2050



°C = degree Celsius; ESEAP = East Asia, Southeast Asia, and the Pacific; INDC = intended nationally determined contribution; PRC = People's Republic of China.
Source: Authors' estimates.

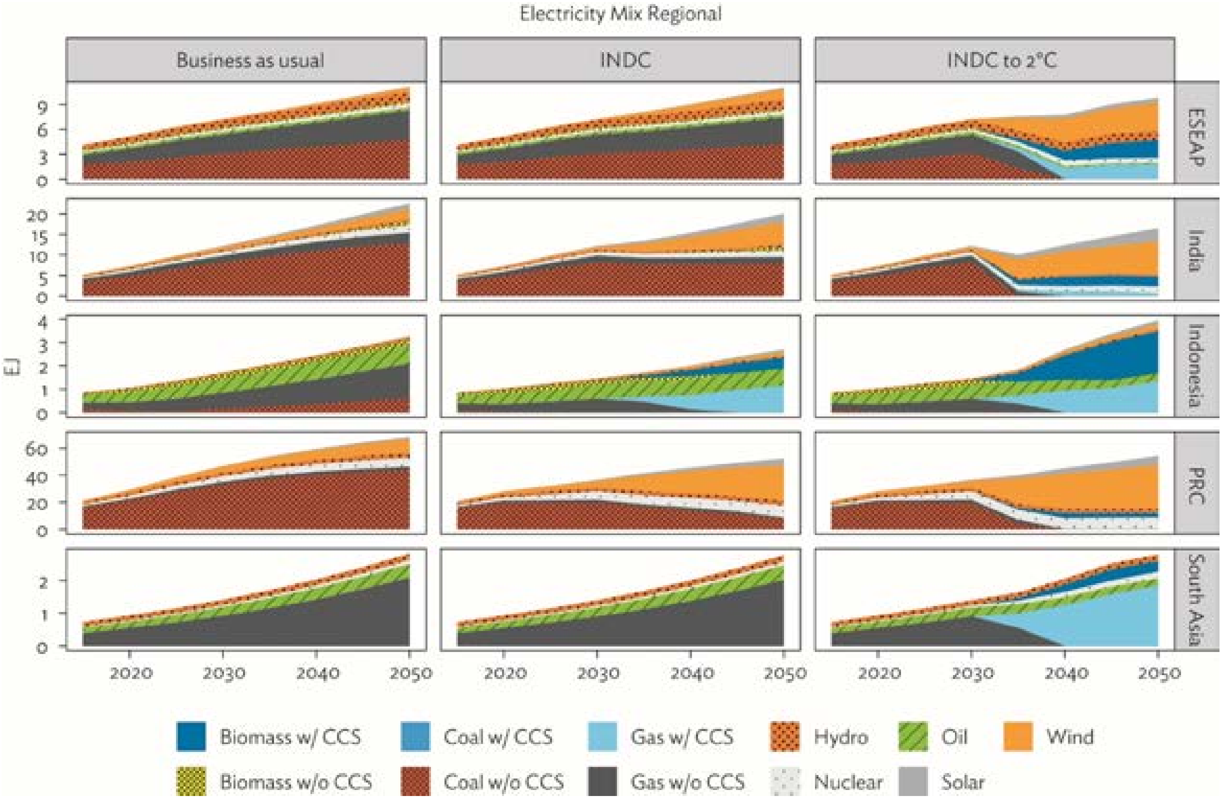
Figure 12: Primary Energy Mix in Developing Asia



°C = degree Celsius; EJ = exajoule; ESEAP = East Asia, Southeast Asia, and the Pacific; INDC = intended nationally determined contribution, PRC = People's Republic of China.
Source: Authors' estimates.

Electricity demand decreases in the INDC scenario, but is not much lower in the INDC to 2°C scenario, due to more use of electricity in transport. Moreover, as mitigation progresses in the INDC to 2°C scenario, the electricity mix becomes less carbon intensive through the use of renewable energy sources, increasing biomass use, and to some extent the use of natural gas with CCS after 2030 and, later in the century, coal with CCS and biomass with CCS (Figure 13). Although under this scenario, CCS makes up a substantial share of the energy mix in some regions, results are not highly sensitive to CCS cost assumptions (see text box).

Figure 13: Future Electricity Mix in Developing Asia

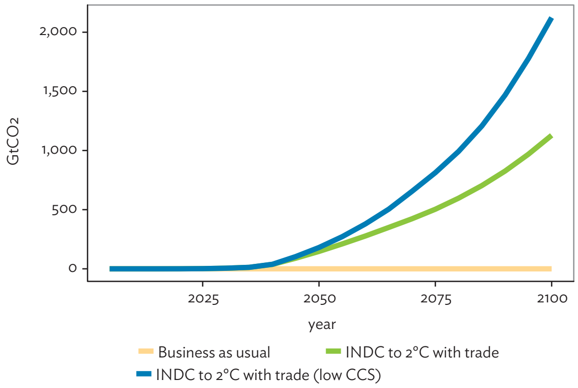


°C = degree Celsius; CCS = carbon capture and storage; EJ = exajoule; ESEAP = East Asia, Southeast Asia, and the Pacific; INDC = intended nationally determined contribution; PRC = People's Republic of China.
Source: Authors' estimates.

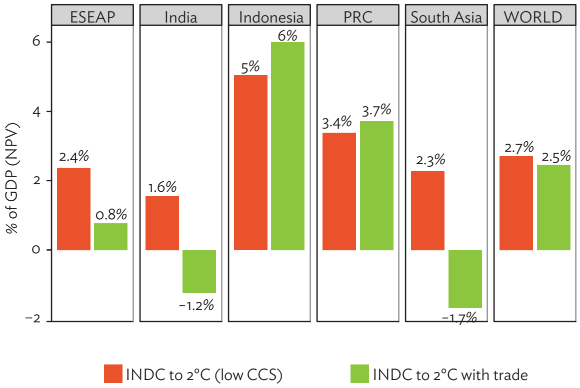
Testing Cost Assumptions for Carbon Capture and Storage

Carbon capture and storage (CCS) can have an important role in deep decarbonization as it can reconcile continued use of fossil fuels with greenhouse gas mitigation. At the same time, CCS is an unproven technology with high costs, due to energy penalties for carbon capture. There are also many uncertainties about the long-term cost of the technology were it to be deployed widely. In the intended nationally determined contribution (INDC) to 2°C scenario, global CCS amounts to about 12 gigatons of carbon dioxide ($GtCO_2$) by 2050. To explore the sensitivity of results to assumptions on CCS, this study ran an additional scenario to consider more optimistic reductions of the costs of CCS for coal, gas, and biomass (implying roughly a reduction by 1% per year of the investment costs), denoted INDC to 2°C_CCS. In this scenario, for the People's Republic of China, the capital cost per kilowatt of installed capacity for a coal-fired power plant with integrated gasification combined cycle and CCS decreases from $3,170 to $2,120 in 2050 and $1,280 by 2100, compared to the cost of a standard pulverized coal plant at about $970 per kilowatt, which is in line with projected total capital costs of CCS (Havlík et al. 2011; Rubin, Davison, and Herzog 2015).

Box Figure 1: Cumulative Carbon Capture and Storage



Box Figure 2: Policy Cost (GDP) CCS



In terms of carbon prices and policy costs, this reduces the costs of climate mitigation (net present value of gross domestic product loss discounted at 5% until 2100) by roughly 10%, which indicates only modest WITCH sensitivity to CCS cost assumptions. Note that these annual figures translate into a cumulative amount of carbon dioxide to be permanently stored by the end of the century of around 2,050 $GtCO_2$, compared with 1,100 $GtCO_2$ in the standard case. This can be compared to a global storage capacity that has been estimated in the range of about 1,000–10,000 $GtCO_2$ (see IPCC 2005; Hendriks, Graus, and van Bergen 2004).

°C = degree Celsius; GDP = gross domestic product; ESEAP = East Asia, Southeast Asia, and the Pacific; NPV = net present value; PRC = People's Republic of China; WITCH = World Induced Technical Change Hybrid.
Source: Authors.

Learning by doing for renewable energy sources, such as wind and solar, leads to a persistent decline of the costs of these two technologies, as shown in Figure 14. For wind, the investment costs are already much lower in leading countries with high potential. The intermittency of these sources means that storage capacity rises to deal with intermittency issues (Carrara and Marangoni 2016). For example, the INDC to 2°C scenario for the PRC requires an investment in electricity storage of about 800 gigawatts (roughly 10% of total installed capacity) by midcentury. Although storage technologies are currently expensive (around $6,000 per kilowatt), costs decline to about $1,000 per kilowatt by 2050.[4]

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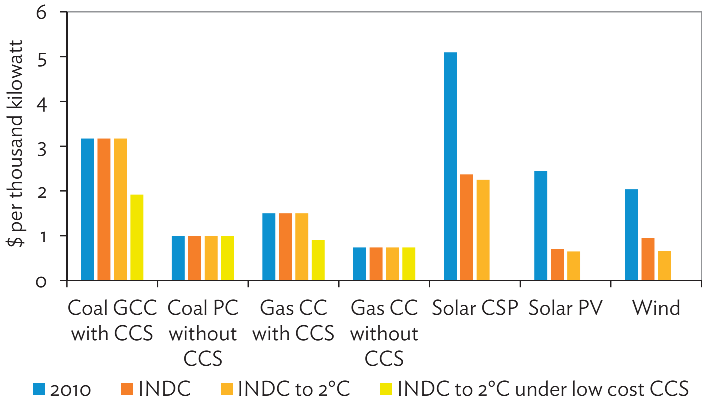
[4] All values are in 2005 US dollars.

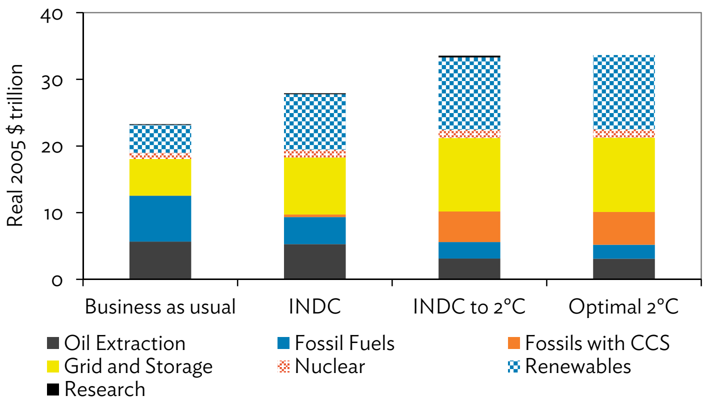
Figure 14: Capital Costs for Energy Technologies by Scenario in 2050



°C = degree Celsius, CC = combined cycle, CCS = carbon capture and storage, CSP = concentrated solar power, INDC = intended nationally determined contribution, PC = pulverized coal, PV = photovoltaic.
Source: Authors' estimates.

A dramatic transition for developing Asia's energy system depends on redirected investment in energy supply. Cumulative energy supply investments from 2015 to 2050 are just over $23 trillion (or $670 billion per year) under BAU and rise to nearly $34 trillion in aggregate for the INDC to 2°C and optimal 2°C scenarios (or about $300 billion more per year). Most of this is directed toward increased investment in renewables, use of carbon capture and storage, the energy grid, and energy storage, which account for $17 trillion under the INDC to 2°C scenario, but about $7 trillion of this is offset by reduced investment in fossil fuels, leaving a net increase of about $10 trillion, or nearly $300 billion per year on average over the period. The additional investment required under the INDC scenario is a bit over half of that of the INDC to 2°C scenario, with most of the additional investment in renewables and the grid.

Figure 15: Investment in Power Supply in Developing Asia, 2015–2050



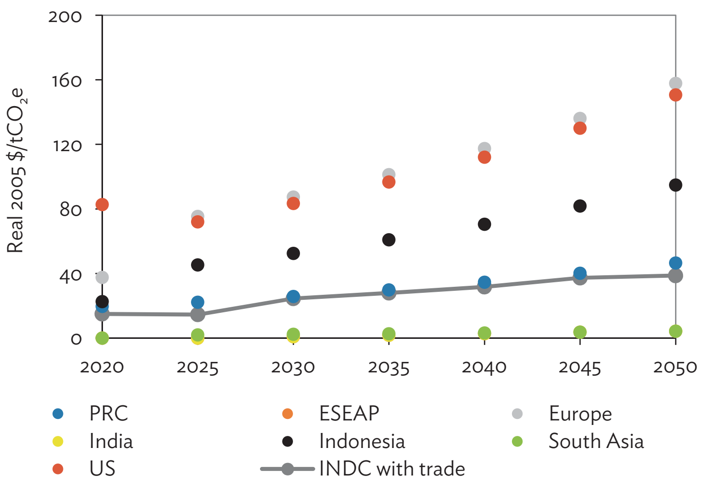
°C = degree Celsius, CCS = carbon capture and storage, INDC = intended nationally determined contribution.
Source: Authors.

The increased investment is evenly split between renewables and the grid, including energy storage needed for grid integration under increased generation by intermittent renewables. Carbon capture and storage investment needs are nearly $5 trillion under the 2°C scenarios but are similar to declines in energy generation using fossil fuels. Investment in energy research increases from $100 billion in BAU to around $250 billion in the 2°C scenarios (Figure 15).

V. POTENTIAL CARBON MARKET DEVELOPMENT

The Paris Agreement starts with a policy architecture with limited integration. Figure 16 shows the marginal abatement costs across the WITCH regions for the INDC scenario over time. The figure shows that the efficiency concern is indeed substantial: carbon prices vary significantly across the world. The industrialized regions have marginal abatement costs in 2030 exceeding $50 per ton of carbon dioxide equivalent (tCO_2e) and as high as $80tCO_2e$, whereas developing economies range between $0/tCO_2$ and $30/tCO_2$.

Figure 16: Marginal Abatement Costs in the INDC Scenario

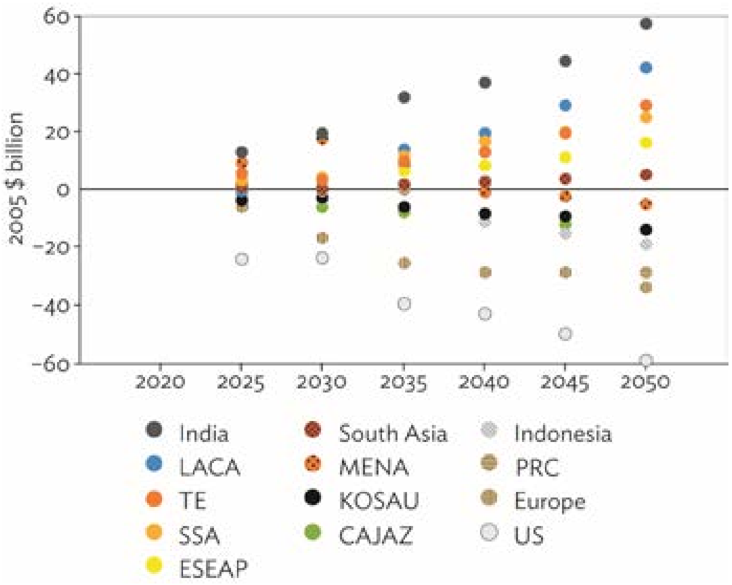


ESEAP = East Asia, Southeast Asia, and the Pacific; INDC = intended nationally determined contribution; PRC = People's Republic of China; tCO_2e = ton of carbon dioxide equivalent; US = United States.
Note: The solid line shows the carbon prices in the case with emissions trading.
Source: Authors.

The large variation in marginal abatement costs creates opportunities for trading CO_2 among regions. The Paris Agreement has included an explicit provision for linking national pledges through ITMOs, which could provide opportunities to reduce emissions where it is cheapest to do so, and thereby reduce the observed price ranges. Figure 16 shows the carbon price that would emerge in the idealized case of a global carbon market, which equalizes marginal abatement costs underlying the INDCs (solid line). The price starts at $14/tCO_2e$ in 2030 and rises to around $40/tCO_2e$ by midcentury.

Although a global carbon market could help improve economic efficiency, the large size of potential markets may also create challenges. Figure 17 shows that significant trade would emerge in a global market. Although this shows the opportunities to harmonize marginal costs, it would also require a major institutional effort at the international level. A carbon market of several gigatons of CO_2 exceeds by far the accumulated experience of existing regional carbon markets. In terms of market value, the market would involve trade of around $50 billion in 2030, growing to almost $200 billion by midcentury due to an increased volume and higher carbon prices.

Figure 17: Sales (Positive) or Purchases (Negative) of Emissions Permits in Value in the INDC Scenario with Carbon Trade



CAJAZ = Canada, Japan, and New Zealand; ESEAP = East Asia, Southeast Asia, and the Pacific; INDC = intended nationally determined contribution; KOSAU = Republic of Korea, South Africa, and Australia; LACA = Latin America, Mexico, and the Caribbean; MENA = Middle East and North Africa; PRC = People's Republic of China; SSA = Sub-Saharan Africa; TE = transition economies; US = United States.
Source: Authors' estimates.

In terms of trading positions, industrialized countries would be the largest buyers of permits, and developing countries—especially India, transition economies, and Sub-Saharan Africa–would be the largest sellers. The specific CO_2 trades for the regions in developing Asia are shown in Table 3. Results from the model suggest that in 2030 all regions in developing Asia would be net sellers of CO_2 permits, with the exception of Indonesia, which faces a relatively stringent INDC pledge. Thereafter, the PRC would turn into a net buyer of permits, becoming one of the largest buyers by midcentury. India, with its relatively lenient pledge and large and relatively cheap abatement potential, would be the largest seller of permits. These regional differences within Asia highlight the potential for a developing Asia emissions trading system (Massetti and Tavoni 2012).

Table 3: Sales (Positive) or Purchases (Negative) of Emissions Permits in the INDC Scenario with Carbon Trade

	Trade Volume (MtCO2e)				Trade Value (2005 $ billion)		
	2030	2040	2050		2030	2040	2050
PRC	1,210	80	−766	PRC	17.6	2.2	−28.6
ESEAP	259	304	433	ESEAP	3.8	8.5	16.1
India	1,348	1,328	1,543	India	19.6	37.0	57.5
Indonesia	−239	−398	−509	Indonesia	−3.5	−11.1	−19.0
South Asia	46	96	135	South Asia	0.7	2.7	5.0

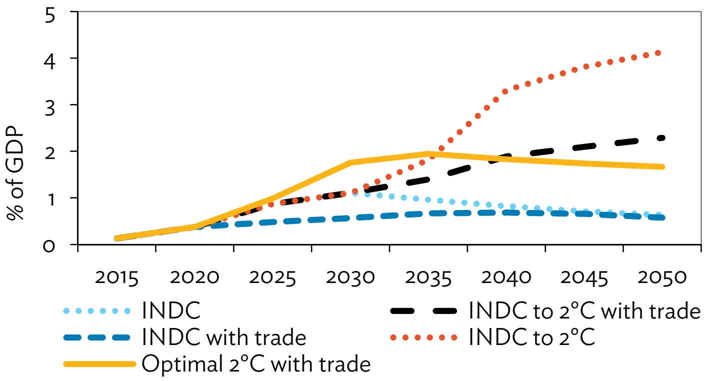
ESEAP = East Asia, Southeast Asia, and the Pacific; INDC = intended nationally determined contribution; MtCO$_2$e = megaton of carbon dioxide equivalent; PRC = People's Republic of China.
Source: Authors' estimates.

VI. POLICY COSTS

Policy costs through 2050 for the 2°C scenarios are under 2% of GDP for all of developing Asia when carbon trade is in place (Figure 18). However, aggregate costs double in the absence of trade, partially due to the elimination of revenues from potential sales of emissions allowances to the rest of the world. The continued INDC scenario shows modest costs that are well below 1% of GDP.

The low regional values mask substantial variation within developing Asia (Figure 19). Establishing compensatory measures, e.g., via carbon markets and equitable allocation of emission rights, can significantly alter the distribution of costs, even leading to gains in countries with a high population and low per capita emissions. Thus, allowing for trade in the 2°C scenarios implies a substantial shift of policy costs across regions.[5] For India and the other South Asian countries, this can lead to 2050 GDP gains of around 5% to 7%.

Figure 18: Economic Cost of Emissions Reduction as a Percentage of GDP in Developing Asia



°C = degree Celsius, GDP = gross domestic product, INDC = intended nationally determined contribution.
Source: Authors' estimates.

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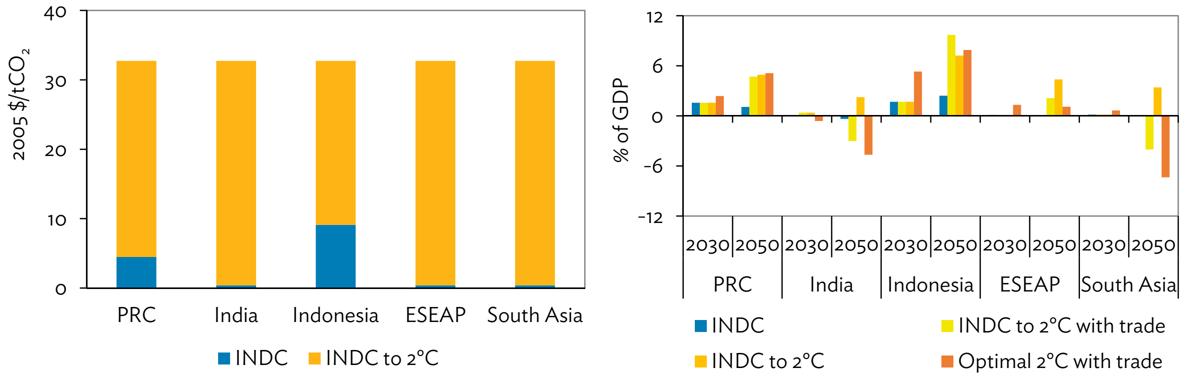
[5] Note that the emissions allowances are allocated using a "contraction and convergence" mechanism, in which emissions allocation is initially grandfathered and shifts to population based allocation over 30 years.

In terms of net present value discounted (at 5%) and policy costs (until 2050), the costs of the INDCs in terms of GDP losses are almost zero for India and above 1% for the PRC and Indonesia which have the more stringent pledges. The PRC's INDC leads to policy costs that are near to the global average relative to GDP. The net present value of carbon prices under the INDC to 2°C scenario remains under \$33/ton CO_2e through 2050 with trade in place and is below \$10/ton CO_2e for all regions under the INDC scenario.

Figure 19: 2050 Marginal Abatement Costs Discounted at 5% (Left) and Policy Costs by Region for 2030 and 2050 (Right)



°C = degree Celsius; ESEAP = East Asia, Southeast Asia, and the Pacific; GDP = gross domestic product; INDC = intended nationally determined contribution; PRC = People's Republic of China; tCO_2 = ton of carbon dioxide.
Source: Authors' estimates.

VII. AIR POLLUTION COBENEFITS

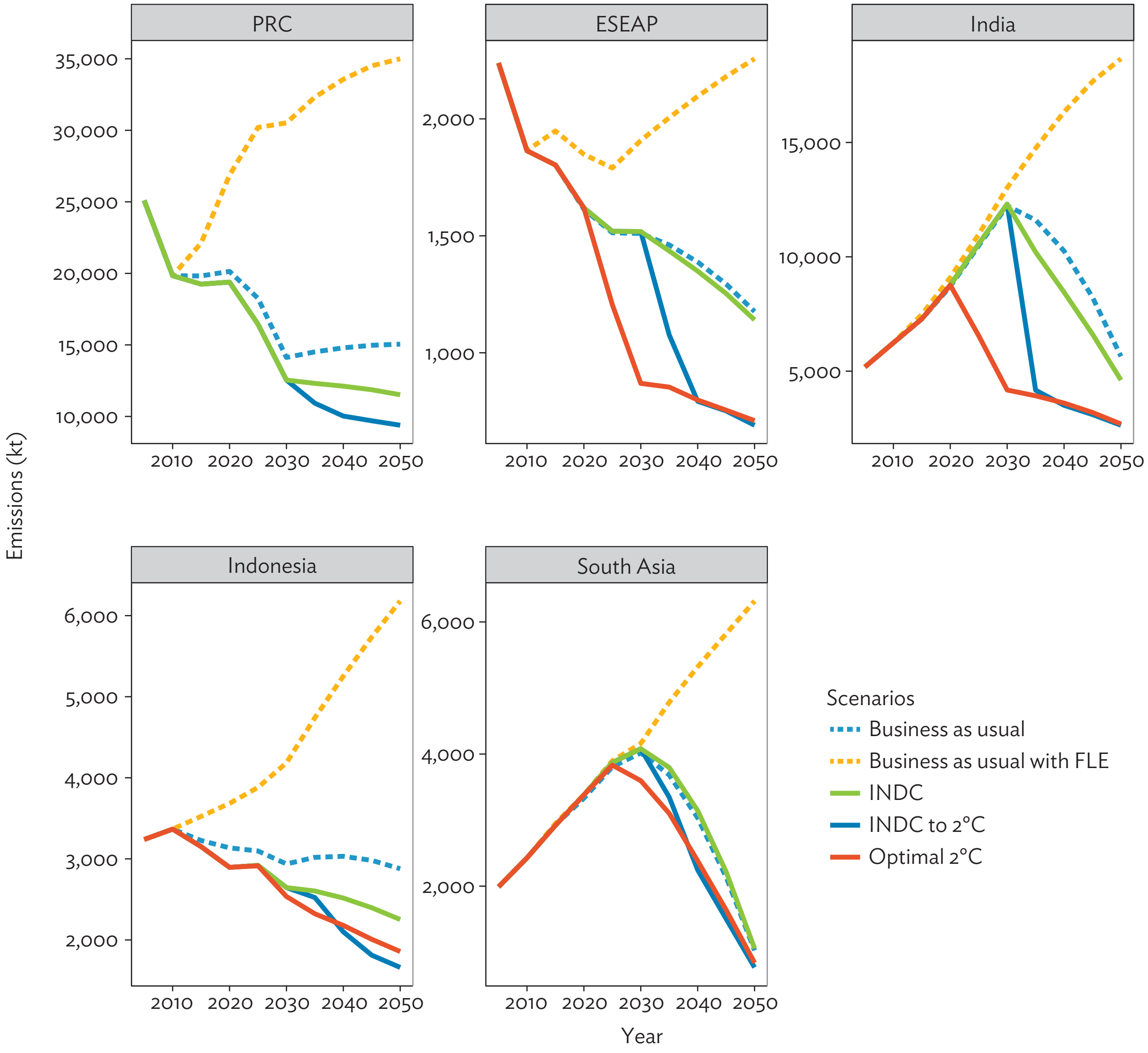
Although INDCs have a direct objective of climate change mitigation, they also may generate benefits in other domains, such as energy security, energy efficiency, fuel prices, technological development, and air pollution. Air pollution is one of the most tangible cobenefits of climate policies because many air pollutant emissions are directly affected when there is a change in GHG emissions. The World Health Organization (WHO) estimated that in 2012 air pollution exposure, both indoor and outdoor, was responsible for approximately 7 million deaths globally (WHO 2014a, 2014b) globally, with an important share in India and the PRC. The effects of pollution or human health are well documented and span diseases such as stroke, heart disease, lung cancer, and chronic and acute respiratory diseases (WHO 2014a, 2014b). Reducing air pollution levels will have important impacts on human health, especially in developing Asia.

The SSP2–BAU scenario for air pollution already projects a reduction of emissions factors through the implementation of end-of-pipe control measures foreseen by current policies. A BAU–FLE scenario is included to show what would happen if air pollution control does not improve, as emissions factors of energy technologies are kept at 2010 levels.

The greatest differences among the various scenarios are found for the key pollutants nitrogen oxide and sulfur dioxide. The optimal 2°C scenario is, as expected, where air pollution emissions are the lowest. The INDCs are found to have relatively minor effects on air pollution emissions relative to the BAU assumptions (BAU scenario) of improving air pollution control. In the absence of improved air pollution controls, air pollution levels rise dramatically over time.

The INDC policies are very important in reducing sulfur levels in the PRC and Indonesia in the short term (Figure 20). In all regions in developing Asia, the 2°C scenario lowers sulfur emissions substantially by 2050. India shows the greatest reduction when moving to a 2°C goal, given an INDC that reflects a relatively small GHG emissions reduction.

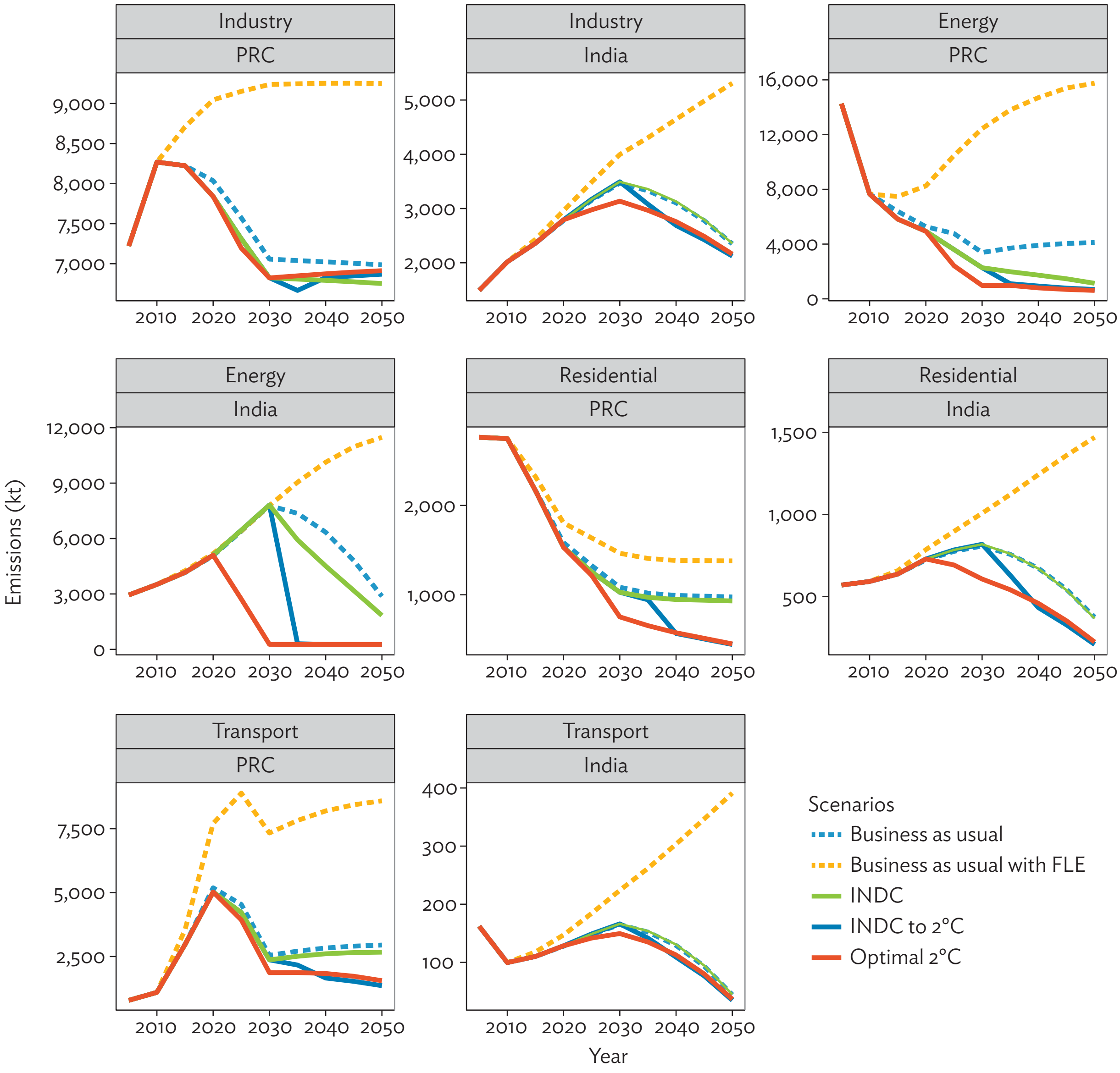
Figure 20: Regional Emissions Profiles of Sulfur Dioxide in Asia



°C = degree Celsius; ESEAP = East Asia, Southeast Asia, and the Pacific; FLE = failed legislation; INDC = intended nationally determined contribution; kt = kiloton; PRC = People's Republic of China.
Source: Authors' estimates.

Figure 21 presents the sector sulfur emissions from the two main emitting regions of Asia. The PRC's INDC helps to reduce sulfur emissions from the energy and industry sector. Reductions of sulfur emissions from the transport sector become effective only after 2020 and remain small in size due to the higher costs of mitigation in this sector. The residential sector experiences the grater reductions from 2040 onward for the optimal 2°C scenario. India shows similar profiles for both scenarios because its INDC reflects a lower emissions reduction.

Figure 21: Sector Emissions of Sulfur Dioxide for the People's Republic of China and India



°C = degree Celsius, FLE = failed legislation, INDC = intended nationally determined contribution, kt = kiloton, PRC = People's Republic of China.

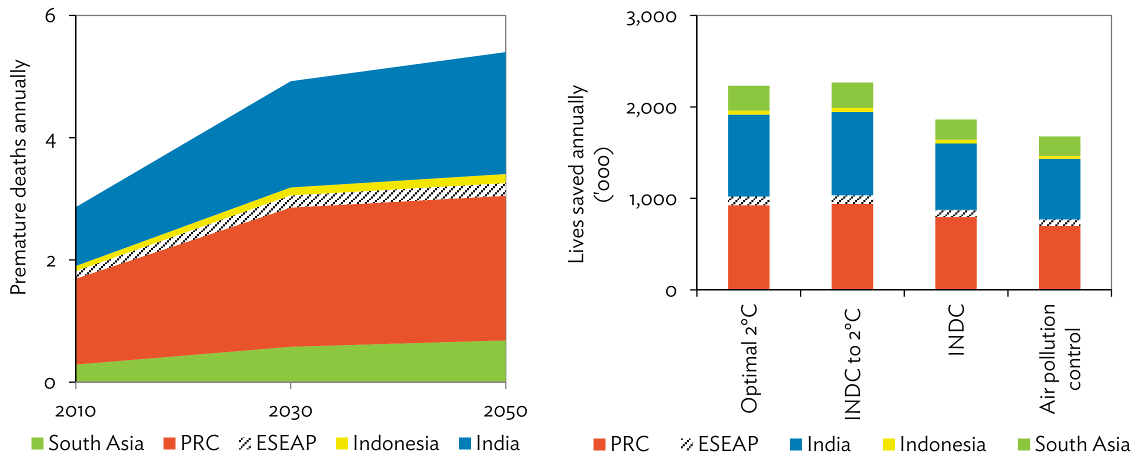
Note: The labels stand for the industry; energy power, conversion, extraction, and distribution; residential and commercial; and transport sectors.

Source: Authors' estimates.

These emissions scenarios are applied to estimate future concentrations of air pollutants using a fixed average future meteorological field, and concentrations are applied to estimate the number of premature deaths and effects on crop yields. Air pollution impacts on mortality are concentrated in the populated areas of India, the PRC, and, to a lower extent, other countries in Southeast Asia.

Figure 22 portrays premature deaths due to PM in developing Asia in 2030 and 2050 in the absence of improved pollution control. Were pollution control not to improve, the number of annual deaths from pollution in developing Asia would nearly double from under 3 million to well over 5 million, with a majority of these in the PRC. Improved air pollution controls, or "end-of-pipe" measures achieve important reductions, but are insufficient to offset the mortality increase over time, as seen by the difference between the BAU–FLE and the other scenarios. The 2°C scenarios add important additional mortality reductions of another 550,000 deaths by 2050. After 2030, climate policies can effectively attain significant health cobenefits.

Figure 22: Estimation of Premature Deaths Estimation in 2030 and 2050 due to Particulate Matter and Ozone Pollution (Left) and Change in 2050 Premature Deaths from Air Pollution Relative to a Scenario without New Pollution Control (Right)



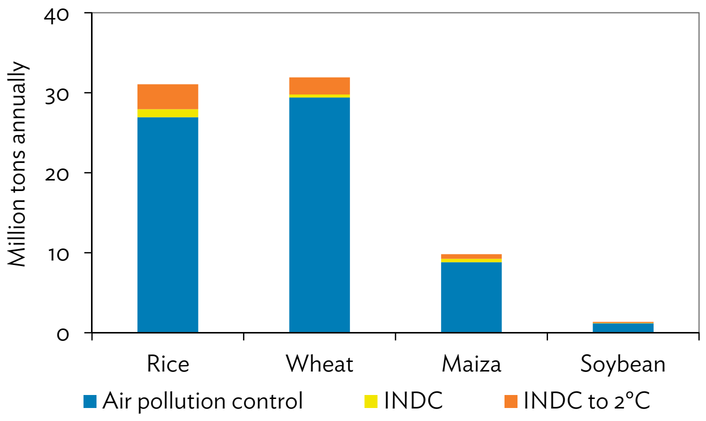
°C = degree Celsius; ESEAP = East Asia, Southeast Asia, and the Pacific; INDC = intended nationally determined contribution; PRC = People's Republic of China.
Notes: Mortality due to air pollution covers ozone and particulate matter pollution only.
Source: Authors' estimates.

Mortality reductions can be valued using value of statistical life (VSL) approaches. A leading source of VSL estimates is the US Environmental Protection Agency, which periodically conducts surveys of estimates in the economic literature to inform VSL estimates used in regulatory cost–benefit analysis. The current agency-recommended VSL is $9.7 million for a mortality event in 2013 (EPA 2016). This VSL is adjusted in relation to GDP for regions in the model and is applied to value mortality changes arising from mitigation. Using this approach finds a mortality cobenefit value in the order of 2.5%–2.7% of GDP for developing Asia by 2050 as a benefit of the 2°C scenarios, over and above improved air pollution control from end-of-pipe measures. The INDC scenario leads to benefits in the order of 1% of GDP.

Air pollution also causes vegetation damage, which reduces crop production and quality (Van Dingenen et al. 2009). As productivity growth in agriculture is slowing, the world faces challenges for food production to keep pace with food demand, and additional crop losses due to pollution may exacerbate this. Ozone is the main pollution cause of crop damage, and leads to significant economic losses, since it can be transported over long distances (Van Dingenen et al. 2009; Fuhrer 2009; Avnery et al. 2011).

The impact of mitigation scenarios on O_3-caused crop losses is shown in Figure 23. Pollution has differentiated effects according to the type of crops, regions, and growing seasons. The highest losses are observed for wheat, both globally and in Asia, which accounts for approximately half of the global crop losses. In developing Asia, rice losses are nearly as large as wheat. Improved air pollution control can be effective in reducing a substantial share of these losses. Gains from climate policy principally occur under the 2°C scenarios, where, gains amount to about 4 million tons of rice and 2.5 million tons of wheat in 2050 over and above improved air pollution control.

Figure 23: Reduction in 2050 Crop Losses from Ozone Pollution in Developing Asia by Modeled Scenario



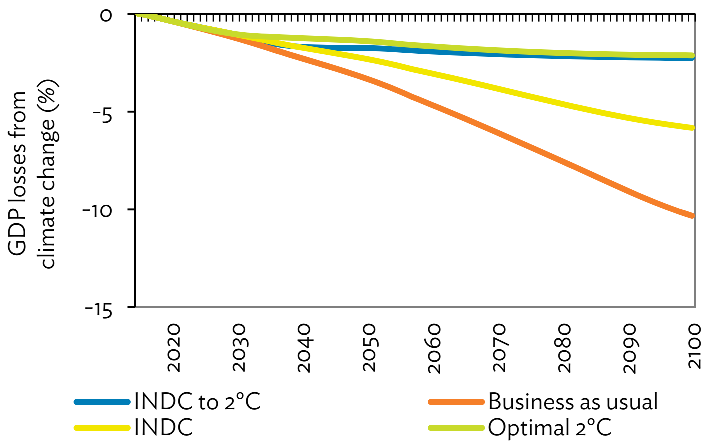
°C = degree Celsius, INDC = intended nationally determined contribution.
Source: Authors' estimates.

VIII. NET COSTS AND BENEFITS OF MITIGATION POLICIES

This primary direct intended benefit of climate change mitigation is to reduce losses from climate change. Lee, Villaruel, and Gaspar (forthcoming) performed econometric analysis of panel data to derive relationships between temperature change and GDP. Coefficients from this analysis were used to parameterize a damage function, and that function used temperature projections derived from these WITCH scenarios to assess potential future additional losses from climate change (Figure 24). The analysis finds that economic losses under BAU from climate change may exceed 10% of GDP by 2100 and may reach nearly 4% of GDP by 2050 (Figure 25).

Mitigation achieved under the modeled scenarios has the potential to limit this damage. Under the 2°C scenarios, losses from climate change are limited to about 2% of GDP over the long term, while the INDC scenario leads to a 6% GDP loss by 2100. This means a gain of 8% of GDP under the 2°C scenarios and a gain of 4% under the INDC scenario in terms of reduced climate change impact.

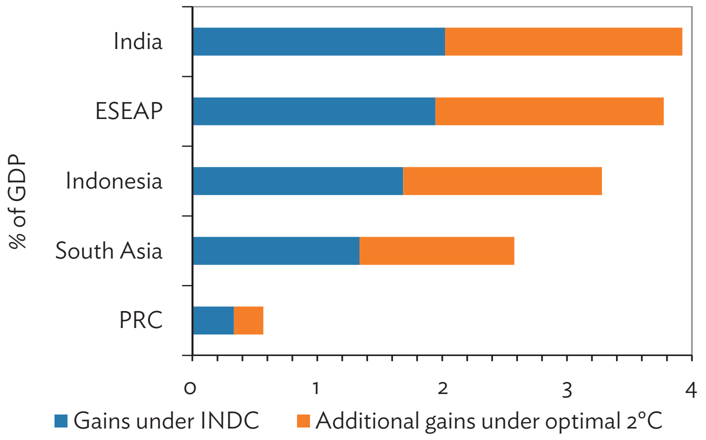
Figure 24: Economic Losses from Higher Temperature in Developing Asia



°C = degree Celsius, GDP = gross domestic product, INDC = intended nationally determined contribution.
Source: Minsoo Lee, Mai Lin Villaruel, and Raymond Gaspar. 2016. Effects of Temperature Shocks on Economic Growth and Welfare in Asia. ADB Economics Working Paper Series No. 501.

Most of these gains are concentrated in India, in East Asia, Southeast Asia, and the Pacific, and in Indonesia (Figure 25). In the PRC, gains are smaller and climate vulnerability is lower. As the PRC accounts for a large share of developing Asian GDP, this means that much of developing Asia's population, especially in poorer areas, experiences more than the mean gains shown in the previous figure.

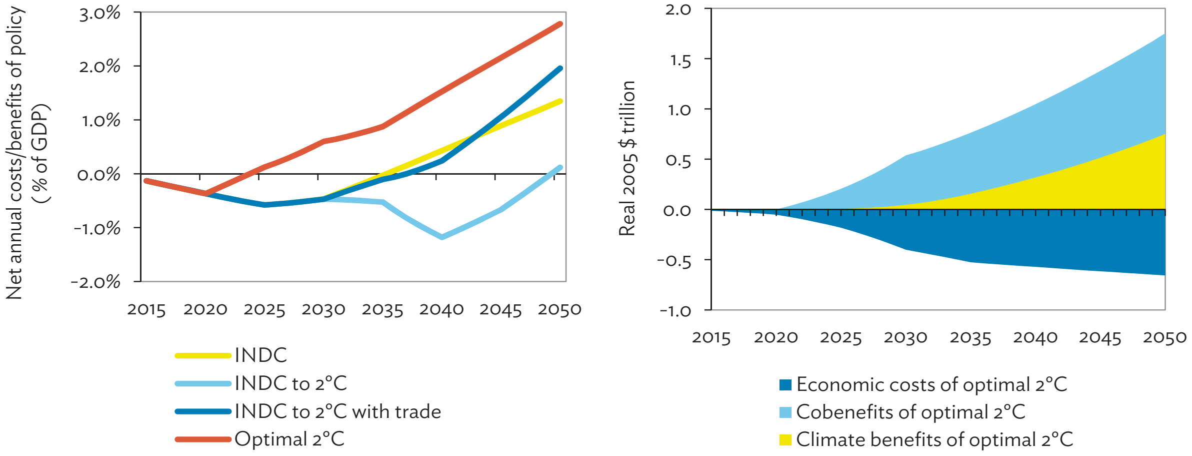
Figure 25: Gains from Mitigation in 2050 by Region under Modeled Scenarios



°C = degree Celsius; ESEAP = East Asia, Southeast Asia, and the Pacific; GDP = gross domestic product; INDC = intended nationally determined contribution; PRC = People's Republic of China.
Source: Authors' estimates.

These estimates of economic benefits from less climate change can be combined with air quality cobenefits and policy costs to explore how mitigation policy affects developing Asia on balance. When benefits and costs are combined, the annual net cost rarely reaches 1% of GDP, even in the most costly scenarios (Figure 26). Strikingly, benefits exceed costs most quickly in the optimal 2°C scenario with carbon trade. In the other scenarios, benefits exceed costs by the mid-2030s to 2040s. By 2050, the net effect on GDP is a 2%–3% gain for the 2°C scenarios with trade, with the highest gain in the optimal 2°C scenario. INDC mitigation has about half of these gains. The lowest gain is in the INDC 2°C scenario without carbon trade.

Figure 26: Net Annual Costs and Benefits of Modeled Mitigation Scenarios for Developing Asia



°C = degree Celsius, GDP = gross domestic product, INDC = intended nationally determined contribution.
Note: Net annual costs and benefits as percentage of GDP (left) and in absolute amounts under the optimal 2°C scenario (right).
Source: Authors' estimates.

As GDP grows over time, effects in levels are even larger than in terms of shares of GDP. In all scenarios, benefits exceed costs during the 21st century. In the optimal 2°C scenario, each dollar of economic cost generates $2.2 of benefits in present value terms (discounted at 5%). Moreover, benefits are greater than costs within a decade of strong mitigation action. Initially, cobenefits generate the largest share of gains, while the effects of avoided climate change dominate benefit streams after 2050.

Compared with the optimal 2°C scenario, the INDC to 2°C scenario with trade effectively delays the onset of ambitious mitigation from 2020 to 2030, which reduces its payoff. In this scenario, each dollar of economic cost creates $1.5 of present value benefits. Removing trade further lowers this to just over $1 of benefits per dollar of economic cost because the economic costs of mitigation rise further for developing Asia. The INDC scenario, because of lower costs under declining marginal benefits from mitigation, has a higher relative benefit–cost ratio, with $2.6 of benefits per dollar of economic cost, but it ultimately generates less than half of the total benefits of the 2°C scenarios.

The difference in absolute flows of benefits compared with costs is better reflected in an internal rate of return (IRR). When this is calculated on the flows of net costs and benefits in levels, the optimal 2°C scenario has an impressive IRR of 22%. The INDC to 2°C scenario with trade has an IRR of 11%, as does the INDC scenario. The INDC to 2°C scenario without trade has an IRR of 7%, far less than what can be achieved with trade and/or earlier action. These results underscore that coordinated, early, and ambitious action has the potential to more than double the returns to the region from investment in climate change mitigation.

IX. CONCLUSIONS

This study has assessed a range of possible future international climate policy architectures using the WITCH integrated economy–energy–climate model. It has simulated a continued bottom–up architecture based on gradual strengthening of the currently proposed INDCs as well as cooperative climate agreement compatible with limiting temperature rise to 2°C. In so doing, this has contrasted policy architectures with complete fragmentation with cases of full harmonization of marginal abatement costs via global carbon markets.

Several insights emerge from this analysis. First, the currently proposed INDCs need to be aggressively ratcheted up in terms of their mitigation ambitions to achieve the emissions reductions for a temperature rise of 2°C or less. The INDC scenario is found to generate around half of the mitigation requirements for this goal. Even under INDCs, the energy and land-use systems of developing Asia would need a transformation toward low-carbon energy and phasing out of land-use emissions. All mitigation scenarios show coal energy peaking by the end of the 2020s. Further, renewable deployment responds rapidly to mitigation policy.

INDCs under the Paris Agreement are found to generate a large range of marginal abatement costs. This price discrepancy is a source of economic inefficiency, which global carbon trade can reduce. Price harmonization would result in a significant trading volume of up to 4 $GtCO_2$ in 2030, corresponding to monetary exchanges of $50 billion. This would require major institutional efforts to ensure emissions reductions are additional and verifiable. As a first step, regional trading systems of smaller size could be linked and have the potential to yield important efficiency gains within developing Asia. For developing Asia, policy costs of INDCs are found to stay below 1% of GDP. Achieving less than 2°C of warming would lead to a GDP cost of 2% by 2050 with trade in place and has a substantially lower cost if action starts earlier.

In terms of air pollution, large reductions are possible through end-of-pipe pollution regulations, but ambitious climate policies further achieve a reduction of the main air pollutants, leading to up to 600,000 additional avoided cases of premature deaths in developing Asia by 2050. Valuation of this mortality suggests that this may equate to 2.5% of GDP. Effects on crops are more minor but still imply benefits of millions of tons of additional rice and wheat annually.

While pollution cobenefits are largely concentrated in the PRC and India, benefits of avoided climate change are much more important in India, in Indonesia, and in East Asia, Southeast Asia, and the Pacific. At an aggregate level, avoided climate change benefits only exceed pollution benefits after about 2050.

Considering climate benefits, cobenefits and the economic costs of climate policy together finds that ambitious coordinated climate policy is in the economic interest of developing Asia, with benefits vastly exceeding costs to the region. However, this outcome is sensitive both to delays in ambitious mitigation or to fragmentation of climate policy. This suggests that the region should support a rapid ramp-up of mitigation ambition far beyond that of the INDCs, with carbon market linkages in place among regions, if it is to capture substantial economic returns from investment in a low-carbon future.

APPENDIX: THE WITCH MODEL–OVERVIEW

WITCH (World Induced Technical Change Hybrid) is an integrated assessment model designed to assess climate change mitigation and adaptation policies.[1] It is developed and maintained at Fondazione Eni Enrico Mattei and the Centro Euro-Mediterraneo sui Cambiamenti Climatici.

WITCH consists of a dynamic global model that integrates in a unified framework the most important elements of climate change. The economy is modeled through an intertemporal optimal growth model which captures the long-term economic growth dynamics. A compact representation of the energy sector is fully integrated (hard linked) with the rest of the economy so that energy investments and resources are chosen optimally, together with the other macroeconomic variables. Land-use mitigation options are available through a soft link with a land-use and forestry model (GLOBIOM). A climate model (MAGICC) is used to compute the future climate.

WITCH represents the world in a set of representative native regions (or coalitions of regions). For each, it generates optimal mitigation and adaptation strategies for the long term (from 2005 to 2100) as a result of a maximization process in which the welfare of each region (or coalition of regions) is chosen strategically and simultaneously accordingly to other regions. This makes it possible to capture regional free-riding behaviors and strategic interaction induced by the presence of global externalities. The noncooperative, simultaneous, open membership game with full information, is implemented through an iterative algorithm which yields the open-loop Nash equilibrium. In this game-theoretic setup, regional strategic actions interrelate through greenhouse gas (GHG) emissions, dependence on exhaustible natural resources, trade of oil and carbon permits, and technological research and development (R&D) spillovers.

The endogenous representation of R&D diffusion and innovation processes constitute a distinguishing feature of WITCH, allowing to describe how R&D investments in energy efficiency and carbon-free technologies integrate the currently available mitigation options. The model features multiple externalities, both on the climate and the innovation side. The technology externalities are modeled via international spillovers of knowledge and experience across countries and time. In each country, the productivity of low-carbon mitigation technologies and of energy depend on the region stock of energy R&D and by the global cumulative installed capacity, two proxies for knowledge and experience, respectively. The R&D stock depends on domestic investments, domestic knowledge stock, and foreign knowledge stock through international spillovers. The spillover term depends on the interaction between the countries' absorptive capacity and the distance of each region from the technology frontier. This formulation of technical change affects both decarbonization as well as energy savings.

The energy sector is fully integrated with the rest of the economy. It distinguishes an electric sector, a transportation sector, and an aggregated nonelectric (industry, services, and residential) sectors. It has a rich array of fuel types and energy technologies (Figure A1.1).

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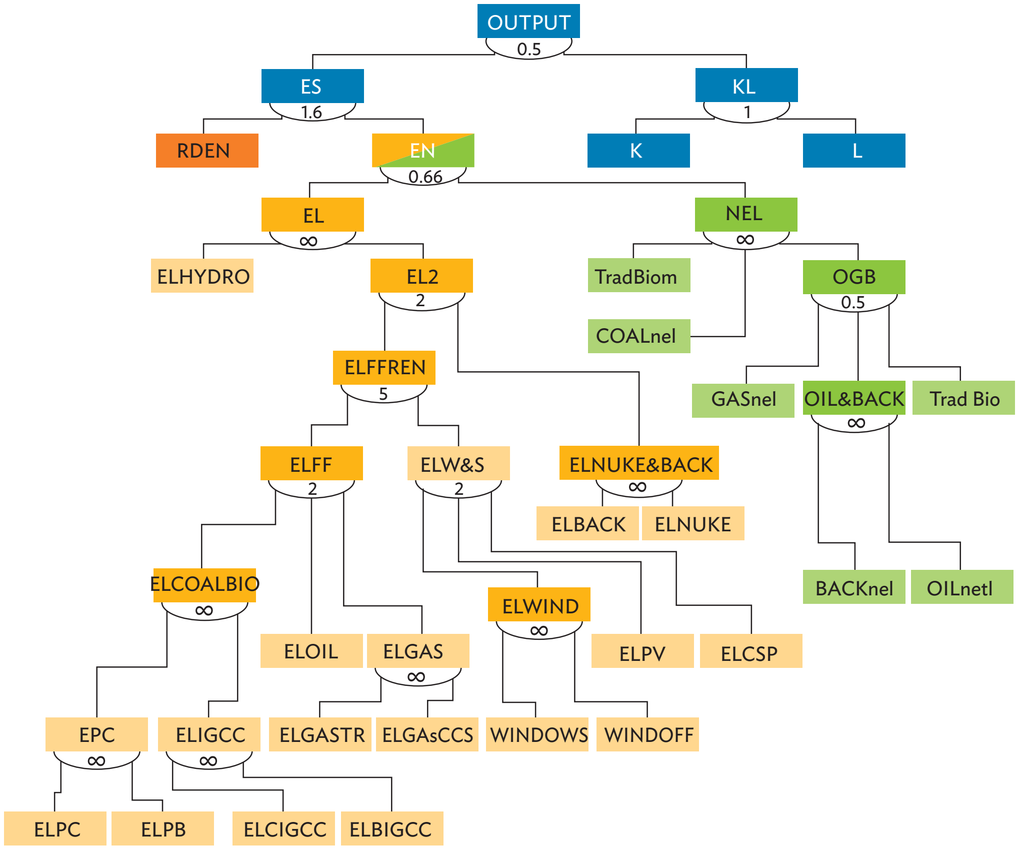
[1] Note that the appendix draws on the standard WITCH description at http://doc.witchmodel.org/general-framework.htm

Appendix Figure: The World Induced Technical Change Hybrid Model Structure



BACKnel = backstop for nonelectric energy, CCS = carbon capture and storage, COALnel = coal for nonelectric energy, EL = electric energy, EL2 = electricity generation without hydro, ELBACK = electricity generated with backstop, ELBIGCC = electricity generated with biomass with CCS, ELCOALBIO = electricity generated with coal and biomass, ELCSP = electricity generated with concentrated solar power, ELFF = fossil fuel electricity, ELFFREN = electricity generated with fossil fuels and renewables, ELGAS = electricity generated with gas, ELGASCCS = electricity generated with gas with CCS, ELGASTR = electricity generated with gas turbines, ELHYDRO = electricity generated with hydroelectric power, ELIGCC = sum of electricity generated through integrated gasification combined cycle (IGCC) with CCS based on coal and biomass, ELCIGCC = electricity generated with coal IGCC plus CCS, ELNUKE = electricity generated with nuclear, ELNUKE&BACK = electricity generated with nuclear and backstop, ELOIL = electricity generated with oil, ELPB = electricity generated with biomass, ELPC = electricity generated with pulverized coal, ELPV = electricity generated with photovoltaics, ELW&S = electricity generated with wind and solar, ELWIND = electricity generated with wind energy, EN = Energy, EPC = electricity generated with coal and biomass without CCS, ES = energy services, GASnel = gas for nonelectric energy, K = capital invested in the production of final good, KL = capital–labor aggregate, L = labor, NEL = nonelectric labor, OGB = oil, backstop, gas, and biofuel, OIL&BACK = oil and backstop for nonelectric energy, OILnel = oil for nonelectric energy without transportation (industrial and residential), OUTPUT = gross domestic product, RDEN = energy research and development capital, Trad Bio = traditional (1st generation) biofuels, TradBiom = traditional biomass, WINDOFF = electricity generated with offshore wind, WINDON = electricity generated with onshore wind.

Source: Johannes Emmerling, Laurent Drouet, Lara Aleluia Reis, Michela Bevione, Loic Berger, Valentina Bosetti, Samuel Carrara, Enrica De Cian, Gauthier De Maere D'Aertrycke, Tom Longden, Maurizio Malpede, Giacomo Marangoni, Fabio Sferra, Massimo Tavoni, Jan Witajewski-Baltvilks, and Petr Havlik. 2016. The WITCH 2016 Model - Documentation and Implementation of the Shared Socioeconomic Pathways. https://ideas.repec.org/p/fem/femwpa/2016.42.html

The original version of the model has 13 regions; however, the regional aggregation is flexible. For this paper, we separated out Indonesia and moreover considered the European Union (EU) as the present EU-28 to represent the EU intended nationally determined contribution (INDC) pledge. The PRC was also separated out, rather than considered in composite with other regions (Table A1.1.)

Appendix Table: The World Induced Technical Change Hybrid Model Regions

Region	Countries	Focus Region Name
CAJAZ	Canada, Japan, and New Zealand	
PRC	People's Republic of China	PRC
EAsia	Southeast Asia and the Pacific (excluding Indonesia)	Rest of East Asia, Southeast Asia, and the Pacific
India	India	India
Indonesia	Indonesia	Indonesia
KOSAU	Republic of Korea, South Africa, and Australia	
LACA	Latin America, Mexico, and the Caribbean	
MENA	Middle East and North Africa	
Europe	European Union (EU) old and new member states and European Free Trade Association	
SAsia	South Asia (excluding India)	South Asia
SSA	Sub-Saharan Africa	
TE	Non-EU Eastern European countries, including the Russian Federation	
US	United States	

The intertemporal equilibrium is calculated as an open-loop Nash equilibrium, but a cooperative solution can also be implemented. Through the optimization process, regions choose the optimal dynamic path of a set of control variables: investments, primary energy supply, oil market price, and permit market price.

The base year is 2005. The time horizon is 150 years, with 30 periods of 5-year time steps. Longer time horizons can also be run until 2300 to avoid any end-of-horizon effect, but 2150 is generally sufficient. Results are usually reported for the period 2005–2100 and the periods 2005, 2010 and 2015 are calibrated to the energy and economic statistics when available.

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The Economics of Greenhouse Gas Mitigation in Developing Asia

This study uses an economy–energy–climate model to assess the long-term effects of Paris Agreement pledges on developing Asia, in comparison with business as usual and more ambitious scenarios to limit warming to 2°C. It finds potential for modest macroeconomic costs of ambitious mitigation, but that clean energy investment needs are substantial. When costs, benefits of avoided climate change, and cobenefits are considered together, investment in mitigation policy is found to have substantial economic returns for the region—if action is taken rapidly and international carbon market mechanisms are implemented to allow mitigation to occur where it is least costly.

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