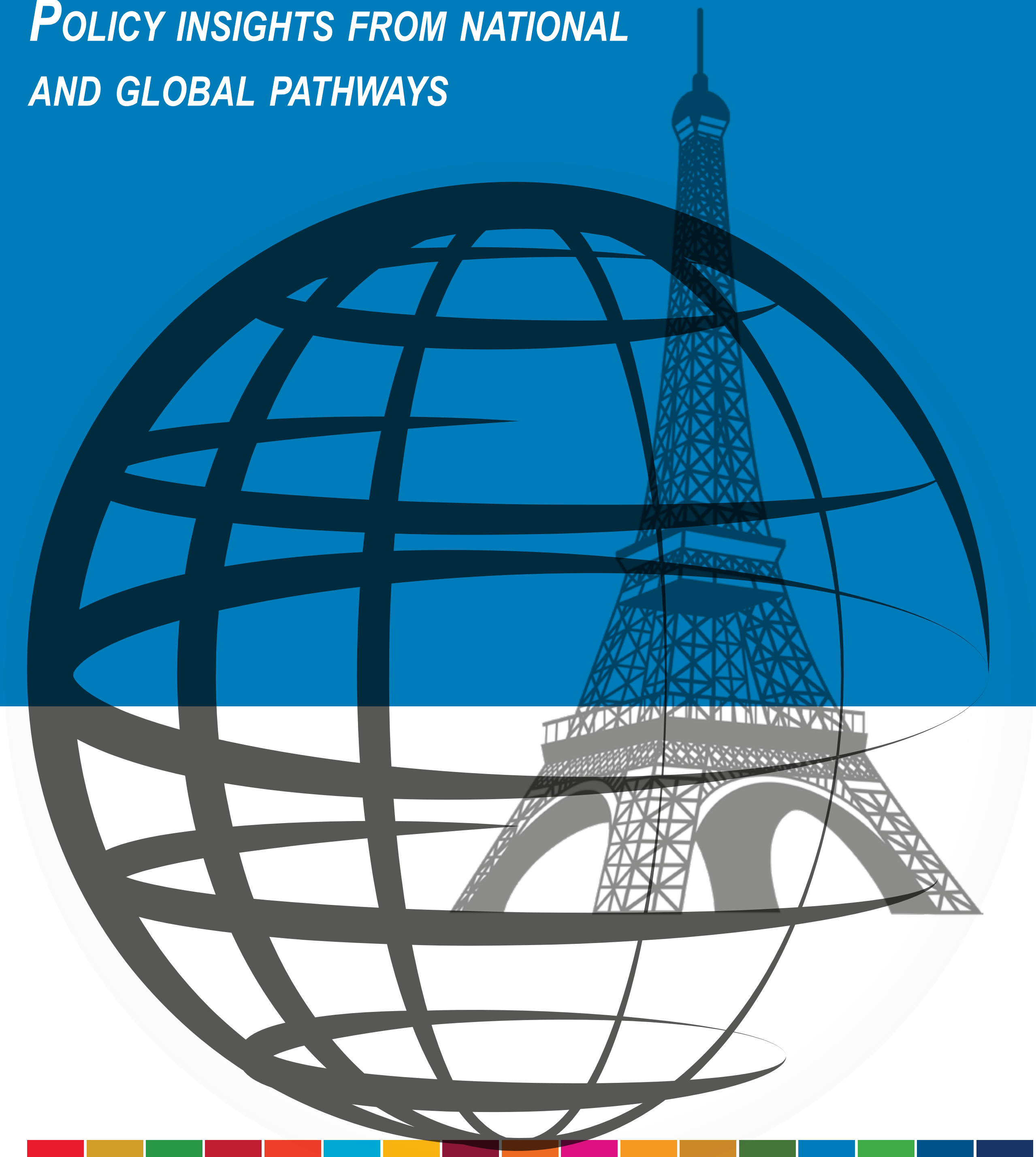
Linking climate and sustainable development

Policy insights from national and global pathways



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For more information on the CD-LINKS project, please visit https://www.cd-links.org/

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Linking Climate and Sustainable Development

Policy insights from national and global pathways

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Additional Information

For more information on the CD-LINKS project, please visit https://www.cd-links.org/

Abbreviations

BECCS- BioEnergy with Carbon Capture and Storage

CD-LINKS- Linking Climate and Development Policies – Leveraging International Networks and Knowledge Sharing

CDM- Clean Development Mechanism

DAC- Direct Air Capture

EU- European Union

G20- Group of 20

GHGs- Greenhouse Gases

Gt CO_2- Gigatons of carbon dioxide

Gt CO_2eq- Gigatons of carbon dioxide equivalent

IAMs- Integrated Assessment Models

IPCC- Intergovernmental Panel on Climate Change

NDCs- Nationally Determined Contributions

SDGs- Sustainable Development Goals

UN- United Nations

UNFCCC- United Nations Framework Convention on Climate Change

Consortium and International Partners

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Potsdam Institute for Climate Impact Research (Germany)

Energy Research Institute (China)

Euro-Mediterranean Center on Climate Change (Italy)

Tsinghua University (China)

Ministry of Infrastructure and Water Management (Netherlands)

Indian Institute of Management Ahmedabad (India)

Institute of Communication and Computer Systems of the National Technical University of Athens (Greece)

National Research University Higher School of Economics (Russia)

COPPE, Universidade Federal do Rio de Janeiro (Brazil)

National Institute for Environmental Studies (Japan)

The Energy and Resources Institute (India)

Research Institute of Innovative Technology for the Earth (Japan)

The Institute for Sustainable Development and International Relations (France)

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Foreword

Understanding the connections between climate change policies and sustainable development is critically important for the implementation of the Paris Agreement and the United Nations Sustainable Development Goals (SDGs). Well-designed climate mitigation policy can lead to significant co-benefits for a range of development priorities, including enhanced energy security and safety and reduced indoor air pollution; however, if not properly managed, mitigation can also lead to trade-offs. Maximizing synergies and avoiding trade-offs thus requires an integrated strategy based on a new generation of technological and socio-economic pathways that includes climate-resilient adaptation strategies.

Over the last four years, CD-LINKS brought together an international team of interdisciplinary researchers with both global and national expertise. Funded by the Horizon 2020 programme of the European Union, the project applied cutting-edge scientific tools and models to explore the linkages between climate policies and sustainable development. Major achievements of the project include the development of globally consistent national low-carbon development pathways, and the formation of a research network and capacity building platform to leverage knowledge exchange among institutions. The project also improved understanding of the linkages between climate change policies and multiple sustainable development objectives and greatly enhanced the existing evidence base on policy effectiveness. A particular asset of the project are the insights related to policy designs that adequately account for mitigation trade-offs across sectors, actors, and objectives. We invite you to learn more about this ground-breaking work in the pages that follow.

CD-LINKS insights critically informed the Intergovernmental Panel on Climate Change (IPCC) special report on Global Warming of 1.5°C, as well as other reports on the assessment of investment and finance needs. Through continued inter-disciplinary global research efforts such as CD-LINKS, we can strategically and systematically work to achieve objectives of energy poverty eradication, increased well-being and welfare, biodiversity, optimal air quality, and sufficient availability of food and water. We would like to thank all external and internal project partners, as well as the project Advisory Board members for their dedicated efforts. It is their concerted efforts that help move us another step closer to a secure and sustainable future for all in the face of an ever-changing climate.

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September 2019

1. Introduction

Incorporating climate action into the broader sustainable development agenda is an important issue for policy makers in the G20 and beyond, encompassing objectives such as energy poverty eradication, increased well-being and welfare, air quality improvement, conserving biodiversity and ensuring food and water availability. However, there have been relatively few scientific analyses that have explored the complex interplay between climate action and development while simultaneously taking both global and national perspectives.

The CD-LINKS project contributed to filling these critical knowledge gaps by exploring the complex interplay between climate action and development through both global and national perspectives, providing information to aid the design of complementary climate-development policies. The project aimed to

- gain an improved understanding of the linkages between climate change policies (mitigation/adaptation) and multiple sustainable development objectives;
- broaden the evidence base in the area of policy effectiveness by exploring past and current policy experiences;
- develop the next generation of globally consistent, national low-carbon development pathways; and
- establish a research network and capacity building platform to leverage knowledge exchange among institutions from the EU and other key players within the G20, including Brazil, China, India, Japan, Russia, and the United States.

The project targeted contributions to the policy dialogue, both nationally and internationally, and developed country-specific policy recommendations for effectively managing the long-term transformation process.

2. The Impact of National Climate Policies on Global Greenhouse Gas Emissions

What will current national climate policies deliver?

The global climate objectives of the Paris Agreement need to be implemented bottom-up through climate policies in individual countries. The Agreement aims to keep the increase in global temperature to below 2°C compared to the pre-industrial period, and if possible, below 1.5°C. To assess whether the world is on track, it includes a periodic stocktake where 'collective progress is assessed towards achieving the purpose of the Paris Agreement and its long-term goals' (UNFCCC, 2015). In 2020, countries are asked to update the Nationally Determined Contributions (NDCs) to the Paris Agreement that contain greenhouse gas emission (GHG) reduction pledges, a key moment to enhance domestic mitigation of climate change. Domestic policies need to ensure achievement of the NDC reduction targets. Models can contribute to this by analyzing pathways towards the overall goals and comparing these with scenarios that explore the impact of NDCs and national policies.

Current implemented domestic climate policies are estimated to reduce GHG emissions 5% by 2030 compared to an emission pathway that assumes no new policies after 2010 (see Box 1). Collecting these domestic policies was a comprehensive effort and resulted in the open source CD-LINKS climate policy database[1] which contains implemented and planned climate, energy and land-use policies for all G20 countries. This inventory was created with the help of national experts from 13 countries. The purpose of this database was to inform the project's integrated assessment models (IAMs, see Box 1). Together with experts, a top-ten list of the most effective policies from this database was selected, which resulted in 215 policies which were implemented in the models. These current implemented domestic policies would result in (median) emission reductions between 3% and 9% for seven large emitting countries (Roelfsema et al. forthcoming, see Figure 1).

NDCs are not compatible with 2°C and 1.5°C targets

Most countries are not on track to meet their own NDCs, and the global reduction expected from all NDCs is inconsistent with the policy efforts to limit warming to well below 2°C. The total pledged emission reduction targets for the year 2030 in the NDCs are not sufficient for being on track to stay well below 2°C by 2030. The (median) emissions gap between the NDCs and the 2°C scenario is 16.5 $GtCO_2eq$, and 21.1 $GtCO_2eq$ compared to the 1.5°C scenario (see Figure 2). The global emissions gap for the year 2030 demonstrates the difference between the projected emission levels after implementation of the Paris Agreement goals with those of the NDCs. The gap is even larger if we consider emissions reductions from current national policies, which fall short of reaching the 2030 NDCs and could result in an additional implementation gap of approximately 3.5 $GtCO_2eq$ (see Figure 2).

1) http://climatepolicydatabase.org/index.php/CDlinks_policy_inventory

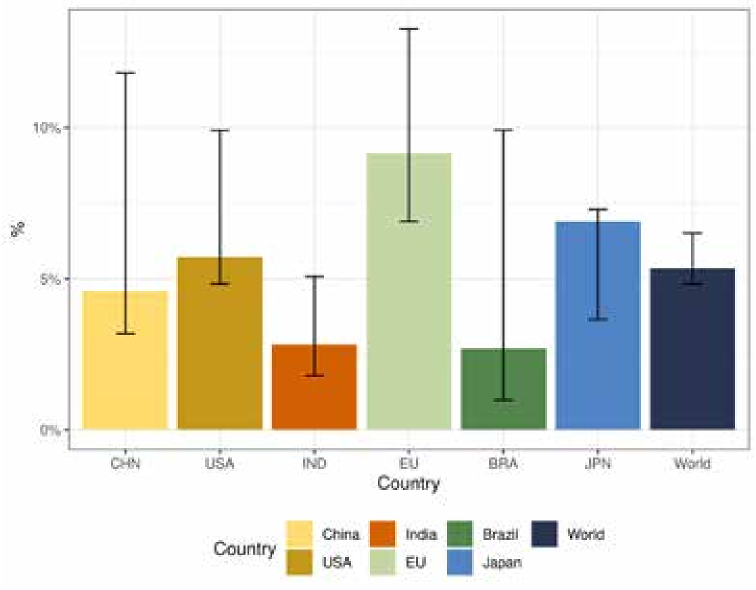


Figure 1: Reductions of current national policies compared to the 'no new policies' scenario by 2030 (colored bars represent the median of nine models, error bars show the 25th–75th percentile range).

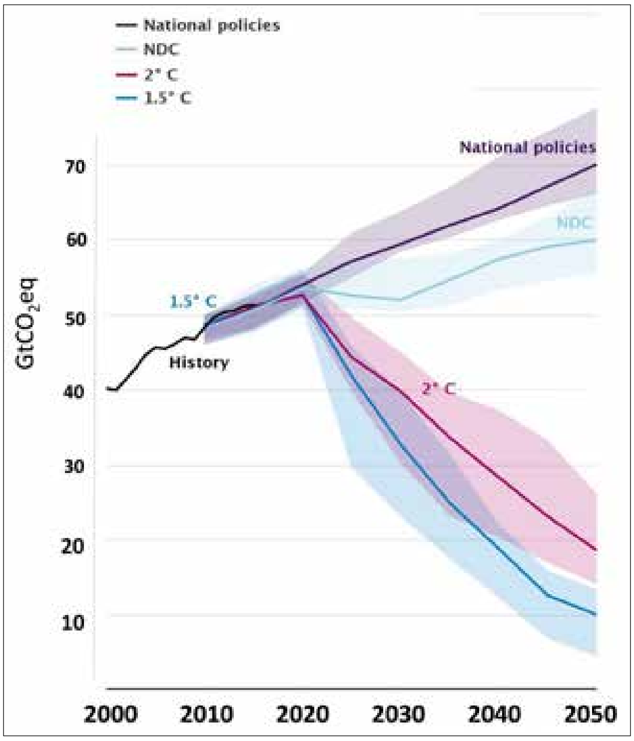


Figure 2: Global GHG emissions of current national policies and NDC and 2°C and 1.5°C pathways. Note: Emission ranges consist of median estimates and 10th–90th percentiles based on nine IAMs.

Assuming the world wants to achieve the 2°C target of the Paris Agreement in a cost-effective way (see Box 2), a large gap exists for all individual large emitting countries with their NDCs (Roelfsema et al. forthcoming, see Figure 3). It can be as large as 5.0 to 7.0 $GtCO_2eq$ for China, 0.35 to 0.85 $GtCO_2eq$ for the United States, 0.06 to 0.65 $GtCO_2eq$ for the European Union and 1.7 to 2.4 $GtCO_2eq$ for India. Although all emissions are to be reduced domestically in this case, the amount of financial resources that will be needed for the domestic upscaling of mitigation action will depend on global political agreements about how the global mitigation effort will be shared across countries. If instead of cost-effective implementation countries would choose a different (fair) way of effort sharing instead (see Box 2), (median) emission estimates in line with 2°C and 1.5°C change significantly (see effort-sharing ranges in Figure 3).

Box 1: Modeling Methods and Scenarios

An important feature of CD-LINKS is the complementary application of national and global IAMs (see Table B1) that enable exploration of the consequences of different policy assumptions and the derivation of globally consistent national low-carbon development pathways. In terms of CO_2 emissions, the CD-LINKS modeling teams cover approximately 70% of the global emissions through individual country expertise. Moreover, the project brought together IAMs with strengths in assessing particular aspects of sustainable development (e.g. employment, access to clean and affordable energy) and disciplinary models to allow assessment of climate change adaptation and the implications of climate policy for a broader range of sustainable development goals, including air quality and health, food security, biodiversity, and a range of environmental indicators.

The different policy assumptions are covered by five scenarios. The **No New Policies** scenario assumes no implementation of new policies after 2010 and is based on the middle-of-the-road Shared Socioeconomic Pathway SSP2 scenario (Riahi et al., 2017). The **National Policies** scenario starts from the no new policies scenario but assumes full impact of domestic climate and energy policies. The NDC scenario assumes full implementation of conditional country pledges from the NDCs to the Paris Agreement. The **2°C scenario** and **1.5°C scenario** represent the objectives of keeping global warming below 2°C and 1.5°C with high probability (>66%, Luderer et al., 2018), starting with cost-effective deep reduction measures after 2020 based on global carbon pricing.

Table B1: Overview of modelling tools applied in the CD-LINKS project. Flags indicate country of host institution and globe icons denote models with global coverage.

National IAMs	Institution	Global IAMs	Institution
AIM/Enduse[Japan]	NIES	AIM/CGE	NIES
AIM/Enduse[India]	IIMA	COFFEE	COPPE
BLUES	COPPE	GEM-E3	ICCS
China-TIMES	Tsinghua U	IMAGE	PBL
DNE21+	RITE	MESSAGEix-GLOBIOM	IIASA
PRIMES	ICCS	POLES	JRC
GCAM	JGCRI	REMIND-MAgPIE	PIK
India MARKAL	TERI	WITCH-GLOBIOM	CMCC
IPAC	ERI		
RU-TIMES	HSE		

Disciplinary Models	Research Area	Institution
CATSIM	Financial disaster risk due to climate impacts	IIASA
GAINS	Air quality and health impacts	IIASA
AIM/Diversity	Biodiversity	NIES
MESSAGE-Access	Energy poverty and access to clean cooking fuels	IIASA
Risk of hunger method	Food security	NIES/WHO
LCA tool	Environmental impacts of power generation	PIK/NTNU

Box 2: Effort Sharing

In the CD-LINKS scenarios, it is assumed that after 2020 climate, policies are implemented where most cost- effective, independent of geographical location. However, this might not be in line with the equity principle from the Paris Agreement, which specifies that countries will respond based on ***common but differentiated responsibilities and respective capabilities, in the light of different national circumstances***. However, even if emissions are mitigated where this is cost effective, these mitigation costs do not necessarily need to be financed domestically. It is intended that together the national contributions add up to the emissions reductions needed to meet the targets of the Paris Agreement. Current NDCs are projected to lead to much higher emission levels. Therefore, the question of who takes up the extra effort to reach the goals is critically important and forms the core of the global stocktake process.

Ideally, every country would want its contribution to be fair compared to other countries. The current model calculations typically provide results for cost-efficient allocation of mitigation efforts—but this leads to relatively high costs for developing countries. In the literature, fairness has been discussed around equity principles, for which many different effort-sharing approaches have been proposed. The CD-LINKS project examined how country-level emission targets and carbon budgets can be derived based on such approaches.

The assumption is not that a new, top-down, regime would be introduced, but instead that in setting up national level targets, countries can compare these ambitions to various equity regimes. Ultimately, domestic policy makers and United National Framework Convention on Climate Change (UNFCC) negotiators will decide what determines a fair contribution to the global mitigation effort. Previously, it was found that in the NDCs the most commonly used equity indicator was a country's (small) share of global emissions, followed by per capita emissions (Winkler et al. 2018).

The CD-LINKS project analyzed the following approaches: equal cumulative per capita emissions, equal per capita emissions (per capita convergence/immediate equal per capita emissions), grandfathering, greenhouse development rights, and ability to pay, covering the full spectrum of possible regimes (Van den Berg et al. 2019). As the results critically depend on parameter settings (e.g. the convergence year), we used the diverse consortium to determine default settings and sensitivity ranges. Results (see Figure B2) show that effort-sharing approaches that calculate required reductions in carbon budgets (relative to baseline budgets) and/or that take into account historical emissions when determining carbon budgets can lead to (large) negative remaining carbon budgets for developed countries. This is the case for the equal cumulative per capita approach and especially the greenhouse development rights approach. Furthermore, for developed countries, all effort-sharing approaches except grandfathering lead to more stringent budgets than cost-optimal budgets, indicating that cost-optimal approaches do not lead to outcomes that can be regarded as fair according to most effort-sharing approaches. This is especially the case when compared to the per capita approaches implicitly preferred by many countries.

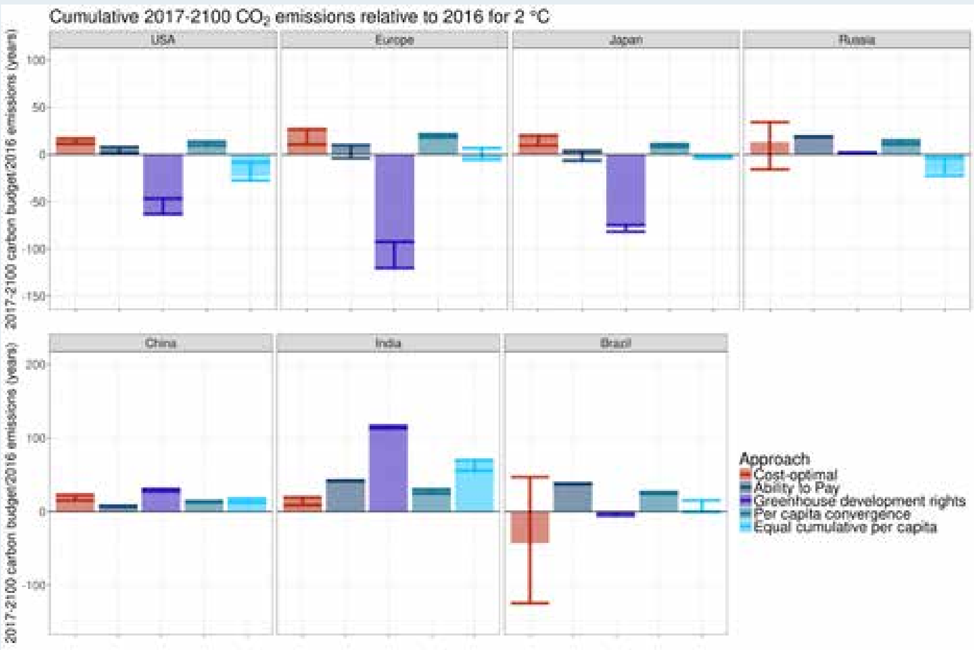


Figure B2: Carbon budgets of different effort-sharing approaches by country. Carbon budgets are given in emission years (2011–2100 CO_2 budget/2016 emissions) and are based on a 1075 $GtCO_2$ global carbon budget for the period 2011–2100. Default values are shown by the filled bars, and error bars illustrate the sensitivity ranges. For Greenhouse Development Rights, the RCI was set at 0.5 (default), and the range indicates varying start years between 1850 (default), 1970 and 1990. Adapted from Van den Berg et al. (2019) using IEA and FAO for 2016 emissions data.

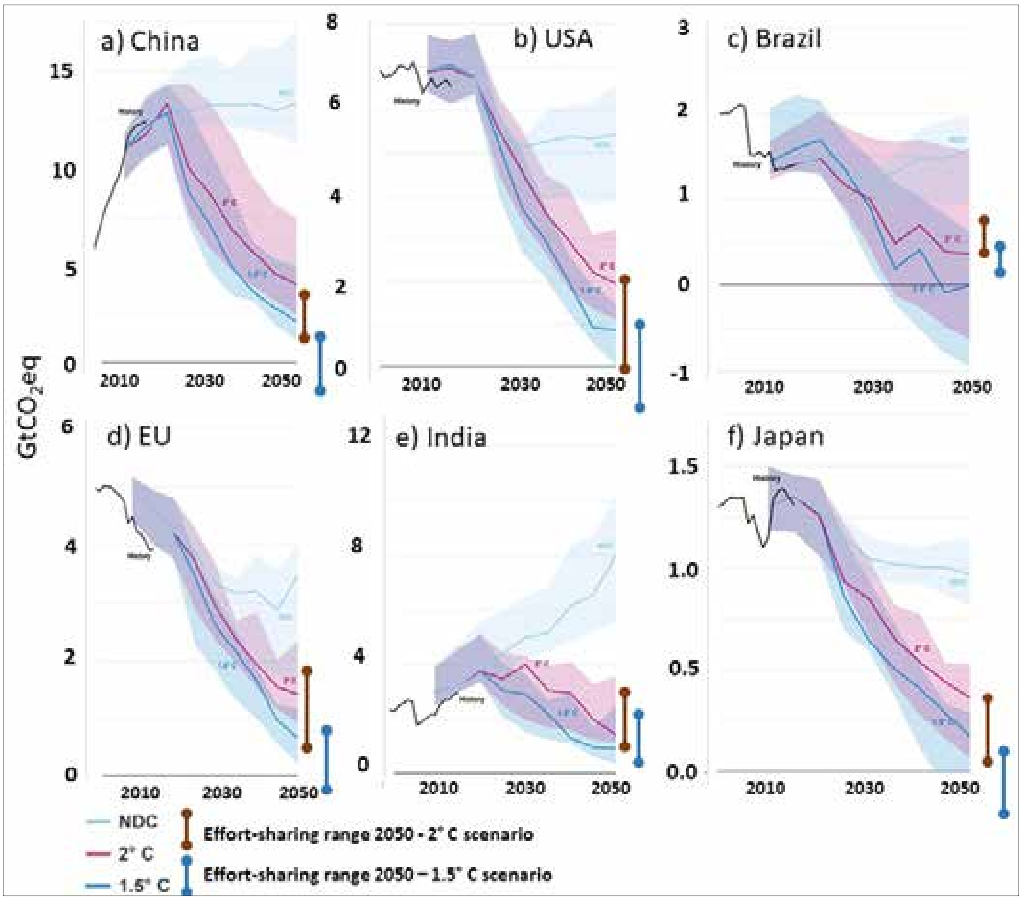


Figure 3: GHG emissions for (a) China, (b) USA, (c) Brazil, (d) EU, (e) India, and (f) Japan under NDCs and 2°C and 1.5°C emission pathways. Notes: Emission ranges consist of median estimates and 10-90% percentiles based on nine IAMs. Effort sharing ranges based on four effort sharing schemes (see Box 2) only show the estimate based on the IMAGE model.

3. Closing the Gaps: Coherent National and Global Low-carbon Development Pathways

Global low-carbon development pathways consistent with the Paris Agreement, and implications for national pathways

Scenarios limiting global warming to well below 2°C or 1.5°C project global emissions peaking by 2020 and declining rapidly afterwards, reaching net zero CO_2 emissions between 2070 and 2090 (2°C scenario) or between 2040 and 2060 (1.5°C scenario). The energy sector is a main contributor to emissions reductions through the replacement of fossil fuels with renewable and other low-carbon energy sources, particularly in the electricity sector. The decarbonisation of electricity generation is leveraged to the entire economy by increased electrification of the industry, transport and buildings sectors. Sustainable land-use management is critical for bringing land-use CO_2 emissions to net zero and eventually using land to remove CO_2 from the atmosphere, for example, by afforestation, soil carbon enhancement and natural land restoration.

For policy makers it is important to have a near-zero emission ambition as an orientation for long-term planning, for countries, regions and cities, as well as for individual sectors. It is clear that the Paris Agreement climate targets require that CO_2 emissions reach zero over the next few decades. This is a massive challenge that requires planning and redirection of policies and investments in all sectors. A clear long-term vision may help facilitate such redirection. Thus far, few countries have formulated long-term decarbonisation targets.

A cost-optimal carbon-neutral global energy system may still imply that certain sectors or countries have residual CO_2 emissions that are compensated by carbon dioxide removal from the atmosphere elsewhere. Potential differences across countries may be warranted for equity reasons (with developed countries reaching carbon neutrality earlier and providing via net negative emissions some extra room for developing countries), while differentiation across sectors might enhance efficiency if costs of carbon dioxide removal are lower than the abatement of residual emissions in sectors such as aviation. However, carbon dioxide removal options such as bioenergy with carbon capture and storage (BECCS), direct air capture (DAC), and afforestation are associated with numerous risks, clearly limiting their potential.

How can national and global perspectives be consolidated?

We identified emission reduction pathways at both global and national levels that are consistent with the Paris Agreement (Kriegler et al. forthcoming). Figure 4 shows the alignment of 2050 emissions for the seven major emitting countries from the aggregate of national scenarios that were developed for the CD-LINKS project with the 2°C pathways from global models. To ensure consistency with the 2°C target, national scenarios go beyond achieving the NDCs in 2030, followed by deep reductions thereafter. Although the policies necessary for such scenarios will require a substantial redirection from current trends, they are attainable from a technical and economic perspective. The collective emissions of national scenarios that pass through the NDCs in 2030 followed by a gradual strengthening of mitigation efforts in the seven major emitting countries were found to be inconsistent with global 2°C pathways.

Main building blocks of national G20 roadmaps

Under cost-optimal mitigation scenarios, the energy supply sector—and in particular electricity generation—is projected to be the largest contributor to greenhouse gas emission reductions, with a near complete decarbonisation by 2050. Figure 4 also illustrates emission reductions per sector. The model calculations identify low-cost potential to mitigate GHG emissions in all countries, with the largest contribution in absolute terms coming from China, the United States and India. From a sectoral perspective the largest contribution comes from the energy supply sector (mostly electricity production); here, many options exist to reduce emissions at relatively low costs. This feature is common for global (see above) and across national scenarios. The industry and transportation sectors also have potential for further emission reductions, with accelerated electrification and a more limited reduction in the carbon intensity of fuel use. The buildings sector offers more limited potential for further reduction of direct carbon emissions until 2050. Regional differences in mitigation potential arise from differences in the development stage, existing differences in energy systems and economic structure and differences in energy resource potentials (renewable and fossil energy resources).

The challenge of energy investment needs for fulfilling the Paris Agreement

The transformation of the energy system towards 2°C and 1.5°C will require a major change in investment patterns globally (McCollum et al. 2018). Low-carbon investments are necessary for driving the energy system transformation specified by both the Paris Agreement and the SDGs, as investments are the 'lifeblood' of the global

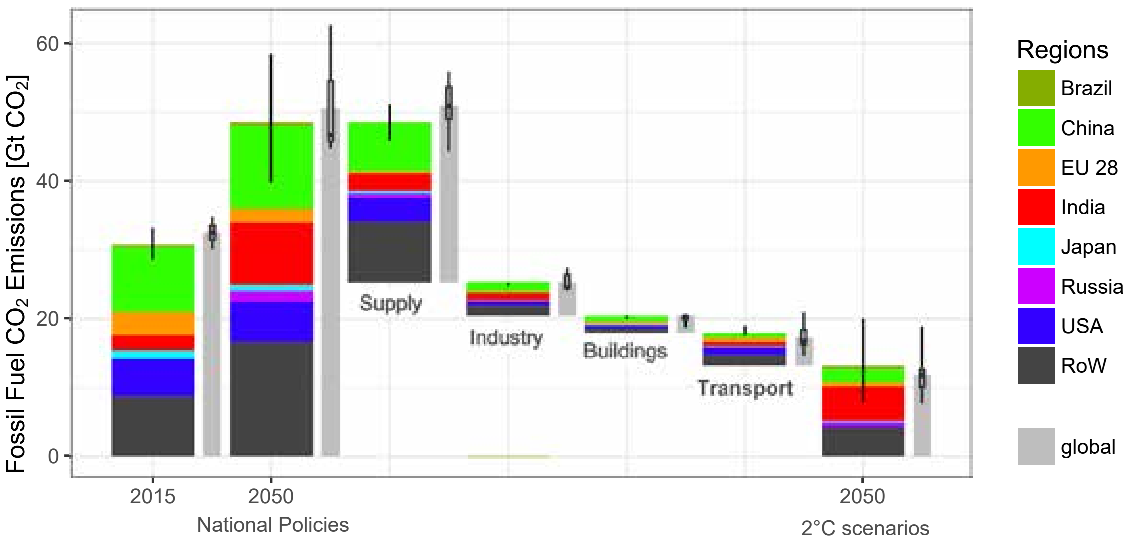


Figure 4: CO_2 emissions in 2010, by 2050 under National Policies and by 2050 under a 2°C scenario, as well as the disaggregation of differences between the latter two. Notes: The colored stacked bars show the aggregate of results from national models (using the mean for countries with two models, and the uncertainty bars give the aggregate maximum and minimum) while the grey bars and boxplots show the median and range of global model results.

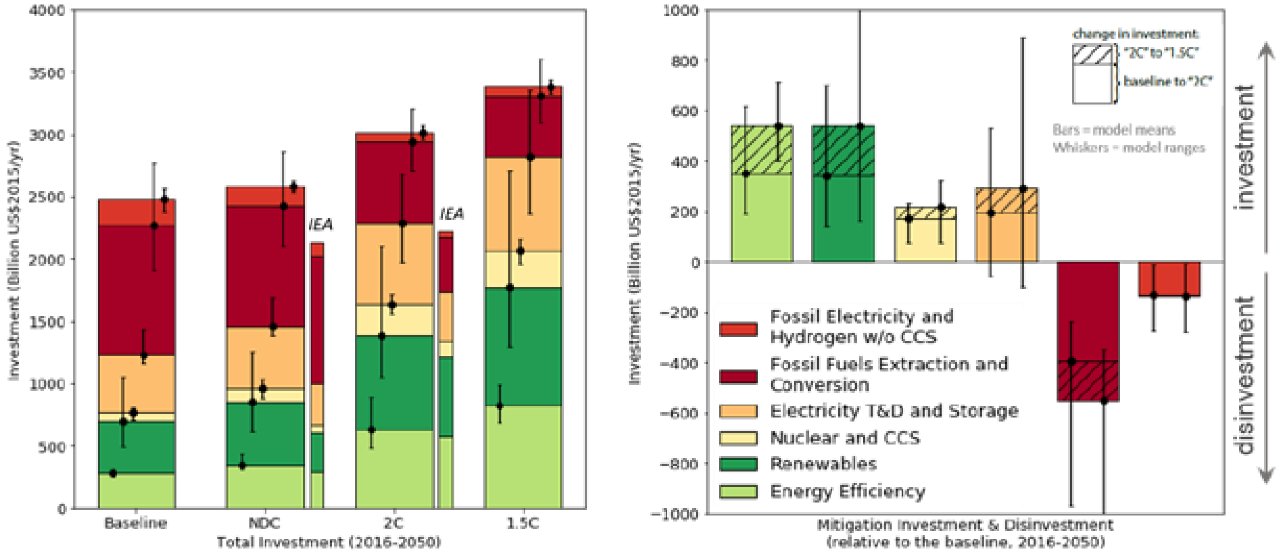


Figure 5: Projected global average annual investments in the different climate policy scenarios (left panel); incremental investments and disinvestments by category relative to the baseline (right panel). Source: McCollum et al. (2018).

energy system. A transformation of the global energy system towards 2°C and 1.5°C does not necessarily require an increase in total investments. Yet, while the magnitude may not change in major ways, the composition of those investments certainly will. In other words, a pronounced reallocation of the investment portfolio is inevitable, from investments into fossil exploration to investments into efficiency and renewables (Figure 5). Countries' current NDCs do not provide the impetus for this structural shift. Beyond a change in investment patterns, trade patterns are also affected with economic implications for different regions of the world (see Box 3 on trade implications of the Paris Agreement).

Substantial 'gaps' in low-carbon energy and energy efficiency investments exist if the 1.5°C and 2°C targets are to be successfully achieved. These gaps represent upwards of one-quarter of total global energy investments otherwise foreseen in a baseline scenario, and for some major economies (e.g. China and India), up to one-half. For the United States, Europe and Latin America, the level of low-carbon energy and energy efficiency investment needed to fulfil the NDCs would already put them on track for achieving the 2°C target in the longer term. The 1.5°C pathway, in contrast, demands a considerably stepped-up investment effort in all regions and countries (McCollum et al. 2018).

The challenge of committed emissions and carbon lock-ins

Delayed mitigation action increases the risk of carbon lock-ins that will make achieving the climate targets of the Paris Agreement cost-effectively more difficult and amplifies the need for negative emissions. Most investments in the energy sector cumulate in long-lived capital, committing to a long stream of emissions without strong incentives to deviate from the pathway manifested by past investments. Therefore, steering the wheel of economies towards decarbonization will become harder as more carbon is locked in through this capital. The aforementioned low carbon and energy efficiency gap will translate into larger committed emissions, consuming the allowable carbon budget to stay within given safeguard temperature targets, thus increasing reliance on carbon dioxide removal technologies to compensate for the extra emissions committed to with earlier, more lenient mitigation targets (Luderer et al. 2018).

'Peak coal power' is a key pre-requisite for the global emissions peak. Countries where this might be more critical are China and India, which might see further coal power expansion under NDCs. Both countries have ambitious near-term renewable plans and have overachieved some (or all) previous renewable targets. However, no clear ambitious targets for renewables in 2030 are set, which would be necessary to bring about the scale-up in renewables investment to prevent further coal build-up (Wang et al. forthcoming; Malik et al. forthcoming).

Box 3: Trade Implications of the Paris Agreement

Following the Paris Agreement, climate policies are emerging rapidly, affecting the operation and decision-making processes of all economic agents. The trade implications and competitiveness effects have been a prime concern of policy makers. A key factor of the environmental policy versus economic impact dilemma is the asymmetry of the ambition of environmental policies across the different trading regions. Faced with this asymmetry, first-mover regions and carbon-leakage exposed sectors are believed to be at greatest risk for loss of competitiveness and can thus claim various kinds of compensation measures to offset the additional costs that put at risk their production levels, and employment.

The GEM-E3 hybrid CGE model was used to quantify the regional and sectoral trade impacts of symmetric and asymmetric climate polices. The scenario framework consists of a symmetric global climate action to keep global warming well below 2°C and an asymmetric global implementation of NDCs, in line with the submission of countries under the Paris Agreement. We find that both asymmetric and symmetric global mitigation actions result in a reduction of global trade activity. Decreasing global demand of fossil fuels is the largest contributor to this drop-in activity given that global fossil fuel exports constitute on average 12% of total merchandise exports for the period 1970–2017 and reach 19% in 2050 in our National Policies scenario. The increasing trade of other energy carriers and low-carbon equipment does not compensate this trade loss. The decarbonization process involves the substitution of a highly traded good (fossil fuels, in particular oil and gas) by electricity that is largely domestically produced, through the electrification of final energy demand. Furthermore, the process involves a transition from operating to capital expenditure; thus demand for continuous trade flows of energy carriers is replaced by an intermittent demand for equipment of clean energy and energy efficiency technologies.

On a regional level, we find that in the presence of asymmetric climate policies (e.g. in the NDC scenario), the effect on exports largely depends on the relative stringency of the climate mitigation policies across the different regions. However, in a symmetric global climate effort to 2°C, changes in exports are primarily driven by the regional levels of carbon intensity, trade openness and other system characteristics that define the cost of transition for each economy. For example, the EU28 registers negative trade impacts in the NDC scenario due to its higher mitigation ambition compared to the remaining regions but shows positive impacts in the 2°C scenario as a result of the lower emission intensity of the EU economy and its presence in clean technology markets. Another indicative example is that of Mexico and Argentina which register higher exports (mainly electric vehicles and biofuels) in both policy frameworks and thus an overall positive effect. By contrast, fossil fuel exporters face important challenges in both scenarios due to the decline of fossil fuel demand.

On a sectoral level, the increasing demand for low carbon technologies, particularly for electric vehicles, brings a positive trade activity in both scenarios, but not enough so to counterbalance the losses. Global trade of energy intensive industries depends on the level of asymmetry of climate policies. In the NDC scenario, large exporters of energy intensive goods are committed to higher emission reductions with subsequent negative impacts on their competitiveness and global sectoral trade.

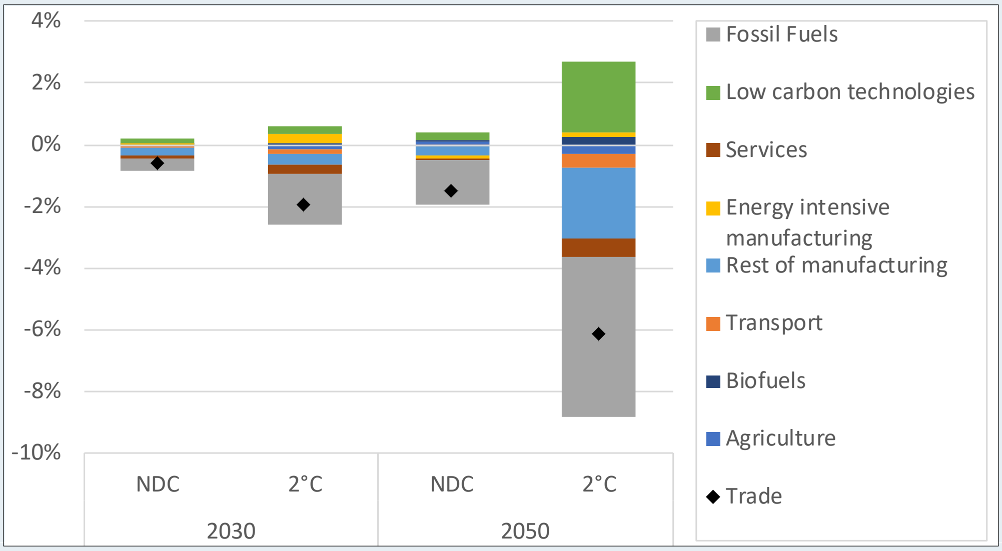


Figure B3: Sectoral decomposition of global trade effects in NDC and 2°C scenarios in 2030 (a) and 2050 (b). Trade is defined as the share of exports and imports. The contribution of each sector to the total change in trade is expressed as the ratio of the net change of sectoral trade to total global trade levels of the National Policies scenario. Trade (marker only) is expressed as a % change from the National Policies scenario. Source: GEM-E3 model.

4. Synergies and Trade-offs between Multiple Sustainable Development Goals

The integrated analysis of a broad portfolio of policy objectives is important for informing the policy process, given that decision-making regularly involves balancing a myriad of objectives in a variety of areas. In the context of sustainable development, it is therefore essential to develop an understanding of the synergies and trade-offs between multiple policy objectives, including climate change mitigation.

Exploring interactions between SDGs

The CD-LINKS project has expanded our understanding of the linkages between climate change goals and a set of other sustainable development objectives, taking into account national and local policy priorities and constraints in key G20 countries. Depending on these national and local circumstances (e.g. development stage, natural resource endowment, domestic food production), a synergy in one place could be a trade-off in another; hence, the various societal priorities are typically weighted quite differently by decision-makers. The central issue explored in CD-LINKS is whether and to what extent achieving climate goals reinforces or potentially impedes reaching other sustainable development objectives.

Recent developments in national and global integrated assessment modeling (Van Stechow et al. 2016; van Soest et al. forthcoming) and combining IAMs with a set of disciplinary analytical tools (see Box 1) allow an assessment of sustainable development objectives other than climate change. Synergies and trade-offs between climate policy and a range of sustainable development objectives have been explored using a set of climate policy scenarios (see Box 2). With varying emphasis placed on climate policy (implementation of NDCs vs. increasing ambition by 2030, in accordance with achieving the 1.5°C or 2°C target in the long-term), the resulting implications for other SDGs, including food security (SDG2), air pollution and its health impacts (SDG3), water availability (SDG6), clean and reliable energy (SDG7), employment (SDG8), efficient resource use (SDG12), and biodiversity (SDG15) were analyzed.

Inclusive climate policies needed to manage potential trade-offs

Inclusive climate policies are needed to ensure that climate change mitigation does not amplify the risk of hunger. Two in-depth studies conducted as part of the CD-LINKS project (Fujimori et al. 2018; 2019) estimated how food security could be negatively affected by the climate mitigation policies implemented by multiple IAMs, as well as identified policy mechanisms and costs associated with avoiding adverse side effects. Climate change mitigation exclusively aimed at attaining climate goals could thus generate a risk of negatively impacting food security. If not managed properly, the risk of hunger due to mitigation policies (e.g. emission pricing in the agricultural sector) could be remarkably amplified; under the 1.5°C and 2°C scenarios, for instance, the risk of hunger drastically changes compared to the baseline scenarios. Depending on the scenario, the results indicate that an additional 130 to 280 million people could be at risk of hunger in 2050. However, through 'inclusive climate policies' that combine climate policies with complementary measures such as agricultural subsidies and food aid to low-income countries, the adverse effect can be avoided with costs significantly smaller than the costs of climate change mitigation (up to 0.5% of GDP).

Consistent with earlier literature, significant co-benefits of climate change mitigation for air quality were found, but trade-offs for a set of mitigation measures, most notably bioenergy, were also identified. The interplay of climate policy and air quality was also studied in detail, in particular targeting the quantification of climate policy effects in individual countries. Rafaj and Amann (2018) evaluated the role of key factors that determined the changes in emission levels of air pollutants in China, India and Japan over the past 25 years and found that energy intensity improvements along with dedicated end-of-pipe air pollution control measures contributed significantly more to limiting the increase in air pollutant emissions compared to shifting to cleaner fuels. Complementing this historical perspective, Portugal-Pereira et al. (2018), Li et al. (2019) and Vishwanathan et al. (forthcoming) examined interactions between future climate change mitigation strategies and air pollution in Brazil, China and India, respectively. Across these studies, strong synergies between climate mitigation and air quality are generally found, with climate mitigation costs being partly offset by reduced costs for end-of-pipe air quality measures (Portugal- Pereira et al., 2018; Li et al., 2019). However, in particular in the case of Brazil, reliance on bioenergy for reducing GHG emissions could lead to increasing levels of particulate matter concentrations (Portugal-Pereira et al., 2018).

Achieving water, energy and climate change mitigation-related SDGs simultaneously requires coordination and additional resources due to their strong interdependency. Jointly achieving the Paris Agreement and SDG6 to ensure universal availability and sustainable management of water and sanitation at the global scale was studied in-depth by Parkison et al. (2019), building on earlier work by Fricko et al. (2016). Water and energy goals are

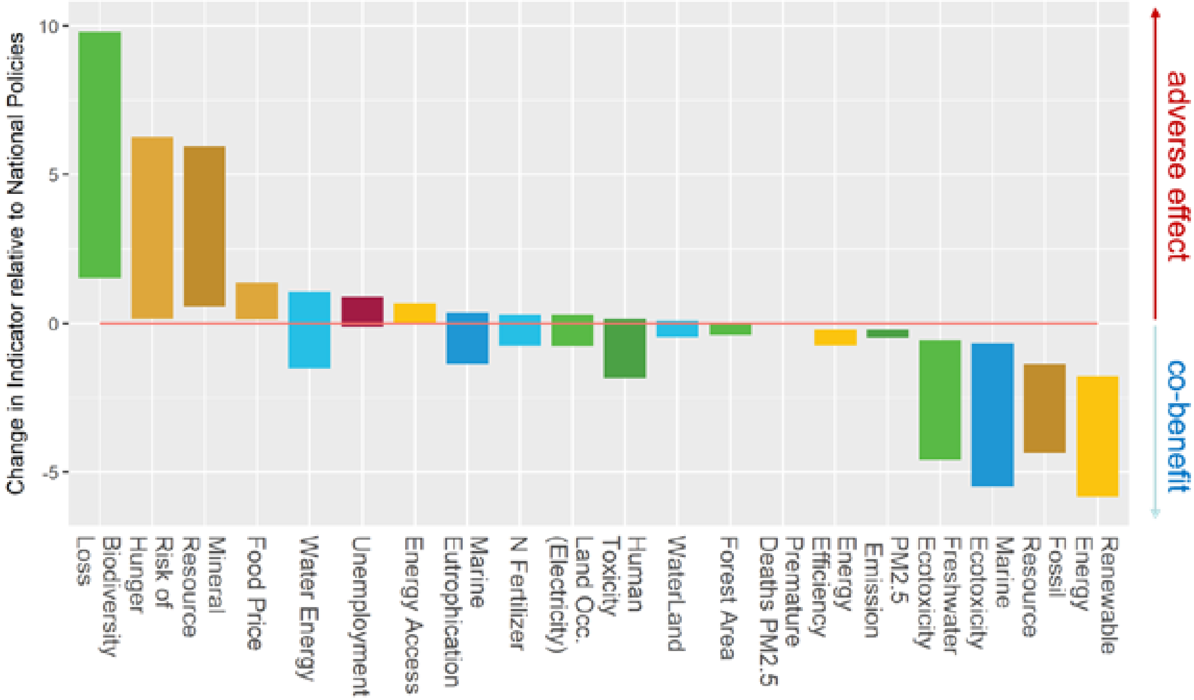


Figure 6: Change in Sustainable Development Goal (SDG) indicators in 1.5°C scenario relative to current policies scenario in 2050. Notes: Coloring of bars indicates linkage to SDGs. Values above the zero-line indicate potential adverse side-effects while values below the zero-line indicate potential co-benefits of climate policy for SDG indicators. The spread represents differences across different IAMs. Indicators on the left side of the figure robustly exhibit a potential for adverse side effects, indicators in the middle which stretch across the zero indicate a dependence of the effect on the actual mitigation strategy implemented which may vary across different IAMs and indicators on the right hand side robustly show co-benefits. Source: Krey et al. (forthcoming).

Box 4: Adaptation

Climate adaptation responses are intricately linked to development and climate mitigation. To address these interlinked challenges in policy and practice, research has to provide scientific evidence on the complex interactions between national and global energy- and land-use systems, and between adaptation and mitigation.

By focusing on coastal impacts due to sea level rise, one of the key economic damages associated with climate change, the linkages between mitigation and adaptation strategies are explored using a multi-model framework. Economy-wide effects of coastal flooding due to sea level rise, both with and without further adaptation and for different scenarios of mitigation are derived.

Results show that, in the shorter run, macro-economic implications are smaller than direct impact costs, as they are partially mitigated by substitution effects (new capital is built to replace the damaged capital). Towards the end of the century, instead, economy-wide effects become larger than the increasingly larger and frequent direct impacts.

Strengthening adaptation, which has an effect already in the short run, will become essential for limiting direct as well as economy-wide impacts from coastal flooding during the second half of the century.

A sensitivity analysis of varying socioeconomic assumptions highlights the role of climate-proof development as a crucial complement to ambitious mitigation and adaptation efforts. Hence, regarding concrete policy suggestions, we put forward the idea of fostering climate-related-risk screening in investment appraisals, particularly in the identified hot-spot countries (Schinko et al. forthcoming).

interdependent, with energy being vital to water and sanitation provision, for example in water pumping and treatment, while the energy sector is itself a large consumer of water—for example, in power plant cooling and fuel processing. The model-based analysis showed that around 1 trillion USD per year will be needed to achieve the SDG6 goals by 2030. Incorporating the climate targets consistent with limiting climate change to 1.5°C will increase these costs further by 8%. The cost of operating and transforming energy systems increases by 2–9% when the SDG6 goals are added, compared to a baseline situation where the SDG6 targets are not included.

Trade-offs and synergies depend on national circumstances

A careful consideration of the potential trade-offs between climate change mitigation policy and a range of other SDG indicators, in particular related to land-use change as well as distributional issues, is needed to avoid these from materializing which may trigger strong opposition to mitigation action (Krey et al. forthcoming). As illustrated in Figure 6, for a set of SDG indicators, including biodiversity, food security, mineral resource use and access to clean energy (see left side of Figure 6), the analysis robustly exhibits a potential for adverse side effects. Indicators in the middle stretch across the zero-line, indicating a dependence of the effect on the actual mitigation strategy chosen (e.g. water implications of shifting to electricity generation based on solar photovoltaic and wind compared to a system decarbonized based on nuclear power or fossil fuels with carbon capture and storage that is generally more water-intensive) which varies across the different pathways explored by IAMs. Finally, for some indicators, co-benefits were robustly found, including reductions in air pollution and health impacts, a reduction of toxicity indicators or an increased deployment of renewable energy sources (see right side of Figure 6). It is important to stress that despite of potential unintended side-effects of mitigation that need to be managed, the primary benefit of mitigation is to reduce climate change impacts which also have negative implications for many SDGs (see Box 4 and, e.g. Byers et al. 2018).

5. Policies to Pursue the Paris Agreement and the Sustainable Development Goals

The United Nations (UN) Sustainable Development Goals (SDGs) and the UN Framework Convention on Climate Change (UNFCCC) Paris Agreement have ushered in a new era of policymaking to deliver on the formulated goals. As highlighted by the scenario analyses featured in Sections 2 to 4, managing the interaction—synergies and trade-offs—between different goals, particularly between climate action and the SDGs, is a key issue in climate policy making. An issue of specific interest is whether trade-offs and synergies increase or decrease with higher policy ambition as required to reach the Paris targets. This makes it necessary to understand how such interactions have unfolded in existing policies that aim to achieve multiple objectives, and to determine best practices for strengthening synergies and reducing trade-offs (NCC 2019).

CD-LINKS investigated interactions between multiple objectives in 17 energy policies globally in a coordinated case study exercise. A first major finding is that typically policy makers aim to achieve multiple objectives with a single policy and do not consider complementary policies to strengthen synergies or alleviate trade-offs. Thus, the potential of better performing policy packages remains untapped. A second major finding is that the relevance of different goals typically changes over time, but policy makers rarely implement design features and processes that facilitate necessary policy adaptation. Accordingly, policies may be locked into a design that does not optimally balance synergies and trade-offs, and thus are at risk of termination. A third major finding is that while policy formulation often relies on and is motivated by multiple goals, comprehensive policy evaluation along all these goals is still extremely rare. Typically, policy makers focus either on economic, environmental or social objectives, without specific regard for other dimensions. This makes assessing synergies and trade-offs very challenging. Finally, a common underlying issue relevant to all three findings is the lack of strong inter-agency coordination and clearly

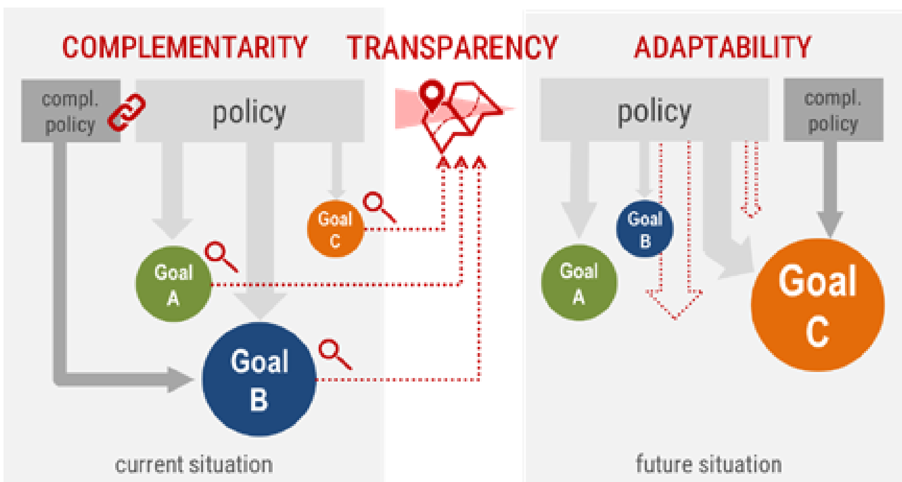


Figure 7: A new multiple-objective policy framework.

Box 5: Lessons from Renewable Auctions and Energy Access Policies

Example 1: Renewable auctions

Our findings show that, using the experiences of Brazil and Germany and their power sectors, renewable energy policies are more effective when the issues highlighted below—grouped by complementarity, transparency and adaptability—are dealt with simultaneously.

Complementarity

- When different set-ups for financing, equipment and capacity expansion are devised for the successful promotion of renewable energy under distinct macroeconomic backgrounds and regulatory frameworks
- When grid aspects are taken into account in early phases of renewable energy expansion programs; different grid conditions create different country-specific issues and can become important bottlenecks for high renewable energy shares
- When co-benefits are also generated as a consequence of renewable energy deployment.

Transparency

- When the inclusion of renewable energy in the wholesale electricity market can help to reduce the integration costs of renewables as a whole
- When auction designs are implemented and are sufficiently transparent and discussed in a timely manner with stakeholders to allow participants to adapt and fulfil all pre-requirements for their successful implementation
- When broad participation of society in renewable energy projects is facilitated, so as to increase their social acceptance by the different segments of the community.

Adaptability

- When a smooth, step-by-step approach towards market integration is pursued to avoid risk perception increases and investment slow-downs, together with a strong and transparent commitment to long-term renewable energy expansion
- When successful experiences are well publicized both domestically and internationally, so that they can be transferred, adapted and adopted in distinct regions, countries and contexts in general.

Example 2: Energy access policies

A cross-national comparison of flagship rural electrification policies of Brazil, India and Morocco provides insights on if and how wider sustainable development dimensions are considered in either policy design or evaluation and provides generalizable lessons for features influencing performance that may have utility in other contexts.

Across all three energy access policy cases, we found that impacts related to the SDG social goals were more likely to be considered than those related to the economy or environment. However, while these policies often explicitly identified potential social, and in some cases, economic objectives, these were rarely pursued or rigorously and independently evaluated. Environmental objectives and impacts were rarely identified explicitly or implicitly; yet in some cases (e.g. in Morocco) the climate benefits of decentralized renewable-based energy access were subsequently recognized and even proposed for funding under the Clean Development Mechanism (CDM). We conclude from this assessment that integrative frameworks for multi-objective policy design and comprehensive policy evaluation across several dimensions are required to exploit the potential of these policies to realize co-benefits.

An assessment of the performance of these energy access policies with a specific focus on aspects related to planning and goal setting, budgetary resources and finance, and governance structures for implementation and monitoring suggests broad lessons for potential replicability and transferability cross-nationally. We conclude that the following aspects were important to the outcomes and achievements of these policies:

Complementarity

- Strong inter-agency coordination and clear specification of responsibilities across implementing bodies
- Horizontal coordination across different branches of government to maximize secondary developmental benefits
- Incentives and regulations to encourage private sector involvement and enable local participation.

Transparency

- Realistic target setting and regular revision based on frequent and comprehensive monitoring and evaluation, and detailed planning for implementation

Adaptability

- Flexible regulatory and technology neutral approaches to allow for selection of centralized and decentralized site-specific options to reduce overall program costs
- Secure and adequate financing, ensuring financial viability of implementers and affordability for the poor.

specified responsibilities across different government branches, levels and implementers, as well as an overall multiple-objective policy framework to enable such coordination.

Given these shortcomings, we propose a new framework based on three policy design principles – complementarity, transparency and adaptability – to improve multiple-objective policymaking in the future (Figure 7). We also point to potential ideal practices for implementation. Complementarity mandates consideration of measures and design provisions that specifically target non-energy objectives. A good practice is the use of local content and supplier requirements in renewable energy policies in combination with industrial policies to support job creation. Transparency mandates that policy impacts should also be tracked comprehensively in non-energy domains to uncover diminishing returns and facilitate policy learning. A good practice is the introduction of an annual monitoring report, which is commissioned by an inter-departmental government agency and explicitly covers indicators for multiple objectives. Adaptability mandates that policies should be capable of adapting to changing objectives and priorities over time. A good practice is the built-in process for revisions and potential reform in several cap-and-trade programs worldwide.

Furthermore, to foster renewable energy deployment in different realities, identifying potential elements for policy transfer beyond their geographical boundaries is key. Therefore, we present more specific lessons from a comparative assessment of selected flagship studies on renewable auctions and energy access policies (Box 5).

6. Networking and Capacity Building

The two flagship research networking and capacity building programs within CD-LINKS are the research exchange program and the CD-LINKS summer school.

The ***research exchange program*** enabled 13 young scholars from varied institutes globally to collaborate with project institutions to research topics such as the development of better modelling of water use in India and more accurate forest sector descriptions in Brazil.

The ***CD-LINKS summer school***, held in Venice in July 2019 hosted 20 students from 13 countries, including India, Russia, Brazil and many others (Figure 8). The school courses, taught by key scientists involved in the CD-LINKS project, covered the topic of IAMs conceived as a tool for science-based policy making. In addition to the history of these models and the necessity to expand them to include more and more dimensions of sustainability, selected experiences in developing national models for the purpose of aiding national policy making were also discussed at length.

To be ready for the next rounds of negotiations, countries will need modelling experts to project, evaluate and assess various scenarios of national contributions. The success of both the research exchange and the summer school demonstrate how national expertise is fervently under development in several fast-emerging economies and developing countries.

Figure 8: Students and faculty at the CD-LINKS Summer School on Integrated Assessment Models: A Tool for Science-Based Policy Making in Venice, Italy in July 2019.

Interactive Policy Tools

For effective dissemination and communication of research results, the CD-LINKS consortium has developed a series of interactive policy tools that are easily accessible to enable further exploitation by the science and policy communities. These tailor-made, open-access data and visualisation tools respond to diverse user needs and include (i) an atlas of climate policy barriers, (ii) a global stocktake indicator tool, (iii) an energy investment tool, (iv) two extensive open- access web-based databases of global and national low-carbon development pathways, and (v) a detailed climate policy database. Further details about each tool are provided below.

Atlas of Climate Policy Barriers

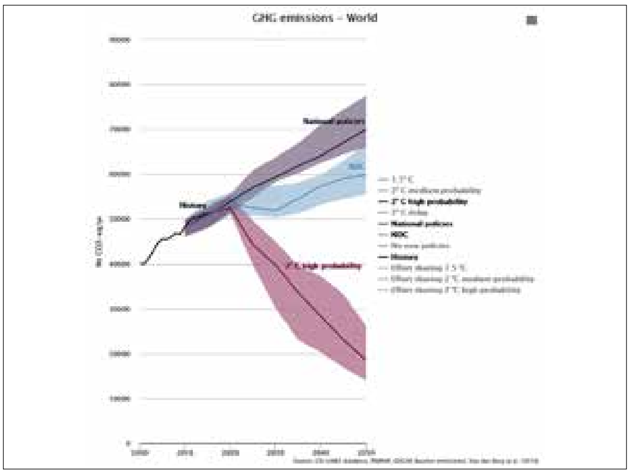
The Atlas of Climate Policy Barriers is an online map tool that visualizes data representing key implementation barriers and challenges to climate policy, ranging from committed emissions to subsidies to fossil fuels, from clean energy investment gaps to emissions embedded in imported goods. It aims at communicating, to a non-technical audience, the major implementation challenges, hot spots and criticalities for guiding climate and sustainable development-related policy making.

Link: https://climate-policy-barriers.netlify.com

Global Stocktake Indicator Tool

The global stocktake indicator tool measures progress towards Paris goals, but not only in terms of GHG emissions. It shows the implications of the implementation of national climate policies and how they add up to the greenhouse gas emission reductions needed to keep global warming below 2˚C or even 1.5˚C. In addition, the tool shows whether current investments, decarbonisation rates, policy coverage and innovations are aligned with long-term goals.

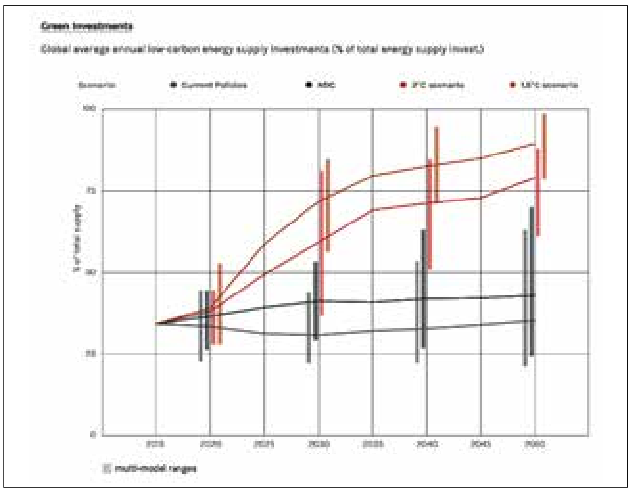
Link: http://themasites.pbl.nl/global-stocktake-indicators/



Energy Investment Tool

CD-LINKS researchers have created an interactive visualization tool that illustrates the need to markedly scale up low carbon investments if the world is to achieve the Paris Agreement's aim of keeping global warming well below 2°C or even 1.5°C. The underlying study (McCollum et al. 2018), published in the journal Nature Energy is based on scenario analysis from six different IAMs that are part of CD-LINKS.

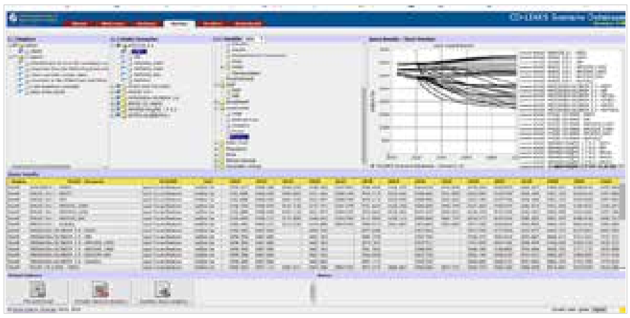
Link: http://www.cd-links.org/energy-invest-vis/



CD-LINKS Scenario Database

The CD-LINKS consortium has developed a set of consistent national and global low-carbon development pathways that take current national policies and the NDCs as an entry point for short-term climate action and then transition to long-term goals of 1.5 and 2°C as defined by the Paris Agreement. These climate policy scenarios are also used as a basis to explore synergies and trade-offs between multiple sustainable development objectives and can be accessed through an interactive scenario database.

Link: http://db1.ene.iiasa.ac.at/CDLINKSDB/



IAMC 1.5°C Scenario Explorer hosted by IIASA

The quantitative, model-based scenario ensemble assessed in the IPCC Special Report on Global Warming of 1.5°C (SR1.5) is accessible through the IAMC 1.5°C Scenario Explorer hosted by IIASA. The ensemble contains more than 400 emissions pathways which focus on limiting temperature rise to below 1.5°C or 2°C above pre-industrial levels. The scenarios were developed by more than a dozen research teams from around the world and provide information on socio-economic development, energy system transformations and land use change until the end of the century.

Link: http://data.ene.iiasa.ac.at/iamc-1.5c-explorer/

Climate Policy Database

The Climate Policy Database collects information on currently implemented policies related to climate change mitigation from countries worldwide. The objective of the portal is to provide an open, collaborative platform for quick information access, policy analysis and good-practice sharing.

Link: http://climatepolicydatabase.org/

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The special issue summarizes the project's insights from the international modelling comparison. These papers explore the diversity of the national approaches, including differences across countries with respect to the requirements for the deployment and upscaling of new technologies, investment and finance needs, and regional (near-term) gaps or inconsistencies compared to the aspirations implied by the long-term objectives of 1.5°C and 2°C. This also includes a critical assessment of whether current policies are on track for achieving the NDCs.

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