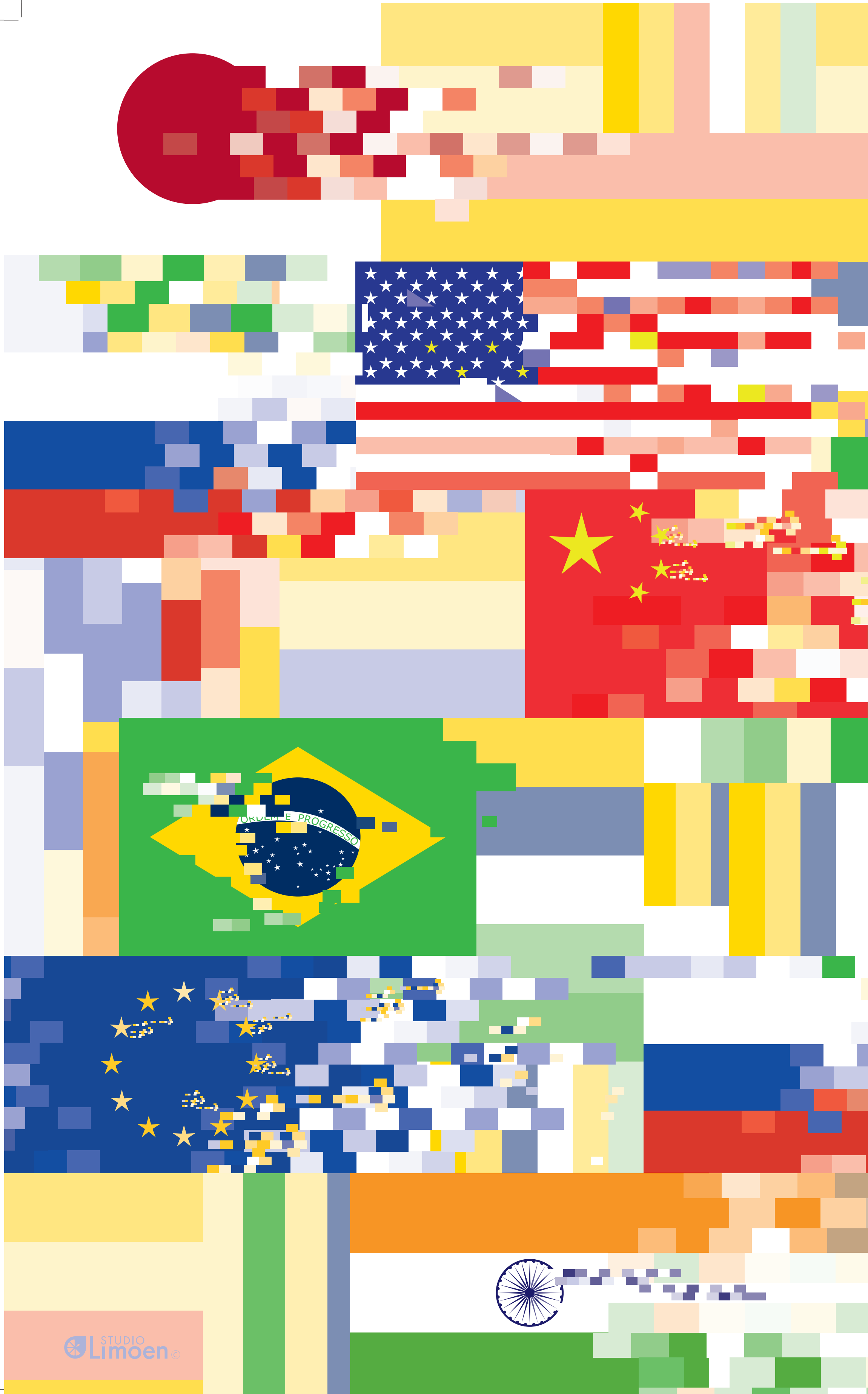

Capturing climate actions in long-term scenarios

Mark Roelfsema

CAPTURING CLIMATE ACTIONS IN LONG-TERM SCENARIOS

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Integrated assessment modelling of state policies and non-state actions implemented to limit global temperature increase to 2 or 1.5 degrees Celsius

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ISBN: 978-90-393-7495-5
Cover design: Angeliek Caelen | www.studiolimoen.nl
Lay-out: Publiss | www.publiss.nl
Print: Ridderprint | www.ridderprint.nl

Provided by thesis specialist Ridderprint, ridderprint.nl

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HOE VANG JE KLIMAATMAATREGELEN IN LANGE-TERMIJN SCENARIO'S?

Modellering van de impact van klimaatbeleid van overheden en maatregelen van niet-statelijke actoren die de mondiale temperatuurstijging onder de 2 of 1,5 graden Celsius moeten houden

Proefschrift

ter verkrijging van de graad van doctor aan de
Universiteit Utrecht
op gezag van de
rector magnificus, prof.dr. H.R.B.M. Kummeling,
ingevolge het besluit van het college voor promoties
in het openbaar te verdedigen op

vrijdag 16 september 2022 des middags te 12.15 uur

door

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The research reported in this dissertation was carried out at the 'Copernicus Institute for Sustainable Development, Faculty of Geosciences, Utrecht University' and the 'Climate, Air and Energy' department of the 'PBL Netherlands Environmental Assessment Agency'. The research was funded by the European Union's Horizon 2020 research and innovation programme under grant agreements no. 642147 (CD-LINKS), no. 821471 (ENGAGE) and no. 837089 (SENTINEL).

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CHAPTER 1

Introduction

1.1 BACKGROUND AND SCOPE

Both mitigation and adaptation are vital to address climate change. Adaptation reduces impacts and risks by making systems less vulnerable to climate change, while mitigation strategies limit climate change by reducing greenhouse gas emissions or removing these gases from the atmosphere. The focus of this thesis is on mitigation. The mitigation strategies would need to result in climate actions which can be understood as the 'choices and behaviour of international organisations, governments, civil society, businesses, and individuals' (Tosun, 2022). An important milestone in this context was the establishment of the United Nations Framework Convention on Climate Change (UNFCCC) in which national governments jointly agreed to mitigate emissions to avoid "dangerous anthropogenic interference with the climate system" (UNFCCC, 1992). Although climate change is a process that takes place at the global scale, mitigation measures need to be taken locally. This makes both domestic action and international cooperation necessary. Countries need to rely on the actions of other countries, for example in terms of reducing emissions, technology development, and economic impacts. In addition, climate actions from business, cities, and regions are vital for on the ground implementation.

The 2015 Paris Agreement presented a critical step in international climate policy. It included an agreement on a concrete and ambitious long-term climate goal and called for national contributions to mitigation, adaptation and finance, and for setting up a monitoring process to track progress towards the long-term goals. The Paris Agreement was a result of a process that started with the 1992 UN Framework Convention on Climate Change (UNFCCC) that defined the contours of the process, and that has resulted in several agreements, including the 1997 Kyoto Protocol (UNFCCC, 1998), the 2010 Cancun Agreements (UNFCCC, 2010b), and the 2015 Paris Agreement (UNFCCC, 2015g).

Throughout this process, policymakers were informed about the latest insights by scientists. Climate policy was assessed and summarised in reports by the Intergovernmental Panel on Climate Change (IPCC) that respond to requests from the parties to the UNFCCC on specific climate matters. In addition, since 2010, the UNEP Emissions Gap reports have provided an annual assessment of the collective short-term efforts towards meeting the long-term temperature goals. Important topics in these reports and the climate negotiations are the relationship between emissions and climate change, impacts, the options for climate change mitigation, mitigation costs, sustainable development, equity, finance and technology transfer. In this context, integrated assessment models (IAMs) are important tools to assess the impact of climate mitigation captured in long-term climate policy scenarios and results from these models feature prominently in the IPCC reports (Van Beek et al., 2020).

The research underlying this thesis has been performed during part of the period in which the negotiations and policy support took place, i.e. from the Copenhagen Accord in 2009 to the climate conference in Glasgow 2021. During this period, climate policy developed from a failed attempt for binding targets at the national level to an elaborate system of ambitions and action at various scales. However, so far, it has not been able to bend the global emissions trend.

1.1.1 A short history of greenhouse gas emissions and the climate negotiations

Greenhouse gases exist in the atmosphere that absorb and re-emit infrared radiation (UNFCCC, 1992). They can be of both natural and anthropogenic origin. In fact, without the natural concentration of greenhouse gases in the atmosphere, the earth would be about 30 degrees colder than it is today. In recent times, however, humans have added an additional amount of greenhouse gases to the atmosphere (see Figure 1-1a), resulting in increasing global temperatures. The radiative forcing defines the balance between incoming sunlight and outcoming radiation. The change in forcing due to anthropogenic substances (greenhouse gases and aerosols) in 2011 was 2.29 W/m2 higher than the year 1750 (Flato et al., 2013).

Greenhouse gas emissions are mainly regulated through UNFCCC, but certain gases that also effect the ozone layer are regulated by the Montreal Protocol (UNFCCC, 1998). Those that fall under the UNFCCC are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and fluorinated-gases (F-gases). F-gases include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), SF6, and since the Paris Agreement also NF3. To get an idea of their aggregated impact, greenhouse gas emissions can be added if they are translated using the Global Warming Potential (GWP) metric in terms of CO_2-equivalent (CO_2eq), that represents the heat absorbed by the gas relative to the heat absorbed by the same mass of CO_2 over a defined period of time.

The UNFCCC is the first climate agreement and forms the framework for subsequent agreements. UNFCCC resides under the United Nations' umbrella. It was initiated at the Rio Earth Summit in 1992 and entered into force in 1994 (see Figure 1-1b). This framework has the principal objective '*to stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system*', secured in Article 2 of the Convention (UNFCCC, 1992).

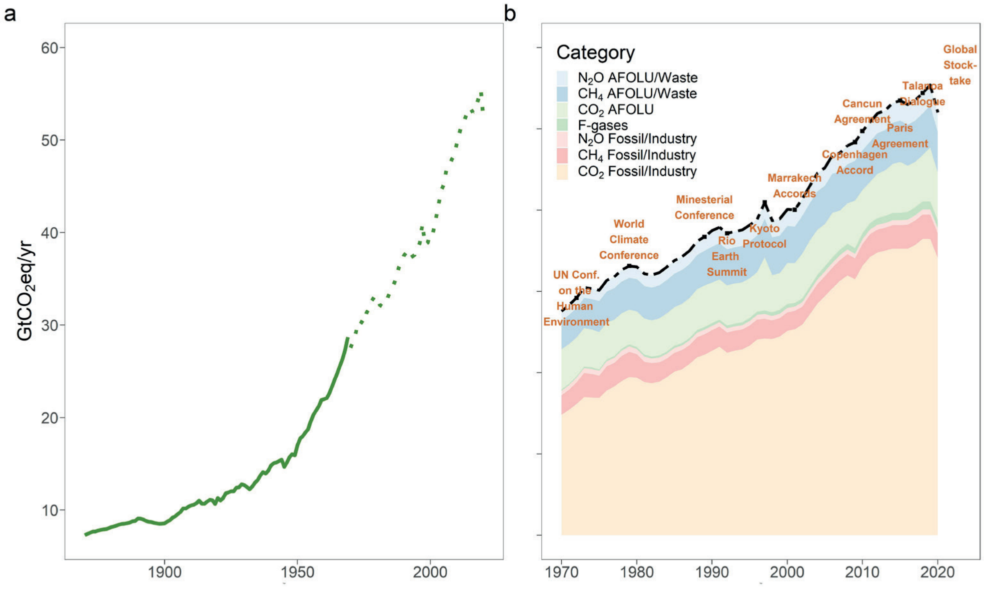

Figure 1-1 a) Anthropogenic greenhouse gas emissions between 1870-2020 period (with AR4 GWPs). b) and in the 1970-2020 period together with relevant moments in the international negotiations. LULUCF=Land Use and Land Use Change and Forestry. The left panel excludes LULUCF and bunker emissions; the right panel includes all emission categories. Sources: (1970-2020) (Friedlingstein et al., 2020) for historical CO2 fossil, industry and land use. (Gütschow et al., 2016) for historical non-CO2 fossil, industry and waste. (FAO, 2020) for historical non-CO2 land use and agriculture (Non-CO2 land use is kept constant between 1970 and 1990). (1870-1969) same as 1970-2020, only (van Aardenne et al., 2001) for Non-CO2 Waste, agriculture and LULUCF

After the UNFCCC entered into force, a process started to formulate concrete reductions goals. In 1995, the Berlin mandate secured the decision that in 1997 at COP3 industrialised countries should take the first steps in emission reductions, while developing countries were allowed to follow later (Aldy and Stavins, 2012). This resulted in the Kyoto Protocol in 1997, in which developed countries (Annex I Parties) agreed to individual legally binding emission reduction targets in the 2008-2012 period compared to 1990. In addition, the agreement provided for market mechanisms such as GHG-emission trading. Although the USA under the Clinton Administration signed the Kyoto Protocol, the Bush administration, after taking office in 2001, declared the Kyoto Protocol fatally flawed (Bush, 2001) and did not ratify it as developing countries did not participate in taking reductions (US Senate, 1997; den Elzen and de Moor, 2002; Kuyper et al., 2018). The 2001 Marrakech Accords included agreements on the rules of meeting the targets that were included in the Kyoto Protocol. The Kyoto Protocol finally entered into force in 2005. In 2012, Canada left the Kyoto regime, and Japan failed to comply with the emission reduction targets (Rosen, 2015). Japan did not participate in the second commitment period from 2013 to 2020, as well as Russia and New Zealand.

A new process was started in 2007 and secured in the Bali Action Plan (UNFCCC, 2007) to set emissions reduction targets beyond the Kyoto Protocol. This process was planned to lead to a universal agreement on binding emission targets at the Copenhagen climate summit in 2009. Although an accord was on the table (UNFCCC, 2009), it was only taken note of by the Parties of the Conference (COP). This summit is generally regarded as a failure as no consensus was reached, although it contained some strings for further actions (Dubash, 2009; Carter et al., 2011). One year later, the Cancun Agreements (UNFCCC, 2010b) secured the limit to keep global average temperature increase below 2 °C above pre-industrial levels and the country pledges, both put on the table during and after the Copenhagen summit.

Since Copenhagen, the idea of legally binding targets underlying the Kyoto Protocol was abandoned. New negotiations started in Cancun and Durban to set a new, more hybrid system that sets global targets but allows countries to formulate their own contributions. The Paris Agreement was adopted in 2015 and included three main goals: 1) ‘hold global temperature increase well below 2 °C above pre-industrial levels, and to pursue efforts to hold it below 1.5 °C’, 2) ‘increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production’, and 3) ‘making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development’ (UNFCCC, 2015g). In contrast to the Kyoto Protocol, the Paris Agreement mandates voluntary contributions, representing a shift from top-down to a hybrid architecture that also encourages non-state actors’ involvement and broadens the scope beyond mitigation to adaptation and climate finance (Kuyper et al., 2018).

In 2018 at COP24 in Katowice, Poland, the Katowice climate package was agreed on, including a rulebook for NDCs (except for Article 6 on market mechanisms). The rulebook was completed and NDCs were updated in 2021 as part of the Glasgow Climate Pact (UNFCCC, 2021a). With rules set, a new phase starts for the climate negotiations with a strong focus on implementation.

1.1.2 Global long-term goals, domestic short-term targets, and non-state climate actions for mitigation in the context of the climate negotiations

The temperature goals agreed in the Paris Agreement sprouted from discussions on what climate change is tolerable or acceptable. The first official reference to long-term climate goals was put forward in the United Nations Framework Convention on Climate Change to '*stabilise greenhouse gas emissions to prevent dangerous anthropogenic interference with the climate system'* (UNFCCC, 1992). Since the establishment of the UNFCCC, this also resulted in discussions around individual country reduction targets. Although the first indications of required country reductions were included in the UNFCCC agreement (UNFCCC, 1992), the first concrete country reduction commitments were captured in the Kyoto Protocol (UNFCCC, 1998). Since the Paris Agreement, also non-Party Stakeholders to the UNFCCC are requested to commit to climate action.

At the 1972 UN Conference on the Human Environment, assessments of dangerous levels of global warming were presented (UN, 1972). A few years later, Nordhaus (1977) mentioned 2 °C as a normal variation of a stable climate regime based on the temperature records from the current interglacial period. Subsequently, the first World Climate Conference was held in 1979, where climate change was considered a serious problem and a call for action was made to act before the year 2000 when the relation of humanity to the planet was bound to change (WMO, 1979). At the 1985 International Conference on the Assessment of the Role of Carbon Dioxide and Other Greenhouse Gases in Climate Variations and Associated Impacts at Villach Austria, scenarios projecting emission levels over the 21st century were presented for the first time. Supported by the Advisory Group on Greenhouse Gases (AGGG), between 1987 and 1989, experts proposed a target warming rate of one-tenth °C per decade (IPCC, 1991), and additionally proposed to limit total global warming to one or two degrees Celsius (Oppenheimer and Petsonk, 2005). Furthermore, after a series of international meetings, the Intergovernmental Panel on Climate Change (IPCC) was established by the WMO and UNEP in 1988 to assess the existing knowledge on climate change (WMO and UNEP, 1988).

An explicit goal to reduce CO_2 emissions was discussed at the first ministerial climate conference in 1989 in Noordwijk, The Netherlands. Although no agreement was reached, the conference proposed to keep climate change within "tolerable limits", which could require 50% reductions of total greenhouse gases, and encouraged the IPCC to assess the target of 20% CO_2 reductions by 2005 relative to 1988 levels (Netherlands Ministry of Housing & Environment, 1989; IPCC, 1991), see Table 1-1. The latter was already introduced at an international conference in Toronto in 1988 (Samson, 2001).

Table 1-1 Goals and targets proposed and agreed since 1990 in the international climate conferences.

Agreement	Goals and targets
Toronto (1988)	(proposal): 20% reduction of GHG emissions by 2005 relative to 1988 levels
Noordwijk (1989)	(proposal) : Keep climate change within tolerable limits
UNFCCC (Rio Summit) (1992)	Stabilisation of greenhouse gas concentrations in order to prevent dangerous anthropogenic interference with the climate system
	(non-binding) : Stabilise GHG emissions at 1990 levels by 2000
Kyoto Protocol (1997)	(binding): 5% reduction by 2008-2012 relative to 1990 as a result of emission reductions in developed countries
Copenhagen Accord (2009); Cancun Agreements (2010)	Reducing GHG emissions so as to hold the increase in global average temperature below 2 °C above pre-industrial levels
	(Voluntary): Cancun pledges
Paris Agreement (2015)	Hold temperature increase above pre-industrial to well below 2 °C and efforts to keep temperature below 1.5 °C (Article 2.1a)
	Peaking of greenhouse gas emissions as soon as possible (Article 4.1)
	Achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century (Article 4.1)

The first convention to set a real long-term goal was the 1992 UNFCCC United Nations Framework Convention on Climate Change (UNFCCC). It proposed to limit global warming in order to prevent dangerous anthropogenic climate change. In addition, it also included a non-binding aim to stabilise GHG emissions at 1990 levels by 2000 (Article 4.2b). A few years later, the Kyoto Protocol (UNFCCC, 1998) elaborated on the UNFCCC objective by including individual commitments from industrialised countries (Annex I) for the 2008-2012 period. These countries committed to legally binding individual country reduction targets (QELROs), which on average would reduce annual GHG emissions by at least 5.2% below 1990 levels. However, due to the withdrawal of the USA, expected surplus emission credits (i.e. hot air), and use of land-use credits, the ultimate aggregated reduction target was reduced significantly (den Elzen and de Moor, 2002).

In 2009, the Copenhagen Accord included the first official reference to a temperature goal, stating that '*deep cuts in global emissions are required … with a view to reduce global emissions so to hold the increase in global temperature below 2 °C'* (UNFCCC, 2009). As there was no full agreement on the Copenhagen Accord, it was only taken note of by the Conference of Parties (COP) to the UNFCCC (Rogelj et al., 2010). National pledges for 2020 were put on the table during and after the conference, consisting of 42 reduction targets from developed countries and 43 from developing countries (UNEP, 2016a). One year later, the Cancun Agreements resulted in a clear path post-2012 (Rajamani, 2011), acknowledged the 2 °C temperature goal, and mentioned that lowering that maximum to 1.5 degrees Celsius in the near future will be considered. In addition, the country pledges were anchored in the Cancun Agreements but had no legal standing in the UNFCCC process (Rajamani, 2011).

The Paris Agreement finally solidified that temperature targets in a real overall treaty. It adopted "the limit to hold global temperature increase well below 2 °C above pre-industrial levels" and also adopted the addition "to pursue efforts to hold it below 1.5 °C" (UNFCCC, 2015g). To achieve this global goal, the Paris Agreement requires countries to communicate Nationally Determined Contributions describing their efforts to achieve the overall goals and to implement domestic mitigation measures to achieve these Contributions (ibid). Already 159 countries submitted Intended NDCs (INDCs) before the Paris summit (Pauw et al., 2018), while in the first quarter of 2021, 191 Parties have submitted an NDC and eight have also updated it (UNFCCC, 2021b).

Scenarios to explore long-term goals

Scientists support the process of international climate policy in many ways. For instance, climate scientists provide information on changes in the climate system as a result of emitting greenhouse gas emissions, other scientists assess future climate impacts at different levels of climate change, and yet another group provides information on mitigation options and expected emissions. An important tool to explore long-term policy goals are so-called model-based scenarios. Scenarios are developed that reveal possible greenhouse gas emission pathways to support the deliberations on emission levels linked to tolerable limits of climate change and implied country reduction targets (see Section 1.3 for details on methodology). The emissions scenarios are projections of future emissions based on socio-economic assumptions such as GDP and population combined with different assumptions on emission control policies (Houghton et al., 1994). The results of scenario studies are summarised in the IPCC reports that provide policymakers with scientific assessments on climate change. The scenarios are developed with integrated assessment models that describe the interaction between the human and natural systems to provide policy-relevant information (Houghton et al., 1994). Specifically, integrated assessment models provide information on the development of the energy and agriculture systems and resulting greenhouse gases and air pollutants emissions and the possible consequences for climate change. The models can be used to develop scenarios that describe current trends and policies and identify least-cost solutions for prescribed climate goals.

In the first assessment report of the IPCC, emission scenarios (IS90) were included of possible future greenhouse gas emissions consisting of a business-as-usual scenario where no or a few steps to reduce emissions are taken and three scenarios that take additional measures to reduce emissions (Girod et al., 2009). In 1992 the IPCC published a supplement with the first official set of scenarios (IPCC, 1992) (IS92) that were developed for the 1994 Special report to the Conference of Parties (COP) to the UNFCCC. The IS92 scenarios describe a wide range of possible future emissions but exclude coordinated policy responses (IPCC, 1992).

The WG III IPCC third assessment report (TAR) included a new set of scenarios that were defined as 'alternative images of how the future might unfold and an appropriate tool with which to analyse how driving forces may influence future emission outcomes and to assess the associated uncertainties' (IPCC, 2001). These scenarios were documented in the Special Report on Emissions Scenarios (SRES) (IPCC, 2000). They were divided into four storylines that differ across two dimensions: globalisation/regionalisation and economic/environmental focus (see Figure 1-2a). Like the SA92 scenarios, they did not incorporate explicit climate policies.

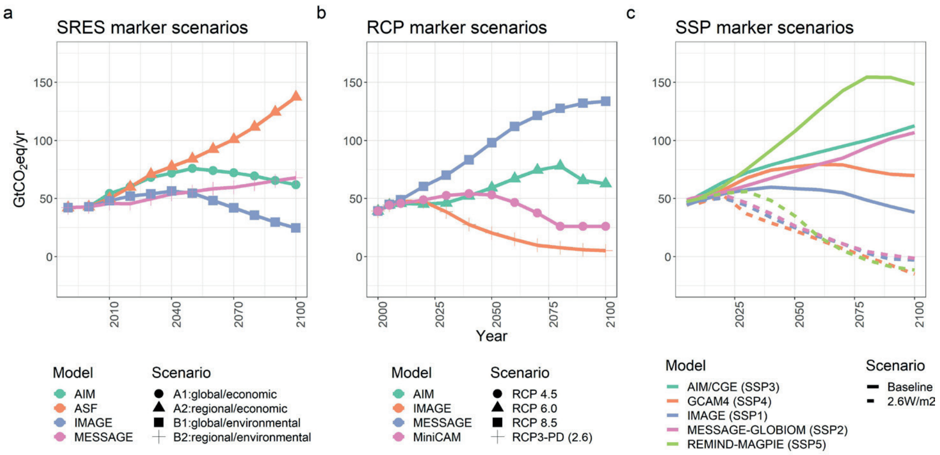

Figure 1-2 SRES, RCP and SSP marker scenarios (GHG emissions have been aggregated with the Global Warming Potential of the IPCC SAR. Sources: (Nakicenovic et al., 2000; Fujino et al., 2006; Clarke et al., 2007; van Vuuren et al., 2007, 2011a; Riahi et al., 2017; Rogelj et al., 2018a; Gidden et al., 2019)

The IPCC Fourth Assessment report presented for the first time a range of mitigation scenarios that illustrated different stabilisation levels. These scenarios assume given levels are achieved by minimising discounted mitigation costs over the century. This was further elaborated in the RCPs (Moss et al., 2010; van Vuuren et al., 2011a) that include four main pathways focussing on the stringency of climate policy and not on socio-economic drivers (see Figure 1-2b). The scenarios range between a low 2.6 W/m^2 target for the year 2100 (van Vuuren et al., 2007, 2011b), consistent with a likely chance (>66%) to limit temperature increase below 2 °C (Clarke et al., 2014), and a very high 8.5 W/m^2 target (Riahi et al., 2011). The discounted mitigation costs are minimised between 2010 and 2100. For each radiative forcing level, one marker scenario was selected from an individual integrated assessment model.

Following the development of the RCPs, the Shared Socioeconomic Pathways (SSPs) combined 'socio-economic conditions' that impact mitigation and adaptation levels with climate policy stringency (van Vuuren et al., 2012), that also includes the SSP2 scenario with intermediate challenges (Fricko et al., 2017; Rogelj et al., 2017), see Figure 1-2c. Socio-economic challenges for adaptation and mitigation are low in SSP1, high in SSP3, adaptation dominates in SSP4, and mitigation in SSP5 (van Vuuren and Carter, 2014). Discounted mitigation costs are minimised between 2020 and 2100. In the context of the IPCC 1.5 °C report (IPCC, 2018a), scenarios were added that limit end-of-century radiative forcing to 1.9 W/m^2 that keep the global temperature in 2100 well below 1.5 °C (Rogelj et al., 2018a). The 1.9 W/m^2 scenarios that start in 2020 with deep mitigation reach net negative GHG emissions around 2070.

Box 1-1 Long-term scenarios presented in the IPCC reports

1.1.3 Short-term policy targets in the context of long-term goals

The Paris Agreement requests a periodic stocktake of collective progress in implementing national policies to reach long-term temperature goals (UNFCCC, 2015g). Climate policies are implemented at the national scale and often with a time horizon of less than ten years. At this point in time, national policies (and NDCs) focus primarily on 2030 emission levels. To verify collective progress, it is possible to compare the projected impact of policies in 2030 with optimal emission pathways that keep the world on track to hold the temperature well below 2 °C or even 1.5 °C. Although not officially requested by the Parties to the UNFCCC, such evaluations are annually provided in the UNEP Gap report. This assessment was already done in 2010 for the 2020 Copenhagen and Cancun pledges (UNEP, 2016a) and the 2 °C temperature limit. It showed that the world was not on track in terms of implementing climate policy compared to the 2 °C scenario. Now, ten years later, that message is still the same, but now for assessing the impact of NDCs in 2030 compared to pathways that start with deep mitigations in 2020 and limit the temperature increase to well below 2 °C or 1.5 °C (UNFCCC, 2016).

Progress towards meeting long-term temperature goals is assessed by comparing aggregated national pathways with global long-term mitigation scenarios (see Box 1-1). These global scenarios demonstrate global cost-effective pathways until the end of the century. Climate policy implemented to achieve global climate goals is generally implemented in the models through carbon taxes after 2010 or 2020. This leads to pathways that incorporate both energy efficiency improvements and increase the use of nuclear power and renewables, carbon capture and storage (CCS) and bioenergy (van Vuuren et al., 2011b) relative to the no-policy (SSP) baseline. Different scenarios are possible due to different assumptions that hold for mitigation levers such as global energy demand, decarbonisation of energy production (i.e. technology costs, resource potentials and system integration (Luderer et al., 2014; van Vliet et al., 2014)), development of land-use management systems, and the pace and scale of carbon dioxide removal (Warszawski et al., 2021), but also the start of deep emission reductions (den Elzen et al., 2010; van Vliet et al., 2012). Variants in policy implementation are reflected in the SSPs through shared policy assumptions that could reflect different regional reduction targets, emission trading, burden sharing, use of policy instruments or regional exclusion of the policy regime due to implementation limits or obstacles (Kriegler et al., 2014).

To assess collective action of countries, global scenario pathways need to explicitly incorporate the domestic Cancun pledges and NDCs. The Cancun pledges describe intended emission reduction targets for countries relative to a base year (and whether they include LULUCF credits) or Nationally Appropriate Mitigation Actions (NAMAs) from least developed countries that in some cases are defined relative to a baseline scenario (UNFCCC, 2009, 2011b, 2011a). Some pledges are conditional on the ability to enact domestic laws, ambitious action from other countries, or financial and technical support (UNEP, 2016a). Since the initial reporting year, Japan, Kazakhstan and New Zealand changed their pledges (UNFCCC, 2011a). Before the Paris Agreement, countries submitted Intended Nationally Determined Contributions (INDCs) for 2025 or 2030, including emissions reduction targets or actions to reduce emissions. There is no differentiation between developed and developing countries, and countries are requested to include their fair contribution. In many cases, the NDC targets are conditional on finance or technical support. Some countries, such as China and India, included emissions intensity targets (relative to GDP), non-fossil targets and forestry targets. The NDC targets can generally be categorised into absolute reduction targets, reduction relative to business-as-usual, emission intensity reduction targets, and reduction projects absent of explicit targets (King and van den Bergh, 2019). INDCs became NDCs once a country ratified the Paris Agreement. Under the Paris Agreement, parties must be transparent on their NDCs, but achieving the targets put forward is voluntary.

Rogelj et al (2016) estimated, based on a suite of models, that 2030 emission levels would be consistent with 55 $GtCO_2eq$ taking into account the uncertainties and conditionality of INDCs. This would lead to an emissions gap of 14 (10-16, 10^{th}-90^{th} percentile range) by 2030 with a cost-optimal pathway that implements Cancun pledges until 2020, least-cost climate policy after 2020, and keeps temperature increase below 2 °C with a probability larger than 66%. This would decrease to 11 $GtCO_2eq$ if conditional pledges would be achieved (ibid). The UNEP emissions gap report updates this analysis every year and also includes 1.5 °C pathways (>50% probability and >66% probability) since 2016.

1.1.4 Alternative or complementary routes: non-state and subnational climate action

As shown in Section 1.1, current global greenhouse gas emissions are still increasing despite the action described in the previous sections (with a temporal dip in 2020 due to Covid-19). This means that further strengthening of national and international climate policy is needed. In addition, it might be attractive to explore new, additional forms of climate action (Jordan et al., 2015). Although climate policy is often formulated on the international and national level, implementation of measures occurs mostly on the local level accompanied by additional local policies. Some scholars and policymakers consider subnational and non-state action as a replacement for international inaction, but others conclude that it should be seen as a complement within the polycentric governance of climate change (Slingerland et al., 2011; Chan et al., 2016; Andonova et al., 2017). For example, subnational actors that act on climate change in parallel with national governments could fill the gap caused by missed opportunities (Hsu et al., 2015). One of the first examples of transnational governance was the municipal networks such as the Climate Alliance and Local Governments for Sustainability (ICLEI), established in the early-1990s. Renewed attention started in the mid-2000s following the ratification of the Kyoto Protocol (Bulkeley and Newell, 2015). In 2002, public-private partnerships on biodiversity and energy were established at the World Summit for Sustainable Development (WSSD) in Johannesburg (Pattberg and Stripple, 2008).

In addition, the IPCC AR4 report discussed these actors for the first time and described voluntary actions by subnational governments and corporations (IPCC, 2007).

Governance and cooperation beyond the UNFCCC often take place in international cooperative initiatives (ICIs) or transnational governance networks (TGN) that operate outside the UNFCC orchestrated by a small group of countries or intergovernmental institutions (e.g. World Bank, OECD) and often include business, sub-national government, NGOs, academia (Andonova et al., 2009; Hale and Roger, 2014; Widerberg and Pattberg, 2015). There exist different types of cooperative initiatives, those that only include public actors, those that include both public and private actors, and those that only include private actors (Andonova et al., 2009; Bulkeley and Newell, 2015). There is a large variation of ICI participation, but it is highest in countries with strong national policies (Andonova et al., 2017). The role of these initiatives is to provide information and network opportunities, support actors to adopt commitments to reduce emissions or energy use, or facilitate implementation with finance or transparency (Hale and Roger, 2014; Bulkeley and Newell, 2015).

A unique addition to the Paris Agreement was the specific text on the contribution of non-Party stakeholders who can attend the negotiations as an observer or as part of a national delegation. They are present to influence states, represent excluded groups such as indigenous peoples, or monitor national action (Bäckstrand et al., 2017; Kuyper et al., 2017). The stakeholders are also companies, cities and other organisations and can contribute to emission reductions. The Paris Agreement welcomes non-Party stakeholders to scale up climate action and registration of this in the Non-State Actor Zone for Climate Action (NAZCA[1]) platform (UNFCCC, 2015g), currently known as the Action Portal (GCAP). This platform was already launched at COP20 (2014) in Peru as part of the Lima-Paris agenda which was renamed to the Global Climate Action Agenda (GCAA) at the Paris Agreement's adoption. Along these lines, the Marrakech Partnership for Global Climate Action was established at COP22 to encourage and facilitate global climate actions of non-Party stakeholders and strengthen the collaboration between governments and key stakeholders (UNFCCC).

In contrast to Tosun (2022), we make a distinction between climate policy from national governments and climate actions from non-state and subnational actions. Therefore, we define 'climate action' as '(voluntary) commitments to act on climate change which come from individual or cooperative initiatives of countries, regions, companies, investors or other organisations (UNFCCC, 2020). These commitments aim to reduce emissions or strengthen climate resilience (Chan et al., 2016). For mitigation, they can be entity-wide emission

[1] https://climateaction.unfccc.int/views/about.html

reduction targets or target more specific quantities such as renewable energy or fuel efficiency from specific activities or sectors. Due to the voluntary nature of these initiatives, it is difficult to assess the commitments and contribution to climate change mitigation (Widerberg and Pattberg, 2015). However, they might provide the option to tighten or close the emissions gap if they increase the effectiveness of implementing mitigation measures, and were seen in 2012 to potentially decrease global emissions by 10 $GtCO_2eq$ by 2020 (Blok et al., 2012).

1.2 AIM OF THE THESIS

This thesis aims to contribute to the understanding of the impact of domestic mitigation strategies in the context of the internationally agreed long-term climate goals. To achieve the global temperature goals, countries are implementing domestic policies guided by the reduction targets from the 2020 pledges and 2030 NDCs, often supported by climate action from non-state and subnational actors. Policymakers and the wider public would need to be informed on the impact of the implemented policies and reduction commitments to see if this would set the world on a pathway to keep temperature increase below 2 °C or 1.5 °C, and if not, what options are available to change course. Furthermore, if not, what options are available to tighten the possible emissions gap? This thesis focuses on key aspects of this, i.e., the emissions trajectories resulting from current policies and the options to strengthen existing climate policy. The research question of this thesis is:

What is the impact on greenhouse gas emissions of implemented climate policy, climate actions, and potential enhancements towards limiting global temperature change to below 2 °C and 1.5 °C above pre-industrial levels?

This raises the following four sub-questions:

1. How can integrated assessment models evaluate current domestic climate policy in the context of long-term temperature goals? (Chapter 2)
2. Are countries on track to meet their 2020 pledges and 2030 NDCs with current policies? (Chapter 3 and 4)
3. How can countries tighten the 2030 emissions gap between NDCs and the well below 2 °C temperature targets and scale up their domestic climate action? (Chapter 5)
4. To what extend can sub-national and business actors contribute to closing the global gap, and how much are actions from these actors additional to national government implementation? (Chapter 6 and 7)

Naturally, this thesis will not address all relevant topics in the context of international climate policy. For instance, we will not discuss the socio-economic impacts of climate policy such as distributional consequences, needed institutional capacity, underlying financial mechanisms, necessary technology transfer or the potential of behavioural change.

1.3 METHODOLOGY

The research questions will be answered by scenario analysis developed with integrated assessment models. The focus is on assessing the impact of climate policies on greenhouse gas emissions with different timing of implementation and target stringency.

1.3.1 Integrated assessment models

Many of the chapters in this thesis present the results of integrated assessment models. Most results are based on or include the IMAGE model (Stehfest et al., 2014). Integrated assessment models represent interactions between the human and earth system, including climate change. Human actions impact the earth system, among others, by emissions of greenhouse gases and land use. The human system consists of people (population), the economy, energy- and agriculture-, and water systems. The earth system encompasses, among others, the climate system, ecosystems, biodiversity and the atmosphere. The negative impacts of humans on their environment can be reduced by various actions, including behavioural change and switching technologies set in motion by policy implementation or innovation.

The integrated assessment models are simplified, stylised, numerical approaches to the complex systems they represent (Clarke et al., 2014). All integrated assessment models have the fundamental characteristic that they optimise aggregate economic costs (in some way) to achieve a specific mitigation goal (Clarke et al., 2014). They can be used for cost-benefit analysis, cost-effectiveness analysis and exploration of possible images of the future (IPCC, 2007). These models have evolved from global representation to those incorporating different scales – spatial, temporal, and sectoral (Fisher-Vanden and Weyant, 2020). Furthermore, integrated assessment models can differ in the representation of the human and earth system. General equilibrium and macro-econometric models represent the full economy, while other models only use economic input, but have a more detailed representation of processes and technologies (IPCC, 2007). In addition, some models have perfect foresight and optimise over time, while others (recursive-dynamic models) make decisions at each point in time based on the currently available information (ibid). Besides these model type characteristics, models can also differ in terms of geographical-, and sectoral coverage (e.g. including/excluding land use), greenhouse gases included (CO_2 only, or all greenhouse gas emissions), as well as sectoral detail (e.g. residential and commercial buildings).

Global integrated assessments have informed policymakers since the start of the climate negotiations. Over the years, integrated assessment models adopted various roles between science and policy, from agenda-setting in early phases to target-setting and monitoring political ambition for mitigation in later phases (van Beek et al., 2020). Since 1990, insights into different climate mitigation strategies that address climate change have been periodically published in IPCC Working group III reports. The scenarios based on integrated assessment model studies included in the WGIII IPCC reports are coordinated and collected by the Integrated Assessment Modeling Consortium[2] (IAMC). In addition, the UN Environment Programme coordinates the emissions gap report published annually since 2010, showing the current status of global climate policy implementation.

1.3.2 Strengths and weaknesses of integrated assessment models

Computer models are abstractions of reality and represent a system consisting of functionally interrelated elements forming a complex whole (Sterman, 1998; Giere, 2004). Integrated assessment models are a specific type of model that mimics the global human and earth system (see the previous section) and are used to develop long-term what-if scenarios that show different futures represented by specific decisions leading to different assumptions for key drivers such as population, GDP, energy demand, and technological change. These models make assumptions on technology, economy and human behaviour. At the same time, as they are global and long-term, detailed system representation is less apparent due to computation times and the question of whether more details lead to better insights.

The strength of integrated assessment models lies in their ability to picture the solution space of mitigation options with varying climate policy and actions, including the feedback and trade-offs between energy system, environment, and economy (Keppo et al., 2021). The focus of integrated assessment models and the feasibility of presented options is mainly on technological and economic change, while social change is underrepresented (Riahi et al., 2015; De Cian et al., 2017; Anderson and Jewell, 2019; Trutnevyte et al., 2019). The energy- and land-use system include different supply- and demand-side technologies. In addition, they represent innovation by deployment-related and R&D learning, although

[2] https://www.iamconsortium.org

cross-sectoral spillovers or co-evolution of technologies are often not included (Gambhir et al., 2019; Keppo et al., 2021). Representation of the economy depends on the type of model. Macro-economic models include feedback between the energy or land-use and economic system. In partial equilibrium models (such as the IMAGE model), the link back to the overall economic system is limited (Keppo et al., 2021).

Most integrated assessment models follow the concept of a single representative agent, although some models reflect heterogeneity of actors and institutions to a certain extent (e.g. the multinomial function in IMAGE, see Section 1.3.3) (Mercure et al., 2016; Keppo et al., 2021). In our complex society, social change is driven by behaviour from heterogeneous actors and governed by institutions. Individual actors choose to change their behaviour to take climate actions such as reducing energy use and buying climate-friendly products (e.g. rooftop PV and electric cars). These actors form part of society where governments, businesses, and other societal groups set goals and take measures to reduce greenhouse gas emissions and govern the process to achieve this. A broad definition of institutions is 'the humanly devised constraints that shape human interaction' and refers to cultural norms or collective decision-making methods such as democracy or dictatorship (North, 1990; Acemoglu and Robinson, 2010). A more narrow definition refers to formal institutions categorised into legal, political and economic (De Cian et al., 2017). However, these actor groups and institutions are not individually represented in integrated assessment models. Agent-based models do include decision making by different actor groups, but most applications focus on specific regions or sectors (De Cian et al., 2017).

Implementation of behaviour and institutions in integrated assessment models focuses on government actions, for which regulations and policies are generally represented as an exogenous shock/disruption implemented by one social planner (De Cian et al., 2017; Trutnevyte et al., 2019). In practice, this is done by adding a carbon tax, changing model input parameters or adding non-market premium costs to economic costs. Trutnevyte recommends mapping and assessing societal assumptions in integrated assessment models. (2019). However, this could lead to more complex models that might be more realistic but less tractable and interpretable (Wilson et al., 2021). In addition, behaviour and the impact of institutions are difficult to grasp in mathematical formulas. Often, this involves modelling the credibility and feasibility of governmental pledges and behaviour. Credibility is the likelihood that promises are kept and feasibility the ability to meet the mitigation costs and the availability of capacity, skill and finance (Averchenkova and Bassi, 2016). Therefore, the key question to add more system components to models is always to ask what details are necessary to capture the overall system behaviour and whether model results may be complemented by or produced in cooperation with other fields such as social science (Anderson and Jewell, 2019; Gambhir et al., 2019; Keppo et al., 2021; Wilson et al., 2021).

To understand the abstractions of integrated assessment models, it is crucial that models are transparent, describing underlying assumptions and limitations. Transparency facilitates debate and provides a clearer evidence base for policymakers (Skea et al., 2021). Nevertheless, integrated assessment models are sometimes criticised for their transparency on topics such as the representation of uncertainty, intemporal discounting, representation of capital markets and finance, economy-energy feedbacks, characterisation of technical change, land use and CO_2 removal (Gambhir et al., 2019; Keppo et al., 2021; Skea et al., 2021; Wilson et al., 2021). For this, the Integrated Assessment Model Consortium (IAMC) is

- Improving documentation (IAMC, 2021),
- helping models to publish open-source code (e.g. Huppmann et al. (2019)),
- systematically comparing different models outputs using harmonised scenario assumptions (e.g. Roelfsema et al. (2020), Fragkos et al. (2021))
- including the comparison of different diagnostic indicators (e.g. Kriegler et al. (2015a), Harmsen et al. (2021))
- and publishing scenario results in online databases (e.g. Rogelj et al. (2018b)).

However, despite these efforts, Skea et al. (2021) recommend including more methodology and assumptions in scientific papers, extending web-based model documentation, including more key inputs and outputs to online scenario databases and IPCC reports, increasing open-source character of models including 'clear explainers' and make sure policymakers grasp the implications of model assumptions.

1.3.3 The IMAGE model

The 'World 3' model can be considered the first integrated assessment model avant-la-lettre used for the Limits to Growth report instigated by the Club of Rome (Meadows et al., 1972). The report discussed and connected several socio-economic and environmental topics, such as climate change. Almost two decades later, the IMAGE[3] and ASF[4] models were the first models included in the IPCC First Assessment Report that discussed the SA90 emission scenarios produced by these models.

The IMAGE model (Stehfest et al., 2014), primarily used in this thesis, represents a relatively

[3] Integrated Model to Assess the Global Environment
[4] Atmospheric Stabilization Framework

detailed representation of both the human and earth system and provides indicators for different environmental problems, but has less detail on the economic system. It includes 26 large regions, of which several represent large countries such as China, USA, India, Brazil, South Africa. The IMAGE model is divided into an agriculture- and land use model, energy supply- and demand model, earth system model, impacts model and policy response model (see Figure 1-3).

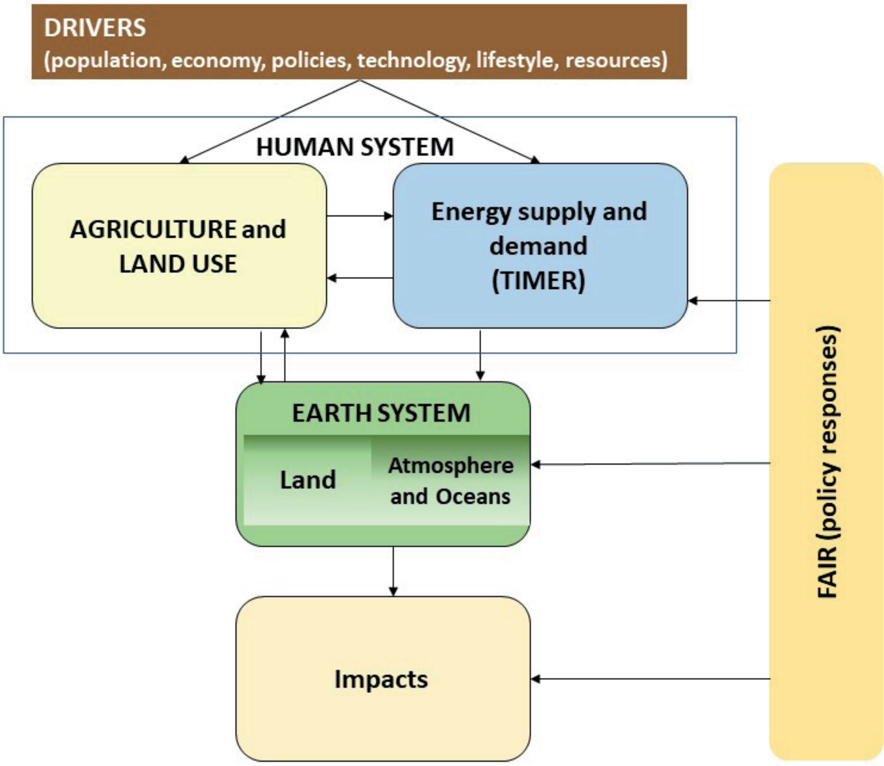

Figure 1-3 IMAGE 3 framework based on Stehfest et al. (2014)

The TIMER energy model is part of the IMAGE model. It describes the world's (annual) energy flows based on a relatively detailed technology mix for energy supply and demand sectors (transport, industry, buildings). It is a recursive-dynamic simulation model describing long-term development pathways in the energy system, including emissions from greenhouse gases and air pollution. Investments in technologies are determined by the multinomial logit function that assumes that the cheapest technology does not always capture the entire market but gets the largest market share (Edmonds and Reilly, 1985; van Vuuren, 2007). The FAIR model is used to assess long-term climate policy goals and targets. In combination with the other IMAGE components, it analyses the interaction between long-term climate goals (in terms of ppm or W/m2) and regional short-term targets based on effort sharing approaches (den Elzen et al., 2014b).

1.3.4 Scenarios

The assessment of the ex-ante impact of climate policies on greenhouse gas emissions requires statements about the future. This can be done using model-based scenario analysis. In such an approach, the results of integrated assessment studies are presented with different quantitative scenarios that picture alternative images of the future based on a consistent set of assumptions and demonstrate the impact on future greenhouse gas emissions of different drivers such as demography and economic circumstances, and also the implementation of mitigation policies (IPCC, 2000). It is important to realize that scenarios are not predictions of the future but a set of possible futures without indicating any likelihood of occurrence. Well-designed scenarios complement (qualitative) storylines highlighting the main characteristics, the relationship between key drivers and dynamics (IPCC, 2007; Fortes et al., 2015). For example, the SSP1 storyline describes a more inclusive development respecting environmental boundaries characterised by improvements in resource efficiency, human development and preferences regarding consumption and production patterns driven by rapid technological developments, low population and low pressure on land (van Vuuren et al., 2017b). The storyline needs to be translated to quantitative projections of the main (socio-economic) drivers. Together with assumptions on costs, learning, resources, technology options, and climate policy, these drivers determine the resulting emission pathways. Instead of using storylines, existing long-term policy goals can be used as point of departure for scenarios. This shows two different types of constructing model-based scenarios. One category of scenarios explores the possible consequences of different future developments (explorative scenario analysis), and a second category explores how specific goals can be accomplished (normative scenario analysis) (Fortes et al., 2015; van Notten et al., 2003) (see Figure 1-4).

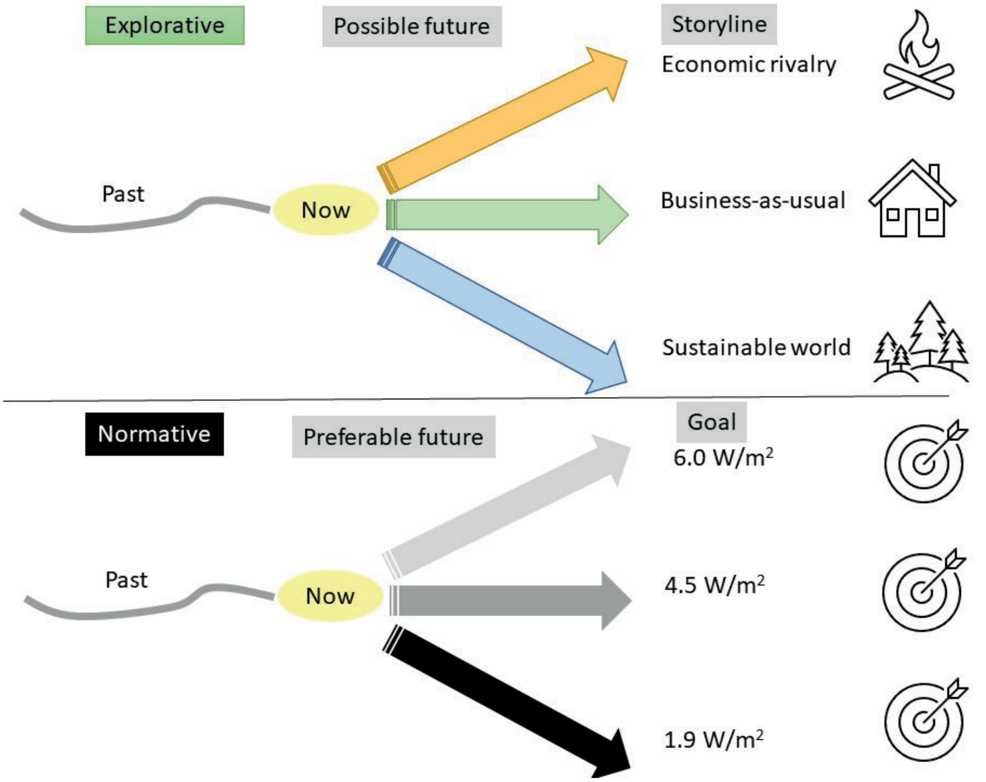

Figure 1-4 Different types of scenarios: descriptive scenarios describe different future developments, and normative explore how specific goals can be accomplished

Scenarios relevant to climate policy are internally consistent projections of the energy and land-use system and the consequences for greenhouse emissions. An example of this is the Shared Socioeconomic Pathways (SSPs) that depicts five socio-economic storylines. This is a set of explorative scenarios that can subsequently be used for climate policy analysis. Normative scenario analysis often starts with a 'baseline' scenario used as a reference scenario to measure emission reductions. It is the starting point for developing policy variants representing increasing stringency of climate policy implementation. In most studies, the baseline scenario is the SSP2 middle-of-the-road scenario (Fricko et al., 2017). Instead of the middle-of-the-road scenario, other explorative scenario variants (e.g. SSP1) can be used to give insights into the uncertainty of emission levels due to differences in key socio-economic drivers (e.g. population, urbanisation, economic growth) as a result of different human preferences or choices. SSPs represent reference pathways, also called the baselines or counterfactual scenarios, and are considered to represent the future where no new climate policies are implemented (O'Neill et al., 2014) after a base year close to the current year (often the latest year for which historical data is available). Although reference scenarios were considered business-as-usual scenarios in the past (see, for example, IPCC SAR WGIII report), this does not represent reality anymore, as more and more countries have implemented climate policies. Therefore, these scenarios merely report relative changes in climate policy implementation and are often intrinsic to integrated assessment models that apply carbon taxes to a counterfactual scenario without climate policy.

More realistic representations of current trends are 'current policies' scenarios that include implemented policies approved by national parliaments or as a result of executive orders. Additional emission reductions can be expected from policies in the pipeline to be approved or aspiration goals announced by governments (in climate plans), captured by the 'planned policies' scenario. However, national governments are not the only actors that act on climate change. The 'current policies and non-state action' scenario also includes climate actions from business and subnational (cities, regions and provinces) governments. The targets included in the Cancun pledges and Nationally Determined Contributions by individual parties to the UNFCCC are captured by the pledge/NDC scenarios, and the global long-term temperature goals that span the 21st century by the NDC and 2 °C and 1.5 °C scenarios.

1.3.5 Policy analysis

The integrated assessment of climate policies in the context of the Paris goals is a specific type of policy analysis that focuses on the ex-ante impact on greenhouse gas emissions of economy-wide policy mixes. These assessments do not analyse individual policies or other impacts of policy mixes such as distribution consequences or reasons for market, governance of behaviour failures (Bouma et al., 2019). They are also oblivious to factors that determine the outcome and effectiveness of policy instruments, such as political economy, vested interests and the like.

In general, the assessments described in this thesis start with establishing and listing effective international goals, national targets and implemented policies, and non-state and subnational climate actions (see Figure 1-5). These are translated to model parameters for implementation in integrated assessment models, and emission levels and reductions are calculated. Different scenarios are analysed by comparing the emission pathways from different scenarios.

Figure 1-5 Policy analysis of the impact of climate policies using integrated assessment models.

The integrated policy assessment borrows definitions and classifications of policies into policy goals and targets from the policy design literature, such as Howlett (2009). This includes the concept of the policy cycle for which different variants exist. In most cases, they include 'agenda setting', 'policy formulation', 'decision making', 'policy implementation 'and 'policy evaluation'. Agenda setting gets problems on the agenda of governments, policy formulation translates these problems into a proposal for specific policies, decision making deals with the questions what policies will be implemented, policy implementation is the process where governments put policies in effect, and policy evaluation monitors the outcome of the implemented policies so that the initial policy can be improved (Howlett, 2011). The assessments presented in this thesis specifically look at those policies that find themselves in the 'policy implementation' stage. However, the results of the presented assessments could play a role in the 'policy evaluation' process and (re-)set the agenda for changes to both the international climate regime and the national policy implementation process.

1.4 OUTLINE THESIS

The research questions are answered in the following chapter (see Table 1-2).

Chapter 2 first introduces a framework on how to implement climate policy in quantitative scenario analysis. This chapter discusses definitions of climate policy, presents a framework, and illustrates how this is implemented in the IMAGE model.

Chapter 3 assesses whether major economies right after the Cancun Agreements are on track to achieve their pledges for 2020. This is done by assessing how much the most effective domestic climate policies in major emitting countries would reduce greenhouse gas emissions and comparing the resulting emission levels with the Cancun pledges.

Chapter 4 takes stock of domestic climate policies to evaluate the implementation of the Paris Agreement. It provides insights into the impact of national policies compared to emission pathways consistent with the NDCs and the overall temperature goals. The emissions gaps are presented in terms of greenhouse gas emissions, low-carbon share and energy intensity for 2030 and supplemented with a brief peek for greenhouse gas emissions to 2050.

Chapter 5 introduces the idea of reducing global GHG emissions by replicating successful sector examples. This is done by evaluating the potential impact on global GHG emissions if all countries worldwide were to implement climate policies similar to successful examples already implemented by other countries.

Chapter 6 assesses the impact of a few international cooperative initiatives that have commitments outside the UNFCCC. For this, it calculates the emission level after implementing these initiatives that existed at the time of COP21 in Paris and the potential overlap with existing pledges and NDCs made by national governments in the context of the UNFCCC.

Chapter 7 assess the impact of individual actors beyond national climate action. For this, the chapter assesses the impact on global GHG emissions in 2030 of region, city, and business commitments.

Chapter 8 presents the summary and conclusions.

Table 1-2 Research questions and layout of thesis chapters

Research question	Chapter 2	Chapter 3	Chapter 4	Chapter 5	Chapter 6	Chapter 7
1 (typology)	X (2030)					
2 (current policies and pledges/NDCs)		X (2020)	X (2030)			
3 Tighten the gap with policy learning				X (2030)		
4 Impact of non-state and subnational action					X (2020/2030)	X (2030)

CHAPTER 2

Developing scenarios in the context of the Paris Agreement and application in the integrated assessment model IMAGE: a framework for bridging the policy-modelling divide

Roelfsema, M., van Soest, H.L., den Elzen, M., de Coninck, H., Kuramochi, T., Harmsen, M., Dafnomilis, I., Höhne, N., van Vuuren, D.P., 2022. Developing scenarios in the context of the Paris Agreement and application in the integrated assessment model IMAGE: A framework for bridging the policy-modelling divide. Environmental Science & Policy 135, 104–116. https://doi.org/https://doi.org/10.1016/j.envsci.2022.05.001

ABSTRACT

The framework presented in this study aims to provide insights into how climate policy is represented in integrated assessment models, responding to the call to link model scenarios with concepts used in public policy literature and related fields. As such, it contributes to increased transparency leading to better understanding across disciplines and communication about the relevance of model outcomes with policymakers. The framework categorises climate policy into policy aims and policy implementation at different stages of the policy cycle, and can be used to demarcate different climate policy scenarios incorporating and linking the international and national level. This approach provides clarity on critical modelling assumptions concerning the workings of policy to scenario users (including policymakers), such as policy stringency and status. We discuss the framework in relation to scenarios exploring pathways meeting the long-term Paris goal to hold temperature well below 2 °C or 1.5 °C, Nationally Determined Contributions submitted to the Paris Agreement, and current implemented policies. Specifically, the application of the framework and model implementation of the scenarios is illustrated with implementation in the IMAGE model. To project the expected policy impact on greenhouse gas emissions, the policy goals and policy instrument targets are translated into model targets. This is implemented in the model by either changing parameters for available policy instruments, such as carbon price or subsidies, or adjusting model parameters such as efficiency and costs to meet targets.

2.1 INTRODUCTION

The strength of process-based integrated assessment models (IAMs) lies in their ability to picture the solution space of climate change mitigation options with varying policy and actions, including the feedback and trade-offs between energy system, environment, and economy (Keppo et al., 2021). The solution space is represented by scenarios characterising different policy stringency and socioeconomic trends, for example, visible in the Shared Socioeconomic Pathways (SSPs) (van Vuuren et al., 2014; Riahi et al., 2017). Over the last decades, IAMs informed policy makers and the general public on possible climate strategies (Schwanitz, 2013; van Beek et al., 2020). Key elements of the IAM research include timing of mitigation action, implications of different long-term climate targets, sectoral contributions, and the role of specific technologies (Clarke et al., 2014). IAMs have played a role in different policy stages, putting climate change on the policy agenda, showing the impact of different long-term goals, and assessing the greenhouse gas impact for large countries.

IAMs are models with a global coverage divided into regions, some representing individual large countries. Therefore, they can provide insights into the required greenhouse gas (GHG) reductions at the national level and evaluate their ambition vis-à-vis global goals and targets agreed at the international level. International climate policy involves agreements made in the global context of the United Nations Framework Convention on Climate Change (UNFCCC), for which the Paris Agreement secured the long-term goal to hold temperature increase to well below 2 °C and to pursue efforts to keep it below 1.5 °C (UNFCCC, 2015h). However, implementation largely depends on ambition and the realisation of climate policies at the national level (Rogelj et al., 2016; Roelfsema et al., 2020). The two climate policy levels are linked through Nationally Determined Contributions (NDCs) and Long-term Strategies (LTS), in which (groups of) countries that have ratified the Paris agreement present their economy-wide efforts toward meeting the long-term temperature goals.

The origin of IAMs can be traced back to systems thinking introduced by Meadows et al. (1972) (van Beek et al., 2020). The what-if scenarios developed with these models initially showed stylised long-term pathways that represented a solution space of different long-term mitigation goals and socio-economic conditions. Mitigation is induced in these models by a global carbon price to identify cost-effective mitigation strategies (Solomon et al., 2007; Clarke et al., 2014). The carbon price in IAMs and the policy instrument of carbon pricing are sometimes assumed to be comparable, but the use in IAMs does not intend to say that this is the only or right instrument to induce innovation for deep emission reductions (Baranzini et al., 2017; Lilliestam et al., 2020). Instead, the carbon price must be seen as a shadow price for mitigation measures, i.e. a tool that IAMs use to induce mitigation action: it equals the marginal abatement costs in an idealised world. The carbon price in IAMs therefore does not represent the policy instrument of carbon pricing. To give insight into, for example, the distributional effects of carbon pricing, (further) specification of different actors, their behaviour, and the role of institutions would be needed.

Since the Paris Agreement, IAMs have been increasingly used beyond the analysis of global emissions pathways. They are now also used to analyse how to reach different long-term goals and are asked to assess sustainability transitions. However, IAMs focus mainly on physical, technical and economic factors and tend to neglect the dynamics introduced by institutions, actors, and power structures (De Cian et al., 2020). Nevertheless, what IAMs have done is including representations of actual policies instead of single carbon prices. For instance, they have analysed policies in the context of the 2020 reduction targets from pledges submitted as part of the Cancun Agreements (Roelfsema et al., 2014; Riahi et al., 2015) or analysed the effectiveness of specific mitigation options resulting from existing policy instruments (Deetman et al., 2015; Kriegler et al., 2018; Roelfsema et al., 2018a; Fekete et al., 2021; van Soest et al., 2021a). The improvement lies in more realistic projections of sectoral energy use and emissions, including interactions between activity levels, efficiency improvements and CO_2 reduction measures. An increasing number of papers have analysed the impact of current climate policies at the national level to meet the NDC targets by 2030 based on the assessment of national and global model studies (Vrontisi et al., 2018; den Elzen et al., 2019; Roelfsema et al., 2020; Kuramochi et al., 2021). In addition, integrated modelling of policy impacts is used in impacts assessments such as the Clean Planet for All (Capros et al., 2018; European Commission, 2018), the assessment of mitigation investment options for the UK International Climate Finance programme (VividEconomics et al., 2020), and the development of long-term strategies (Weitzel et al., 2019). The emerging literature has shown that the representation of policies in models is not unambiguous. Studies have implemented policies differently, e.g. focusing on the stated aims or representing the exact policy instrument and measures. Also, interpretation and coverage of current policies may differ between studies (den Elzen et al., 2019). Therefore, transparency is important, especially as these pathways are increasingly developed in cooperation with political, behavioural and other social science disciplines.

We conclude, that to further improve the realism of model-based policy scenarios, linkages with or embedding results in a variety of social sciences, in particular public policy and political science, is necessary (Victor, 2015). Different approaches exist to link social science to IAM scenarios. Most approaches discussed in literature so far, aim to link or integrate social science insights into IAM model implementation. A second approach (discussed in this article) is to show how existing IAM scenario assumptions can be embedded in policy design literature. This embedding does not change the model results (much) but ensures speaking the same language between different scientists and policymakers and aims to increase model transparency.

For the first approach, different strands of social science are currently working together with IAMs and aim to increase the realism of model results. Arguably, the sustainability transitions and system innovation studies domain has most prominently sought collaboration with IAMs, resulting in insights into differences and commonalities, mutual learning and a research agenda (Geels et al., 2016; Köhler et al., 2019; Trutnevyte et al., 2019). For example, Geels et al (2020) developed socio-technical scenarios based on technological substitution or broader system transformation in which included various interactions between models and multi-level perspectives. Another example is shown in Gambhir et al (2021), who link technology innovation system analysis to technology costs projections. An extension of the systems thinking field is the introduction of transition dynamics in IAMs, to be able to identify intervention points (Meadows, 2008) that can set off self-reinforcing feedback loops and provide more insight into those factors that balance the system and include lock-in and path dependency that lead to inertia and stable regimes (Geels, 2002; Köhler et al., 2019). Social tipping points (Otto et al., 2020) and tipping cascades (Sharpe and Lenton, 2021) have been identified as potential accelerators of transformational change at a national and sectoral level. A recent development is the implementation of such insights in an integrated assessment model, which leads to faster transitions and different global dynamics (Mercure et al., 2018). Another strand of social science is earth system governance exploring political solutions and effective (global) governance mechanisms, where inequality or climate justice is becoming a central topic (Burch et al., 2019). Although justice issues are scarcely included in integrated assessment models thus far (Gupta and Lebel, 2020), other earth system governance topics such as climate clubs are starting to be investigated (Paroussos et al., 2019).

The second approach is the focus of this article, and aims to link concepts from public policy design to existing climate policy scenarios. One important step towards improving the realism of scenarios has already been taken by accounting for the impact of actual implemented policies instead of using a single carbon tax. What is missing in the step towards actual policy implementation is a theoretical framework for climate policy scenarios that could help modellers to better communicate the relevance of their results to policymakers by providing a familiar policy context and cross the bridge to political scientists by relating to their language and increasing transparency on assumptions of the policy scenario implementation.

One of various important issues in policy scenarios implementation is the interpretation of the term 'climate policy' across different disciplines, which is often interpreted and used differently (Rogge and Reichardt, 2016). Political scientists support effective policy implementation by studying the multi-level policy cycle and distinguish between policies implemented by governments and other actors, including their drivers and interests. 'Public policy' is defined as anything that governments do and do not do and as decisions taken by governments to select goals and means to achieve them (Howlett, 2009, 2011). Economists, in most cases, consider climate policy (implementation) instruments (e.g. Emission Trading System (ETS)) and assess the welfare-enhancing effects based on multiple objectives (Bouma et al., 2019) such as effectiveness, induced innovation and equity. Finally, integrated assessment modellers use the term climate policy to represent levers that decrease greenhouse gas emissions levels, often focussing on least costs.

Therefore, this article aims to give a conceptual foundation of climate policy scenarios implemented by IAMs based on concepts from the policy design literature combined with policy terms used in IPCC reports, and use this to increase transparency. We use the experience obtained during the CD-LINKS (CD-LINKS, 2017a) and SENTINEL (2020) projects. The CD-LINKS project explored the interaction between climate policy and development, for which climate policy scenarios including explicit representation of current policies and comparing them to scenarios that represent long-term temperature goals was one of the main objectives (CD-LINKS, 2016). The SENTINEL project aims to build a suitable model for assessing the EU low carbon transition. Within these project policy design concepts where used, and the results and insights from both projects are brought together to develop a climate policy framework. This framework can be linked to policy scenarios, and especially gives an indication of the policy stringency and sufficiency, status of implemented policies, and uncertainty of implementation underlying the represented policies. This information can inform policymakers about the system-level impacts of their actions, help scholars operate the science-policy interface more effectively, and enable actors to hold politicians accountable. To illustrate the application of the framework and increase transparency, we use it to document the implementation of different policy scenarios in the IMAGE model (Stehfest et al., 2014).

This article adds to the literature by linking IAM scenario development to public policy design concepts used to increase the transparency of model implementation and contextualise policy stringency of model scenarios. Although elements of the public policy design were (implicitly) used in developing earlier climate policy scenarios (Roelfsema et al., 2020), this was never discussed in literature. We first developed a climate policy framework by comparing the definition of 'policy' between policy design literature and IPCC reports. Subsequently, this framework was used to define the contours of different climate policy scenarios, showing how this materialises for policies implemented in the international UNFCCC climate negotiations and the EU (and other economies in the Supplementary Information). Finally, we show how these scenarios are developed by translating policy assumptions to model inputs, illustrated with results from the IMAGE model.

2.2 CLIMATE POLICY FRAMEWORK

The climate policy framework defined in this article is based on a comparison and combination of policy concepts from the Howlett policy design framework (Howlett, 2009, 2011) and climate policy terms consistent with the WGIII IPCC reports.

2.2.1 Policy design literature compared with IPCC reports on climate policy

One noteworthy observation from the comparison of policy terms from the selected policy design literature and IPCC reports is the agreement on terms, but also two clear differences: 1) Howlett (2009, 2011) uses the terms 'goals' and 'objectives' differently from the IPCC reports (see Table 2-1), and 2) policy instruments in IPCC reports are only considered at the decision-making stage, while Howlett (2009, 2011) dicusses instruments at all stages of the policy cycle. In this article, we comply with the language and practice of IPCC reports.

Policy design scholars aim to give insights to policymakers into the implementation of effective and efficient policies. Although several frameworks exist (e.g. Rogge & Reichardt (2016)), the policy design framework from Howlett ((2009, 2011) is often referred to in climate policy literature, see for example, Harris (2014), Pahle et al. (2018) and Schaffrin et al. (2015). In this framework, policy is analysed at multiple levels that change from less tangible to more concrete policymaking: governance mode, policy regime and programme (Howlett, 2009, 2011), see Table 2-1. Governance modes are a favoured set of ideas and instruments; the policy regime defines the preference for general policy tools and a generic set of policy objectives, and the programme matches means to specific policy targets (Howlett, 2011). Each level comprises complex entities consisting of policy aims achieved by policy means (see Table 2-1). Policy aims are basic aims and expectations of governments, while policy means are tools to attain these aims (Howlett, 2011). A policy aims to change from abstract policy objectives to operationalizable goals and concrete policy targets resulting from policy instrument calibration. Policy means are often viewed as (technical) implementation instruments in the decision-making stage. However, they are in this public policy design framework also regarded as less technical (e.g. procedural instruments) to occur in all stages of the policy cycle (ibid). The policy levels in this framework correspond to the policy cycle, which is an idealised process of policymaking divided into several stages: agenda setting, policy formulation, decision-making, policy implementation and policy evaluation; problems come to the attention of governments, policy options are formulated, governments adopt a particular course of action, policies are put into effect and finally evaluated (Lasswell, 1956; Howlett, 2011). Note that the policy cycle is a simplifying representation of the policy process with the aim to reduce complexity and enable better examination (Howlett, 2009). In reality, the different stages could overlap. This especially holds for the decision-making and implementation stage that both involve policy targets, and the stages could be passed through interactively (Table 2-1). Nevertheless, they differ in aims and means because setting a specific target and calibrating the policy instrument parameters is done in the decision-making stage, while implementing measures to achieve the policy targets with available organisational capacity, resources and given rules of procedures is done at the implementation phase (Howlett, 2011, 2018).

Table 2-1 Policy design framework from Howlett (2009, 2011)

Policy level / Policy component	**Governance mode** **Favoured set of ideas and instruments****	**Policy regime** **Preference for general policy tools and generic set of policy objectives**	**Programme** **Matching of the program means to specific policy targets**	
Policy aim* Basic aims and expectations of governments	Abstract policy objectives	Operationalizable goals*****	Policy targets	Achieve policy targets
Policy means Tools used to attain the aims	General implementation preferences	Policy instruments choices	Policy instrument calibration	Organisational capacity, resource availability, rules of procedures)
Policy cycle stage	**Agenda setting**	**Policy formulation**	**Decision-making**	**Implementation**

* Note that the terms 'aims' and 'goals' used in this table are the 'goals' and 'objectives' as used in Howlett (2009, 2011). We changed it here to match the terms used in IPCC reports (and 'aim' is now used as the general term to cover 'objectives, goals and targets')

** Favoured set of ideas and instruments (legal, corporatist, market and network governance). See Howlett (2009) for detailed explanation.

IPCC reports summarise scientific information on climate change from different scientific disciplines, and specifically the IPCC Working Group III reports focus on climate mitigation policies and results of IAM studies. In these reports climate policy is not explicitly defined, but policy terms are used coherently (See Supplementary Information for references).

The definition of the term 'policies' is broad, and covers all procedures developed and implemented by governments (IPCC, 1996), and are a course of action taken and/or mandated by a government (IPCC, 2014a). **Policy objectives** capture general notions, often qualitative, such as mitigating climate change and cost effectiveness, but also improving food security, energy security, energy access and air quality (IPCC, 2001, 2007), see Figure 2-1. Furthermore, **policy goals** make the objectives more concrete, are defined as 'long-term and systemic', and are established in agreements to capture what needs to be achieved (IPCC, 2014c). They can be set at varying degrees of specificity (IPCC, 2007), either descriptive or using a quantitative target.

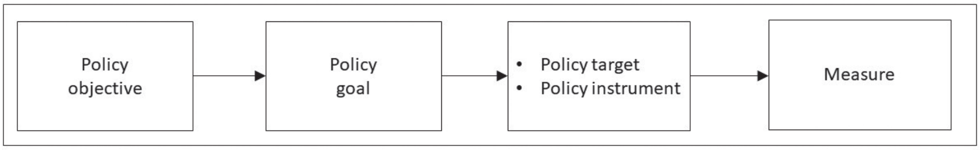

Figure 2-1 Climate policy terms with decreasing abstraction level from IPCC WG III reports (IPCC, 1995, 1996, 2001, 2007, 2014c, 2018b)

Technologies, policies and institutional settings are means to achieve climate policy goals (IPCC, 2014c). **Policy targets** follow from policy goals, are 'near term and specific', and can be classified according to whether they require absolute greenhouse gas reductions relative to a historical base year or baseline scenario, or reductions relative to economic output, population growth, or business-as-usual projections (intensity targets) (IPCC, 2014c). **Policy instruments** are not explicitly defined in the IPCC WG III reports, but are divided into economic, regulatory, voluntary and R&D (Gupta et al., 2007; IPCC, 2007). Up to now, these instruments are mainly discussed in the chapters not concerned with IAM results (but gain ground in IAM literature, see Introduction). They are identified as those being implemented by a group of countries (e.g. Internationally Transferred Mitigation Outcomes (ITMOs), see Edmonds et al. (2021)), by individual countries unilaterally (i.e. feed-in-tariffs) or in a multilateral agreement (i.e. Bonn Challenge) (IPCC, 1995). In addition, the IPCC report considers measures and are defined as 'technologies, processes or practices that contribute to mitigation, for example renewable energy technologies, waste minimization processes, public transport commuting practices' (IPCC, 2014a). In accordance with the policy means from the policy design framework, a distinction is made between policy measures and technical measures, where a **policy measure** (e.g. ETS) is the same as a policy instrument or policy tool (Givoni et al., 2013), and **a technical measure** is the installation of technologies, for example solar PV. In this article, we will not use the term ‘policy measure’, but refer to it as policy instruments. In addition, measures signify ‘technical measures’.

2.2.2 The framework

The combination of abstract policy concepts and terms from Howlett (2009, 2011) and the IPCC reports discussed in Section 2.1 constitute the building blocks of the climate policy framework that we develop in this paper and which includes climate policy components at different stages of the policy cycle (see Figure 2-2 Climate policy framework). This framework defines key terms and concepts applicable to the assessment of climate mitigation policy in IAMs.

The foundation of the climate policy framework is the broad definition of the term ‘climate policy’ in all its forms, that is used in integrated assessments. We use the definition from Roelfsema et al. (2020) and adjust it to ‘*the result of agenda setting, formulation, decision-making and implementation by (groups of) governments considering actions to mitigate climate change at the international and economy-wide level that encompasses (aspirational) objectives and goals not necessarily secured by legislation, national targets secured by legislation, and policy instruments and targets designed and calibrated to implement these goals and objectives’*

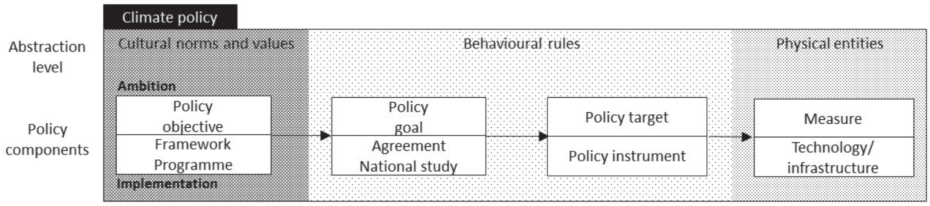

Figure 2-2 Climate policy framework

The climate policy framework is divided into two dimensions that both apply to international and economy-wide climate policy. The first dimension represents policy components and is divided into policy aims and policy means; the second dimension representsA the different stages in the policy cycle. Applying this hierarchy to the identified climate policy terms from the previous section, one could see that climate policy is captured by objectives in the agenda setting stage and implemented through formalised goals defined in the policy formulation stage and targets in the decision-making stage in guise of policy instruments that are translated into (technical) measures to implement technologies and infrastructure. The changes in the physical system result in reductions in energy use, land use change and finally in reduction of greenhouse gas emissions. Note that opposite to Howlett (2011) the term 'instrument' is only used to refer to policy instruments which are calibrated in the decision-making stage, conform use in IPCC reports.

2.3 THE CLIMATE POLICY FRAMEWORK USED TO DEFINE CONTEMPORARY CLIMATE POLICY SCENARIOS

Scenario analysis in IAMs is used to assess possible future patterns of greenhouse gas emissions, their drivers and their effect on the atmosphere (IPCC, 1995). In the CD-LINKS (2016) and SENTINEL (2020) project different policy scenarios (CD-LINKS, 2017b; Roelfsema et al., 2021) were developed that represented different policy stringency levels. Based on this experience, the climate policy framework from the previous section was developed, and is now used as starting point to document scenario assumptions representing contemporary policymaking in the context of the UNFCCC and its linkages to national and economy-wide levels. The framework is suitable for laying the foundations of climate policy scenarios as it presents the different levels of policymaking and established aims and instruments in a structured manner. The resulting aims and means from each policy stage (see Figure 2-2) represent the main substance of each scenario. As the framework represents all stages from the policy cycle, it can be used for any future policy environment. However, in this paper we focus on scenarios of contemporary climate policy implementation. For this purpose, we first describe the current policy environment and distil key goals, targets and instruments that define the climate policy scenarios.

2.3.1 Current climate policy environment

Current climate policy implementation is occurring at two levels that are interlinked. At the international level climate mitigation objectives and goals are negotiated within the UNFCCC. However, actual implementation takes place at the domestic or economy level (e.g. political union); for example, the EU has a long history of climate policy (European Commission, 2000; Delbeke and Vis, 2015; Nascimento et al., 2021). EU policies are analysed in the SENTINEL project (2020) to assess the transition to a low-carbon energy system, and it showed that current implementation covers all energy- and land use sectors, and is clearly documented (European Commission, 2022). For this reason, the EU is used as an example in this article. As the EU pledges a collective commitment to the UNFCCC, and is included as one economy in most IAMs, we do not consider the policies from different Member

States, and refer to EU policies as being implemented economy-wide. We describe the EU policy context in this section, but policies from other large countries can be found in the Supplementary Information.

Climate policy was put on the global agenda by scientists in 1972 during the UN Conference on the Human Environment (UN, 1972), and continued at the first World Climate Conference in 1979 (WMO, 1979) where climate change was the only topic on the agenda. In 1992, the UNFCCC was established in 1992 and formulated the ultimate objective to ‘stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system’ (UNFCCC, 1992) (see Table 2-2 Climate policy framework applied to the international (UNFCCC) and national (EU as example) context). This objective is translated in the Paris Agreement into the long-term goal to hold global increase in temperature well below 2 °C above pre-industrial levels and to pursue efforts to limit the increase to 1.5 °C (UNFCCC, 2015h). In order to achieve this goal, Parties to the agreement need to prepare, communicate and maintain NDCs that present national mitigation efforts to reach the climate goals of the Paris Agreement (UNFCCC, 2015b, 2018), which represent the national or economy-wide ambition. NDCs are the link between international and national climate policy, as they include national ambition towards meeting the Paris goals. They are instrumental (i.e. procedural instruments) to the Paris Agreement but need to be achieved at the domestic or economy level. In addition, instruments exist to transfer domestic mitigation outcomes between countries (Edmonds et al., 2021), such as Internationally Traded Mitigation Outcomes secured in the Paris Agreement’s rulebook. In addition, Parties to the Paris Agreement are currently setting long-term targets in Long-term Strategies

On the national level, climate policy is captured by legislation and climate strategies (Dubash et al., 2013; Iacobuta et al., 2018). Climate legislation is approved by parliament or equivalent processes containing objectives to reduce greenhouse gas emissions, whereas national climate strategies are non-binding, cover all sectors and promote climate change mitigation (Dubash et al., 2013). The climate strategies often include aspirational goals for greenhouse gas reductions, energy- and land-use. To achieve the national targets, policy instruments are implemented at the economy-wide level, with the climate strategies serving as the starting point for target level setting. The strategies result in implementation of several policy instruments, often as part of an instrument mix, which is a combination of instruments aimed at one or multiple policy objectives (Rogge and Reichardt, 2016; Bouma et al., 2019). Within the EU, climate policy formulation and decision-making is done at the overarching Union level, but implementation takes place at Member State level. The EU policy documents clearly define 'policies and measures' that are 'all instruments which aim to implement commitments [..], which may include those that do not have the limitation and reduction of greenhouse gas emissions as a primary objective' (EEA, 2019). Within this context, policy is a general term that sets an overarching frame that could include targets that do not aim for greenhouse gas (GHG) reduction (e.g. efficiency improvement, renewable share) and could include several (technical) measures that are concrete actions to implement a certain policy (e.g. insulation of buildings). The policy objective describes the expected effect of a policy, and targets specify how the general objectives are met (EEA, 2019).

The NDCs of three-quarter of all countries include emission targets (Climate Watch, 2021), but some countries also include other types of targets such as non-fossil shares and intensity targets (see Table 2-2 Climate policy framework applied to the international (UNFCCC) and national (EU as example) context**.** and Supplementary Information). As part of their NDC, the EU pledged a GHG reduction target of 40% below 1990 level by 2030, which has been updated to a reduction of net GHG emissions (including land use and land use change (LULUCF)) of at least 55% (European Commission, 2020b). NDC targets for other countries can be found in the scenario protocol in the Supplementary Information. Although implementation takes place at Member State level, we consider the EU as one economy as, since the Kyoto protocol, Parties are allowed to pledge and meet emission commitments collectively (UNFCCC, 2000). The EU has established the European Climate Change Programme in 2000 in response to the Kyoto Protocol, with the objective to address climate change to help identify the most environmentally and cost-effective policies (European Commission, 2020b). Recently, the EU published the Green Deal roadmap with the goal to accomplish carbon neutrality defined as '*no net emissions of greenhouse gas emissions in 2050´* (European Commission, 2019). In 2014 the EU proposed a 40% reduction target of GHG emissions relative to 1990, which has now been secured by the Climate & Energy framework. This framework is a mix of different policy instruments, of which the Emission Trading System (ETS) and the effort sharing mechanism are the main policy instruments. The 2030 targets for these policy instruments are respectively 43% and 30% emission reduction relative to 2005. In response to the European Climate Law, both the EU Council and Parliament adopted the target to reduce GHG emissions by 55% relative to 1990 (European Commission, 2020b). The policy plan Fit-for-55 that ensures implementation of this target is published (European Commission, 2021), but has not been accepted yet. Therefore, we label the 55% reduction as a planned policy target, and the 40% reduction as a current target. The full list of EU policies and those for other G20 countries is found in the model protocol in the Supplementary Information.

Table 2-2 Climate policy framework applied to the international (UNFCCC) and national (EU as example) context

Climate policy	Components/ stages	Agenda setting	Policy formulation	Decision making	Implementation
International (UNFCCC)	Policy aims	**Policy objective** Article 2: Stabilise greenhouse gas concentrations in the atmosphere at a level that 'would prevent dangerous interference with the climate system'	**Policy goals** Hold the increase in global average temperature to well below 2 °C above pre-industrial levels; and to pursue efforts to limit the increase to 1.5 °C Reach global peaking of greenhouse gas emissions as soon as possible To achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century	**Policy targets** Targets in NDCs (submitted to Paris Agreement): Emission reduction targets (e.g. EU: 55% reduction relative to 1990 by 2030) non-fossil targets (e.g. China: 20% non-fossil share by 2030) afforestation (e.g. India: additional carbon sink of 2.5-3 $GtCO_2eq$ by 2030) Targets in LTS (submitted to Paris Agreement): (e.g. EU: net-zero emissions by 2050)	
	Policy means	**Framework, Programme** UNFCCC	**Agreement, Protocol, Accord, Treaty** Paris Agreement	**Articles of the Paris Agreement (instruments)** Article 4.2: NDC Article 6: internationally Transferred Mitigation Outcomes (ITMOs)	
Economy-wide (EU)	Policy aims	**Policy objectives** EU: cut greenhouse gas emissions by taking the most environmentally and cost-effective policies and measures	**Policy goal** EU: Climate neutral through net zero greenhouse emissions by 2050	**Policy targets** EU: (current) economy-wide emission reduction target: 40% reduction relative to 1990 (current) ETS emission reduction target: 43% reduction relative to 2005 (current) effort sharing reduction target: 30% reduction relative to 2005 (planned) emissions target of 55% below 1990 levels by 2030	

Climate policy	Components/ stages	Agenda setting	Policy formulation	Decision making	Implementation
	Policy means	**Programme** European Climate Change Programme	**Legislation** European Climate law **Climate strategies, roadmap** Green Deal	**Policy instrument (mix)** 2030 climate & energy framework with ETS and effort sharing as main policy instruments	**Measure** Installation of renewable energy (e.g. solar PV), insulation of residential buildings, reforestation

2.3.2 Climate policy scenarios

The goals, targets and policy instruments from the applied climate policy framework (Table 2-2 Climate policy framework applied to the international (UNFCCC) and national (EU as example) context) are the basis for the climate policy scenarios. As the UNFCCC policy objective from the agenda-setting phase has already been translated to the temperature goals in the Paris Agreement, the focus in the CD-LINKS project was on these global goals and policy implementation for large G20 countries, from which we only address global and EU policy in this section. However, the scenarios from the Special Report on Emission Scenarios (SRES) could be seen to represent the assessment of the UNFCCC objective to stabilise greenhouse gas concentrations (Riahi et al., 2007) from the agenda-setting phase. Nevertheless, we only consider the policy formulation stage at the international level where agreements on collective goals are made, and the decision-making stage at the international and economy-wide level where policy targets, policy instruments and measures are implemented. The international policy aims from the climate policy framework are the basis for the 2 °C, 1.5 °C and NDC scenarios, while the policy targets connected to the policy means from the economy-wide level are input to the current policies scenario (see Table 2-3). The policy targets and policy instruments that are implemented in the model result in implementation of specific measures (e.g. renewable energy technologies such as solar PV, see Section 4).

The temperature goals underlying the 2 °C and 1.5 °C scenarios were established during the policy formulation stage and hold for the global level. These two scenarios together give a range for the implementation of the Paris climate goals. It is assumed the temperature targets hold for the end of this century, which implies that overshoot is allowed. However, the temperature goals can only be met with a certain probability due to climate system uncertainty. Common practice is to use >66% probability ('likely' according to IPCC parlance (Mastrandrea et al., 2010)). The NDCs are the results of the decision-making stage, and the NDC scenario assumes full implementation of the conditional pledged targets that are submitted on the international level, but need to be achieved at the economy level. These pledges are in some cases conditional on finance or international cooperation (den Elzen et al., 2016). Note that most countries have (also) pledged unconditional targets. NDC targets can be divided into 1) economy-wide absolute emission reduction targets from historical base-year emissions, 2) emission reductions relative to a business-as-usual projection, 3) emission intensity reduction targets, 4) submitted actions absent of GHG-emission targets (UNEP, 2015f; King and van den Bergh, 2019), 5) fixed level targets and trajectory targets (Climate Watch, 2021), and a few include additional non-fossil and forestry targets (CD-

LINKS, 2017b; Roelfsema et al., 2020). The current policies scenario is also categorised under the decision-making stage, but at the economy-wide level. The end state of the decision-making process is the introduction of the policy instrument and the connected (quantitative) policy target. The current policies scenario assumes all domestic or economy-wide (sectoral) policies to be implemented if they are secured in legislative decisions, executive orders or equivalent, and no additional measures are taken (Averchenkova et al., 2017; UNEP, 2019). Planned policies that are in the pipeline to be adopted, are not included including targets set in economy-wide or national climate strategies (e.g. EU 2030 Climate Plan). Many studies also include a reference or baseline scenario in which no or few steps are taken to limit GHG emissions (IPCC, 1995). Since almost all countries have implemented climate policies by now this has become less significant and is only used as a starting point for the policy scenario model implementation, and is a hypothetical reference to determine the impact and costs of climate policy. Generally, the no new policies scenario relies on general narratives of alternative futures for societal development, such as the SSPs (van Vuuren and Carter, 2014; Riahi et al., 2017).

Table 2-3 Translation of climate policy framework to climate policy scenarios and examples of implementation in the IMAGE model. The agenda setting and implementation phase have been dropped as agenda setting for choosing the goals that would stabilise greenhouse

Climate policy	Policy formulation	Decision-making
Policy aims at international level (UNFCCC)	**2 °C/1.5 °C scenario**	**NDC/LTS scenario**
	By 2100: translation to W/m^2, CO_2 budget, ppm	Carbon price to implement (pledged/calculated) NDC targets
		Carbon price to implement CO_2/GHG intensity target
		Non-fossil target by adding minimum requirement to non-fossil technologies in investment decision
Policy means at economy level	(**not modelled**)	**Current policies scenario**
	Aspirational goals are checked afterwards and need to be achieved by implemented policy targets	Carbon price or energy tax (e.g. Canada carbon tax)
		Change model input parameter to enforce target (e.g. Appliance standard)
		Translate policy target to appropriate model input parameter (e.g. net-zero emissions buildings to 0 GJ/m^2)
		Use aspirational goal from climate strategy (e.g. renewable auctions in Brazil)
		Planned policies scenario
		(not modelled)
No new climate policy		**No new policies scenario**

2.4 IMAGE IMPLEMENTATION

After having developed and applied the climate policy framework to the present-day climate policy environment, we show how this was implemented in the IMAGE model (see Table 2-4)This clearly illustrates that more stringent and less abstract scenarios involve more details on assumptions and increased modelling efforts.

The IMAGE model is an integrated assessment model analysing global change by identifying future challenges and constructing different scenarios (Stehfest et al., 2014). The model is built up from different sub-models and includes 26 geographical regions covering all energy, industry, agriculture, and land use sectors. The IMAGE land use model includes agricultural production, land cover and land use. The TIMER model includes the energy supply and demand sectors and are relatively detailed in terms of activities and technologies. Investment decisions are represented by the multinomial logit (MNL) function that assigns market shares based on (time dependent) production costs including also non-economic costs, for instance to represent behaviour, and assigns the highest share to the cheapest option (van Vuuren, 2007). The model describes dynamic relationships in the energy system, such as inertia and learning-by-doing in capital stocks, depletion of the resource base and regional trade. Innovation in TIMER is modelled through ‘learning-by-doing’ to represent technological development (van Vuuren, 2007). The FAIR model analyses mitigation costs, benefits, emission reductions after emissions trading and climate goals (Hof et al., 2017). More detailed information on the IMAGE model is found at PBL (2020b, 2020a). For assessments such as defining optimal policy packages based on different economic and social criteria or assessments of smaller countries, other types of (national) models and tools need to be used.

The starting point for the current policies scenario is the no new policies scenario, which excludes the impact of climate policies after a certain recent historical date (e.g. 2020). The SSP2 scenario (Fricko et al., 2017) is a middle-of-the-road scenario and the IMAGE implementation is used and calibrated to historical data to include the historical impact of climate policies. In the CD-LINKS project (2017a, 2017b) different climate policy scenarios were implemented (McCollum et al., 2018; Roelfsema et al., 2020), which were updated for this article based on updated SSP scenarios (Vuuren et al., 2021) and COVID impact assessments (Dafnomilis et al., 2021). The policies included in this scenario were retrieved from the Climate Policy Database (NewClimate Institute, 2015; Iacobuta et al., 2018), which is an open, collaborative platform and collects information on currently implemented policies from countries worldwide (see Figure 2-3). From this database, a selection of quantifiable high-impact policies was made based on literature, expert judgement, and the criterion that no evidence exists of implementation barriers (Roelfsema et al., 2020).

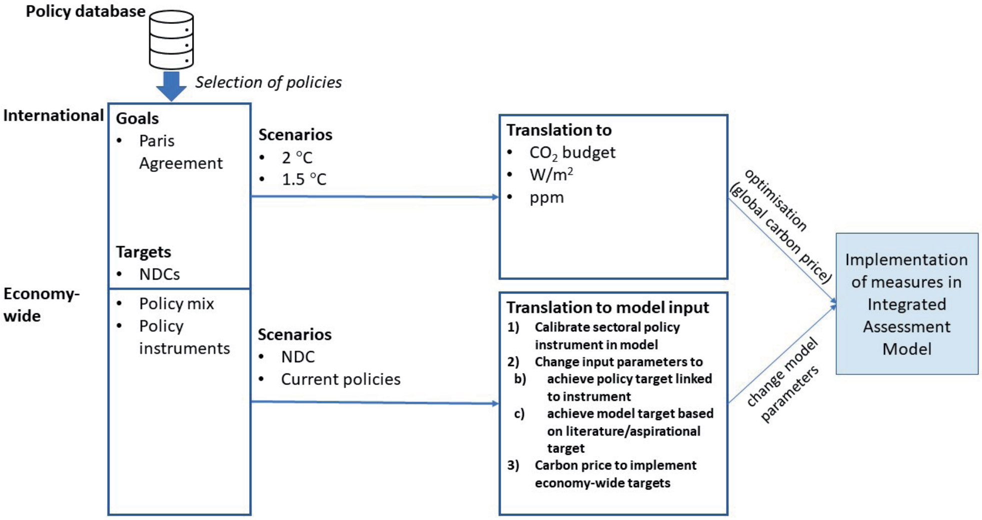

Figure 2-3 Implementation of climate policy scenarios in integrated assessment models: a selection of policies (in terms of goals or targets) are translated into model input for models and result in the implementation of measures

Current policies are implemented in the model with a focus on replicating the expected impact of climate policies on GHG emissions, energy-, and land use. There are three possibilities to implement a specific policy instrument into the model, and a fourth to implement an economy-wide target (see box 'Translation to model input' in Figure 2-3). First, in some cases, the policy instrument is included in the IMAGE model, and the existing carbon price, energy tax or subsidy can be directly implemented (see Figure 2-3). This price results in technology investments with lower GHG intensity or higher energy efficiency. An example is the carbon tax in Canada. Second, the policy target can be implemented by changing model parameters. For this purpose, two variants exist: a) the policy target linked to the policy instrument can be directly implemented by changing an input parameter to the model, for example the target for EU appliance standards (after the target year, the TIMER model gradually reverts to the standard (SSP2) parameters); b), if no explicit policy targets exist (e.g. renewable auctions in Brazil), either a literature estimate is used or the underlying aspirational target from the national climate strategy (e.g. renewable electricity target from the energy plan PNE 2030 (Brazilian Ministry of Mines and Energy, 2007) is assumed to be implemented until the target year. This target year is possibly beyond the current phase of the instrument for which policy settings are fixed (e.g. Renewable auction period) (Roelfsema et al., 2020). Third, economy-wide targets from legislation or connected to policy mixes (e.g. 40% reduction target in the EU) are implemented for NDCs through an economy-wide carbon price, but are not explicitly implemented in the model for current policies as the aggregated impact of the underlying policy targets (connected to policy instruments) should result in achieving this target. However, attainment of these targets is checked afterwards by comparing the overall targets with model results. Table 2-4 describes how each identified policy type is implemented in IMAGE. The list of policies and linked policy targets for different countries can be found in the Supplementary Information.

Table 2-4 Description of policy implementation per policy type in the IMAGE model (PBL, 2020b, 2020a)

Policy type	Example policy instruments	Implementation in IMAGE
AFOLU	Forest code	Mitigation is introduced via increased protection levels for carbon-intensive ecosystems and reforestation of degraded or abandoned land
Appliances	energy labels, energy conservation standards	The autonomous efficiency improvement for specific appliances is increased to meet the set target
Biofuels road transport Electric vehicle adoption targets	biofuel/renewable fuel standard subsidy, reward as part of vehicle standard	The biofuels target applies to the full fleet, while the electricity target to new vehicles. The results of the multinomial logit (MNL) model (investment shares) is adjusted to the level that meets the target; the share of (non-bio) fossil fuelled cars is decreased, keeping the original oil, gas ratios constant.
Building Code	building code	The policy target is achieved by increasing the insulation level. If this does not reach the building code target, additional heat pumps are installed to cover heating demand efficiently. Finally, rooftop PVs are installed to reach the target level.
Carbon price	carbon tax, cap and trade (emission trading system, certificates/permits)	Carbon price is endogenous to the TIMER model, resulting in higher fossil technology prices affecting the MNL, resulting in changed allocation
Efficiency vehicles (cars, trucks)	CO_2 performance standards, fuel economy standard	The MNL without constraints is adjusted by minimising the difference between new and original new fleet composition, and adding the constraint to meet the average fleet efficiency set by the target
F-gases	ban/penalty	Tax is levied on F-gas emissions and is implemented with a MAC curve. The tax is set to the level that would meet reduction target

Policy type	Example policy instruments	Implementation in IMAGE
Power Plants	CO_2 or efficiency standard for new and existing plant	Restrictions are imposed on the MNL to prevent installing power plants with CO_2/kWh or efficiency above/below set target
		Existing power plants that do not meet the target are early depreciated (with lag of 3 years)
Renewable Electricity	renewable auction, feed-in-tariff, renewable portfolio standard	Capacity targets- The MNL without constraints is adjusted to meet the set targets, and the fossil-capacities are decreased making sure the original mutual ratio is preserved
		Renewable generation share - First the MNL is calculated without constraints resulting in different weights per technology. The weights are adjusted for those technologies in the generation share. The remaining weights are adjusted making sure the original ratios apply

If the target belongs to a country that is part of a larger model region, the regional target is a weighted average assuming that the other countries would follow no new policies scenario trends (CD-LINKS, 2017b), see Supplementary Information. Targets for Australia, Argentina and Republic of Korea are first aggregated from country to model region. EU climate policies are implemented in both the Western- and Central European region of IMAGE, although those contain non-EU countries as well, accounting for approximately 5% of the total regional GHG emissions (in 2015).

Figure 2-4 shows the emission pathways from the current policies scenario, and illustrates the impact of adding one policy type at the time starting from the no new policies scenario into the IMAGE model for the World and EU (in order of the TIMER sectors supply, industry, transport, buildings, second from the IMAGE AFOLU sectors). GHG emissions are expressed using the 100-year global warming potentials (GWPs) from the IPCC Fourth Assessment Report. The policies were categorised into ten policy types (see Table 2-4). Note that the impact depends on the order policy types were added to the decomposition, but discussion on this falls outside the scope of this article. It shows that both on a global and EU level, carbon pricing (Canada carbon tax, EU and South Korea ETS, India's PAT scheme) has the largest impact. The global reduction due to the renewable energy policies is much lower than presented in Roelfsema et al. (2020) due to update of the SSP2 scenario, which takes into account the fast decrease in costs and high penetration of these technologies in the last few years.

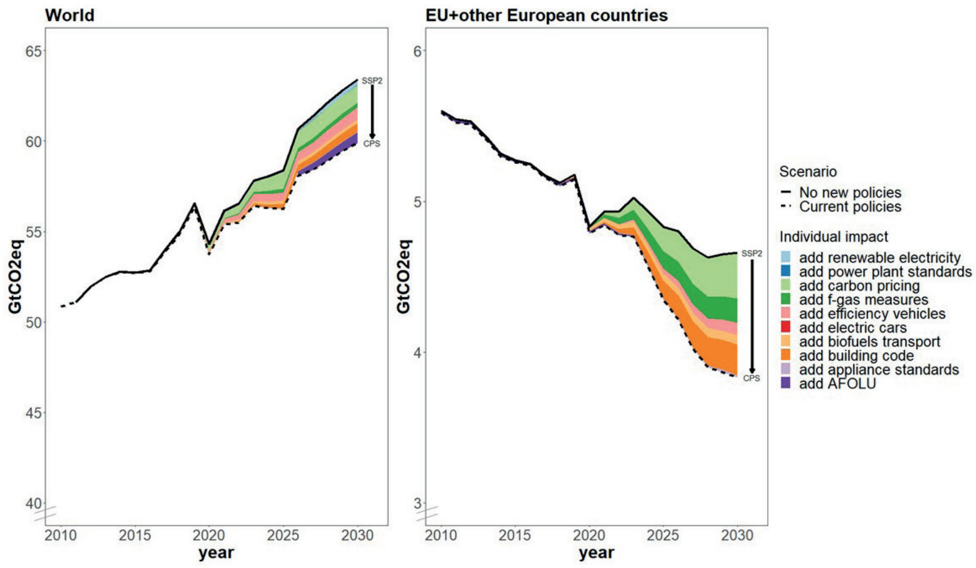

Figure 2-4 Contribution of the impact of individual policies in the aggregate emission reduction between the no new policies scenario (SSP2) and the current policies scenario (CPS). The impact of each policy (implemented into the model in the order shown in the legend) is shown by each coloured area and model implementation is described in Table 2-4.

For the NDC scenario, a list of NDC targets for major emitting countries was developed in the ADVANCE project (Luderer et al., 2018; Vrontisi et al., 2018), and was adjusted for G20 countries in the CD-LINKS project (McCollum et al., 2018; Roelfsema et al., 2020). The targets were updated with the NDCs for the EU, Brazil and China (announcement) as submitted in December 2020. NDC targets are implemented through a country or regional carbon price on top of the current policies scenario that additionally includes non-fossil and intensity targets included in a few NDCs (e.g. China, India). The LTS scenario is work in progress, and therefore out of the scope of this paper.

The 2 °C and 1.5 °C scenarios represent the implementation of the long-term climate goals of the Paris Agreement. Given the choice of target year and probability, these targets are translated into a concentration goal (ppm), carbon budget ($GtCO_2eq$) or radiative forcing (W/m^2) to be implemented in IAMs. In the CD-LINKS project, the 2 °C and 1.5 °C temperature limits were translated to carbon budgets for the period 2011 to 2100 of 1,000 $GtCO_2$ and 400 $GtCO_2$ in accordance with keeping temperature increase below the temperature goal with a 66% probability, as often used in assessments included in IPCC reports (IPCC, 2014c; Roelfsema et al., 2020). In the updated scenarios we aimed to achieve a radiative forcing of 2.6 and 1.9 W/m² respectively. The 2 °C or 1.5 °C scenarios were implemented in the IMAGE model by implementing a global carbon price starting in a specific year and assuming climate policies are implemented where this has lowest costs. We chose the starting year of cost-effective implementation immediate (e.g. 2020). Optimisation is done in the FAIR model which is soft-linked to the TIMER and IMAGE land use models that supply MAC curves as input.

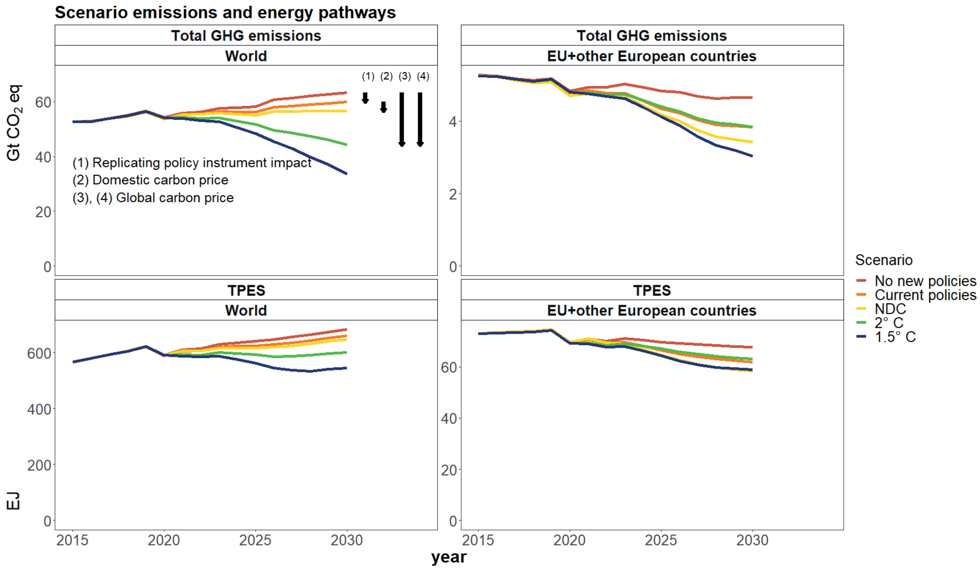

Figure 2-5 Impact of climate policy on global and economy-wide greenhouse gas emissions and total primary energy supply (TPES) for the World and EU.

Figure 2-5 shows the resulting emissions and primary energy pathways for the World and EU from the IMAGE model implementation between 2015 and 2030. The results confirm the insights that the world is not on track to achieve the Paris temperature goals, both with current policies and NDCs (Roelfsema et al., 2020; UNEP, 2020). Note that the results illustrate the results for one model, while for example the Emissions Gap report (UNEP, 2020) gives a multi-model range (10^{th}-90^{th} percentile) showing by 2030 39-46 $GtCO_2eq$ global emissions for the 2 °C scenario, and 31-41 $GtCO_2eq$ global emissions for the 1.5 °C scenario. The updated EU NDC target (55% reduction relative to 1990) now lies between the 2 °C and 1.5 °C emission levels by 2030.

2.5 DISCUSSION AND CONCLUSION

The climate policy framework that we introduced categorises climate policy terms from the IPCC WGIII reports and maps them to policy scenarios with increasing ambition levels secured by policy objectives, goals and targets. This framework attempts to respond to call to integrate social sciences insights, in particular public policy design (Victor, 2015), and to the criticism that IAMs lack transparency on input assumptions and have an inadequate representation of real-world policies (Gambhir et al., 2019).

Climate policy questions at both the international and national level have changed since the Paris Agreement from 'where do we go' to 'how do we get there', two of the key questions from the Talanoa Dialogue (Winkler and Depledge, 2018). This resulted in a shift of focus to domestic and economy-wide actions. Therefore, IAMs have started to include explicit representation of domestic and economy-wide climate policies, enabling them to compare the aggregated impact of these policies to pathways adhering to the global temperature targets established in the Paris Agreement. It shows that IAMs have changed from cost-effective implementation to real policy impact on the short-term until 2030.

However, it is clear that not all elements concerning climate policy can be analysed with IAMs. Cost-effective implementation of long-term climate policies assumes an economy with frictionless markets that produces a social optimum achieved by a fully informed social planner (Staub-Kaminski et al., 2014) and tends to emphasize technological rather than social constraints (Anderson and Jewell, 2019). This implies that most models have only a limited ability 'to reflect the specific social and economic dynamics of the developing and transition economies' such as market imperfections, institutional barriers or dynamics of the informal sector (IPCC, 1995). Also, political credibility and feasibility is not well represented. Credibility means that countries will fully implement their international commitments (Averchenkova et al., 2017). Political feasibility encompasses the ability to intervene in the economy and to create a path for actors to realize set policy aims (Jewell and Cherp, 2020). For this, it is necessary to be able to meet the costs of action and the availability of capacity and skills, finance for successful implementation (Averchenkova et al., 2017). Currently, linkages and integration of feasibility and social acceptance concepts are being developed (Geels et al., 2020; Jewell and Cherp, 2020).

We identify two next steps for the climate policy framework. First, this framework could for example be used by IAM modellers and public policy design scholars to work together and learn from historical climate policy implementation by linking past IAM scenarios to introduction or changes of climate polices within the policy cycles. This could improve current policy scenario implementation, and give insights into the effectiveness of individual or mix of policies or identify the effects of political economy insights (Peng et al., 2021). Second, it can be used to expand the suite of climate policy scenarios, by including policies not having climate as primary objective (but with impact on GHG emissions), planned policies, propose enhanced policies (as done in van Soest et al (van Soest et al., 2021b) or 2 °C or 1.5 °C scenarios that achieve long-term goals with a specific mix of policy instruments (see for example (Pollitt et al., 2019). This would enable including more local circumstances in the scenario design. Future work might expand the coverage of the current policies scenario to also include subnational governments (e.g. cities, regions, states and provinces) and bilateral or multi-lateral agreements such as the International Maritime Organisation (IMO). However, including subnational policies in IAMs is not straightforward due to the difficulty of matching actor baselines and the overlap with national policies (Hsu et al., 2019; Kuramochi, Roelfsema et al., 2020). Another extension is to include submitted net-zero emissions goal for the second half of this century (UNFCCC, 2015h) and country contributions secured in the Long-Term Strategies submitted to the UNFCCC. Finally, future research could develop a 2 °C and 1.5 °C scenario based on a selection of policy targets and instruments instead of a global carbon tax

We conclude that clarifying the conceptual climate policy framework by linking public policy and political science to IAM scenarios improves both the understanding of policy stringency and transparency and avoids misunderstanding of use climate policy scenarios. However, complementary analysis to integrated assessments is required (Staub-Kaminski et al., 2014; Gambhir et al., 2019), but this does not mean that improvements cannot be taken to increase real-world representation of IAMs even further, and linking and integrating these model with social science insights.

CHAPTER 3

Are major economies on track to achieve their pledges for 2020? An assessment of domestic climate and energy policies

Roelfsema, M., Elzen, M.D., Höhne, N., Hof, A.F., Braun, N., Fekete, H., Böttcher, H., Brandsma, R., Larkin, J., 2014. Are major economies on track to achieve their pledges for 2020? An assessment of domestic climate and energy policies. Energy Policy 67. https://doi.org/10.1016/j.enpol.2013.11.055

ABSTRACT

Many of the major greenhouse gas emitting countries have planned and/or implemented domestic mitigation policies, such as carbon taxes, feed-in tariffs, or standards. This study analyses whether the most effective national climate and energy policies are sufficient to stay on track for meeting the emission reduction proposals (pledges) that countries made for 2020. The analysis shows that domestic policies of India, China and Russia are projected to lead to lower emission levels than the pledged levels. Australia's and the EU's nationally legally binding policy framework is likely to deliver their unconditional pledges, but not the conditional ones. The situation is rather unclear for Japan, South Korea, Brazil and Indonesia. We project that policies of Canada and the USA will reduce 2020 emission levels, but additional policies are probably needed to deliver their pledges in full. The analysis also shows that countries are implementing policies or targets in various areas to a varying degree: all major countries have set renewable energy targets; many have recently implemented efficiency standards for cars, and new emission trading systems are emerging.

Keywords: National climate and energy policies; reduction pledges; 2 degree climate goal

3.1 INTRODUCTION

Since the climate negotiations in Copenhagen in 2009, many countries have submitted quantitative economy-wide greenhouse gas (GHG) emission reduction targets, or pledges, for 2020, as anchored in the 2010 Cancún Agreements (UNFCCC, 2010a). To achieve these targets, most of these countries have planned or implemented climate and energy policies (REN21, 2011; GLOBE International, 2013)). Although many studies have analysed whether these pledges are sufficient for limiting global temperature increase to 2°C (for an overview, see Höhne et al (2012); UNEP (UNEP, 2012)) or analysed the ambition level of individual pledges (www.climateactiontracker.org/), no study to date has analysed whether the pledges are likely to be achieved. This study fills this gap by assessing how much the most effective domestic climate policies in major emitting countries would contribute to reducing GHG emissions, and by comparing the resulting emission levels with the pledges. As future emission levels without specific climate policies are uncertain, depending largely on economic growth and factors such as technological innovations (to exploit shale gas, for instance), we take into account uncertainty in business-as-usual (BAU) emissions, by using a range in BAU projection, and determining the emission levels resulting from implementing climate policies starting at BAU levels.

This paper is organised as follows. Section 2 provides the methodology of calculating the effect of domestic policies. Section 3 presents the expected emission levels from the policies and Section 4 discusses the caveats of this analysis and concludes.

3.2 METHODOLOGY AND DATA

3.2.1 General methodologies and data sources

The quantification of the pledges was based on den Elzen et al. (2013) and Hof et al. (2013). The selection of the most effective policies was done based on expert judgment (interviews of national experts) and literature review. For the calculation of the impact of domestic policies, three methods were used: (i) the policy evaluation module of the PBL FAIR policy model, (ii) bottom-up calculations by Ecofys (energy sector) and IIASA (agriculture and forestry sector), and (iii) literature research.

The policy evaluation module of the PBL FAIR policy model (www.pbl.nl/fair) consists of a spreadsheet with specific bottom-up calculations for each policy type, as described in Section 2.2. The spreadsheet is based on PBL/IIASA BAU projections including all Kyoto GHGs, except CO_2 emissions from land-use change. These projections were developed for the OECD Environmental Outlook (OECD, 2012), and were calculated using the PBL energy model TIMER (van Vuuren et al., 2011b) and the PBL land-use model IMAGE (Bouwman et al., 2006), based on GDP projections of the OECD (2012). For the Annex I countries, land-use credits are based on the agreed accounting rules for emissions from land use, land-use change and forestry (LULUCF) (Grassi et al., 2012; UNFCCC, 2012). Data on CO_2 emissions from LULUCF (e.g. deforestation) of non-Annex I countries were based on the IIASA forestry model G4M (Kindermann et al., 2008). The projections are harmonised to historical 1990-2010 emissions, which are based on the UNFCCC National Inventory Submissions, Common Reporting Format Tables for Annex I countries. The EDGAR database (JRC and PBL, 2012) and/or the national communications are used for the non-Annex I countries. Energy statistics data until 2010 is based on IEA (IEA, 2012a).

Bottom-up calculations by Ecofys were used for different subsectors, making use of emission projections by the countries themselves, as reported in the national communications, if available. Furthermore, data on energy-related CO_2 emissions were taken from projections of the World Energy Outlook of IEA (IEA, 2011b) (hereafter WEO 2011) and data for non-CO_2 GHG emissions from US EPA projections (EPA, 2006). The calculations of Ecofys were supplemented with calculations for land-use policies using the IIASA forestry model.

The most important literature sources include the Climate Action Tracker (CAT) of Ecofys, PIK, and Climate Analytics (Ecofys & Climate Analytics, 2011, 2012), Globe Climate Legislation Study (GLOBE International, 2013), REN21 report (REN21, 2011)and various national studies as explained in Section 3.

The first two methods for calculating the impact of different policy instruments and targets on reducing emissions are similar, with only few differences. Implementation barriers, domestic legislation and underlying policy instruments are taken into account in projecting the effect of specific targets, for instance by assuming that only a fraction of the target is achieved.

3.2.2 Methodology for specific policy instruments and targets

For all the policies and targets analysed in this paper (Table 3-1), the methodology for calculating the effect on emissions is described briefly below (for more details, see Supplementary 3).

The effect of *renewable mix targets* is calculated based on the difference in the share of primary energy consumption coming from renewable resources between the BAU projection and a projection of a scenario in which the renewable target is achieved, using emission factors per unit of primary energy consumption. If the target applies to electricity generation, a similar method is used, in which the primary energy consumption is calculated using the efficiency of power plants.

The effect of *renewable capacity targets* is calculated by estimating the primary energy consumption coming from fossil fuel resources that is avoided compared to BAU by replacing the fossil fuel resources by renewables resources, using emissions factors per unit of energy consumption.

The effect of *energy intensity targets* is calculated based on GDP projections (assuming GDP growth is not affected), and on BAU trends in the energy mix and emission factors per unit of primary energy consumption.

The effect of *power plant standards* (i.e. the CO_2 emissions per unit generated electricity) is estimated by calculating the difference in emissions per unit generated electricity of the new installed power plants between BAU projection and a projection in which all new fossil fuel plants are gas-fired to meet the standards or exceed them. It further accounts for the possible differences in energy efficiencies for the new power plants in both projections.

Table 3-1 Overview of major domestic policies per country analysed in this study

Australia	**Emission Trading System**	**Indonesia**	**Forestry policy**
	Renewable mix target (electricity)		Renewable mix target (primary energy) Renewable energy target
	Renewable Portfolio Standard		Biofuel target
	Power plant standard	Japan	(unknown)
Brazil	Forestry policy	Mexico	Renewable mix target (electricity)
	Grazing land management		Forestry policy
	Renewable capacity target	Russia	Gas-flaring target
	Renewable mix target (electricity)		Renewable mix target (primary energy)
Canada	Car standard		Energy intensity target
	Power plant standard	South Africa	Renewable capacity target
China	Emission intensity target		Feed-in-tariff
	Energy intensity target	South Korea	Emission trading system
	Renewable mix target (primary energy)		Renewable mix target (primary energy)
	Renewable capacity target	Ukraine	Feed-in-tariff

Australia	Emission Trading System	Indonesia	Forestry policy
EU	Emission trading system		Energy-intensity target
	Renewable mix target (primary energy)	USA	Renewable mix target (electricity) (regional)
	Energy efficiency target		Car standard
India	Renewable mix target (electricity)		Power plant standard
	Renewable capacity target		Emission trading system (regional)
	Renewable Portfolio Standard (PAT Scheme)		Biofuel quota

The impact of *feed-in-tariffs* on the growth of installed renewable capacity is calculated based on the relationship between growth and level of the subsidy from historic data from Germany and Spain and accounting for barriers such as grid access, long-term perspectives and guaranteed purchase. The calculation of the effect of the additional renewable capacities is described above.

Emission levels resulting from the implementation of an *Emissions Trading Systems* (ETS) are determined by applying the proposed emission caps to emissions of the sectors that are covered by the ETS, also taking into account implementation barriers. The difference with BAU emissions determines the reductions.

The effect of *fuel efficiency standards for cars* is calculated by two methods. The first method uses the PBL TIMER transport model (Girod et al., 2012); the effect on emissions is calculated by running a scenario with improved car standards, taking into account the higher purchase costs for such cars (Deetman et al., 2013). The second is based on replacing cars that do not satisfy the new efficiency standards for cars that do, where the replacement rate is based on the average life time of cars.

The effect of *biofuel targets*, finally, is also calculated by two methods. For the first method the TIMER transport model is used (Deetman et al., 2013). The second method of Ecofys is based on substituting energy use from gasoline or diesel cars by biofuels, using different emission factors from literature.

3.3 ANALYSIS OF REDUCTIONS BY MAJOR ECONOMIES

3.3.1 Australia

Australia has developed a portfolio of regulations and policies, including a carbon price scheme. Our assessment indicates that their combined effects could reduce emissions to the level of the unconditional pledge. However, the uncertainty in the effect of the regulations on 2020 emission levels is large: according to different national studies (Australian Government, 2010, 2011b, 2011a) and PBL FAIR model calculations, current policies could lead to an emission level ranging from 480 to 650 $MtCO_2e$ (excluding LULUCF emissions) by 2020 (Figure 3-1). This large range is mainly caused by uncertainty of the way the Australia's carbon pricing mechanism is implemented, which in general lacks bipartisan support, casting doubt over its political durability (Jotzo, 2012). The emission level is consistent with the least ambitious pledge of 5% below 2000 levels and is about 505 $MtCO_2e$ (excluding LULUCF).

Under BAU, Australia's emissions are projected to increase to around 620 to 650 $MtCO_2e$ by 2020 (based on the above studies of the Australian Government and PBL projections), from 550 $MtCO_2e$ in 2010. Australia has pledged to decrease its emissions by 5%, 15%, or 25% below its 2000 emission level, including Afforestation, Reforestation and Deforestation (ARD) emissions. These pledges represent a range in emission levels of 390 $MtCO_2e$ to 503 $MtCO_2e$, excluding land-use emissions, and thus also excluding ARD[5] emissions, as communicated by Australia (Grassi et al., 2012).

According to the Climate Action Tracker country assessment report (Ecofys & Climate Analytics, 2011) and the Treasury modelling report (Australian Government, 2011d), the Clean Energy Future Plan has the potential to become the cornerstone instrument for low carbon development in Australia – but only with substantial enhancement it could lead to meeting the more ambitious pledges. Key features of the strategy include introduction of an ETS ("Carbon Pricing Mechanism") in 2012 with a fixed carbon price, followed by a flexible carbon price from 2015. The ETS will cover around 500 of the largest polluters in Australia and covers around 60% of national emissions. Not all sectors are directly involved: Agriculture, parts of land-sector emissions, transport fuel for households, and emissions from light-road vehicles are excluded in ETS. According to the Australian Treasury's assessment (Australian Government, 2011d) the scheme is expected to have major impacts on energy generation and industry and could lead to reductions towards the level of the unconditional pledge. According to PBL TIMER projections, the impact is somewhat smaller.

[5] 71 $MtCO_2$ in 2000 and 34 $MtCO_2$ in 2020

Impact climate policies on greenhouse gas emissions for Australia

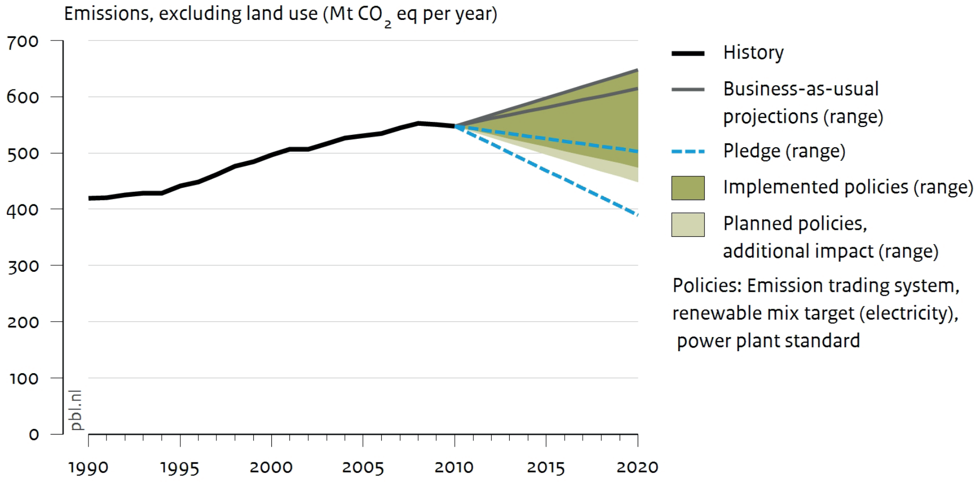

Figure 3-1 Impact of climate policies on greenhouse gas emission projections for Australia

For the energy supply sector, which is the main source of CO_2 emissions in Australia, a 20% renewable electricity generation target by 2020 is set via the Renewable Energy Target Scheme (RET), introduced in 2009[6]. The policy instrument is supported by a renewable portfolio standard with a high penalty for non-compliance. In order to be successful, some administrative barriers (such as spatial planning regulation) would need to be removed. The impact of RET is therefore uncertain; we project that it would lead to a share of renewables in electricity generation of 16%[7] to 20% by 2020. This would lead to a reduction in emissions by 35 to 50 $MtCO_2e$ (Australian Government, 2011d), but these reductions are not additional to the reductions achieved by implementation of the ETS. Another measure targeted at energy supply is a power plant standard, which would result in closing down highly polluting coal-fired electricity production plants, which together are responsible for about 2000 MW electricity generation. Replacing them by gas power plants would decrease CO_2 emissions around 10 $MtCO_2$, based on estimates from the Australian Government (Australian Government, 2011c) and on PBL FAIR calculations. Only few additional policies are in the planning phase, which, according to our analysis, are not expected to reduce emissions significantly beyond the implemented policies.

[6] http://ret.cleanenergyregulator.gov.au/

[7] A recent NGO report (http://www.climate-connect.co.uk/Home/?q=node/2057) indicates that the country would be able to achieve a reduction of 16% to 17% by 2020.

3.3.2 Brazil

Brazil pledged an emission reduction target of 36% to 39% below BAU in 2020, including emissions from LULUCF. The effects of policies on emission reductions compared to BAU are uncertain, as BAU emission projections themselves are very uncertain. This holds especially for policies related to reducing LULUCF emissions.

Brazil's BAU emission level, including LULUCF emissions, is projected at 2,480 to 3,240 $MtCO_2e$ by 2020. The upper end of this range is based on national projections (Government of Brazil and Government of Brazil, 2010), while the lower end results from the PBL/IIASA BAU emission projections. The national BAU projections and the targets are now part of the national climate law. This means that the target emission level from the pledges is between 1,980 and 2,070 $MtCO_2e$ in 2020. In its pledge, Brazil announced specific emission reductions targets per sector. Most reductions are expected from the agriculture and forestry sector.

Along with India and Mexico, Brazil is one of the few non-Annex I countries that currently have suitable capacities and long experience in forest inventories and monitoring (Romijn et al., 2012). Based on satellite information embedded in a publicly accessible system, Brazil can track deforestation events at real time and with high accuracy. There are several policies targeted at the agriculture and forestry sector of Brazil. Central to our analysis were the Action Plan for Deforestation Prevention and Control in the Legal Amazon (PPCDAm) and in the Cerrado (PPCerrado). The PPCDAm should result in a reduction of 80% of the annual deforestation surface in the Amazon, compared to the historical average of 1996-2005. The national projection shows that, based on the avoided deforested surface and assuming a constant biomass density (484 tCO_2/ha), this would avoid about 760 $MtCO_2$ of emissions by 2020. The PPCerrado calls for a reduction of 40% of the annual deforestation surface in the savannahs, compared to the historical average from 1999-2008. When assuming a constant biomass density (206 tCO_2/ha) in the savannah, this would avoid about 130 $MtCO_2e$ of emissions by 2020 compared to national projections. We assume the full implementation of both plans for our calculation.[8] The total reduction of the above forestry emissions is about 890 $MtCO_2e$ in 2020, based on the national BAU projection of 1400 $MtCO_2e$. The BAU projection of IIASA is 1070 $MtCO_2e$, showing the high uncertainty of agricultural and forestry BAU emissions. Based on these BAU projections, we find the reduction caused by the above action plans could be much lower, namely 560 $MtCO_2e$ in 2020.

[8] The planned revision of the Forestry code (Law 4.771/1965) could seriously undermine the full implementation. Scientific studies of the Institute for Applied Economic Research (http://www.socioambiental.org/banco_imagens/pdfs/Cod_Florestal_Ipea_Jun_2011.pdf) estimate that deforestation could be 47% higher in 2020, if this new law is approved.

Apart from these action plans, Brazil announced policies to achieve a restoration of grazing land to increase productivity and carbon storage in grasslands, leading to a pledged reduction of 80 to 100 $MtCO_2e$ (UNFCCC, 2011a). According to the IIASA calculations, such a reduction would require additional management actions for approximately 15% to 25% of total Brazilian pastures, assuming a constant and generic sequestration rate. This is about twice the targeted area, implying that the average sequestration potential might be overestimated. We assume therefore that policies targeted at grassland restoration will only realize 50% of the expected emission reductions, which amounts to 40 to 50 $MtCO_2e$ in 2020.

Apart from measures in forestry, Brazil's ten-year plan states that the country will triple its use of "new" energy, excluding hydro renewables, by 2020, and that much of that will be wind energy. The total share of electricity from new renewables (excl. large hydro) is targeted at 16% in 2020. If these targets are reached, it would result in a reduction of emissions by 0-40 $MtCO_2e$. The low end is based on the TIMER BAU projections that already includes a large share of biomass used for electricity production.

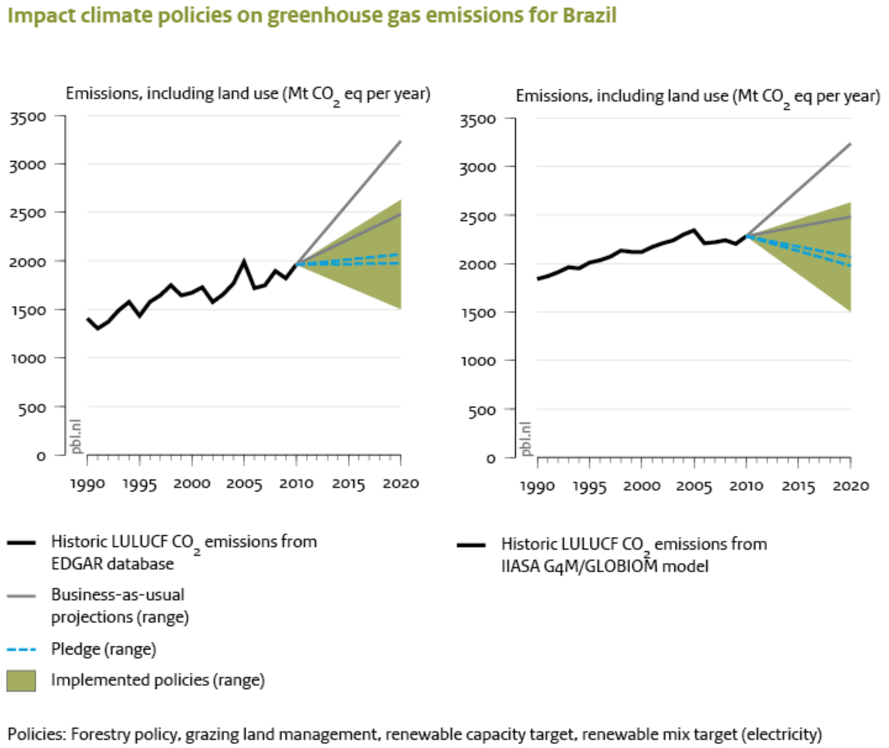

Figure 3-2 Impact of climate policies on greenhouse gas emission projections for Brazil using the historical LULUCF CO2 from EDGAR (left) and IIASA (right)

Despite the assumption of a successful implementation of measures to reduce emissions from deforestation the total emission levels for Brazil remain increasing (see Figure 3-2). This is also due to an expected increase especially in emissions from livestock management.

3.3.3 Canada

We project that Canada's major climate policies would lead to an emission level of 730 to 780 $MtCO_2e$ by 2020, which is only slightly below BAU projections. Canada pledged to reduce its GHG emissions by 17% below 2005 levels in 2020, which implies an emission target of 610 $MtCO_2e$ in 2020. BAU emissions are projected at 750 to 790 $MtCO_2e$ by 2020. According to Canada's 2011 Emission Trends Report, BAU emissions would reach 790 $MtCO_2e$ in 2020 (Environment Canada et al., 2011). This figure has been revised downwards to 750 $MtCO_2e$ in the 2012 Emission Trends Report (Environment Canada, 2012a), due to a stronger than expected effect of the recession, methodology updates, the accounting for forestry emissions and new policies. The PBL TIMER BAU projection is within the BAU range.

The most important national climate policies include a fuel efficiency standard for light duty vehicles and a carbon standard for coal-fired power plants. The fuel efficiency standards are aligned with those of the USA and consist of two phases with increasing standards. The second phase will start in 2017 and ends in 2025 with an average emission intensity standard of 101 g/km. As the first phase of the efficiency standard is already incorporated in the national BAU development, the impacts on CO_2 emissions are projected to occur mainly after 2020. A larger reduction compared to the PBL TIMER BAU is found, as this does not take into account the first phase. The emission levels after implementation of the standard are similar, however.

The carbon standard for coal-fired power plants was published in September 2012 and will come into effect mid-2015 (Environment Canada, 2012b). Power plants constructed after June 2015 will have to stay below a limit of 420 tCO_2e/GWh, which is the emissions intensity level of the Natural Gas Combined Cycle technology – a high-efficiency type of natural gas generation. We project only a small effect on 2020 emissions levels, based on national studies (Environment Canada et al., 2011) and FAIR model calculations, because the standard does not affect existing power plants, which can be in operation for another 50 years. Furthermore, Carbon Capture and Storage (CCS)-ready power plants are exempt from the regulation. Finally, the share of coal is already projected to decrease in national BAU (in favour of gas).

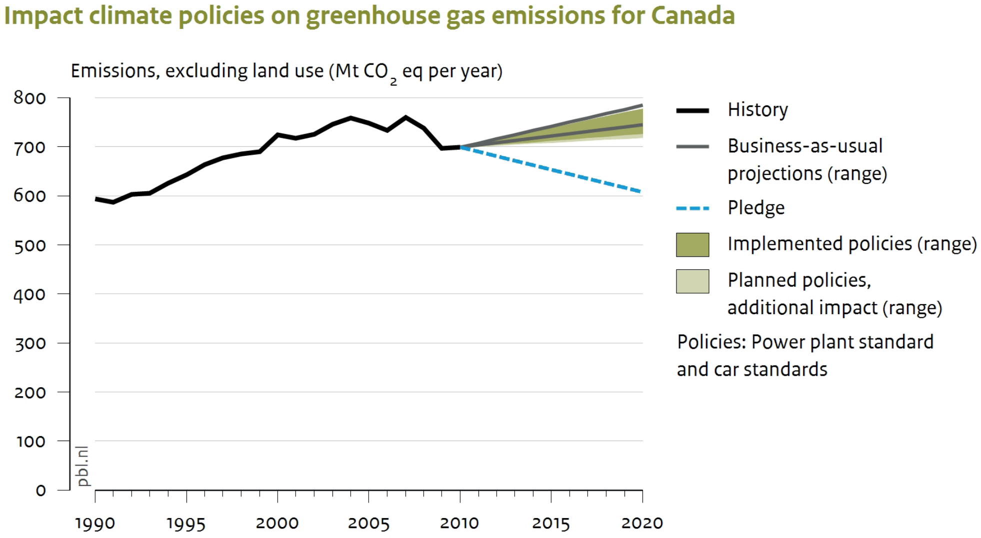

Figure 3-3 Impact of climate policies on greenhouse gas emission projections for Canada

3.3.4 China

China's national policies are projected to lead to lower emission levels than levels consistent with the pledge. However, the absolute emission level resulting from the pledge strongly depends on economic growth, which is very uncertain.

China's pledge includes reducing CO_2 emissions intensity (emissions per unit of GDP) by 40 to 45% in 2020 compared to 2005 levels, increasing non-fossil energy to 15% in 2020, and increasing forest coverage by 40 million hectares (UNFCCC, 2011a). China's emissions would be between 12.9 and 13.8 $GtCO_2e$ in 2020 if it meets this pledge. The lower end is based on the energy-related CO_2 emissions projection of the enhanced policy scenario, as published in the second national communication (Government of China, 2012), whereas the upper end is based on the calculated emission level of a 40% intensity reduction, using the GDP data of the national communication. Both projections are supplemented with industry-related CO_2 and non-CO_2 GHG emissions trends from the PBL/IIASA BAU (Den Elzen et al., 2013). There is still some uncertainty in these emission levels resulting from the pledges, due to uncertainty in i) GDP projections, ii) historical emissions data (as for example illustrated by Guan et al. (2012)), iii) the impact of the non-fossil target, and iv) non-CO_2 GHG emission projections. The national communication assumes an GDP growth of 7% between 2010 and 2020. A 1% higher growth rate would increase the emission level from the pledge by about 1 $GtCO_2e$ (Den Elzen et al., 2013). The BAU emission levels range from 14.1 to 17.4 $GtCO_2e$ in 2020. For

BAU emission projections and the effect of the pledge, we rely on four data sources: WEO 2011 (IEA, 2011b), a report of Energy Research Institute from China (ERI, 2009), PBL TIMER projections, and the Second National Communication.

National climate policies are developing fast. Economy-wide climate and energy policies for the period 2011-2015 are established in the 12th Five-Year Plan. We analysed the effect of planned renewable capacities, which increased more than twofold for some technologies in the 12th Five-Year Plan for renewable energy development (China National Energy Administration and China National Renewable Energy Centre, 2012) compared to the previous version. The total targeted renewable capacity is now 700 GW in 2020, 420 GW of which consists of hydropower, 200 GW of wind energy, 50 GW of solar and 30 GW of biomass electricity. Additionally, targets for increasing solar thermal water heating, biogas and biofuels, which are included in the Medium and Long-term Plan for Renewable Energy (2007), are included.

Our assessment of the effects of some policies takes into account high data uncertainty. Despite this uncertainty, it is known that emissions in China have increased faster than previously expected and have reached around 11 $GtCO_2e$ in 2010 (JRC/PBL et al., 2012). We conclude that the new capacity targets would lead to a more ambitious level of renewable energy than the internationally pledged 15% non-fossil target, and to a lower emission level than is expected from the CO_2 emissions intensity target. Therefore, the planned renewable capacity targets are likely to result in overachieving the pledge.

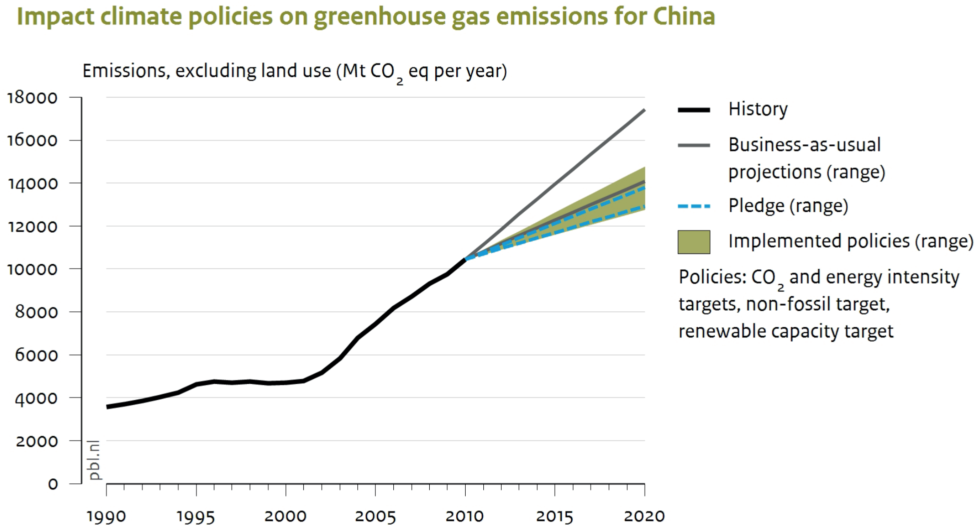

Figure 3-4 Impact of climate policies on greenhouse gas emission projections for China

3.3.5 European Union

The EU-27 is enforcing the nationally legally binding framework to deliver its unconditional 20% GHG reduction pledge by 2020. This pledge excludes emissions/removals from LULUCF and includes emissions from aviation. Projections of GHG emissions by the European Environment Agency (EEA, 2012) show that the EU is close to meeting its 20% target with currently implemented national measures: the EEA projects a reduction of 19% below 1990 levels in a scenario with implemented policies, which results in an emission level of 4.5 $GtCO_2e$ in 2020. Currently planned policies would not be sufficient to meet the conditional pledge of 30% reduction below 1990 in 2020. These measures include an ETS, renewable energy targets and support, energy efficiency policies, and CO_2 standards for light-duty passenger cars. To deliver the conditional target of 30%, the EU would need to develop and implement additional policies and measures beyond the policies currently planned by Member States: all planned policies could result in an emission level of 4.2 $GtCO_2e$, while about 3.9 $GtCO_2e$ would be required for the 30% conditional pledge (see Figure 3-4). The EU emission level was at approximately 4.6 $GtCO_2e$ in 2011, according to the EEA.

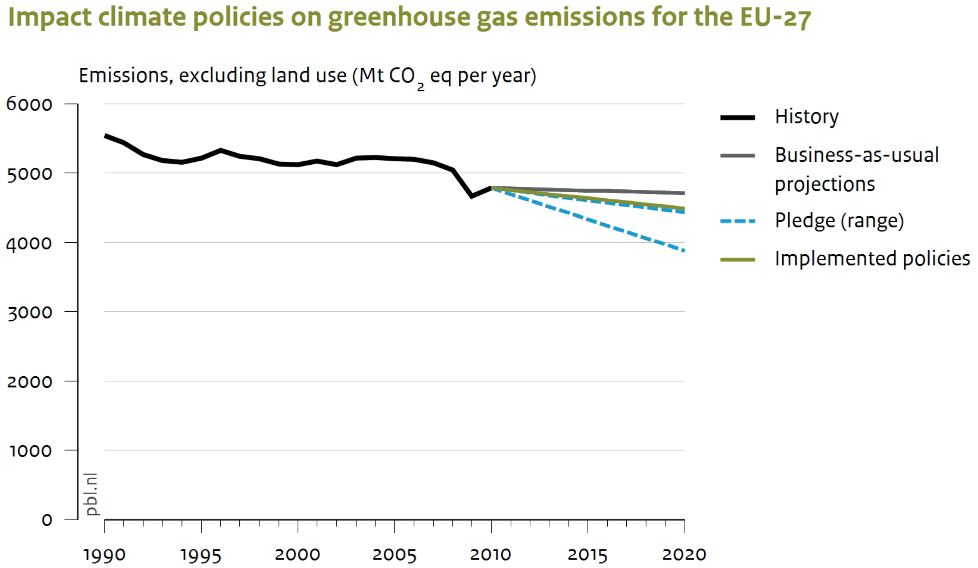

Figure 3-5 Impact of climate policies on greenhouse gas emission projections for the EU-27

3.3.6 India

The emission level resulting from India's pledge strongly depends on GDP growth. The pledge can either lead to considerable reductions or to emissions far above the current BAU projections. Even in the case where the pledge led to considerable reductions, we project that the pledge is likely to be overachieved if the national policies we evaluated are implemented.

India pledged a 20% to 25% emission intensity reduction of its GDP by 2020, compared to 2005 (excluding emissions from the agricultural sector). India provided an official quantification of emissions as a result of this pledge, based on annual GDP growth projections of 8% and 9% (Planning Commission Government of India, 2011). Based on 8% GDP growth and historic data from the Planning Commission report, the emission level is projected at 3.5 to 3.7[9] $GtCO_2e$ in 2020. The projections for future BAU emission development in India differ substantially among studies and range from 3.2 to 5.3 $GtCO_2e$ in 2020 (excluding forestry emissions), based on a report by the Climate Modelling Forum (Climate Modelling Forum, 2009), PBL TIMER, and WEO 2011 projections.

On federal level, India implements two major renewable energy targets. The strategic plan for new and renewable energy contains capacity targets for renewables by 2017 and 2022 (Government of India, 2011). The renewable capacity targets for 2017 are 27.3 GW wind, 4 GW solar, 5 GW biomass and 5 GW other renewables, and for 2022 they are 38.5 GW wind, 20 GW solar, 7.3 GW biomass and 6.6 GW others. India also committed to a renewable electricity generation target for 2020 of 15% excluding large hydro (Government of India, 2012). Total projected reductions of these renewable targets are between 30 and 140 $MtonCO_2e$, where the low end is based on PBL TIMER BAU projections that already include high biomass electricity production, and the high end is based on Ecofys calculations using WEO 2011 data. Indian states have introduced several policies regarding renewable energy deployment which, as yet, are not harmonized on a federal level. We did not look in detail into state policies, and recognize there could be large regional differences, which could increase overall emission reductions.

The Indian government agreed upon the Perform, Achieve and Trade (PAT) Mechanism on 30 March 2012. This energy efficiency cap-and-trade scheme covers the largest industry and power generation facilities, which in total cover more than 50% of the fossil fuel used in India. The target is to achieve a 4% to 5% reduction of energy consumption in 2015 of the participating facilities, which are from the power sector (60%) and the industry sector (40%).

[9] Excluding agricultural and LULUCF emissions, but these are not expected to significantly change the total emissions level (Planning Commission Government of India, 2011)

National studies estimated that the PAT Mechanism would reduce annual CO_2 emissions around 25 $MtCO_2e$ by 2015, which compares to 20 $MtCO_2e$ projected by the PBL FAIR model. The effect after 2015 heavily depends on the rules of the continuation of the scheme, which yet have to be decided. It could range from 100 (assuming that the policy will stop in 2015 and energy use will continue to grow as in BAU) to 300 $MtCO_2e$ (assuming a continuous decline in energy use) reduction in 2020.

To calculate the total emission reduction of the renewable energy targets and PAT scheme, the Ecofys calculations subtract the emission reductions from electricity consumption due to the PAT scheme from expected electricity generation in 2020 after implementation of the renewable target. In the PBL FAIR policy evaluation module an overlap of 25% is assumed.

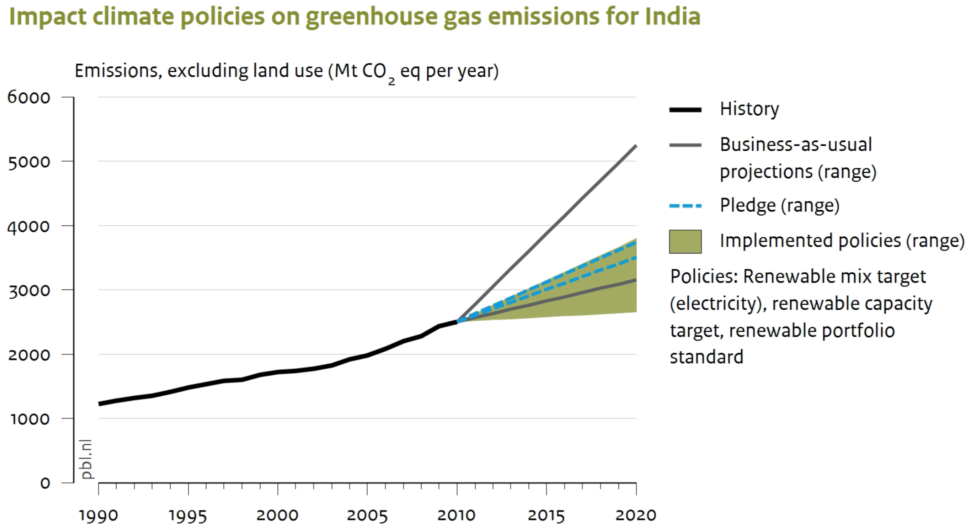

Figure 3-6 Impact of climate policies on greenhouse gas emission projections for India

3.3.7 Indonesia

Reductions from the assessed policies are smaller than the uncertainty around emissions from land-use changes and forestry (which also include peat lands), so the remaining emissions after implementation of policies cannot be determined.

Indonesia submitted an unconditional pledge to reduce emissions by 26% from its BAU emission projections. Indonesia also entered a high, conditional pledge of 41%, announced prior to the conference in Copenhagen. High uncertainty regarding emissions from forestry dominates the evaluation of Indonesia's pledges. The emission target, including land-use changes and forestry emissions, resulting from the pledges would be between 1.7 and 2.2 $GtCO_2e$ using the BAU projection of the Indonesia Second National Communication (Republic of Indonesia Ministry of Environment, 2010). This compares to BAU emissions ranging from 1.6 to 3.0 $GtCO_2e$ in 2020 based on the national communication and PBL/IIASA BAU projections. The BAU in 2020 from the Second National Communication includes peat land emissions of about 1.0 $GtCO_2e$, besides peat fire emissions of about 0.5 $GtCO_2e$. The historic emissions data from the green paper of the Ministry of Finance (Ministry of Finance Indonesia, 2009) does include peat fire emissions but not 'other peat land emissions' (see Figure 3-7). About half of the emissions for Indonesia are from forestry and peat lands, but achievement of deforestation reductions as part of the pledge is difficult to assess. While the forest area that needs to be monitored to assess compliance with regulations is of a similar magnitude to that of Brazil, transparency, quality and accessibility of national wide data lag behind in Indonesia (Fuller, 2006). Overcoming this lag is essential for forest law enforcement.

Indonesia has a target of 15% renewable energy sources in 2020[10]. The emission reductions from this target are relatively low, as according to the National Energy Policy, mainly oil (with lower emissions per kWh than coal) is replaced, while the share of electricity generated by coal-fired plants is not reduced. The renewable energy policies lead to emission reductions between 20 and 80 $MtCO_2e$ by 2020 compared to BAU, based on PBL FAIR calculations and on calculations based on Energy Outlook Indonesia[11].

One policy aimed at achieving the renewables target is the biofuel quota, which consists of 15% biofuels for all transportation fuels by 2025. The target is supported by the Biofuel Price Subsidy, which guarantees a certain price and obliges the national oil company to purchase the products of national biofuel producers. Today's transport emissions are expected to increase drastically, because of the very high demand expected for transportation in the coming decade. If the quota is enforced fully, this law reduces emissions of the transport sector by 15-30 $MtCO_2e$. In comparison, BAU emissions are projected at 200 to 240 $MtCO_2e$ in 2020, based on Indonesia Second National Communication (Republic of Indonesia Ministry of Environment, 2010) and calculations from the PBL FAIR

[10] "National Energy Policy" determined by the Presidential Regulation No5/2006. In the 2nd National Communication, Indonesia reaffirms the target, but for the year 2025. For our calculations, we looked at both possibilities: we assume that the target is either reached in 2020 or in 2025.

[11] http://www.esdm.go.id/publikasi/indonesia-energy-outlook.html

model[12]. As the renewable energy target includes assumptions on increase of biomass, the reductions from this policy are not additional.

Under the Forest Law Enforcement, Governance and Trade (FLEGT) programme, Indonesia has a “Voluntary Partnership Agreement” with the EU, guaranteeing to only export legally harvested timber to the EU. This is a step to stop illegal logging and to decrease emissions from land use and forestry. Illegal logging seems to be the major cause of GHG emissions. Indonesia’s forest area encompasses around 133.6 million ha with an area under production of around 61.5 million ha (46%). We assume that this area is most vulnerable for illegal logging. Current illegal logging volumes are estimated to be between 20 and 50 Mm^3, estimated as the difference between timber demand and current production (Luttrell et al., 2011). We have translated this into an affected area of 200,000 to 500,000 ha (assuming a yield of 100 m3 per ha[13]). Probably only a fraction of that is exported. However, a successful implementation of FLEGT will lead to reduced illegal logging overall in Indonesia. In the calculations we assume that about 50% of the areas affected by illegal logging are deforested and lose their carbon stock. The remaining area is likely to be degraded after illegal extraction of wood, but will also regrow to some degree. We further assume that all illegal logging is banned by the policy. In our analysis, the emission reductions as a result of FLEGT are based on emission factors of about 500-700 tCO_2e/ha from the IIASA G4M model and two national studies (DNPI, 2009; Ministry of Finance Indonesia, 2009). We project emission reductions of this programme of 70 to 130 $MtCO_2e$ in 2020.

[12] The emission reductions depend heavily on the emission factor of biofuel production. For our calculations, we assume a factor of 0% to 80% smaller than the average fossil fuel.

[13] The average growing stock in Indonesian forests is about 120 m^3 according to FAO Forest resource Assessment 2010 (FAO (2010) Global Forest Resources, Assessment 2010. Food and Agricultural Organization of the United Nations (FAO), Rome, Italy, http://www.fao.org/forestry/fra/fra2010/en/. Not all the standing volume is suitable for timber and is commercially attractive. We assume that 20 m^3 are slash material, lower quality timber and harvest losses, while 100 m^3 per ha could potentially be extracted and traded as timber and energy wood.

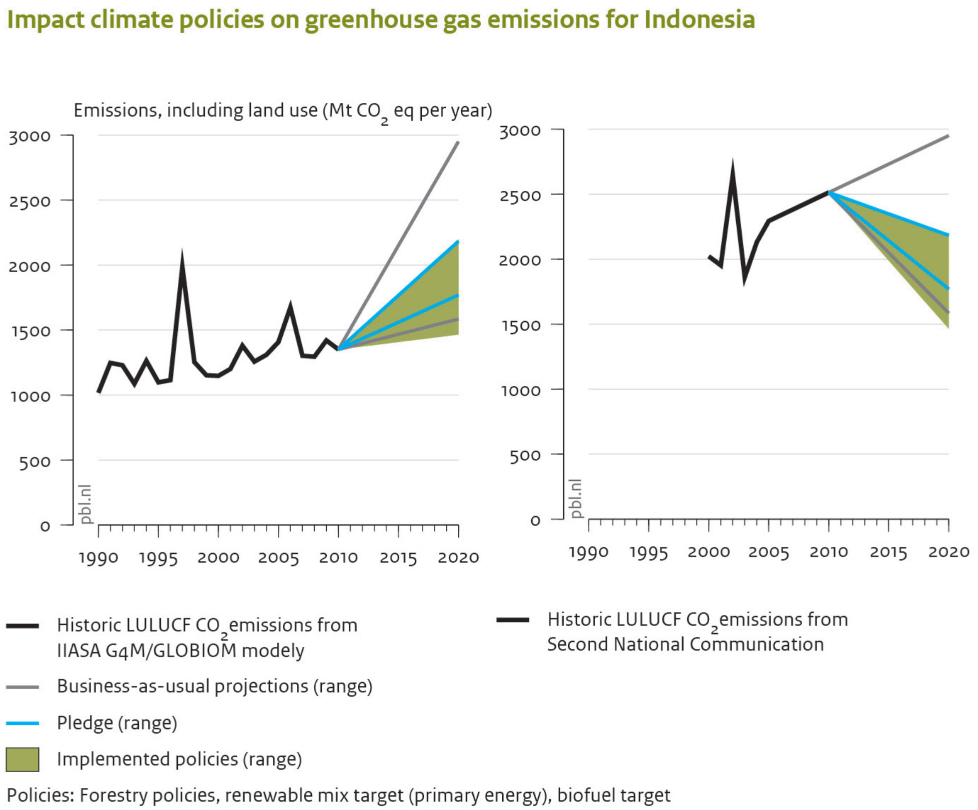

Figure 3-7 Impact of climate policies on greenhouse gas emission projections for Indonesia using the historical LULUCF CO2 from IIASA (left) and the Second National Communication (right). IIASA data between 1990 and 2020 is supplemented with constant 2005 peat fire emissions from the Indonesian Ministry of Finance (2009)

3.3.8 Japan

Japan pledged a conditional reduction of 25% in 2020 relative to 1990, which results in a total target emission level of 950 $MtCO_2e$ in 2020. This compares to an expected BAU emission level of around 1200-1300 $MtCO_2e$. It is not possible to assess whether Japan will meet its pledge, as it depends to a large extent on the future energy plan, which is still under discussion. This plan should give insight how Japan will redesign its energy market, especially as Japan announced a phase out of nuclear power in its 'Revolutionary Energy and Environment Strategy', that would imply high investments in emission free energy sources to meet the pledge.

3.3.9 Mexico

Our findings indicate that with currently implemented polices, Mexico will achieve substantial emission reductions, but not yet sufficient to meet its conditional pledge of 30% emission reductions relative to BAU. Mexico has established structures and framework policies, such as the General Law for Climate Change[14], adopted in April 2012. In June 2012 the General Law on Climate Change was published, setting a solid institutional arrangement to support mitigation. It also includes a binding 30% reduction by 2020 below BAU emission, conditional on adequate financial and technological support from Annex I countries. Mexico is translating those structures into concrete actions in its Low Emission Development Strategy (LEDS), which is being developed at this moment.

Two studies project that Mexico will achieve roughly half of the pledge with currently implemented policies. According to a presentation by SEMARNAT[15], Mexico can achieve reductions of about 130 $MtCO_2e$ with current policies. This compares to a reduction objective of 288 $MtCO_2e$ (calculated as the difference between BAU emissions of 960 $MtCO_2e$ (NCCS, 2013) and the target emission level of the pledge of 672 $MtCO_2e$). Most of these reductions result from measures in the forestry sector, from addressing fugitive emissions in the oil and gas sector and from the sustainable cities program that is targeting transport and waste. This conclusion is confirmed by the Climate Action Tracker's country report on Mexico (NCCS, 2013).

With the General Law for Climate Change, Mexico also has set a renewable energy target of 35% of electricity to be generated via renewable technologies by 2024. Achieving 29% renewables by 2020 (which is on linear path towards 35% in 2024) has limited impact, because the carbon intensity of the Mexican electricity supply is projected to decrease substantially even without the law, which is mainly due to projected low gas prices. The renewable energy target is not yet translated in implementing decisions.

The General Law also wants to achieve a zero-carbon net loss from forest ecosystems in 2020. The necessary reductions should come from the ProArbol program and the current REDD+ projects. The ProArbol program is set up to generate development and contribute to the economy from valuation, conservation, restoration and sustainable production of forestry resources. It contains targets for reducing deforestation and forest degradation and implement reforestation projects. The reductions from these measures is around 30 $MtCO_2eq$ reductions, based on SEMARNAT calculations[16].

[14] http://gaceta.diputados.gob.mx/Gaceta/61/2012/abr/20120412-IV.html

[15] Presentation of National Institute of Ecology (Mexico) at Workshop Enhanced Action Towards Effective Mitigation Goals: Issues & Strategies, Seoul, South-Korea, September 2012

[16] Presentation of National Institute of Ecology (Mexico), September 2012

Impact climate policies on greenhouse gas emissions for Mexico

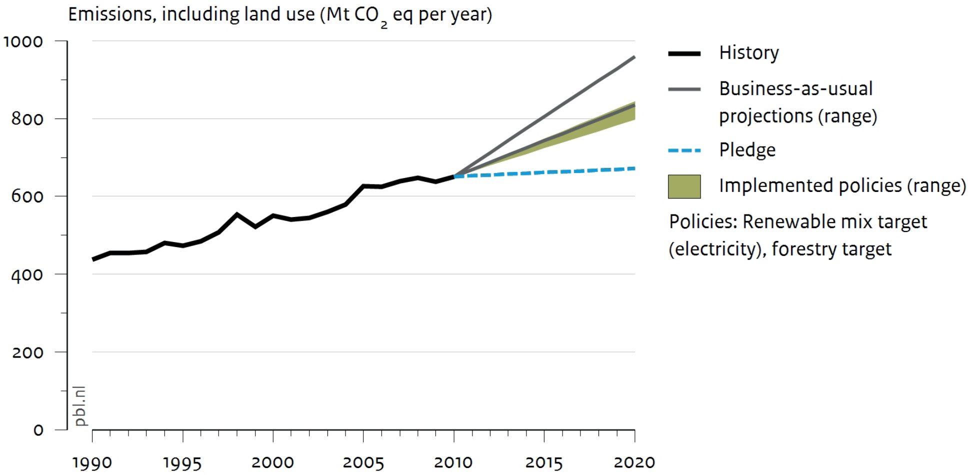

Figure 3-8 Impact of climate policies on greenhouse gas emission projections for Mexico

3.3.10 Russia

Russia's pledge is not projected to lead to substantial reductions relative to BAU emissions. Implemented policies are expected to reduce emissions from BAU levels of 2.4-2.8 $GtCO_2eq$ to 2.1-2.5 $GtCO_2eq$ by 2020. By implementing the full policy package relating to the decrease of 40% energy intensity, another 10% could be reduced.

Russia committed to a reduction of GHG emissions of 15% to 25% relative to 1990 levels by 2020, resulting in an emission target level of 2.5-2.8 $GtCO_2e$. This range is comparable to the BAU range based on the projection of a moderate and an innovative scenario in Russia's fifth national communication (Ministry of Natural Resources Russian Federation, 2010), WEO 2011, and the PBL TIMER projection.

In June 2008, Russia committed to a reduction of the energy intensity of GDP by 40% by 2020 compared to 2007 levels (Presidential Decree No.889). The Russian Energy Agency (2011) presented that Russia could reduce its energy intensity of GDP by about 26% by 2020, without additional government support (by autonomous improvements, sector shifts etc.). As a 26% improvement of energy intensity would lead to emission reductions of 90 to 230 $MtCO_2e$ compared to the BAUs considered here (WEO 2011, PBL TIMER) and thus implies additional action, we consider this as a domestic policy. Other implemented policies are Russia's renewable target and gas flaring measures, as described below. As there appear to be no additional measures taken or planned to achieve the remaining reduction to a decrease of 40% energy intensity, we considered this additional reduction as a planned policy, leading to reduction of 400 to 530 $MtCO_2e$.

In 2009, the Russian government published guidelines for enhancing energy efficiency of renewables-based electricity through 2020 (Ministry of Natural Resources Russian Federation, 2010), which called for the increase of the share of renewable energy sources to 4.5% by 2020. This target only leads to small emission reductions, as this share of renewables is almost reached in the PBL TIMER and WEO 2011 BAU projections. In 2010 and 2012 there were further discussions regarding additional state energy efficiency programs, but so-far, none have been implemented.

Another important policy area relates to emissions from flaring, as Russia is one of the most important oil and gas producers in the world. In January 2009, a government decree sought to reduce emissions from gas flaring. A 5% limit for gas flaring has been set for 2012 and subsequent years, with fines being imposed if this threshold is exceeded or if

Impact climate policies on greenhouse gas emissions for Russia

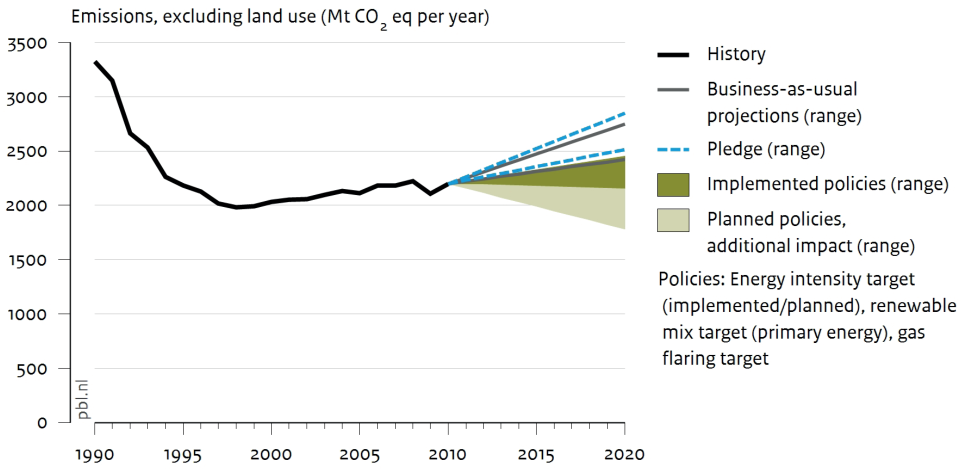

Figure 3-9 Impact of climate policies on greenhouse gas emission projections for Russia

there is no monitoring equipment. The 5% can also be reformulated as a 95% utilization of Associated Petroleum Gas (APG). Based on crude oil production projections (IEA, 2011b), on the assumption that no autonomous improvement on APG utilization will take place, and on projected losses and leakages from the PBL TIMER model, full implementation of this law would result in reductions between 130 and 230 $MtCO_2e$ in 2020. However, complex technological, economic and political factors may impede increased APG utilization. While many existing oil fields are located in remote areas without infrastructure and technological solutions for APG utilization, new oil fields are planned in even more remote areas, without access to gas transportation systems. Consequently, increased APG utilization will require large investments and/or lead to limitations on oil production. Therefore, we assume an implementation barrier of 50%, leading to a reduction range between 65 and 115 $MtCO_2e$ in 2020.

3.3.11 South Africa

South Africa has pledged to reduce its emissions by about 34% below BAU by 2020, conditional on adequate financial, technological and capacity-building support. Depending on national emission projections (South Africa provided a range of from 590-860 $MtCO_2e$ by 2020 (South Africa Department of Environmental Affairs, 2011), the pledge would result in an emission level of 390 to 570 $MtCO_2e$ in 2020. The national policies included in our analysis could reduce emissions to 560 to 690 $MtCO_2e$ in 2020.

The effectiveness of South African climate policy strongly depends on implementation issues. For example: in 2009, South Africa implemented a promising feed-in-tariff, with rates for wind energy that were larger than those offered in Germany and those proposed in Ontario, Canada. However, the tariff has had no impact on the renewable deployment so far due to political circumstances and infrastructure characteristics like lack of sophisticated power distribution lines.

The government has announced plans for a bidding process to replace the feed-in scheme, which should lead to 10,000 GWh generated by renewable sources in 2013. In addition, there is also a new installed renewable capacity target of 17.8 GW renewable energy for 2030. These targets would lead to a reduction of 10 to 25 $MtCO_2e$ in 2020, based on own calculations using projections from literature (Greenpeace International and EREC, 2009) and assuming a load factor of 1500 hours (Beurskens and Hekkenberg, 2011). Our assessment assumes that the short-term target will not fully be reached due to the lack of support policies. For the final electricity mix, we used the latest version of the integrated resource plan (South Africa. Department of Energy, 2011), which assumes 24.5 GW cumulative capacity of installed renewables in 2030.

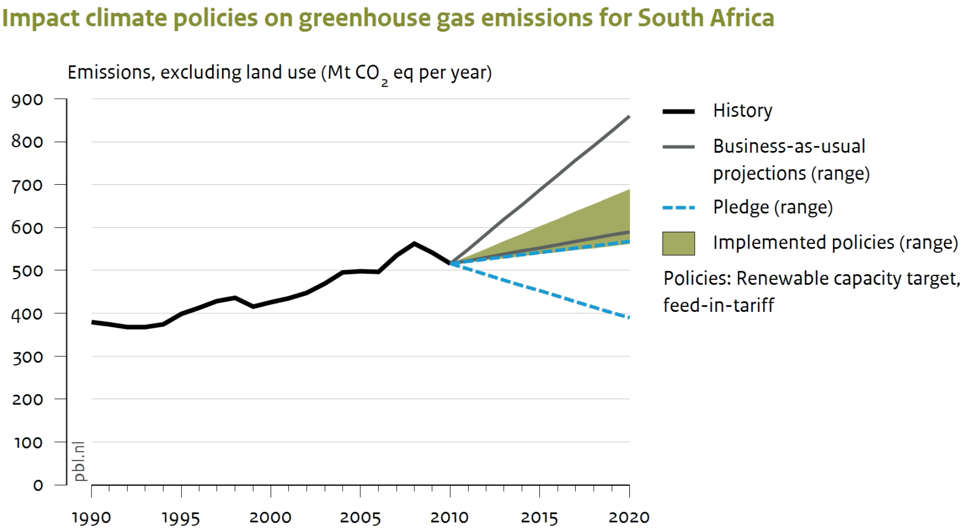

Figure 3-10 Impact of climate policies on greenhouse gas emission projections for South Africa

3.3.12 South Korea

The introduction of the national ETS system and the renewable target are expected to significantly impact South Korea's GHG emissions. Achieving the pledge of 30% below BAU level in 2020 will depend on the final design and implementation of the ETS and implementation of other policies.

The BAUs used in the evaluation have 2020 emission levels ranging from about 780 (South Korea. Ministry of Environment, 2012) to 810 $MtCO_2e$[17], compared to a pledged target emission level of about 540 $MtCO_2e$.

South Korea introduced a "Target Management System" (TMS) in 2012, which is an instrument for preparing the national ETS system. Currently, 60% of total emissions are covered under the TMS. The ETS, which starts in 2015, will cover all installations in the industrial and power sectors with annual emissions higher than 25 $ktCO_2e$. The absolute emission cap of the ETS is expected to be in line with the pledge. However, it is not yet clear what percentage of total national emissions will be covered under the system. For this study, it is assumed to be the same as for the TMS based on (Yong-Gun, 2012). As there is uncertainty whether a comprehensive Measuring Reporting and Verification system of emissions is in place, we have assumed that

[17] http://www.greengrowth.go.kr/?page_id=42461

only 90% of the total pledged cap will be reached. . This leads to a reduction range between 135 and 140 MtonCO_2e, based on PBL TIMER projections and national projections.

Apart from the ETS, South Korea has targeted a 6% renewable share in the primary energy mix by 2020 and a 11% share by 2030.[18] The impact of this target, if fully implemented, is a reduction between 30 and 50 MtCO_2e by 2020, based on WEO 2011 projections and calculations from the PBL FAIR model. This is given the assumption of a constant share of nuclear over time.

Full implementation of the above policies would lead to an expected emission level of 630 to 670 MtCO_2e by 2020.

Impact climate policies on greenhouse gas emissions for South Korea

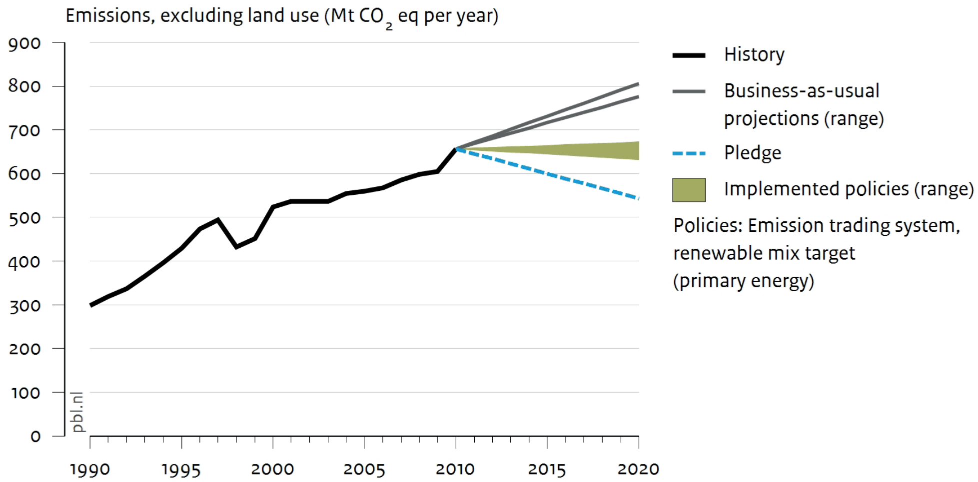

Figure 3-11 Impact of climate policies on greenhouse gas emission projections for South Korea

3.3.13 Ukraine

Ukraine's internationally pledged emission level of 745 MtCO_2e (20% below 1990)[19] for 2020 is on the upper limit of the range of BAU emission projections (450 MtCO_2e from PBL TIMER projections to 755 MtCO_2e from the 5th National Communication (Ukraine, 2010). This high-end range would decrease to around 670 MtCO_2e if more recent trends on demand policies

[18] http://www.mke.go.kr/language/eng/laws/laws.jsp

[19] This could be capped at 390 MtCO_2e, which is the average of 2008-2010 emissions (Hof et al., 2013) due to the Doha amendment to the Kyoto Protocol, Paragraph 3.7ter

and efficiency improvements would be used, according to our calculations. All implemented policies could reduce emissions to 350 to 660 $MtCO_2e$ by 2020, depending on BAU emissions.

In 2008, Ukraine introduced a feed-in-scheme with fixed prices, the so called "green" tariff for electricity. The green tariff also guarantees grid connectivity to all renewable power generated from the project. The feed-in tariffs are relatively high with 42 c€/kWh for solar PV and 11 c€/kwh on average for wind. We expect that this leads to about 8% renewable electricity in 2020, taking into account implementation barriers such as grid access. The share of renewable electricity was 7.5% in 2009, almost completely from hydro, which is not supported through the feed-in-tariff.

Total installed capacity for PV in Ukraine amounted to only 3.2MW by the end of 2009. Moreover, all the solar power installed before 2009 is for private use and is not connected to the grid. Administrative and bureaucratic barriers coupled with political unrest are restricting growth of the industry.

In 2006, Ukraine introduced a target to decrease energy intensity by 50% below 2005 levels by 2030. This target will lead to low additional reductions of about 0 to 25 $MtCO_2e$, as Ukraine's relatively high emission intensity is expected to decrease strongly in the BAU.

There are plans to introduce a domestic emission trading scheme, which has not been considered in this analysis. In 2010, a bill that laid the foundations for introducing a domestic emissions trading system passed the first reading in the Ukrainian Parliament. However, since then the ETS legislation is pending.

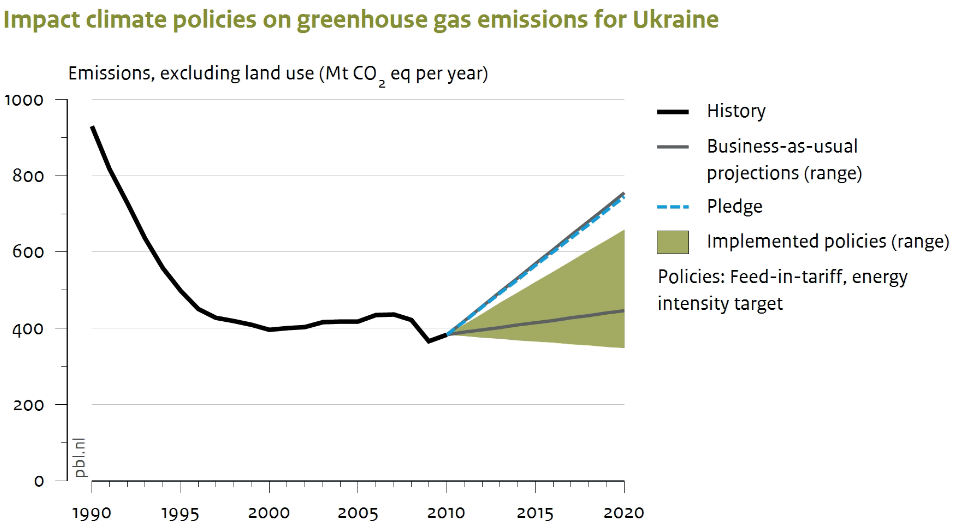

Figure 3-12 Impact of climate policies on greenhouse gas emission projections for Ukraine

3.3.14 United States

Current national implemented climate policies in the USA will not be sufficient to decrease GHG emissions as pledged (17% below 2005 levels by 2020) unless accounting of land use and forestry would lead to significant additional reductions. New actions taken at the federal and state levels without the need for new legislation from the U.S. Congress, such as the power plant standard for existing power plants, could bring emissions closer to the pledge (Burtraw et al., 2012; Bianco et al., 2013).

Official emission projections presented by the USA are now lower than previous estimates (Pershing, 2012). The Annual Energy Outlook (AEO) published by the Energy Information Administration (EIA) projects a 2020 CO_2 emission level of 8% below 2005 levels by 2020 (EIA, 2012), compared to a projected emission level of 25% above 2005 levels by 2020 by the AEO2005. Major reasons include the economic crisis and structural developments in the energy market, leading to a shift from coal to natural gas, which is less emission intensive (CCS, 2011). These developments interact with policies that target more efficient use of energy, and therefore comparison with BAU development is not straightforward.

According to our assessment, which includes the most promising policies (a fuel economy standard, the New Source Performance Standard, the energy efficiency programme Energy Star, state level renewable targets, the Californian emission trading system), the emission level with policies will result in 6.3 $GtCO_2e$ to 6.5 $GtCO_2e$ by 2020, compared to a pledged emission target of 6.0 $GtCO_2e$. Including regional energy efficiency programs and additionally planned policies, such as a standard for existing power plants, might get the US emission levels by 2020 closer to the pledge (Burtraw et al., 2012; Lashof Yeh et al., 2012).

The fuel economy standard is divided in two phases: the first phase starting in 2013 and the second phase in 2017. [20] The standard for light duty vehicles sets a fuel economy standard of an average 29.7 mpg (miles per gallon) in 2012 to 34.1 mpg in 2017 (~160 g/km) for new cars. This first phase is already incorporated in the national BAU development. The emission standards for light duty vehicles have been extended to a second phase, 2017-2025 increasing the ambition to 101g/km in 2025 for new vehicles. Out of all the recent policies examined, the second phase of the fuel economy standard is likely to have the largest overall impact in the long term, but has only limited impact by 2020, as it only affects new vehicles sold in 2017 and later. The US EPA estimates the impact of phase II to be 30 $MtCO_2e$ below BAU in 2020 (EPA, 2011b), which is only represents 1.5% of total emissions

[20] For details see: http://www.nhtsa.gov/Laws+&+Regulations/CAFE+-+Fuel+EconomyModel+Years+2012-2016:+Final+Rule

from transport in 2005. The standard for medium- and heavy duty trucks differ over a large number of truck types (EPA, 2011a). The projected standards are expected to decrease emissions in 2020 by 10-20% (Pershing, 2012), i.e. 40 to 80 MtCO_2e reductions compared to AEO2012 transport BAU projections (EIA, 2012), which is similar to the estimate in the EPA regulatory impact analysis (EPA, 2010).

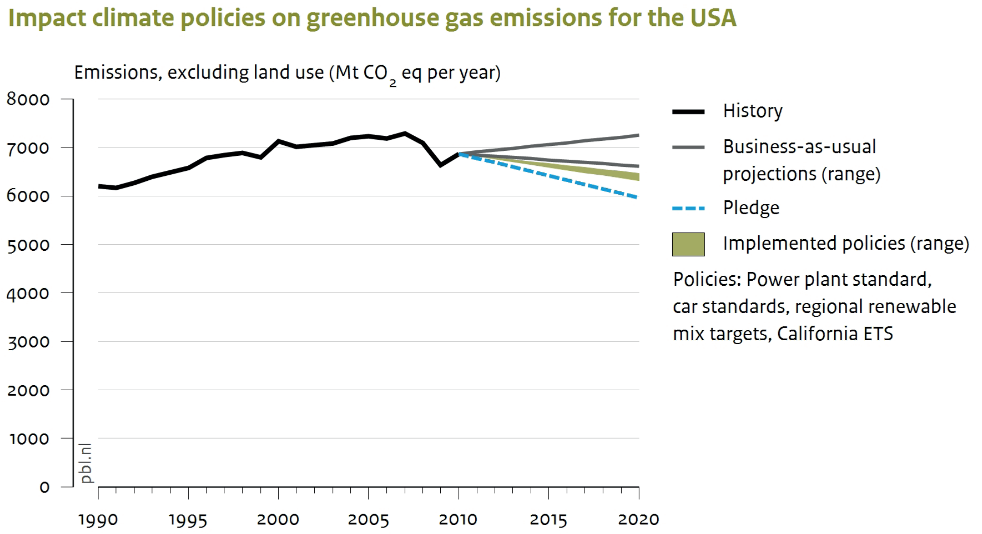

Figure 3-13 Impact of climate policies on greenhouse gas emission projections for the USA

The New Performance Standard limits the emission intensity of new constructed power plants to 450 gCO_2e/kWh. The standard will hardly have an effect on future emissions, both according to our calculations and those of the US EPA (2012). This is because low gas prices already incentivise natural gas over coal-fired power plants. However, were gas prices to increase, the standard could lock in current emission projections.

Many states have a renewable target for electricity production which aggregates to a 14% renewable share at the country level in 2020. As the renewable share under BAU projections is already 14% (EIA, 2012) and PBL TIMER), there are no additional reductions to be expected from these measures.

The ETS of California consists of a cap in 2020 equal to the 1990 emission level. It starts with electricity and large industries in 2013 and will be extended to transportation in 2015. The ETS encompasses a mandatory GHG reporting program, with every facility emitting 25 ktCO_2e or more required to submit annual reports of GHG emissions to EPA. The GHG data is disclosed publicly. For the quantification, we assumed a range of 90% to 100% effectiveness of the system. Based on PBL FAIR model calculations and emission projections from the California Environmental Protection Agency (California Environmental Protection Agency, 2010), reduction between 70 and 90 MtCO_2e is expected, where the 2007 emission level is 470 MtCO_2e.

3.4 CONCLUSIONS

Our assessment shows that the pledges have induced efforts in all countries to plan and implement national policies. While the policies are likely to deliver emission reductions, for many countries – especially for those countries for which we project relatively low reductions from policies –uncertainty in BAU emissions plays a larger role in future emission levels than implementation of climate policies. We estimated that for some countries domestic climate policies could deliver higher emission reductions than pledged under the Cancún Agreements. In other countries, further policies have to be implemented to demonstrate pledges will be met in 2020. Table 3-2 gives an overview of the evaluation.

Table 3-2 Overview on individual country results (sorted by size of current emissions)

Country (2010 GHG emissions)	**2020 pledge (calculated resulting emissions)**	**Analysed mitigation actions**[21]	**Result**
China (10.5 GtCO2e)	· 40%-45% decrease of CO2 emissions per GDP below 2005	· CO2 / energy intensity targets	Likely to meet pledge but rapid GHG increase up to 2020
	· 15% share of non-fossil energy	· non-fossil target	
	· Forestry target	· renewable energy capacity targets	
	(12.9-13.8 GtCO2e)		
USA (6.8 GtCO2e)	· 17% below 2005 levels	· CO2 standard for new fossil power plants	Emissions expected to be lower than estimated in earlier US publications, which can partly be attributed to policies. Expected emissions still above pledge
	(6.0 GtCO2e)	· Car standards	
		· State renewable targets	
		· California ETS	
		· Biofuel target	

[21] Only the most relevant policies were analysed for most countries

Country (2010 GHG emissions)	2020 pledge (calculated resulting emissions)	Analysed mitigation actions [21]	Result
EU **(4.7 GtCO2e)**	· 20% below 1990 levels (unconditional) · 30% below 1990 levels (conditional) (3.9-4.4 GtCO2e)	· Comprehensive policy portfolio including emission trading system, renewable energy targets and support, energy efficiency policy	Likely to meet unconditional pledge. Planned policies would bring emissions even further down, but not sufficient yet to meet the conditional pledge
India **(2.5 GtCO2e)**	· 20%-25% decrease of CO2 emissions per GDP below 2005 (3.5-3.7 GtCO2e)	· Renewable energy targets · Efficiency in industry and energy supply (PAT scheme)	Likely to meet pledge, huge uncertainty in projections.
Russia **(2.2 GtCO2e)**	· 15-25% below 1990 levels (2.5-2.8 GtCO2e)	· Energy efficiency plan · Renewable target · Reduction plan for flaring	Likely to meet pledge, BAU emissions are projected to be below pledged emission level
Brazil **(2.3 GtCO2e)**	· 36%-39% below BAU levels (2.0-2.1 GtCO2e)	· Anchored pledge in national law, forestry policy · Grazing land management · Renewable targets	The high share of emissions from LULUCF and the high uncertainty in future projections makes it difficult to evaluate whether pledge will be met
Indonesia **(1.4-1.8 GtCO2e)**	· 26%-41% below BAU levels (1.7-2.2 GtCO2e)	· Action on forestry · Renewable energy target · Biofuel target	High uncertainty in emissions from LULUCF in Indonesia makes it difficult to determine the ambition level of the pledge and whether pledge will be met
Japan **(1.3 GtCO2e)**	· 25% below 1990 levels (1.0 GtCO2e)	· Not available (the new energy policy will be released in May 2013)	Japan's energy policy will change significantly as an effect of the Fukushima accident. Therefore it is uncertain whether pledge will be met

Country (2010 GHG emissions)	2020 pledge (calculated resulting emissions)	Analysed mitigation actions [21]	Result
Mexico (0.7 GtCO2e)	· 30% below BAU levels (0.7 GtCO2e)	· Framework climate law with pledge · Renewable target · Forestry target	Unlikely to meet pledge with currently implemented policies. New strategy that is under construction could lead to levels closer to the pledge
Canada (0.7 GtCO2e)	· 17% below 2005 levels (0.6 GtCO2e)	· Car standards · Power plant standard · Subnational ETS	Unlikely to meet pledge with currently implemented polices
South Korea (0.7 GtCO2e)	· 30% below BAU level (0.5 GtCO2e)	· ETS planned (precursor TMS until 2015) · Renewable target	Unclear whether pledge will be met with current and planned policies. Much will depend on the effectiveness of the national emissions trading scheme, which South Korea will launch in 2015
Australia (0.5 GtCO2e)	· 5% below 2000 levels (unconditional) · 15-25% below 2000 levels (conditional) (0.4-0.5 GtCO2e)	· Comprehensive carbon price mechanism (ETS) · Renewable targets · Power plant standard	Likely to meet unconditional pledge with currently implemented polices, but relatively high uncertainty due to the uncertain future of climate policy. (opposition announced to repeal the carbon price mechanism).
South Africa (0.5 GtCO2e)	· 34% below BAU level (0.4-0.6 GtCO2e)	· Renewable target and respective support mechanism	Unlikely to meet pledge with currently implemented policies due to implementation difficulties
Ukraine (0.4 GtCO2e)	· 20% below 1990 levels (0.7 GtCO2e)	· RE feed-in-scheme · Energy intensity target	Likely to meet pledge

India, China, Russia and Ukraine are likely to achieve or overachieve their international pledge; their implemented policy portfolio contributed to this. The EU's nationally legally binding policy framework is likely to deliver its unconditional pledge and the EU is working on developing new policies which would deliver additional mitigation. For achieving its conditional pledge, new policies would have to be developed and implemented. We project that Australia's nationally legally binding framework would deliver its unconditional pledge. Additional policies would be needed to achieve the conditional pledge.

The situation is rather unclear for Japan, South Korea, Brazil and Indonesia. The level of emission reductions of Japan depends to a large extent on the future energy plan, which is still under discussion. Whether South Korea will achieve its unconditional pledge depends on the final design and implementation of the agreed emission trading system. Uncertainty in emissions from LULUCF in especially Indonesia make it difficult to make a valid assessment, while Brazil has a long experience in forest inventories and monitoring (Romijn et al., 2012) and therefore can track deforestation events with high accuracy.

We project that policies of Canada, USA, and Mexico have an effect on 2020 emission levels, but these countries will probably need to develop and implement additional policies to deliver their pledges in full. USA's expected emissions for 2020 are lower than expected previously due to economic decline, low gas prices and implementation of some policies, but the projected emission level by 2020 is still likely to be higher than what is needed to achieve the pledge. Both the USA and Mexico have measures in the pipeline that could bring emissions closer to the pledge.

A few trends emerge regarding policy measures. All major countries have set renewable energy targets, many of which supported by national policies. Several countries have recently implemented efficiency standards for cars (for instance the USA and Canada) or in the energy supply sector (e.g. Russia). Policies such as CCS are still in their explorative phase and in its current form are not yet expected to lead to considerable reductions by 2020. Finally, new emission trading systems are emerging that overarch several sectors, for instance in the EU, Australia, and South Korea.

Figure 3-14 compares the total effect of all policies on 2020 emission levels with the emission level implied by the pledges and with business-as-usual emission projections for all countries analysed in this study excluding Japan (for which no assessment could be made). The uncertainty in BAU emissions is large: all lowest projections combined lead to a 2020 emission level of about 40 $GtCO_2e$, while all highest estimates combined lead to 48 $GtCO_2e$. The range in the emission levels implied by the pledges is much smaller: between 35.6 $GtCO_2e$ and 38.4

$GtCO_2e$ (Hof et al., 2013). The range in the emission level resulting from the most effective domestic policies is again large, due to both uncertainty in BAU emissions and uncertainty in the effectiveness of policies. The optimistic projection is that all major policies lead to an emission level of 35 $GtCO_2e$, which would be an overachievement of the pledges. The upper bound of 41 $GtCO_2e$, however, would lead to an emission level which is within the range of BAU emissions. It should also be noted that globally, the pledges would lead to a 2020 emission level which is above the level of cost-optimal emission pathways to achieve a 2°C target in the long run (UNEP, 2012; Hof et al., 2013). From Figure 3-14, it can be concluded that the same holds for the emission projections resulting from the domestic policies.

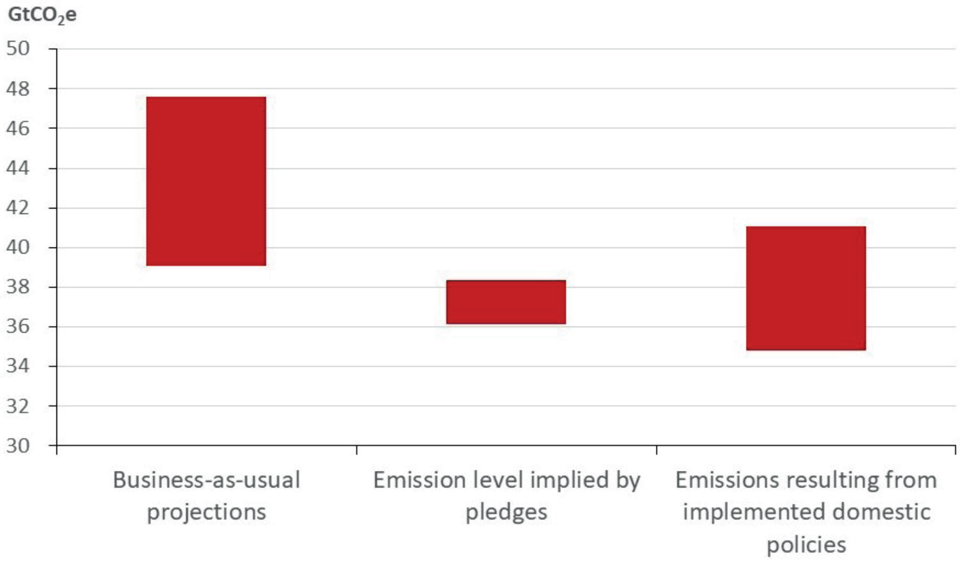

Figure 3-14 Total business-as-usual emissions, emission levels implied by pledges, and emission levels resulting from implemented domestic policies of all countries analysed in this paper excluding Japan (for which no assessment could be made). These countries were responsible for 70% of global greenhouse gas emissions in 2010.

There are some caveats with this assessment. First of all, it only includes the most effective national climate and energy policies and therefore does not provide a complete assessment of all policies. This has the risk of underestimating the total impact of all efforts in a country to reduce emissions. One example is the USA, where sub-national policies can contribute significantly to emission reductions. Secondly, existing policies may change and new policies may be implemented. This implies that all numbers are subject to change; this study provides the current state of the art.

Countries are implementing policies in various areas to a varying degree. A few trends emerge: All major countries have set renewable energy targets, many to be achieved by national support policies. Several countries have recently implemented efficiency standards for cars (for instance the USA and Canada). New emission trading systems are spreading globally with systems adopted in Australia, South Korea and China. Finally, Brazil succeeded in reducing its deforestation rate significantly, one of the biggest contributions to reductions globally by a single policy.

Concluding, our study shows that countries are developing and implementing national climate policies with effect on GHG emissions, but more action is needed to reach international pledges in most countries assessed.

ACKNOWLEDGEMENTS

The project was financed by the European Commission, Directorate General Climate Action, and the Dutch Ministry of Infrastructure and the Environment. We would also like to thank Pieter Boot (PBL) for comments and Durk Nijdam (PBL) for the graphics.

CHAPTER 4

Taking stock of national climate policies to evaluate implementation of the Paris Agreement

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ABSTRACT

Many countries have implemented national climate polices to accomplish pledged Nationally Determined Contributions and to contribute to the temperature objectives of the Climate Paris Agreement. In 2023, the global stocktake will assess the combined effort of countries. Here, based on a public policy database and a multi-model scenario analysis, we show that implementation of current policies leaves a median emission gap with the optimal pathways to implement the well below 2 °C Paris goals of 22.4 to 28.2 $GtCO_2eq$ by 2030. If Nationally Determined Contributions would be fully implemented, this gap would be reduced by a third. Interestingly, the countries evaluated were found to not achieve their pledged contributions with implemented policies (implementation gap), or to have an ambition gap with optimal pathways towards well below 2 °C. This shows that all countries would need to accelerate the implementation of policies for renewable technologies, while efficiency improvements are especially important in emerging countries and fossil-fuel-dependent countries.

4.1 INTRODUCTION

The objective of the Paris Climate Agreement is ‘to hold average global warming to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C (UNFCCC, 2015g). While this objective is formulated at the global level, the success of the agreement critically depends on the implementation of climate policies at the national level. This is organised in the agreement by the requirement of countries to submit Nationally Determined Contributions (NDCs). Countries are expected to update their NDCs in 2020. While NDCs should be submitted by every country and updated every five years, their policies and targets are not legally binding. Previous studies have highlighted that taken together, the NDCs and national policies fall significantly short of the overall ambition of the Paris Agreement (Rogelj et al., 2016; Vandyck et al., 2016; Vrontisi et al., 2018). To achieve the targets from the NDCs, countries are implementing policies at the national level. The Paris Agreement facilitates a global stocktake in 2023, which is expected to take stock of the collective efforts and to inform the preparation of more ambitious NDCs. For this, clear insights are needed into the impact of current implemented national policies from individual countries. At the moment, no peer reviewed literature exists that has assessed the global and country impact of national climate policies on the basis of a comprehensive policy inventory by using a suite of integrated assessment models, and using this to guide additional policy implementation. Such a multi-model approach using a range of model types (simulation/optimisation, general or partial equilibrium) adds to the robustness of the assessment.

The aim of this article is to fill this knowledge gap and to provide insights into the impact of national policies in comparison to emission pathways consistent with the NDCs and overall goals of the Paris Agreement. Consequently, we divide the total emissions gap between national policies and well below 2 °C pathways into an implementation gap referring to the difference between the impact of national policies and the NDCs, and an ambition gap referring to the difference between the impact of the NDCs and well below 2 °C emission pathways. The results are presented for seven large economies and the world. The analysis was done by first establishing a list of high impact policies (CD-LINKS, 2017a) for each G20 economy selected from a detailed open-access policy database (NewClimate Institute, 2015), and translating these to input parameters for integrated assessment models. Subsequently, the model results allowed to assess the direct impact of these policies as well as their interactions. The results are also presented in terms of the Kaya identity allowing to indicate how to close the implementation and ambition gaps (Le Quéré et al., 2019). The nine integrated assessment models (see Methods) used in this study have all submitted data for the 1.5 °C scenarios to the IPCC 1.5 °C report (Rogelj et al., 2018b). To evaluate the coherence of the national pathways, we compared the aggregated results of the integrated assessment models with similar runs of national models for the same countries.

Model-based scenarios have played a major role in supporting international climate policy already for a few decades. The focus of model analyses, however, has been mostly on exploring cost-optimal response strategies required to meet the climate temperature goals and simplified representations of national policies, typically incorporating them as overall emission reduction targets implemented via carbon prices (Clarke et al., 2014; Riahi et al., 2015; Luderer et al., 2018). The new phase of climate policy after Paris requires new information on the long-term contribution of specific policies. While some assessments have accounted for more explicit climate policy formulations in different parts of the world, these are typically single model exercises or focus only on the NDCs (Kriegler et al., 2014, 2015b; Riahi et al., 2015; Tavoni et al., 2015; den Elzen et al., 2019). As such, the current work adds to the literature.

Due to the aggregation level of most IAMs, our analysis is limited to the national policies and NDCs for G20 economies that represent 75% of total 2010 greenhouse gas emissions. It is estimated that the countries with high impact policies, but not included in our assessment, represent around 5% of global 2010 emissions (see Supplementary Table 4-1). The collected policies have been made available in an open-access database (NewClimate Institute, 2015) and cover implemented and planned national policies up to 2017. As introduction of new policies mostly occur simultaneously with key international accords (Iacobuta et al., 2018), this inventory contains most of the relevant policies that were introduced around the Paris Agreement. A selection from this database was made that consisted of around ten policies for each G20 country that were expected to have high impact on greenhouse gas emissions based on literature or national expert opinion, which were adopted by national government trough legislation or executive orders, and no evidence exists of large barriers to implementation. The results are presented at the global level and for the seven large emitting economies for which national models were available, i.e. Brazil, China, the European Union, India, Japan, the Russian Federation and the United States, together representing around 65% of global 2010 greenhouse gas emissions (Gütschow et al., 2016).

The results show that if no additional action is taken beyond current implemented national climate policies, greenhouse gas emissions are projected to increase substantially between 2015 and 2030, although 5.3% lower compared to the hypothetical situation if these policies would not have been implemented. Current national policies together, leave a median global total emissions gap by 2030 of 22.4 Gigaton CO_2 equivalent ($GtCO_2eq$) with a cost-optimal

2 °C emission pathway, and 28.2 $GtCO_2eq$ with a 1.5 °C pathway. The 2 °C global emissions gap can be reduced by a third, if conditional NDCs were fully implemented, which would close the global implementation gap, but would still leave a significant ambition gap. For seven large individual countries (China, the United States, India, the European Union, Japan, Brazil and the Russian Federation), policy implementation is expected to reduce emissions at the national level by 0% to 9% (median estimates) compared to the hypothetical situation if no policies would be implemented. This leaves a small implementation gap for China, India, Japan, Russian Federation as they are close to achieving their NDC, while this is not the case for the European Union, United States and Brazil, but their ambition gap is smaller as NDCs are close to the cost-optimal 2 °C pathways.

4.2 RESULTS

In total, five scenarios were evaluated (see Table 4-1, and Supplementary S4.5). The starting point of all scenarios is the SSP2 scenario (Fricko et al., 2017; van Vuuren et al., 2017a), which is a middle-of-the-road scenario assuming a business-as-usual conduct representing no new climate policies implementation after 2010 (no new policies scenario). The national policies scenario represents the impact of policies implemented domestically to fulfil the NDC promises which are included in the NDC scenario. The 2 °C and 1.5 °C scenarios look into cost-optimal implementation of the overall goals of the Paris Agreement. To provide guidance on enhancing policy implementation, the impact of policies is decomposed by computing a set of indicators based on the Kaya identity (see Supplementary S4.7). Besides greenhouse gas emissions, also the share of low-carbon (no fossil-fuel without carbon capture and storage) technologies and energy efficiency is presented.

4.2.1 Global implementation and total emissions gap

Under the No new policies scenario, the models project an increase in global greenhouse gas emissions to 63.9 $GtCO_2$ eq (61.0–69.1; median and 10th to 90th percentile range over all model results) by 2030. This is mostly driven by an increase in emissions related to transport, industry and power production in developing countries, but still to lower per-capita levels than developed countries. Implementation of national policies is not projected to reverse the increase of global emissions by 2030, and would results in emission levels of 59.3 $GtCO_2$ eq (58.4–63.7) (*Figure 4-1*), which is a 5.3% (3.8%–7.9%) reduction relative to the No new policies scenario (see Table 4-2). However, it covers 15.4% (10.8%–19.0%) of the emissions gap between No new policies and the *2 °C* pathway by 2030, and this is 11% (7.6%–15.9%) for the 1.5 °C pathway.

Table 4-1 Main assumptions on climate policy implementation per scenario

Scenario	Policy assumptions until 2030	after 2030
No new policies	None	None
National policies	Implementation of current domestic policies	Equivalent effort to policy implementation before 2030
NDCs	Full implementation of conditional national NDCs	Equivalent effort to NDC implementation before 2030
2 °C/1.5 °C	Each country implements current implemented polices until 2020 and starts with cost-effective implementation to achieve the 2 °C/1.5 °C target between 2020 and 2030 with high (>66%) probability, thereby staying within a global carbon budget of 1,000 $GtCO_2$ and 400 $GtCO_2$ in the 2011–2100 period	Continuation of cost-effective implementation to achieve the 2 °C/1.5 °C target

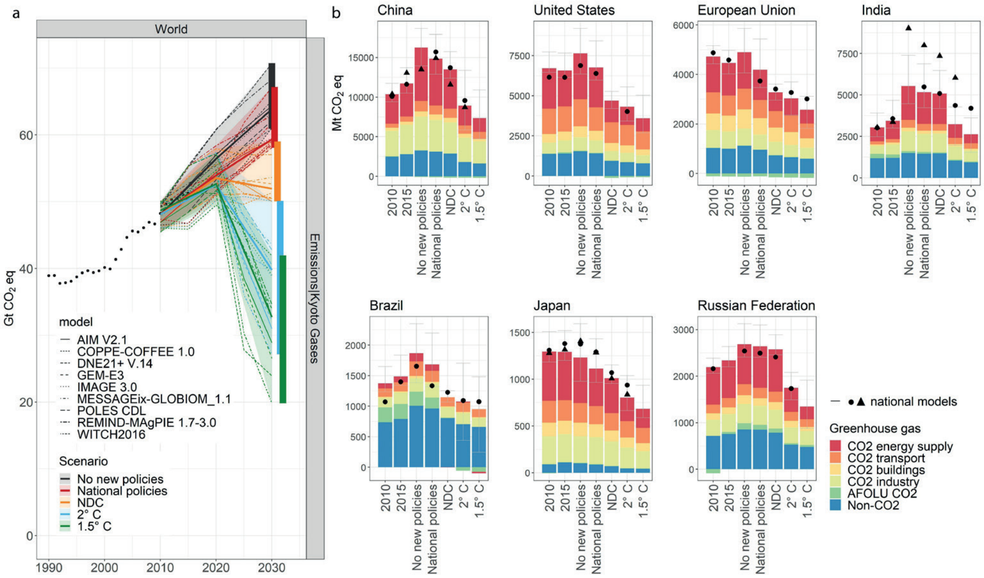

Figure 4-1 Greenhouse gas emissions on a global level and seven large countries under different scenarios. a) global greenhouse gas emissions for total greenhouse gases (in GtCO2eq) and nine integrated assessment models between 2010 and 2030. b) average greenhouse gas emissions (in MtCO2eq) of all models by 2010, 2015 and 2030 for CO2 emissions per sector and total non-CO2 emissions (blue), including the 10th–90th percentile ranges for total greenhouse gas emissions of the multi-model ensemble (error bars). CO2 emissions have been separated into those related to energy supply (red), transport (dark orange), buildings (light orange), industry (yellow) and AFOLU (agriculture, afforestation, forestry and land-use change) (green). National models are China-TIMES and IPAC for

China, GCAM-USA for the United States, PRIMES for the EU, AIM India and India MARKAL for India, RU-TIMES for the Russian Federation, BLUES for Brazil and AIM/Enduse and DNE21+ for Japan. For both panels, CO2 equivalent greenhouse gases have been calculated using the 100-year Global Warming Potential from the IPCC Fourth Assessment Report. The data is available in the source data.

Although the global low-carbon share of final energy increases by 1 percentage point (1 pp) to 14.3% (9.3%–19.8%) by 2030, and the energy intensity improves by 20.5% (16.1%–24.7%) between 2015 and 2030, final energy use still increases (see Figure 4-2). Most emission reductions under the National policies scenario are induced by high-impact policies that target CO_2 emissions (*Figure 4-1*). Furthermore, 45% (30%–70%) of the emission reductions are projected to come from OECD countries.

Table 4-2 Absolute (GtCO2 eq) and percentage impact of policy implementation relative to no new policies scenario, and implementation gap with NDC scenario for the world, China, United States, India, EU, Japan, Brazil and Russian Federation (median value and 10-90% in brackets)

Economy	**Absolute impact of policy implementation relative to no new polies scenario (GtCO2eq)**	**Percentage impact of policy implementation relative to no new polies scenario (%)**	**Absolute reductions between national policies and conditional NDCs (GtCO2eq)**	**Percentage reductions between national policies and conditional NDCs (%)**
World	3.5 (2.3, 5.2)	5 (4, 8)	7.7 (5.3, 9.7)	13 (9, 16)
China	0.7 (0.5, 2.3)	5 (2, 14)	0.9 (-0.5, 3.7)	6 (-3, 22)
United States	0.4 (0.3, 1.2)	6 (4, 13)	2.1 (1.5, 3.2)	31 (22, 38)
European Union	0.5 (0.3, 0.6)	9 (7, 15)	0.7 (0.6, 1.8)	19 (15, 33)
India	0.1 (0, 0.5)	3 (0, 7)	0.1 (-0.1, 0.3)	2 (-3, 6)
Japan	0.1 (0, 0.1)	7 (2, 8)	0 (0, 0.3)	4 (-4, 23)
Brazil	0.0 (0, 0.2)	3 (0, 11)	0.5 (0.2, 1)	30 (14, 44)
Russian Federation	0.0 (0, 0)	0 (0, 2)	0.1 (-0.1, 0.2)	3 (-3, 7)

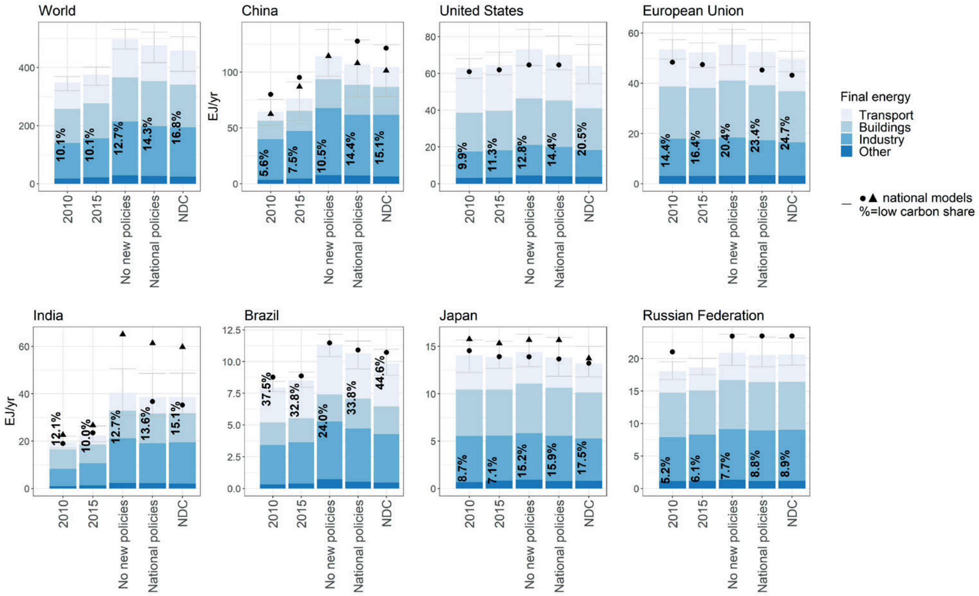

Figure 4-2 ***Final energy and the low carbon share of final energy on the global level and seven large countries under different scenarios.*** *Average total final energy for 2010, 2015 and 2030 of nine global integrated assessment models is subdivided into sectors: transport, buildings, industry and other. Total final energy includes the 10th to 90th percentile ranges for total final energy (error bars). The black dots/triangles indicate final energy based on national model estimates (China-TIMES and IPAC for China, GCAM-USA for the United States, PRIMES for the European Union, AIM India and India MARKAL for India, RU-TIMES for the Russian Federation, BLUES for Brazil and AIM/Enduse and DNE21+ for Japan). The data is available in the source data.*

For achieving conditional NDCs, deeper reductions are necessary than those achieved by national policies only. The implementation of conditional NDCs (NDC scenario) is projected to results in 51.9 (50.4–57.4) $GtCO_2$ eq greenhouse gas emissions by 2030, a low-carbon share of final energy at 16.8% (12.6%–25.2%), and 23.5% (17.9%–30.0%) in energy-intensity improvement between 2015 and 2030. This means that national policies together leave a significant global implementation gap with respect to the NDC targets by 2030, which is 7.7 (5.3–9.7) $GtCO_2$ eq for emissions (see Table 4-3). This gap by 2030 can be closed by increasing the low-carbon share by 2.8 pp (1.5–4.7 pp), and decreasing energy intensity by 12.7% (9.1%–16.1%). Final energy reductions under the NDC scenario compared with the national policies scenario, occur especially in the transport and buildings sector (see Figure 4-2).

Table 4-3 Absolute (GtCO2 eq) and percentage emissions gaps by 2030, on the global level and for China, the United States, the European Union, India, Japan, the Russian Federation and Brazil.

	Absolute emissions gap between national policies and 2 °C scenarios	Emissions gap in percentages between national policies and 2 °C scenarios	Absolute emissions gap between national policies and 1.5 °C scenarios	Emissions gap in percentages between national policies and 1.5 °C scenarios
World	22.4 (13.6, 29.6)	36 (23, 49)	28.2 (19.8, 42.2)	45 (33, 65)
China	5.9 (4.2, 8.4)	41 (24, 59)	7.2 (5.3, 11)	53 (33, 66)
United States	2.3 (1.5, 3.9)	37 (24, 47)	2.9 (2.2, 5)	43 (33, 66)
European Union	1.6 (0.6, 1.9)	31 (14, 43)	1.4 (0.9, 3.1)	33 (25, 65)
India	2.1 (1.1, 2.7)	33 (21, 54)	2.6 (1.6, 3.2)	45 (34, 63)
Japan	0.4 (0.1, 0.5)	25 (14, 40)	0.5 (0.3, 0.6)	37 (28, 47)
Brazil	0.7 (0.4, 1)	40 (20, 70)	0.9 (0.4, 1.2)	54 (23, 83)
Russian Federation	0.9 (0.5, 1.2)	34 (23, 43)	1.3 (0.7, 1.9)	49 (26, 68)

4

4.2.2 Uncertainty range

The different integrated assessment models provide a range of outcomes for changes in greenhouse gas emissions due to policy implementation between 2015 and 2030. This range is a result of the differences in historical emissions (Rogelj et al., 2017), different assumptions about socio-economic growth rates, different impact of policy implementation in models, and finally real uncertainty as a result of structural model differences (see Methods). The differences in historical emissions is in line with estimates of uncertainty in historical emission inventories (10% in total greenhouse gas emissions)[22], but it clearly translates into a contribution to uncertainty for 2030. In addition, an estimate of the contribution of socio-economic factors can be obtained by comparing the 2015 and 2030 emission range under the No new policies scenario. This shows a 2030 range that is 50% larger than the 2015 range. The different impact of policies implemented in models has been estimated by considering the impact of all policies implemented in the models and estimating those that were not included based impact based on the IMAGE model results (see Methods). Based on this analysis, it can be concluded that assumptions on socio-economic factors explain the largest part of the ranges in the results for 2030; while the differences in policy impact explains about 1/3 of them.

4.2.3 Impact of national policies for seven large G20 economies

The scenarios allow for evaluation of climate policy at the national level (although obviously limited by model detail). Policy implementation is estimated to result in reductions of 0% (0%–2%) for the Russian Federation to 10% (4%–12%) for the United States, relative to the no new policies scenario (see Table 4-2). The largest absolute emission reductions under the National policies scenario occur in the CO_2 energy supply and transport sector, in all countries, except for Brazil, where reductions also occur in the AFOLU sector (although AFOLU emission estimates are inherently uncertain, already for historical estimates (Weyant et al., 1995). The largest percentage of reductions is projected in the transport sector for the United States and India, the industrial sector for the EU, and the energy supply sector for China and Japan. In the Russian Federation, the National policies scenario hardly triggers emission reductions, compared to the no new policies scenario.

Implementation of national policies still leaves an implementation gap with NDCs of 3% (3%–7%) for the Russian Federation to 28% (22%–37%) for the United States (see Table 4-2). With national policies until cut-off date before 2017, China, India, Japan and Russian Federation are projected to come close to achieving their NDC targets with national policies by 2030. In Brazil, the European Union, and the United States, the median estimate of the National policy scenario is further removed from the NDC level. Note that very recent policy updates since 2017, or planned policies in the pipeline to be implemented were not included. We have compared the results of the global models also to the outcomes of the same scenarios from national models from each individual country. These results confirm the above trends, although the absolute levels differ in a few cases (*Figure 4-1/*Figure 4-2)

4.2.4 Global emissions gap and for seven large G20 countries

In order to implement the objectives of the Paris Agreement, all national policies together should reduce emissions enough to keep global warming below the 2 °C and 1.5 °C temperature limits. We evaluate this by comparing the results of the policy scenarios with cost-optimal scenarios for these temperature targets. This shows a total emissions gap between the National policies scenario and the cost optimal scenarios in 2030 of 22.4 $GtCO_2$ eq (13.6–29.6) for the 2 °C limit (high probability), and 28.2 $GtCO_2$ eq (19.8–42.2) for the 1.5°C limit (see Table 4-3). This is respectively a global reduction of 36% (23%–49%) and 45% (33%–65%) by 2030 relative to the national policies scenario.

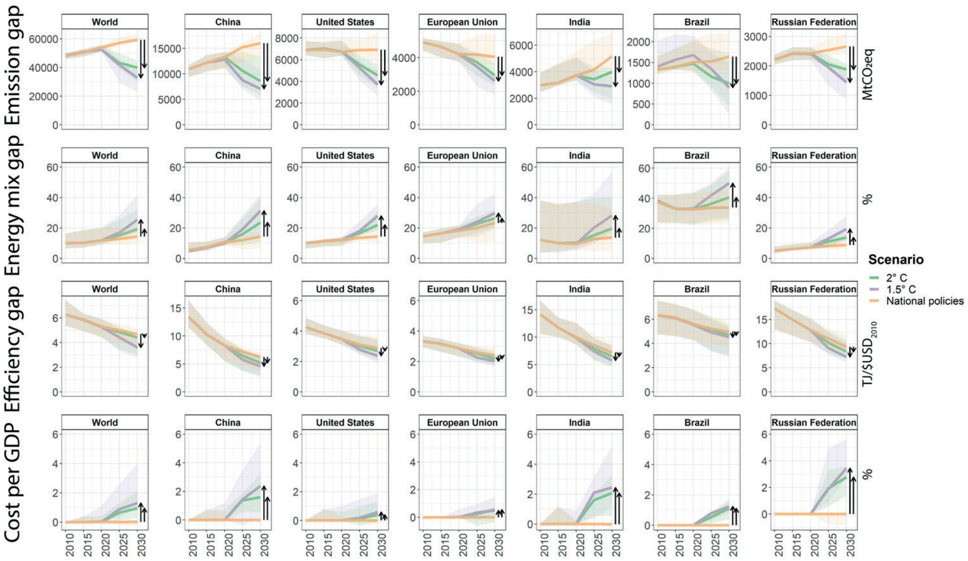

Figure 4-3 Indicators derived from Kaya identity and costs per GDP between 2010 and 2030 on a global level and for seven large countries under different scenarios. The median (lines) and 10th–90th percentile ranges (areas) from nine integrated global assessment models on emissions, energy mix and efficiency gaps and mitigation costs per GDP. These gaps are represented by total greenhouse gas emissions (MtCO2 eq), low-carbon share of final energy (%), final energy intensity in GDP (TJ/USD2010) and total mitigation costs per GDP (%) between national policies and well below 2°C scenarios. The data is available in the source data.

The Kaya identity allows to break this up into an energy mix gap (share of low-carbon emitting technologies in final energy) and an efficiency gap (final energy-intensity improvement relative to the results of the implementation of national policies), and a carbon-intensity gap (see Supplementary Figure 4-1 and Supplementary Figure 4-2). To close the gap by 2030 with the National policies scenario, the non-fossil share would need to increase by 6.9 pp (4.0%–12.3%) (energy mix gap), and the energy-intensity needs to improve by 9.6% (4.8%–24.7%)) (efficiency improvement gap). These numbers are 13.0% (7.2%–24.0%) and 17.5% (12.5%–26.8%) for the 1.5 °C case (see Figure 4-3). Global annual mitigation costs per GDP by 2030, under the national policies scenario, are small, and increase to 0.9% (0.3%–2.2%) under the 2 °C scenario, and to 1.3% (1.0%–4.0%) under the 1.5 °C scenario (see Figure 4-3). The global emissions gap with the 2 °C scenario can be reduced by a third, if conditional NDCs would be fully implemented, leaving a median ambition gap of 16.5 $GtCO_2eq$ (6.4–21.0) with 2 °C pathways and 21.2 $GtCO_2eq$ (12.2–31.6) with 1.5 °C pathways.

For the seven individual G20 countries, greenhouse gas emissions by 2030 would need to decrease compared to the national policies scenario by 25% to 41% (median) to stay on track to keep temperature below 2 °C, while this is 33% to 54% (median) under the 1.5 °C scenario (see Table 4-2 and). These gaps can be closed by strongly increasing the low-carbon share of final energy by 5.4 pp for the European Union to 8.5 pp for China to stay below 2 °C, and between 5.4 pp in the European Union to 20.2 pp in China for the 1.5 °C case. Projections for final energy intensity give a different picture, where the difference between the National policies scenario and the 2°C scenarios are small for the European Union, Japan and the United States, somewhat larger (and more uncertain) for Brazil, and largest for China, India and the Russian Federation (See Figure 4-3). Closing the gap between national policies and 2 °C or 1.5 °C pathways by 2030 would result in additional median mitigation costs per GDP of between 0.5% for the European Union to 2.8% for the Russian Federation for the 2 °C case, while this is 0.6% to 3.4% for the 1.5 °C case (see Figure 4-3).

4.2.5 Mid-century impact of national policies

To give an indication of the short-term impact of national policies in the context of the long-term global targets, we present the indicator that is defined as the cumulative emissions in the 2011–2050 period divided by the 2010 emissions, and in addition assume countries pursue the same national efforts between 2030 and 2050 under the National policies scenario by keeping total percentage emission reductions relative to the No new policies scenario constant. The indicator allows for comparing countries with different absolute emission levels, and provides the number of years you can emit at 2010 emission levels while staying below the total cumulative emissions of the next 40 years. A value of 40 indicates that, on average, the emission level will remain constant. In the same way as for the shorter period until 2030, comparison of the results with the trajectories for the 2 °C and 1.5 °C maximum temperature increases shows a large gap (Figure 4-4). Interestingly, the NDC projections by 2050 for the European Union, Brazil, and the United States are relatively close to the 2 °C scenario, suggesting that these regions would mostly need to ensure that their national policies more closely lead to the NDC target (which may possibly already be achieved through very recent policy updates). It should, however, be noted that cost-optimal implementation (equal marginal costs in all regions) leads to higher costs, as a percentage of GDP, in low-income regions and, therefore, is a fair way to implement the Paris Agreement (see Supplementary S4.8.1) only if complemented by financial transfers. Effort-sharing approaches based on equity considerations tend to suggest larger reduction targets for high-income regions (van den Berg et al., 2019a).

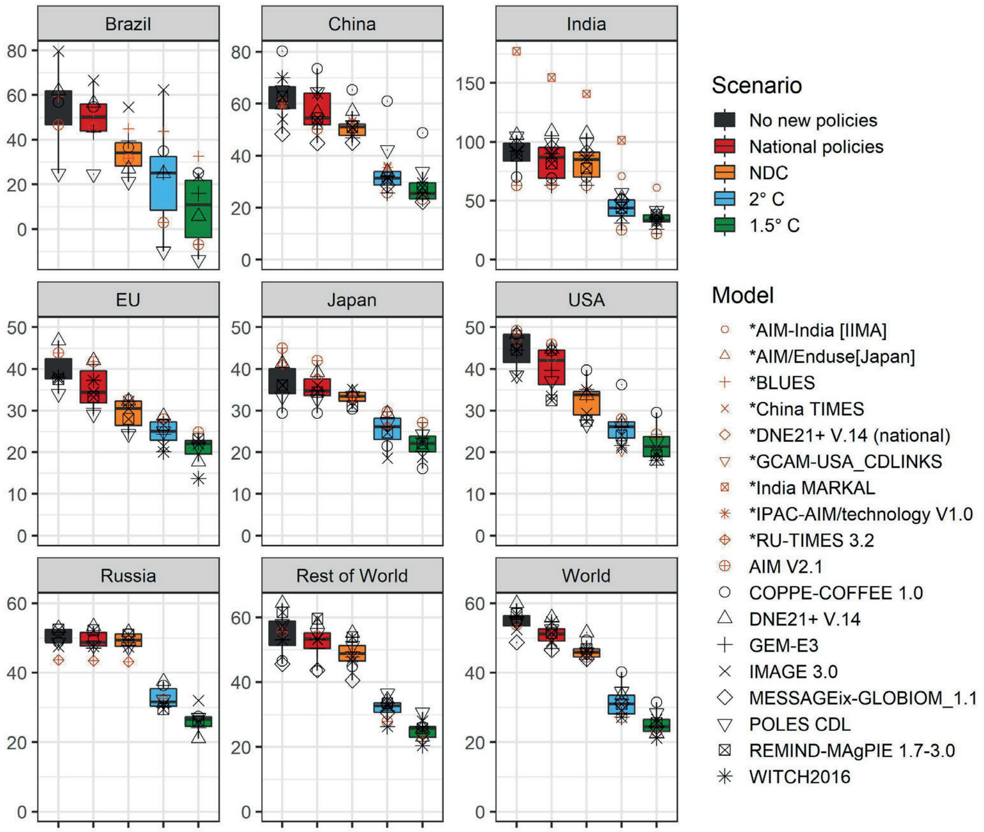

Figure 4-4 Cumulative CO2 emissions in the period 2011–2050 period relative to 2010 emissions on the global level and for seven large countries under different scenarios. The box plots indicate the median, 25th to 75th percentile range, while the black data points show the full global model range. The brown coloured markers indicate the results from the national models. The data is available in the source data.

The 2° C and 1.5 °C model ranges for Brazil are large as a result of the uncertainty in land-use-related emissions. In terms of cost-optimal mitigation, large reductions in each G20 economy are necessary to stay within the 400 Gt carbon budget. The median estimate for cumulative emissions relative to 2010, under this scenario, is at a similar level, between 20 and 25, except for Brazil and India, indicating that given the estimated cumulative emissions in the national policies scenario, strong efforts are essential by almost all countries.

4.3 DISCUSSION

The results show that for all countries there is either a significant implementation gap or ambition gap. Unless governments increase ambition, the collective effort of current national policies significantly stays short of the objectives of the Paris Agreement and even fails to meet the joint ambition secured in NDCs. The results have strong implications beyond 2030. Previous literature has shown that inadequate near-term reduction efforts imply that a substantially higher rate of transformation will be needed to comply with the 2 °C limit (den Elzen et al., 2019), stranded assets (Mercure et al., 2018) and substantially higher mitigation costs in the long term, and reduced techno-economic mitigation potential due to carbon lock-in (Davis et al., 2010).

2 °C and 1.5 °C pathways in this study are calculated assuming cost-optimal implementation, but it might not be the most realistic approach to deriving national reduction targets, as it would typically lead to relatively high costs in low-income countries. In contrast, effort-sharing approaches based on equity principles would lead to lower allowance of cumulative emissions in the EU, Japan, the Russian Federation and the United States, and to higher allowances for India (see Supplementary Figure 4-3), resulting in an opposite impact on the gap between national policies and these allowances. If cost-effective climate policy would be adopted, emission trading or transnational climate financing could still ensure a cost-optimal implementation. If less cooperation between countries is assumed, a different allocation would increase total costs of implementation.

One crucial question that arises from this analysis is how to speed up implementation to achieve NDCs, and increase ambition to stay on track to meet well below 2 ° goals? The current policy implementation is weak and includes significant gaps (e.g. industry, freight transport policies). Moreover, it is also often fragmented in terms of the use of policy instruments and the coverage of sectors and countries. A redesign of current policy mixes consisting of more coherent policies, including for instance the use of economy-wide financial instruments (Bertram et al., 2015), may respond to the current call for strengthened policies. In practical terms, it is possible to draw lessons from the policy mixes used in our analysis – for instance by identifying to most successful mitigation measures. In identifying such “good practices” it is important evaluate measures in terms of cost effectiveness but also in terms of reducing public policy constraints such as distribution of costs (Stiglitz, 2019), ability to address uncertainty (Goulder and Parry, 2008), and political feasibility to intervene in the economy (Jewell and Cherp, 2020). A careful redesign in combination with international cooperation could avoid carbon leakage to other sectors and countries, avoid stranded assets (Rozenberg et al., 2020), and increase regulatory power of governments.

In 2020, countries are expected to submit updated NDCs to the Paris Agreement. However, the global stocktake discussed in this article shows that large enhancements are necessary if we want to maintain the window to limiting temperature increase to well below 2 °C, or even pursue efforts to limit this to 1.5 °C. In order to do so, all countries would need to accelerate the implementation of renewable technologies, while efficiency improvements are especially important in emerging countries (China, India, Brazil) and fossil-fuel-dependent countries (Russian Federation). From this we conclude that the global stocktake in the Paris Agreement's process would need to go beyond presenting emission gaps, but insights and guidance for how to close this gap are important. Integrated assessment models can support the policy process. At first, the national policy scenario used in this analysis could be assessed in more detail and give insights into the impact of different individual policies. In addition, the models are well furnished to present effective mitigation options to countries for policy enhancement by giving the trade-offs between impact and costs of different policy packages in the context of global efforts. Other effectiveness criteria could be captured with different scenarios. Finally, as the new policy questions require more detailed information, model development could go into the direction of including more countries, sectors and actors or link to bottom-up energy and land use models.

4.4 METHODS

4.4.1 Model exercise

The assessment of the impact of national climate policies on greenhouse gas emissions is based on the model exercise that was done as part of the CD-LINKS project, and for which guidelines were described in the global and national model protocols (CD-LINKS, 2017b, 2017c). This project aimed, among other things, to develop global low development pathways on a global level and for G20 economies, including an explicit representation of near-term policy trends. For this paper, we selected seven large G20 economies in terms of greenhouse gas emissions (Brazil, China, the EU, India, Japan, Russian Federation, United States), for which also national climate and energy models were available in the project.

4.4.2 Integrated Assessment Models

Integrated assessment models (IAMs) describe key processes in the interaction of human development and natural environment and are designed to assess the implications of achieving climate objectives[2,33]. The model exercise that assessed the impact of climate policies was done by nine IAMs that have global coverage, and ten national models that represent a specific G20 economy (See Table 4-4). A more detailed description of model structure and policy implementation can be found in the Supplementary S4.9, and for some models at the ADVANCE wiki (IAMC, 2017). These models differ in country and sector aggregation level, and also in the way they mimic decisions on climate policy. All models include dynamic pricing, and therefore local climate policy will result in lower implementation in other regions with less policies. However, only the economic models explicitly account for carbon leakage. In addition, as most models assume one central planner, behaviour or decisions of different actors and the role of institutions is often not explicitly taken into account. This implies that most models (especially with simple representation of the economy) have only a limited ability 'to reflect the specific social and economic dynamics of the developing and transition economies (Weyant et al., 1995). Some phenomena, such as the green paradox, can only be represented by most models in an explicit scenario design. However, the models with less economic detail often have a more detailed representation of technologies in different sectors enabling them to take into account technological learning.

Table 4-4 Participating Integrated Assessment Models in the model exercise to assess the impact of climate policies

Model	Coverage IAM model	Institute	Model type
AIM V2.1	Global	Kyoto University and National Institute for Environmental Studies (NIES, Japan)	Recursive dynamic, general equilibrium
COPPE-COFFEE 1.0	Global/national	Energy Planning Program, COPPE, Universidade Federal do Rio de Janeiro (COPPE, Brazil)	Perfect foresight, general equilibrium
DNE21+ V.14	Global/national	Research Institute of Innovative Technology for the Earth (RITE, Japan)	Perfect foresight, partial equilibrium
GEM-E3	Global/national	Institute of Communication and Computer Systems (ICCS, Greece)	Recursive dynamic, General Equilibrium
IMAGE 3.0	Global	PBL Netherlands Environmental Assessment Agency (PBL, The Netherlands)	Recursive dynamic, partial equilibrium
MESSAGEix-GLOBIOM_1.0	Global	International Institute for Applied Systems Analysis (IIASA, Austria)	Perfect foresight, general equilibrium
POLES CDL	Global	Joint Research Centre (JRC, EU)	Recursive dynamic, partial equilibrium
REMIND-MAgPIE 1.7-3.0	Global	Potsdam Institute for Climate Impact Research (PIK, Germany)	Perfect foresight, general equilibrium (REMIND) recursive dynamic, partial equilibrium (MAgPIE)

Model	Coverage IAM model	Institute	Model type
WITCH2016	Global	Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC, Italy)	Perfect foresight, general equilibrium
AIM/Enduse[Japan]	National	Kyoto University and National Institute for Environmental Studies (NIES, Japan)	Recursive dynamic, partial equilibrium
AIM-India [IIMA]	National	Indian Institute of Management (IIM, India)	Recursive dynamic, general equilibrium
BLUES	National	National, Institute is Energy Planning Program, COPPE, Universidade Federal do Rio de Janeiro (COPPE, Brazil)	Perfect foresight, partial equilibrium
China TIMES	National	Tsinghua University (TU, China)	Recursive dynamic, partial equilibrium
GCAM-USA_ CDLINKS	National	Pacific Northwest National Laboratory (PNNL, United States)	Recursive dynamic, partial equilibrium
India MARKAL	National	The Energy Resources Institute (TERI, India)	Dynamic least cost optimization
IPAC-AIM/ technology V1.0	National	National Development and Reform Commission Energy Research Institute (NDRC-ERI, China)	Recursive dynamic, general equilibrium
PRIMES_V1	ICCS	Institute of Communication and Computer Systems (ICCS, Greece)	Perfect foresight, partial equilibrium
RU-TIMES 3.2	National	National Research University - Higher School of Economics (HSE, Russian Federation)	Perfect foresight, partial equilibrium

4.4.3 Selection and model implementation of policies

Climate policy on the national level, in this research, is defined as the result of climate policy formulation and climate policy implementation that encompasses aspirational goals not secured by legislation, national targets that are secured by legislation, and policy instruments designed to implement these targets. Only implemented policies were included in this analysis, and are defined as policies adopted by the government through legislation or executive orders, and non-binding targets backed by effective policy instruments.

First, climate policies were collected with the help of national experts and a literature study (see Supplementary Table 4-2), and were stored in an open-access database (NewClimate Institute, 2015). With the help of national experts, a selection of high-impact policies was made and translated into model input indicators (CD-LINKS, 2017a). This inventory includes climate and energy policies for the G20 economies, and details the instruments, targets and sectors (see Table 4-5 and Source Data). It was evaluated with and expanded by national experts in two rounds. The cut-off data for the selection of policies was 31 December 2016, and it should be noted that the policy environment is constantly changing. Two policy changes with a possibly high impact have occurred since this date: the United States is not likely to implement the 2025 standards for light-duty vehicles, although current standards are implemented until 2021 (The Clean Power plan, already was not included in the list of high-impact policies), and the European Union adopted a comprehensive set of climate actions that goes beyond the policies that we included in our analysis. In addition, although the United States announced its withdrawal of the Paris Agreement, this would only enter into effect by November 2020.

Table 4-5 Number of high-impact policies selected for implementation in the IAM models, per sector and country (details in , Supplementary Table 4-3).

Sector	**Brazil**	**China**	**European Union**	**India**	**Japan**	**Russian Federation**	**United States of America**	**Other G20 countries**	**TOTAL**
Economy-wide	3	9	11	0	3	1	1	11	39
Energy supply	6	10	0	9	7	6	3	37	78
Transport	5	10	2	9	2	0	5	20	53
Buildings	1	1	2	0	1	1	6	4	16
Industry	0	3	0	4	1	0	0	1	9
AFOLU	4	3	0	2	2	0	1	8	20
TOTAL	19	36	15	24	16	8	16	81	215

Policy instruments were represented in the integrated assessment as explicit as possible, but simplification was sometimes necessary, thereby considering replicating the impact on greenhouse gas emissions and energy as most important. In practice, policy instruments are implemented to achieve national, often aspirational goals (not secured by legislation or executive orders). These aspirational goals are documented in national policy documents (e.g. National Communication, strategy documents). In some cases, we could directly implement policy instruments in IAMs, such as carbon taxes or regulations (e.g. vehicle fuel-efficiency standards). In other cases, we included aspirational policy targets to represent currently implemented policies, but only if they were backed by effective policy instruments. This was for example the case with feed-in tariffs or renewable auctions. If the policy instrument would end before the policy target year, we assumed continuation of this instrument until the target year of the aspirational goal. In case a G20 country is part of a larger model region, the policy (indicator) is aggregated by assuming business-as-usual for those countries without policies, and implementation of the policy for countries with policies (CD-LINKS, 2017b). In some cases, models with less sector detail used policy indicators (such as CO_2 or final energy reduction) based on the impact of policies from more detailed models or on literature. See the Supplementary S4.9 and Supplementary Table 4-4) for information on how policies were implemented for each global model.

4.4.4 Scenarios

The starting point for the scenario design was the ADVANCE project (Luderer et al., 2018; Vrontisi et al., 2018). The National policies scenario corresponds to the inventory that contains energy and climate policies implemented in G20 economies (CD-LINKS, 2017a). Between 42% and 94% of the high-impact policies from the seven G20 economies were implemented in the nine IAMs considered in this paper, and are estimated to represent 50% to 100% of possible greenhouse gas reductions (see Supplementary Table 4-5). Note that global results also include G20 policies for Argentina, Australia, Canada, Indonesia, Mexico, Republic of Korea, Saudi Arabia and South Africa, which were not individually addressed in this paper. The national policies were implemented for the period from 2010 to 2030, and equivalent effort was assumed after 2030. This was defined as a constant percentage reduction relative to the No new policies scenario or similar forms of continued ambition. The NDC scenario was based on information from the NDCs on greenhouse gas reduction targets energy and land-use policies and on additional information from Kitous, et al. (2016), den Elzen, et al. (2016) Grassi et al. (2017) (land use estimates), and information from the UNFCCC (see Supplementary S4.5 for details). The NDC targets can be divided into absolute emission reduction targets, business as usual reductions, emission-intensity reductions, and projects absent of greenhouse gas emission targets (King and van den Bergh, 2019). All G20 countries NDCs are of the first three types. In general, NDC targets for G20 economies are defined for the year 2030, but the US NDC target is defined for the year 2025. The NDCs for China and India are represented by greenhouse gas intensity targets, renewable targets and forestry measures, which could not be translated into one specific absolute greenhouse gas emission level. The 2 °C scenario assumes implementation of national policies until 2020 and cost-optimal mitigation measures after 2020, to stay within the carbon budget of 1,000 $GtCO_2$ between 2011 and 2100. This is in line with the carbon budgets of 590 to 1,240 $GtCO_2$ from 2015 onwards, which would limit global warming by 2100 to below 2 °C, relative to pre-industrial levels with at least 66% probability. The 1.5 °C scenario starts with cost-optimal deep mitigation measures after 2020, and explores the efforts necessary to keep global warming below 1.5 °C by 2100, with about 66% probability, keeping cumulative carbon emissions within 400 $GtCO_2$ between 2011 and 2100. Both budget assumptions are based on the ADVANCE project[10], and in line with the estimate for 66% probability from Table 2-2 from the IPCC AR5 Synthesis report (IPCC, 2014b).

4.4.5 Indicators to track progress

To give insights into policy impact, we have used a variant of the framework of tracking indicators related to the Paris Agreement (Peters et al., 2017; Le Quéré et al., 2019) (see Formula 1.1–1.3). CO_2 per GDP can be decomposed into energy intensity (final energy/GDP), low-carbon share of final energy (%), and utilisation rate (CO_2/fossil energy). The most pronounced differences between countries and scenarios for these indicators are visible for the low-carbon share of final energy (%) and energy intensity (final energy/GDP) (results are shown in Supplementary Figure 4-1 and Supplementary Figure 4-2), and are discussed in the article. However, not only was the impact of policies on CO_2 emissions analysed, but also total greenhouse gas emissions and individual greenhouse gas emissions (CO_2 energy, CO_2 industrial processes, CO_2 AFOLU, non-CO_2). In addition, we have added mitigation costs per GDP to assess the affordability of climate policy implementation. Partial equilibrium models such as IMAGE and POLES report these costs in terms of area under the MAC curve (e.g. direct mitigation costs), while equilibrium models such as MESSAGE, REMIND and WITCH report in terms of consumption losses. “MAC cost measures tend to exclude existing distortions in the economy” (Paltsev and Capros, 2013). But as GDP is an exogenous variable in partial equilibrium models, consumption loss is not available.

The Kaya decomposition is $\mathrm{CO_2} = \mathrm{POP} * \frac{\mathrm{GDP}}{\mathrm{POP}} * \frac{\mathrm{CO_2}}{\mathrm{GDP}}$

(1.1) $$CO_2 = POP * \frac{GDP}{POP} * \frac{CO_2}{GDP}$$

(1.2) $$\frac{CO_2}{GDP} = \frac{TPES}{GDP} * \frac{CO_2}{TPES} = \frac{TPES}{GDP} * \frac{FE}{TPES} * \frac{CO_2}{FE} = \frac{FE}{GDP} * \frac{CO_2}{FE}$$

(1.3) $$\frac{CO_2}{GDP} = \frac{FE}{GDP} * \frac{FE_{\mathrm{fossil}}}{FE} * \frac{CO_2}{FE_{\mathrm{fossil}}} = \frac{FE}{GDP} * \left(1 - \frac{\mathrm{FE_{non-fossil}}}{FE}\right) * \frac{CO_2}{FE_{\mathrm{fossil}}}$$

where

POP = population
GDP = Gross domestic product
TPES = Primary energy
FE = Final energy

RESULTS

The results are presented (unless otherwise stated) using the median estimate of all model results, and in addition presenting the 10th and 90th percentiles of these ranges. Differences in greenhouse gas emissions between scenario's (e.g. implementation gap and total emissions gaps) are calculated by first taking the difference per model and then determining the median and percentiles of the range of differences.

The results from this study show that, for national policies, greenhouse gas emissions by 2030 would be somewhat higher and for well below 2 °C scenarios lower than earlier studies indicated (Vandyck et al., 2016; van Soest et al., 2017; Vrontisi et al., 2018) (which were based on only one model or had less detail on national policy implementation) (see Supplementary Figures 4-7).

4.4.6 Uncertainty

Emission growth under the National policies scenario by 2030 can be decomposed into five drivers that, together, represent the total impact (blue bar in Figure 4-5). First, historical calibration, which is calculated as the difference between 2015 model emissions and the PRIMAP (Gütschow et al., 2016) (version 1.2) data set. Second, socio-economic growth assumptions, calculated as the emission growth between 2015 and 2030 under the No policy scenario. Third, policy impact on greenhouse gas emissions, calculated as the difference between 2030 emissions under the No policy scenario and the National policies scenario, including an estimate for the emission reductions for those policies (see Supplementary Table 4-5, Supplementary Table 4-9) that could not be implemented in certain models (See Supplementary Table 4-9). Fourth, real uncertainty represented by model form and heterogeneity.

This shows that the impact of historical calibration on the projected global growth in emissions between 2015 and 2030 is small; this growth is much more dependent on socio-economic factors such as GDP and population growth. Of the total impact, the policy impact is around one third, and a somewhat larger part is real uncertainty.

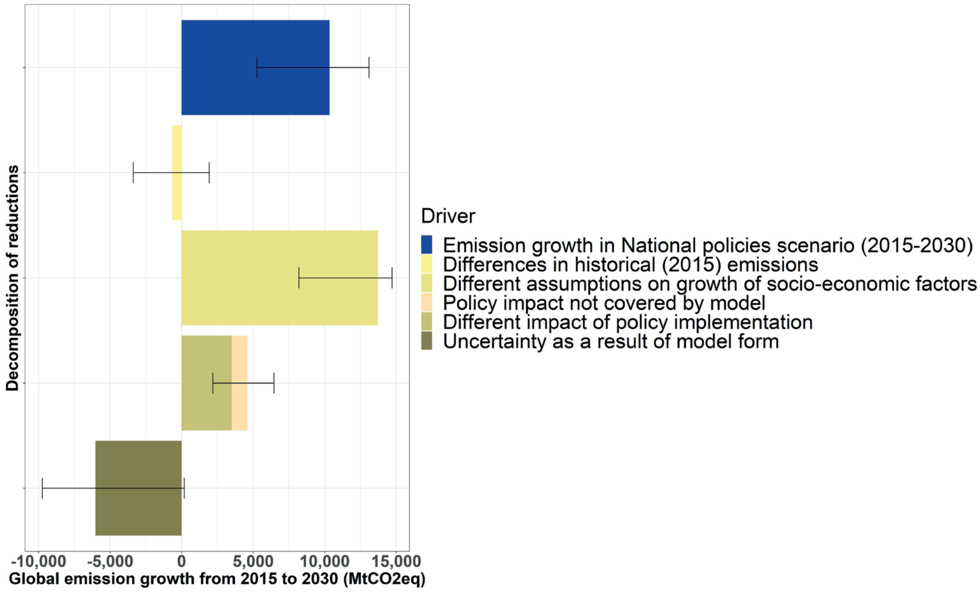

Figure 4-5 Decomposition of total median emission growth between 2015 and 2030 under National policies scenario, error bars range between 10th to and 90th percentiles. The data is available in the source data.

4.4.7 Effort-sharing

The 2 °C and 1.5 °C scenarios assume cost-optimal implementation of the reduction measures after 2020 with the lowest overall mitigation costs. The result is implementation of measures in countries where this is cheapest, but this does not imply that the implementing country would need to face all the costs. These costs can be shared, and thus financed by other countries. The financial flows could be calculated if emission allowances per country are based on so-called effort-sharing approaches representing different equity principles (Höhne et al., 2014; Raupach et al., 2014; van den Berg et al., 2019b) , for example, categorise the effort-sharing approaches in the literature based on the four basic equity principles, i.e. responsibility, equality, capability and cost effectiveness, and present the regional greenhouse gas emission allowances in 2020, 2030 and 2050 for these categories. The equity principles were also applied to the carbon budgets (cumulative emissions) for both the 2011–2050 and the 2011–2100 period (van den Berg et al., 2019b), based on calculations from the FAIR model (Stehfest et al., 2014), see the Supplementary Figure 4-3, for comparison with the results from our study.

4.4.8 Model result adjustments

some model results were adjusted due to missing data on sectors and sub-sectors, different accounting approaches or too broad regional definitions. The DNE21+ (on country level) does not include the Agricultural, Forestry and Land Use (AFOLU) sector. Therefore, these were supplemented with average estimates from the other global models. Although the POLES model does include AFOLU CO_2 emissions, based on estimates from national communications, they were harmonised with those from FAOSTAT (FAO, 2020), as the accounting approaches of the individual countries were not consistent with the other IAMs. The COPPE-COFFEE model does not include F-gas emissions, which were supplemented with average estimates from the other global models. Some national models only cover energy CO_2 emissions (China TIMES, China IPAC-AIM V1.0, AIM India, MARKAL India, PRIMES, RU-TIMES) and industrial CO_2 emissions and non-CO_2 emissions were supplemented with average model estimates from global models.

4.4.9 Data availability

Data reported in figures and the selection of policies implemented in IAMs can be found in the Source Data. The source data files are also available at [doi: 10.17632/2j7sksfh2h.1. The list of policies is based on the open source Climate Policy Database. The scenario protocol and the selection of high-impact policies that were included in the protocol are found under Work Package 2 of the deliverables & publications page of the CD-LINKS project. Model results can be found in the open-access CD-LINKS database. Policy relevant data is available in the Global Stocktake tool.

Table 4-6 Data availability

CD-LINKS inventory	http://www.climatepolicydatabase.org/index.php/CDlinks_policy_inventory
Climate policy database	http://climatepolicydatabase.org/index.php/Climate_Policy_Database
Deliverables & publications	http://www.cd-links.org/?page_id=620
CD-LINKS database	https://db1.ene.iiasa.ac.at/CDLINKSDB/dsd?Action=htmlpage&page=30
Global Stocktake tool	https://themasites.pbl.nl/global-stocktake-indicators/

4.4.10 Code availability

The code from the twenty integrated assessment models is not available in a publicly shareable version, although several have published open source code, visualisation tools or detailed documentation (see Supplementary Table 4-10 for details). A model description (see Supplementary S4.9), and a description of how national climate policies have been implemented (see Supplementary Table 4-4) is available.

ACKNOWLEDGEMENTS

We would like to thank the following people for reviewing the CD-LINKS climate policy database: Chenmin He from Energy Research Institute of the National Development and Research Commission, China (NDRC-ERI), Zbigniew Klimont, Nicklas Forsell, Jessica Jewell and Olga Turkovska from International Institute for Applied Systems Analysis (IIASA), Amit Garg from the Public Systems Group at the Indian Institute of Management, India (IIM), Roberta Pierfederici from Institute for Sustainable Development and International Relations (IDDRI), Ucok WR Siagian from Institut Teknologi Bandung, Indonesia (ITB), Jiyong Eom and Cheolhung Cho from Korea Advanced Institute of Science and Technology, Republic of Korea (KAIST), Takeshi Kuramochi from NewClimate Institute (NCI), Junichiro Oda from Research Institute of Innovative Technology for the Earth, Japan (RITE), Aayushi Awasthy and Swapnil Shekharf rom The Energy and Resources Institute, India (TERI), Hongjun Zhang from Tsinghua University, China (TU), Nick Macaluso from Environment and Climate Change Canada (EC), Michael Boulle, Hilton Trollipp from Energy Research Centre, South Africa (ERC) and Daniel Buira (Mexico), Vladimir Potachnikov from National Research University Higher School of Economics (Russian Federation).

This work is part of a project funded by the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No. 642147 (CD-LINKS), and is supported by European Union's Horizon 2020 Research and Innovation Programme under grant agreement No. 821471 (ENGAGE) and European Union's DG CLIMA and EuropeAid under grant agreement No. 21020701/2017/770447/SER/CLIMA.C.1 EuropeAid/138417/DH/SER/MulitOC (COMMIT)

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Jacques Despres, Kimon Keramidas[**] Disclaimer: The views expressed are purely those of the writer and may not in any circumstances be regarded as stating an official position of the European Commission.

5

CHAPTER

Reducing global greenhouse gas emissions by replicating successful sector examples: the "good practice policies" scenario

Roelfsema, M., Fekete, H., Höhne, N., den Elzen, M., Forsell, N., Kuramochi, T., de Coninck, H., van Vuuren, D.P.D.P., 2018a. Reducing global GHG emissions by replicating successful sector examples: the 'good practice policies' scenario. Climate Policy 18, 1103–1113. https://doi.org/10.1080/14693062.2018.1481356

ABSTRACT

This article shows the potential impact on global greenhouse gas emissions (GHG) emissions in 2030, if all countries were to implement sectoral climate policies similar to successful examples already implemented elsewhere. This assessment was represented in the IMAGE and GLOBIOM/G4M models by replicating the impact of successful national policies at the sector level in all world regions. The first step was to select successful policies in nine policy areas. In the second step, the impact on the energy and land-use systems or GHG emissions was identified and translated into model parameters, assuming that it would be possible to translate the impacts of the policies to other countries. As a result, projected annual GHG emission levels would be about 50 $GtCO_2eq$ by 2030 (2% above 2010 levels), compared to the 60 $GtCO_2eq$ in the "current policies" scenario. Most reductions are achieved in the electricity sector through expanding renewable energy, followed by the reduction of fluorinated-gases, reducing venting and flaring in oil and gas production, and improving industry efficiency. Materialising the calculated mitigation potential might not be as straightforward given different country priorities, policy preferences and circumstances.

Key words: successful policies, sector indicators, integrated assessment modelling, enhancing ambition, 2°C limit

Key policy insights

- Considerable emissions reductions globally are possible if a selection of successful policies were replicated and implemented in all countries worldwide.
- This would significantly reduce, but not close, the emissions gap with a 2°C pathway.
- From the selection of successful policies evaluated in this study, those implemented in the sector 'electricity supply' have the highest impact on global emissions compared to the 'current policies' scenario.
- Replicating the impact of these policies worldwide could lead to emission and energy trends in the renewable electricity, passenger transport, industry (including F-gases) and buildings sector, that are close to those in a 2°C scenario.
- Using successful policies and translating these to policy impact per sector is a more reality-based alternative to most mitigation pathways, which need to make theoretical assumptions on policy cost-effectiveness.

5.1 INTRODUCTION

Most countries have ratified the Paris Agreement, which aims at reducing greenhouse gas (GHG) emissions in order to keep the increase in global mean temperature to “well below” 2°C above pre-industrial levels, and preferably below 1.5°C (UNFCCC, 2015g). The collective impact of all Nationally Determined Contributions (NDCs) submitted by countries to indicate their pledges for emission reductions for the period to 2025/2030 are not expected to achieve those temperature goals. Based on different cost-optimal 2˚C scenarios from integrated assessment models, Rogelj et al. (2016) find a projected emissions gap for 2030 of 10 to 16 billion metric tonnes of CO_2-equivalent emissions ($GtCO_2eq$), between the global emission level consistent with warming below 2°C and the range associated with a full implementation of unconditional NDCs for 2030. Emission levels consistent with 2°C are between 31 to 44 $GtCO_2eq$ (10-90% percentile). The Paris Agreement encourages Parties to increase their pledged GHG emission reductions. The momentum created in Paris could be captured by continuing with the same NDC process and scaling up ambition (Höhne et al., 2017).

In this context, it is important to note that there are already examples of successful sector policies in specific countries that significantly reduce GHG emissions. An important question is whether other countries can learn from such sector policies and achieve similar results. In the literature, it has been suggested that a possible route forward could be to promote a process of international policy learning and “the emergence of a global marketplace of ideas” (Hadjiisky et al., 2017). Although it is clear that ‘policy transfer’ is limited by the country’s specific context, countries are learning from both successful and failed actions implemented elsewhere. Examples are the Chinese emission trading system that uses experience gained with the ETS in the European Union (EU) (Gippner, 2016), Chinese renewable energy production and policy implementation induced by policy interventions in Germany and Denmark (Höhne et al., 2017), and energy appliance labelling based on US EPA’s Energy Star Program in Canada and Japan (Energy Star).

The aim of this paper’s assessment is to evaluate the potential impact on global GHG emissions if all countries worldwide were to implement climate policies similar to successful examples already implemented by other countries. For this, we first made a shortlist of successful policies per sector. Second, we selected a policy that is most ambitious and potentially replicable to other countries. Third, we translated the result of these successful sector policies by assessing their historical impact on the energy- and land-use system, and on GHG emissions. Fourth, this impact was translated into model parameters for each model region to analyse the impact in the IMAGE and GLOBIOM/G4M models. The final outcome was an estimate of global GHG emission levels, taking into account overlaps in effects between sectors. These were then compared to GHG levels implied by current policy implementation, NDC targets and the Paris Agreement's objective to keep global temperature increase well below 2°C.

We focus on the potential GHG impact of "policy transfer". The "what-if" analysis does not account for local contextual conditions, as for example was done by (Bataille et al., 2016). They explicitly took into account national technical, social and economic priorities and circumstances. In this analysis, we assume that countries can learn from each other, and that countries implement policy instruments (e.g. feed-in-tariff) adjusted to their national circumstances to achieve the implied policy targets. The main contribution of this paper is an integrated assessment model analysis of GHG reductions from replicating policy impact of ambitious sector policies that have demonstrated successful implementation. Historically, countries have often implemented policies that are (somewhat) different from the cost-optimal mix (Trutnevyte, 2016).

A few studies have earlier looked into the question of what the impact on GHG emissions could be if countries were to learn from others while implementing reductions beyond current policies or NDCs. Den Elzen et al. (2015) argue that enhanced policies implemented in 13 major emitting countries/regions could reduce emissions by 6.1 $GtCO_2eq$ in 2030 relative to a 'current policies' scenario Sitra (2015), based on Ecofys (2015c), assessed 17 'success stories', and showed that upscaling could result in 12 $GtCO_2eq$ reductions by 2030 relative to a baseline based on current policies and trends. Kuramochi et al. (2018b) turn it around and determine policy benchmarks for the short term if the Paris Agreement temperature limit is to be met.

Our study is more comprehensive in the coverage of policy areas and enhanced mitigation measures compared to den Elzen et al (2015). We go beyond the work of Sitra (2015) by using an integrated assessment model that enables dynamic, internally consistent and simultaneous assessment of both energy supply and demand sectors. Such a model allows us to correct for possible overlaps between the different policies, for instance policies that at the same time promote renewable energy technology in power supply and reduce electricity demand in end-use sectors.

This paper is structured as follows. In Section 2, we discuss the overall methodology and present the successful policies per sector that have been selected. In this section we also discuss how the policies have been represented in the IMAGE and GLOBIOM/G4M models. In Section 3, we present the results relative to GHG emission pathways of current implemented policies and NDCs, and in accordance with the 2°C limit. Finally, in Section 4, we provide a discussion and the conclusions.

5.2 METHODOLOGY

5.2.1 Model and scenario design

The emission pathways for the energy and industry sectors in our study were estimated using the energy model TIMER. This model forms part of the integrated assessment model IMAGE 3.0 (Stehfest et al., 2014). It describes future energy demand and supply for 26 global regions and is able to assess the implications of energy system trends for all major greenhouse gases and air pollutants. The TIMER model is well suited for a policy impact assessment at sector level, given its relatively high degree of detail for an integrated assessment model. It represents the activity levels in the different sectors in terms of physical indicators (e.g. transport demand or steel production), allowing for a rather straightforward interpretation of the policies implemented. This model simulates long-term energy baseline and mitigation scenarios (Van Vuuren et al., 2014) on the global and regional levels. The investments into different energy technologies are calculated by a multinomial logit function that accounts for relative differences in costs and preferences (technologies with lower costs gain larger market shares). The model is build up from different modules, including energy demand modules for transport, industry, buildings and modules for energy supply, industrial processes and emissions. The policy instrument often used in TIMER is a carbon tax, which often represents a generic policy effort. It is, however, possible to implement other policy instruments, such as fuel efficiency standards, by setting, and thus regulating, the efficiency of new cars sold.

For estimating the impact of policies on land use and land-use change and forestry (LULUCF) emissions and removals, the Global Forest Model (G4M) was used in conjunction with the Global Biosphere Management Model (GLOBIOM) framework. The G4M (Kindermann et al., 2008; Gusti, 2010) model was used to estimate the impact of forestry activities (afforestation, deforestation and forest management) on biomass and carbon stocks. The model itself estimates forest area change, carbon sequestration and emissions from forests, impacts of carbon incentives (e.g. avoided deforestation) and supply of biomass for energy and non-energy uses. For this work, the G4M was linked to GLOBIOM outputs to provide projections for the forest sector consistent with the development of other land use categories. GLOBIOM (Havlík et al., 2011, 2014) itself is a partial equilibrium model with detailed sector coverage, detailed representation of production technologies, and geographically explicit representation of land use and associated GHG emissions.

As a starting point for the calculations, the SSP2 scenario (Riahi et al., 2017) was used as baseline in the models (IMAGE/GLOBIOM/G4M). SSP2 describes a middle-of-the-road scenario in terms of economic and population growth and other long-term trends such as technology development. The main drivers of this scenario for the energy and industry sectors are: population, GDP, lifestyle and technology change (van Vuuren et al., 2017b), and for the LULUCF sector: agricultural productivity, bioenergy and wood demand (Fricko et al., 2017). The current policies scenario used in this assessment takes into account climate policies that are implemented in 25 major emitting countries based on the IMAGE/GLOBIOM/G4M calculations (Kuramochi et al., 2016a). The result of our assessment is modelled in a scenario called the 'good practice policies scenario'. This scenario was implemented by changing model input parameters to achieve the policy impacts (see Table 5-2). The 'good practice' feature is applied to policies that have proven themselves in one or several countries, and have significantly decreased GHG emissions there, or led to a significant change in other GHG-relevant metrics.

5.2.2 Overall methodology

The assessment consisted of four steps, which are further elaborated below and with more detail in the Supplementary Information:

1. A shortlist of successful policies was identified for nine major emitting sectors.
2. For each sector, we selected the most successful policy based on historical trends of a sector-specific indicator. Policies that could clearly not be translated to other regions (e.g. because they depend on a large hydropower potential) were excluded.
3. For each policy we determined the impact, based on the historical performance of the sector indicator, and translated them to suitable parameters for input to the models.
4. Subsequently, the policy impacts were replicated for the period 2015 to 2030 for all regions using the IMAGE energy model and for the period 2010 to 2030 for the GLOBIOM/G4M land use models.

In our selection of policies, we focussed on the following sectors: electricity generation, oil and gas production, industry energy use, fluorinated gases (F-gases), residential buildings, passenger car use and LULUCF. These sectors covered around 65% of global GHG emissions in 2010. The selection was done by first compiling a shortlist of successful policies from the Climate Policy Database (NewClimate Institute, 2015), literature sources (den Elzen et al., 2015; Höhne et al., 2015a; Forsell et al., 2016; Healy et al., 2016) and technical papers from the UNFCCC on mitigation benefits of actions, and initiatives and options to enhance mitigation ambition (UNFCCC, 2013, 2014a). To our knowledge, these sources together include the vast majority of currently implemented policies that can be modelled by IMAGE.

This resulted in a shortlist of sector policies that have proved successful in some countries. Then, for each sector, the most successful policy was selected on the basis of the historical performance of a sector specific indicator (see Table 5-1 and S5.2).

The historical performance of the policy was used to determine impact at the sector level (see Table 5-1 and Supplementary 5), which was then replicated through setting specific model parameters at the regional level in the IMAGE and GLOBIOM/G4M model for the period 2015 to 2030. This resulted in a level of GHG emissions, assuming that these impacts based on successful policies were implemented everywhere. This approach, based on proven success, is more realistic than many deep mitigation scenarios normally explored in models that tend toward the goal of minimising the aggregate economic costs of achieving mitigation outcomes (Clarke et al., 2014).

Table 5-1 Overview of sectors, policy actions, indicators, target and implementation

Main sector	Policy action	Successful policy instrument	Policy impact
Energy supply	Increase renewables in electricity production	Renewable portfolio standard, feed-in-tariff in the UK and Germany	+1.35% points growth in share of renewable electricity generation per year
	Reduce flaring and venting in oil and gas production	Regulation and carbon tax in Norway	4.4% annual reduction of oil/gas intensity (ktCO_2eq/Mtoe) until 2030
Industry	Enhance energy efficiency of industrial production	Energy agreements in Ireland	1% annual energy savings improvement above current efforts until 2030
	Reduce fluorinated emissions	Proposal to the Montreal protocol	70% reductions of F-gas emissions below 2010 levels by 2030
Buildings	Enhance efficiency of residential building envelope	EU regulation	Energy intensity of 0 kWh/m² by 2030 (space heating)
	Set efficiency standards for appliances and lighting	Appliance standards in EU countries	Average efficiency improvement of 1.8% per year until 2030
Transport	Improve fuel efficiency of cars	Fuel economy standard in the EU	Fuel economy standard of 26 km/l in 2030
	Increase number of electric cars (charged with renewable electricity)	Tax levies and investments in infrastructure in Norway	25% share of new electric vehicles in 2020, 50% in 2030
LULUCF	Reduce deforestation	Regulations and enforcements in Brazil	Decreasing deforestation rate relative to 2010 by 22% in 2020, 44% in 2030.

As an example, the electricity sector shortlist consisted of policies from Costa Rica, Denmark, Dominican Republic, Germany, Morocco, Tuvalu, the United Kingdom (UK), and Uruguay. For each country, we calculated performance using increase in the share of renewables as the sector indicator (based on IEA data, see Supplementary Information). Some countries were found to have performed well, but under particularly favourable conditions, which would be difficult to replicate in other countries. Such conditions are for example mountain regions for installing hydropower technologies (e.g. Uruguay) or large availability of grid connections with neighbour countries (Denmark). The UK implemented a renewable obligation support scheme, obliging electricity suppliers to generate a portion of the electricity from renewables, and Germany implemented a feed-in-tariff. They showed on average a 1.35 %-points annual increase in the renewable electricity share over the period 2004–2012. As these two countries' renewable energy policies were demonstrably successful and were the only ones remaining on the shortlist, their policies were selected. The annual increase of 1.35 %-points was used to represent the policy impact, which was replicated for all regions in the TIMER model by setting a floor on the minimum renewable share in electricity between 2015 and 2030 (see Table 5-1). Using this floor as a constraint, the mix of energy carriers for electricity production in the model was calculated using a multinomial logit function, that gives the highest weight to the cheapest option (see Table 5-2). In our model calculations, we assume that successfully integrating renewable energy or add storage capacity is possible, based on the evidence that it already has been achieved by some countries (IRENA, 2017).

A short description of model implementation for each policy area can be found in Table 5-2. A more detailed description of all successful policies per sector, together with how policy impact was determined, can be found in the Supplementary Information.

It should be noted that this method does not allow for tailoring these replicated policies to country or region specific circumstances. It merely shows by how much global GHG emissions could be reduced by scaling up trends from selected policies that have worked in specific countries. In addition, we do not account for rebound effect that might results from implementing efficiency policies. This approach does constrain implementation to the technological potential of countries, as this is endogenous to the model. However, it does not account for obstacles to effective implementation, such as the need for significant subsidies, the challenges of renewable electricity integration, and immature technologies (e.g. carbon capture and storage) (Mathy et al., 2016). In order to account for national technical, social and economic priorities and circumstances, more bottom-up pathways are necessary (Bataille et al., 2016). Although some policies, such as fuel efficiency standards, have already been implemented in many countries others need more careful consideration before implementing them worldwide. Therefore, our approach must be seen as a simplified one, which could be used as a starting point for countries to increase ambition. It stimulates countries to learn from successful policy implementation by others, and possibly improve or adjust policies to local circumstances (see Discussion for more details).

Table 5-2 Description of implementation in TIMER and GLOBIOM/G4M models for the period 2015 to 2030

Policy impact	**TIMER implementation**
1.35% growth in share of renewable generation per year	First the share of technologies used for electricity production is determined in the usual way (multinomial logit function).Then, if the annual increase would reach a renewable share higher than the current policies scenario, the ratio of renewable to fossil technologies is increased until the total renewable share is reached, keeping the ratio between the renewable technologies, and also between the non-renewable technologies, the same.
4.4% annual reduction of oil/gas production intensity (ktCO_2eq/ Mtoe) until 2030	It is assumed that the level of oil and gas production for each region remains the same as in the current policies scenario. As this is an end of pipe measure, additional flaring/venting measures are implemented that decrease GHG emissions to the level that would achieve the annual reduction target of the oil/ gas emission intensity. The current oil/gas intensity target of Norway (10 Mtoe/ktCO_2eq, based on IEA and UNFCCC data) is used as an absolute floor.
1% annual industrial energy savings improvement above current efforts until 2030	The energy efficiency improvement for the cement, steel and other industry sector is fixed at a level of 1% annual improvement above the current policies scenario. This improvement is accomplished through individual technologies, that differ between the different industry sectors (cement, steel, other)
70% reductions of F-gas emissions below 2010 levels by 2030	A carbon tax on F-gas emissions per region is set at a level, that would achieve the reductions as prescribed by the Kigali Amendment.
Average efficiency improvement of 1.8% per year until 2030 in appliances	The price-induced efficiency per unit energy of consumption for appliances (refrigerator, microwave, washing machine, clothes dryer, dish washer, tv, DVD/VCR, PC) is fixed at 1.8% per year additional to the current policies scenario,.
Energy intensity of 0 kWh/m² by 2030 in residential buildings	Useful heating efficiency (input parameter in terms of MJ/ m2/HDD) is set to zero for new residential buildings by 2030, and interpolated between 2015 and 2030. This induces use of different heating technologies and increased insulation and assumes used electricity is 100% renewable.
Fuel economy standard of 26 km/l in 2030 for new passenger cars	The fuel efficiency of new cars is an input parameter and is fixed for the year 2030 and interpolated between the already implemented CAFE standard target year and 2030, and capped by the current policies scenario efficiency. Non-fuel costs of cars are changed accordingly.

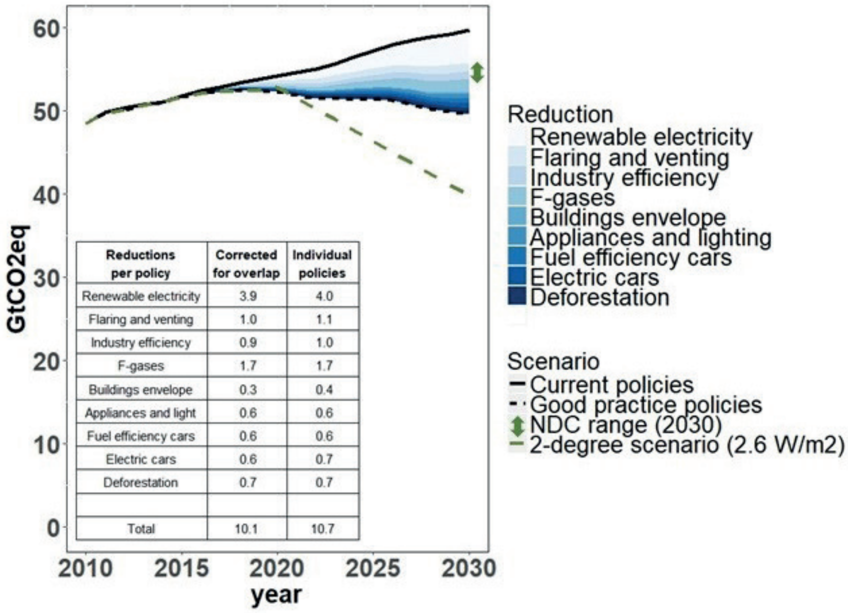
Policy impact	TIMER implementation
25% share of new electric vehicles in 2030 (from renewable electricity)	First the share of each car type (diesel, biofuel, electric etc.) is determined in the usual way (multinomial logit function). Then the share of electric cars is increased to meet the target level. The remaining share of each remaining car type is decreased, keeping the ratio between these car types the same. Renewable electricity is increased with the same level as electricity use in the transport sector.
Decreasing deforestation rate relative to 2010 by 22% in 2020, 44% in 2030.	A carbon tax for deforestation and afforestation activities is set in G4M to the level that equals the annual reduction of the deforestation rate for each country.

5.3 IMPACT ON GHG EMISSIONS

5.3.1 Global impact on GHG emissions and sectors

The good practice policies scenario was projected to result in global GHG emissions, including LULUCF, just above 2010 levels by 2030. In this scenario, emissions at first increased to 52.3 $GtCO_2eq$ in 2020 (about 8% above 2010 levels), and then decreased to 49.6 $GtCO_2eq$ by 2030 (2% above 2010 levels). Figure 5-1 shows each policy's impact on GHG emissions, compared to the current policies scenario (GHG emissions in 2030 are 59.7 $GtCO_2eq$) , and their collective impact on narrowing the global emission gap for meeting 2ºC. Around 35% of emissions in 2010 were emitted in sectors that were not covered by the selected policies (see Methodology). Total primary energy supply (TPES) by 2030 in the good practice policies scenario decreases by 10% relative to the current policies scenario; electricity production by 3%; the renewable share in TPES increases from 11% to 16%. If the impact of individually implemented policy targets are added together, and overlap in implementing different policy targets is therefore omitted, the GHG impact would be 0.6 $GtCO_2eq$ larger. This shows that using an integrated assessment model to evaluate GHG impacts therefore avoids overestimating the effect of the individual policy targets in the good practice policies scenario.

Figure 5-1 shows the global emission reductions in the good practice policy scenario for all policy areas, and compares the results corrected for overlap to the impact from individual implementation in the table at the bottom (individual policies). The single largest impact on global emissions compared to the current policies scenario comes from increasing renewable electricity in the 'electricity supply' sector. Other sectors with significant emission cuts are the reduction of F-gases, reduced flaring and venting in the oil & gas production sector, and improved energy efficiency in the industry sector.



Reductions per policy	Corrected for overlap	Individual policies
Renewable electricity	3.9	4.0
Flaring and venting	1.0	1.1
Industry efficiency	0.9	1.0
F-gases	1.7	1.7
Buildings envelope	0.3	0.4
Appliances and light	0.6	0.6
Fuel efficiency cars	0.6	0.6
Electric cars	0.6	0.7
Deforestation	0.7	0.7
Total	10.1	10.7

Figure 5-1 The impact of implementing the selected nine good practice policies together on global emissions (including LULUCF). The emission levels are compared to global emissions resulting from the full implementation of the NDCs based on den Elzen et al. (2016)*.*

The results are compared with NDC and 2°C pathways from the IMAGE model. The global implementation of the good practice policies scenario goes beyond the impact of NDC implementation, which is projected by den Elzen et al. (2016) to be in the range of 53.4 to 55.9 $GtCO_2eq$. In addition, the emissions gap in 2030 with the cost-effective 2°C least-cost pathway from IMAGE[22], is projected to narrow from 19.8 $GtCO_2eq$ in the current policies scenario, to 9.7 $GtCO_2eq$ in the good practice policies scenario.

5.3.2 Sector results

The results of the good practice policies scenario per sector are shown in Figure 5-2, in terms of sector indicator projections. Some efficiency indicators are presented in terms of GDP and population, and not in terms of physical units (e.g. tonnes of produced material), as these do not allow for comparison across different industrial or residential processes (Patterson, 1996). The impacts on GHG emissions presented in this section are based on individual implementation of each (sector) policy action.

[22] 66% probability of staying below 2°C, and starting with cost-optimal implementation in 2020 from emissions levels implied by national pledges under the 2010 Cancun Agreements.

Scaling up the impact of successful renewable energy policies in the electricity supply sector was projected to increase the renewable share by 2030 from 30% in the current policies scenario to 45% in the good practice policies scenario (see Figure 5-2a). Implementation on a global scale was projected to reduce emissions by 4.0 $GtCO_2eq$ by 2030. This projection is just below the mitigation potential indicated in the Emissions Gap Report 2014 (UNEP, 2014) of 5 $GtCO_2eq$, but is at the low end of the potential in the 2 °C scenario from the 'Decarbonising development' report (World Bank, 2015a) and the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (Working Group III) (2014a). These reports indicate a 30% renewable electricity share by 2025 and a 35% share by 2030.

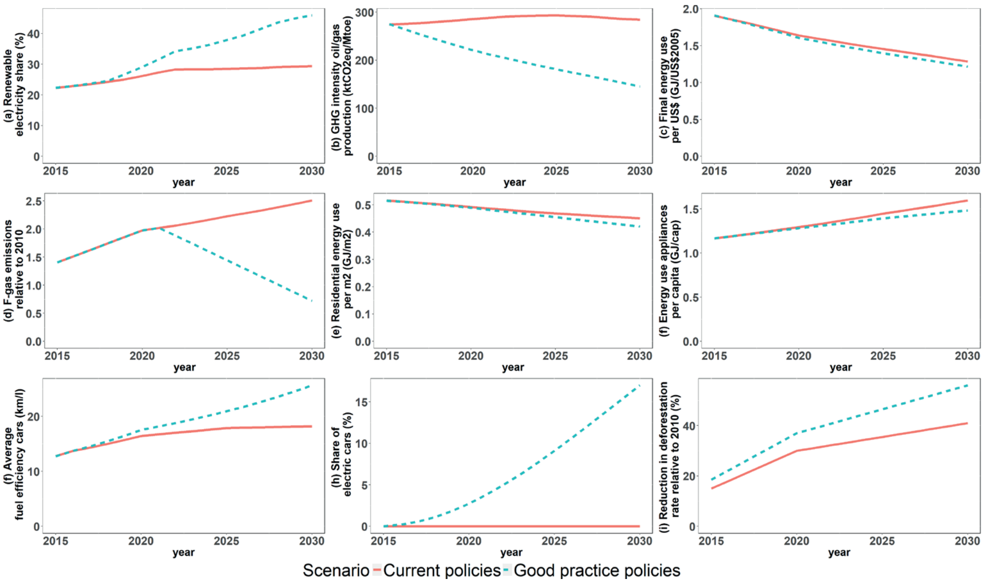


Figure 5-2 Sector impact indicators for a) increase renewable electricity share, b) reduce flaring and venting, c) enhance energy efficiency in industry, d) reduce F-gas emissions, e) enhance energy efficiency of building envelope, f) improve efficiency of appliances and lighting, g) improve fuel efficiency of cars, h) support electric cars charged with renewable electricity, i) reduce deforestation (starting in 2010)

Replicating the impact of Norway's policy in the oil and gas production sector was projected to decrease energy intensity in this sector from 285 $ktCO_2eq$/toe in the current policies scenario to 115 $ktCO_2eq$/toe by 2030 in the good practice policies scenario (see Figure 5-2b). This was projected to result in 1.1 $GtCO_2eq$ emission reductions by 2030 relative to the current policies scenario.

The impact of global implementation of industrial efficiency policies was estimated to slightly decrease energy intensity from 1.3 kWh/Industry Value Added (IVA) (US$(2005)) in the current policies scenario to 1.2 kWh/IVA (US$(2005)) in the good practice policies scenario (see Figure 5-2c). The reductions relative to current policies in terms of GHG emissions were projected at 1.0 $GtCO_2eq$ by 2030. If we compare the results for the good practice policies scenario in terms of final energy demand with the 2°C scenarios presented in the AR5 IPCC (2014a) WGIII report, the final energy reductions in the industry sector relative to the current policies scenario (approximately 15%) are at the lower end of the IPCC 2°C pathways range[23].

Implementation of the good practice F-gas reduction target on a global scale was projected to result in a decrease of global F-gas emissions by 70% relative to 2010 (see Figure 5-2d). This is a reduction of 1.6 $GtCO_2eq$ by 2030, relative to the current policies scenario. The projected reductions were in line with the global mitigation potential at €20/tCO_2eq presented in Schwarz et al. (2011). In addition, these reductions were in line with the emission reduction in the 2°C scenario from Labat et al. (2015).

Implementation of measures to enhance the energy efficiency of new buildings in the residential sector was projected to lead to a decrease in energy consumption from (existing and new) residential buildings per square metre from 0.45 GJ/m^2 in the current policies scenario to 0.42 GJ/m^2 (see Figure 5-2e). As a result, GHG emissions were projected to reduce by 0.4 $GtCO_2eq$ by 2030.

Replicating the policy impact from improving appliance efficiency and lighting was projected to lead to indirect (from electricity) GHG emission reductions of 0.6 $GtCO_2$ by 2030, while the impact on direct (from fuels, heat) emissions was negligible. The impact of these policies on per capita electricity consumption (see Figure 5-2f) was small because of the relatively small size of the residential sector compared to population size.

The two presented policy areas described above are both in the residential buildings sector. The aggregated final energy reductions (in percentages) in this sector relative to the current policies scenario were somewhat below the IPCC 2°C range from (Lucon et al., 2014) (in AR5 WGIII report), but the latter also includes reduction measures from the commercial buildings sector.

Good practice fuel efficiency standards for cars could improve fuel efficiency of the car stock by 2030 to 25.7 km/l (see Figure 5-2g), from a global average of 12.8 km/l in 2015. The

[23] Although the IPCC range is presented as reduction relative to baseline, the ’current policies scenario’ in our study does not include many industry policies.

GHG emissions by 2030 in the good practice policies scenario were projected to reduce emissions by 0.6 $GtCO_2$ by 2030. Already under the current policies scenario, fuel efficiency of cars increased relative to a no-policy baseline, as many countries have implemented these standards. The projected fuel efficiencies in this study are around those of the IEA 2 °C scenario (IEA, 2012b) by 2030.

The share of electric cars increased to 19.5% by 2030 in the good practice policy scenario. This share was zero in the current policies scenario (see Figure 5-2h). The projected GHG reductions from this good practice policy was 0.7 $GtCO_2eq$ by 2030 relative to the current policies scenario.

Replicating the impact of successful policies on deforestation was projected to reduce global LULUCF emissions by 0.7 $GtCO_2eq$ in 2030 relative to the current policies scenario. Overall, the policy leads to an overall 55% reduction of the global deforestation rate by 2030 relative to 2010, while the current policies scenario lead to an overall 40% reduction of the global deforestation rate relative to 2010. This deforestation rate is still substantially higher than the 84% reduction of the global deforestation rate by 2030 relative to 2010 in the 2°C scenario obtained from (Popp et al., 2017).

5.4 DISCUSSION

One question that arises from our study is to what extent policies are replicable to other countries, given different country circumstances. Policies that have been successfully implemented in some countries were the starting point of our analysis. Our approach is different from studies in the literature showing pathways to stay (well) below the globally agreed 2°C temperature increase, as it changes the focus from cost-optimal pathways to sector policy implementation based on past success.

Although our approach comes closer to what can realistically be expected from implementation of the NDCs or 2°C pathways than more theoretical, “not-real-world-proven” assessments, we identify at least two main shortcomings in our approach. First, we do not take full account of country-specific circumstances that affect local implementation success. This could be improved by defining sector policy targets more in line with bottom-up national priorities and circumstances. More research into country needs and priorities, as for example done in (Bataille et al., 2016), would support this. In addition, research into successful policies at lower aggregation levels of sectors, for example the cement and steel industry sector, would contribute to this improvement.

Secondly, rather than the implementation of these policies, our focus is on replicating policy impact trends and their aggregate impact on GHG emissions. For this, we use the integrated assessment model IMAGE, which does not allow for assessment of socio-economic or governance aspects. Other models and methods, which could be linked to IMAGE, would be needed to begin resolving this issue.

The policy literature may provide some valuable guidance on replicability, i.e. the possibility of “policy learning” and “policy transfer”. Policy learning is a voluntary process where policymakers draw lessons from policy implementation in other countries, while policy transfer goes one step further and is often done in the context of (indirect) coercion, especially in the context of trade agreements, or via international institutes such as the World Bank or the IMF (Hadjiisky et al., 2017). Globalisation and the rapid growth in communication technologies may also lead to policy convergence (Evans and Davies, 1999).

In order to work with more realistic assumptions on policy transfer, we turn to Dolowitz and Marsh (1996, 2000), who identify complexity of the policy landscape, insufficient information about policy content, lack of insight into the success of the policy, and differences between the economic, social, political and ideological contexts as barriers to policy learning and transfer that need to be taken into account for other countries. For example, with regard to the case cited in the introduction to this paper, namely, ETS policy transfer from the EU to China, lessons from the EU were transparently documented and pilots were run in China reflecting a more Chinese style of policymaking (Gippner, 2016). In the new ETS proposal, allowance allocation methods are chosen that “mirror the nature of the Chinese NDC” (Jotzo et al., 2018).

Our approach should be considered as a first step towards a more bottom-up, realistic use of integrated assessment models that begins to consider implementation barriers. This complements top-down cost-optimal implementation such as that assessed in UNEP (2017) and for the most part in Chapter 6 of the IPCC (Clarke et al., 2014).

5.5 CONCLUSION

We conclude that considerable emission reductions globally are possible if the impact from successful policies evaluated in this paper were to be replicated in different parts of the world. This could keep global emissions by 2030 close to the level of those in 2010. The good practice policies scenario, based on nine selected successful policies, is projected to decrease GHG emissions relative to current policies to 49.6 $GtCO_2eq$ by 2030. This would considerably narrow, but not fully close, the emissions gap by 2030 with the 2°C pathway to

9.7 $GtCO_2eq$. The largest sector contributors to narrowing the gap based on our approach are the electricity sector (4.0 $GtCO_2eq$ emission reductions by 2030 compared to current policies scenario), followed by the F-gases (1.7 $GtCO_2eq$), flaring and venting in the oil and gas sector (1.1 $GtCO_2eq$) and industry efficiency (1.0 $GtCO_2eq$).

Most, but not all, policy impacts are in line with sector studies by other assessments that meet the 2°C goal. The sector indicator in the renewable electricity sector is projected to be close to the 2°C benchmark from UNEP (2014), World Bank (2015a) and IPCC WGIII reports (2014c). For cars, the projected results from this study are around or below the IEA 2 °C benchmark for new passenger light duty vehicles. However, the deforestation rate in the LULUCF sector improves relative to the current policies scenario, but is still projected to be at a higher level compared to the 2 °C scenario from Popp et al. (2017).

CHAPTER 6

Integrated assessment of international climate mitigation commitments outside the UNFCCC

Roelfsema, M., Harmsen, M., Olivier, J.G., Hof, A.F., van Vuuren, D.P., 2018b. Integrated assessment of international climate mitigation commitments outside the UNFCCC. Global Environmental Change 48, 67–75. https://doi.org/10.1016/j.gloenvcha.2017.11.001

ABSTRACT

In the Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC), countries agreed on taking efforts to keep global temperature rise well below 2 degrees Celsius. For the first time, non-Party stakeholders were addressed in the international negotiations and were explicitly invited to act on climate change. Indeed, there are many international cooperative initiatives (ICIs) outside the UNFCCC, driven by non-state actors or national governments, which aim at reducing greenhouse gas (GHG) emissions or at taking actions which indirectly lead to GHG emission reductions. This study assessed the impact of a selection of large ICIs on global greenhouse gas emissions and to which extent these may overlap with pledges and Intended Nationally Determined Contributions (INDCs) as submitted to the UNFCCC. ICIs are shown to be an important driver for GHG reductions; the eleven selected initiatives together – if fully implemented – could possibly deliver annual GHG emission reductions of 2.5 $GtCO_2eq$ by 2020 and of 5.0 $GtCO_2eq$ by 2030 from a no-policy-baseline emission level of 53.7 $GtCO_2$ and 61.1 $GtCO_2eq$, respectively. However, these reductions may overlap with those of international pledges and INDCs. The maximum estimate of overlap is around 70% by 2020 and 80% by 2030. The combined impact on global GHG emissions of ICIs and INDCs, assuming a maximum overlap, would lead to emission levels between 53 and 55 $GtCO_2eq$ by 2030, compared to a level of 54 to 56 $GtCO_2eq$ resulting from INDCs alone.

Keywords: international cooperative initiatives; non-state actors; cities, companies; climate policy; INDCs;

6.1 INTRODUCTION

International climate policy within the United Nations Framework Convention on Climate Change (UNFCCC) so-far has focused mostly on commitments from national governments. In the Paris Agreement (UNFCCC, 2015g), countries world-wide agreed to keeping 'the increase in global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit temperature increase to 1.5 °C'. As a first step towards this goal, countries have submitted Intended Nationally Determined Contributions (INDCs) in the run-up to the COP21 meeting in Paris, which after ratifying the Paris Agreement become NDCs. It has been shown that together, the NDCs are not expected to reduce greenhouse gas (GHG) emissions sufficiently towards a 2 °C emission pathway: the median emissions gap between GHG emission levels resulting from NDCs and the 2° C limit by 2030 is estimated to be between 11 and 14 $GtCO_2eq$ (Rogelj et al., 2016).

The change towards more bottom-up action within the UNFCCC also included the acknowledgement of non-Party stakeholders as important parties in taking climate action (UNFCCC, 2015b). Non-Party stakeholders can be defined as any group participating in global (climate) governance that is not a sovereign state (Chan et al., 2016; Nasiritousi et al., 2016). They include non-state actors such as civil society, the private sector, financial institutions, cities and other subnational authorities. Note that the definition of non-state actors is often not made explicit in literature. Here, the categorisation of the NAZCA portal is used: "NAZCA brings together the commitments to action by companies, cities, subnational regions, investors and civil society" (UNFCCC, 2015f), and thus include sub-national actors. Many take actions as a member of International Cooperative Initiatives (ICIs), that share a common goal and are mostly driven by likeminded countries (Widerberg and Pattberg, 2015). In addition, coalitions of the willing, which are groups of national governments, are also taking action on climate change outside the UNFCCC, often under the umbrella of other UN organisations. All these initiatives widen the scope of international climate policy by including new actors beside national governments (Hajer et al., 2015), and new coalitions outside the UNFCCC.

To clearly demarcate these new initiatives, we use Slingerland et al. (2011) that identified the above occurrences as "alternative routes that offer specific advantages in terms of increasing societal support for greenhouse gas (GHG) reductions". In this paper, we focus specifically on transnational emission reduction initiatives (TERIs), which can be defined as *international activities outside the UNFCCC driven by non-state actors or coalitions of national governments that have committed to reduce greenhouse gas emissions*. TERIs often operate in specific sectors and/or together with specific actors. It was decided to focus on international activities in this paper (in contrast to national-scale initiatives) as these can be expected to lead to most reductions (UBA, 2016), thus complying to a pragmatic reason to restrain the analysis to a clearly defined list of measures and avoid too much overlap between them.

Clearly, it is important to assess the potential reduction potential of TERIs and their contribution beyond current NDCs. Previous studies have shown that the potential impact of TERIs can be large, but assessments also differ substantially. The differences are caused by selecting different climate initiatives or including different overlap assumptions or baseline assumptions. A first group of studies have addressed the mitigation potential of initiatives beyond national governments. According to Blok et al. (2012), 21 coherent major initiatives, already existing or proposed, together are estimated to reduce GHG emissions by 10 $GtCO_2eq$ by 2020 relative to a 56 $GtCO_2eq$ business-as-usual level, assuming that a significant upscaling of existing initiatives is possible and that proposed initiatives will organise themselves. The New Climate Economy (2015) estimates that state- and non-state actors would together achieve emission reductions of 16 to 26 $GtCO_2eq$ by 2030 relative to the business-as-usual level of 69 $GtCO_2eq$, if they cooperate, scale up ambition and remove barriers. A second group of studies focused on existing commitments of initiatives only, based on current participation levels. Hsu et al. (2015) analysed 29 existing action statements with quantifiable targets, announced at the New York Climate Summit, and projected a total reduction of 2.5 $GtCO_2eq$ by 2020, relative to the business-as-usual level of 59 $GtCO_2eq$. UNEP (2015a) estimated that a wide selection of non-state climate initiatives with concrete mitigation actions and/or quantified mitigation targets would reduce emissions by 2.9 $GtCO_2eq$, with a range of 2.5-3.3 $GtCO_2eq$ by 2020 relative to the Current Policy Scenario of the World Energy Outlook 2014. UBA (2016) estimates that 19 initiatives, based on their quantifiable goal, are estimated to reduce between 511 $GtCO_2eq$ annual reductions by 2030 compared to an NDC emission level of 53-56 $GtCO_2e$

This study uses the Integrated Assessment Model (IAM) IMAGE (Stehfest et al., 2014) to get an order estimate of the emission level after implementation of TERIs that existed at the time of COP21 in Paris, and the potential overlap with existing pledges and NDCs made by national governments in the context of the UNFCCC. We focus on a list of TERIs available just before the Paris Agreement, as more information is available on these measures allowing quantitative assessment. To our knowledge, this is the first study on the effectiveness of TERIs that uses an IAM framework. The advantage of doing so is that the analysis is based on a consistent emission scenario, including both energy-related and agriculture, forestry and land-use (AFOLU) emissions, which enables not only an estimate of the global impact of TERIs in terms of total reductions, but also the total emission level after implementation of TERIs. The IMAGE model represents a useful tool for analysis given the relatively detailed sectoral representation of this IAM compared to others. This study goes beyond existing studies on TERIs by assessing the impact of a selected set of large TERIs in a more consistent way, but also by paying more attention to the overlap with pledges/NDCs by discussing our results in the context of different existing methods. In order to assess the effectiveness of TERIs it is crucial to know how the TERIs overlap with government policies. So-far, this question has only been partly addressed by Hsu et al. (2015), UNEP (2015a) and UBA (2016). We use information on the TERIs to assess the maximum potential overlap, which should be regarded as a conservative approach.

It should be noted that TERIs often have other objective than direct emission reductions, such as networking and knowledge sharing (Chan et al., 2016; Michaelowa and Michaelowa, 2017), which were not included in our assessment. However, it is important to note that these are considered relevant for successful implementation (Widerberg and Pattberg, 2015) (see discussion).

In addition, it should also be noted that analysing the reductions resulting from TERIs involves some important challenges. First, there is no GHG accounting framework in place yet for non-state action, and no global model exists that can assess climate policy of non-state actors. Second, individual actor emission estimates, targets and trends are not publicly or readily available. Third, no existing consistent framework is available yet that could assess TERI commitments. Given these limitations, our assessment should be regarded as a first attempt to quantify the effect of TERIs by connecting business-as-usual projections developed in the IMAGE model to aggregated actors and sectors. This paper can be seen as starting point for further analysis of new or expanded emission reduction initiatives.

6.2 METHODOLOGY AND DATA

6.2.1 Selection of TERIs

The TERIs assessed in this study have been selected from the Climate Initiatives Platform (Ecofys et al., 2015) and supplemented with potentially high-impact initiatives found in UN (2015); UNFCCC (2013, 2014b); Wouters (2013). The aim was to select the largest initiatives that cover most economic sectors. Overlap between initiatives was kept small by selecting the largest initiative per sector. This selection should enable making a first-order estimate of the impact on GHG emissions that can be expected from climate action outside the UNFCCC.

Only those TERIs were selected i) that include multiple parties and act in multiple countries/ regions (i.e. no bilateral initiatives were included), ii) that have a large expected global impact (roughly 0.1 $GtCO_2eq$ or more), iii) that have clear commitments with quantified mitigation targets or concrete measures, or estimates are available based on GHG emissions from publications or literature iv) for which it is specified how the overall target (if any) is applied to individual actors, v) that only include direct GHG emission target or specific measures, e.g. no finance, subsidies and carbon taxes. The supplementary material includes the full list of TERIs including our assessment on the above criteria. This material also includes a description of TERIs that were not selected, but have potential future impact if scaled up. The cut-off date for selection was 1 May 2015 (meaning that sufficient material was available to make an assessment of the impact). Clearly, in the future the list of TERIs included can be further expanded, but given the fact that this paper for the first time presents an assessment of TERIs in an IAM the focus here is mostly on presenting a first order estimate and showing how such analysis can be done.

6.2.2 Implementation of TERIs in IMAGE

While analysis of climate policies in models has often been done by implementing a generic carbon price to induce cost-effective policies in all sectors, here instead we try to implement reduction targets or measures as specifically formulated by the TERIs, in a similar manner as been done to assess country pledges and domestic climate policies by Roelfsema et al. (2014) and deep reduction measures by Deetman et al. (2015). The first step was to identify the possible impact of TERIs on GHG emissions, based on the assumption that TERIs deliver on their commitments.

Ideally, the model would include sufficient detail to represent the commitments made by TERIs. At the same time, however, global IAM models often operate at a more aggregated scale in order to ensure transparency (see Section 6.5.1 for more discussion on this topic). This proves a challenge in representing the TERIs.

The IMAGE 3.0 model is a dynamic integrated assessment framework to analyse global change (Stehfest et al., 2014), and has the advantage that among the IAM models it is relatively detailed, making it suitable as a starting point for our work. The model consists of 26 world regions and the economic sectors energy supply, industry, transport, buildings, agriculture and land use. The model output comprises AFOLU GHG emissions from the IMAGE land-use model and energy-related emissions from the energy-model TIMER. The main drivers of the baseline scenario are population and GDP, the projections of which are

taken from the SSP2 scenario (Dellink et al., 2017; Kc and Lutz, 2017; Riahi et al., 2017).
The assessment consisted of four steps for each TERI, after which the total impact on the global level was determined

1. Determine aggregated 2010 GHG emissions, based on publications by the initiatives;
2. Determine TIMER/IMAGE baseline projections for emission growth, selecting specific sectors and accounting for overlap between actors;
3. Determine GHG emission reductions, and make simple assumptions for overlap between actors based on literature estimates and applying the overlap factors after construction of baselines;
4. Determine overlap with pledges/NDCS. The assumption is that there is full overlap if TERIs and pledges/NDCs apply to the same country and same actor.

Non-state actors are not modelled explicitly in the IMAGE model, and therefore, this assessment relies on literature estimates to derive globally aggregated targets or reduction estimates. Details on assumptions per TERI are found in the supplementary material. As national policies are expected to be implemented to achieve NDCs, and to avoid complexity of overlap between national policies and non-state policies, we did not include national climate policies in the baseline (see discussion).

The baseline emission projections for sector and actor initiatives were derived in two steps. This was done at an aggregated global level for actor initiatives (cities and companies) and on IMAGE region level for sector initiatives. First, a sector baseline trend was derived for the sectors in which TERIs have targeted emission reductions. For initiatives that act in multiple sectors, an emission baseline trend was constructed using the weighted average of the IMAGE sectoral trends, the weighting being based on the emission shares of the relevant sectors. A global companies baseline trend was constructed based on the global baseline emissions from the industry and service sectors (The Greenhouse Gas Protocol, 2012); for the global cities baseline trend it was assumed that they act in the following sectors: urban buildings, passenger transport (excluding aviation), and small industry sectors (excluding cement and steel sector), including electricity supply for these sectors (Greenhouse Gas Protocol and The Greenhouse Gas Protocol, 2012). Although CH_4 emissions from waste are an important source, they were excluded because the aggregated emissions and targets as published by the initiatives were CO_2 only. Second, a baseline for individual TERIs was constructed based on information about current emission levels as published by the TERIs and the emission trend as derived in step 1. If no information regarding current emission levels was available, the baseline was constructed by downscaling the IMAGE baseline based on the percentage of emissions in 2010 represented by participants (which was available). Overlap between individual cities was based on literature (see Section 6.3.1), and overlap between cities and companies was based on assuming full overlap of indirect (electricity) emissions (that represent 50% of total 2010 global city emissions) and assuming 50% of overlap in location (i.e. for those companies that are located in cities and both have reduction targets) . The latter was assumed as no literature estimates were found. These overlaps were applied after the construction of the actor baselines.

Emission reduction targets for actor initiatives are mostly set on individual basis for cities and companies. We have aggregated these to global targets, based on literature or TERI publications, and applied them to the global IMAGE business-as-usual projection. In general, emission reduction targets from sector initiatives were applied to each IMAGE region and aggregated to the global level. For TERIs with targets before 2030, targets were extrapolated to 2030 on the assumption that an equivalent effort will be made, i.e. the same relative emission reduction compared to baseline until 2030 was assumed. Targets after 2030 were linearly interpolated (see Table 6-1 for actual target years). TERIs were assumed to overlap each other if they act in the same country and sector. As no individual non-state actor data was available, the level of overlap was calculated based on the fraction of total emissions from the overlapping sectors and regions in 2010 and applied to 2020 and 2030 reductions. More specifically for cities and companies, assumptions on overlap in reductions were the same as those assumed for the baseline development. Overlap between initiatives was calculated after global emission reduction for individual initiatives were calculated. The latter was done in a specific order (see Section 3) and was an arbitrary choice, but does not affect the total overlap between TERIs. Where possible and relevant, the calculation of the level of overlap was done at a regional level.

6.2.3 Overlap with NDCs

In addition to overlap between different TERIs, emission reductions from TERIs may overlap with reductions put forward by countries in the context of the UNFCCC. To show the additionality of the TERIs to pre-2020 pledges and post-2020 NDCs, we have included a pledge/NDC scenario, based on the emission ranges from the UNEP (2014) and UNEP (2015f) reports. To estimate the maximum potential overlap between TERIs and pledged reductions, it was assumed that TERIs do not lead to additional reductions in countries that submitted pledges or NDCs, provided that these occur in sectors that are included in the pledges and cover the same greenhouse gases. It is assumed that TERI targets that are more ambitious compared to pledges/NDCs will be compensated with less or downscaled ambition by other actors (see Discussion).

6.3 SELECTED CLIMATE INITIATIVES

The long list of TERIs consisted of 184 climate initiatives from the Climate Initiatives Platform, and 13 were added from Wouters (2013), 7 from UNFCCC (2013), 5 from UNFCCC (2014b) and 3 UN lead initiatives from UN (2015). From this long list, eleven were selected: seven international cooperative initiatives, three UN lead initiatives, and one private governance network (see supplementary Information).

6.3.1 Description of individual international initiatives

This section briefly describes the individual TERIs. In the long list of climate initiatives were no large international cooperative initiatives of companies that are expected to result in significant emission reductions (see Supplementary Information for criteria). However, outside these initiatives many have committed themselves to GHG reduction targets, as reported by the **Carbon Disclosure Project** (CDP). The CDP is a transnational private governance network that engages in climate action in the business sector (Bulkeley and Newell, 2015). CDP encourages companies to set GHG emission reduction targets (CDP, 2014) and collects and captures data company commitments and emissions (which is not publicly available). The aggregated emission level of 70 of the world's largest publicly listed companies in 2014 was 3.4 GtCO_2eq , 65% of which have set emission reduction targets (CDP, 2015b, 2015a). The latter group can be divided into 35% that have set targets in line with staying on track by 2030 to meet the global 2 °C goal, 15% that have set less ambitious targets, and 15% that have set targets which are not expected to lead to GHG emission reductions. The annual emission reduction rate for companies consistent with achieving the 2 °C goal is estimated at about 1.4% (CDP, 2012; Moorhead Nixon, T., 2014). As no information exists on the expected emission reduction for companies with less ambitious targets, we have simply assumed half of the annual emission reduction, so 0.7%. These reduction rates were applied until 2030. The future baseline trend was based on the global IMAGE baseline trend for all business sectors, excluding China, as almost no companies in this country are participating in the CDP programme.

Two **city initiatives** were included in this analysis: 1) The C40 Cities initiative and 2) the Covenant of Mayors. The cities included in these initiatives are, based on our IMAGE baseline, responsible for approximately 25% of GHG emissions from all the world's cities in 2010. The **C40 Cities** is a network of 75 megacities representing 5% of global GHG emissions (C40 Cities, 2014). The analysis of the C40 initiative is based on the C40 Cities publication (2013), in which it is estimated that the 59 cities that were taking part at the time could achieve 11% reduction by 2020 relative to the baseline. These emissions were scaled to the population of the additional 16 cities that have joined since 2013 (C40 Cities, 2015). The **Covenant of Mayors** currently has more than 5,700 signatories (Covenant of Mayors, 2015), representing 186 million people. The participating cities are expected to commit to meet and exceed the EU 20% reduction target for 2020. Of all signatories, 3,400 have composed Sustainable Energy Action Plans which have been analysed and accepted by the Covenant of Mayors. It constitutes a 28% overall GHG reduction target for 2020 relative to the base year, which is 1990 for 26% of the cities, 2000 for 12% and 2005-2008 for 62% (Kona et al., 2015). The baseline trajectory was calculated by applying IMAGE baseline emission growth rates for GHG emissions to the 1990 and 2005–2008 emission levels and scaling the results to the population of the participating cities for which action plans have not yet been analysed and accepted. The overlap between the two city initiatives is assumed to be 25%, based on Wouters (2013), and is applied both to baseline projections and emission reductions. The latter are equal to 0.1 GtCO_2eq.

The **Cement Sustainability Initiative** (CSI) has set company targets to reduce CO_2 intensity in line with the Cement Technology Roadmap from IEA and WBCSD (2009). This initiative represents 24 companies accounting for 30% of global cement emissions (WBCSD, 2012). It aims at reducing CO_2 emissions through four key technology options (IEA and WBCSD, 2009): 1) thermal and electric efficiency improvement, 2) alternative fuels in the cement kiln heating process, 3) producing cement with a lower clinker content, and 4) carbon capture and storage (CCS). The CSI technology roadmap includes global targets for 2050 and estimates for CO_2 emission intensity reductions, defined as tonnes CO_2 emissions per ton cement, resulting from these technologies up to 2050 (IEA and WBCSD, 2009). Until 2030, mainly the first three technology options are relevant and are estimated to reduce CO_2 emission intensity by 25% relative to 2012 levels (IEA and WBCSD, 2009).This reduction is in line with the overall 2050 target of a 45% decrease in CO_2 intensity relative to 2012 (ibid).

The **Global Fuel Economy Initiative** (GFEI) aims to reduce fuel consumption of new cars by 50% in 2030 compared to average 2005 levels and works together with government and partners to achieve this goal. This overall target is applied to all participating countries in the initiative. It also states a long-term goal for 2050, which consists of an average 50% increase in fuel efficiency for all cars compared to 2005. At the end of 2013, 20 countries participated in the GFEI, of which countries in Asia, Central and Eastern Europe, Latin America and Africa (GFEI, 2014). The emission reductions were projected by implementing the increased efficiency in the IMAGE transport model (Girod et al., 2012) for the model regions that include the 20 countries that are participating in the GFEI.

The **Kigali Amendment to the Montreal Protocol**, aims for a phase-down of HFC emissions with a delayed phase-down for developing countries (UNEP, 2016b). Although mitigation of HFC emissions is dealt with in the UNFCCC negotiations, this has not led to substantial reductions up to now. With no impending global controls on HFCs, inclusion of HFCs under the Montreal Protocol would likely stimulate more stringent emission reductions (Velders et al., 2012). All countries participate in the Montreal Protocol, therefore, to assess the impact of this protocol on GHG emissions relative to the business-as-usual pathway, all countries are expected to act according to the Amendment targets. The analysis of the impact of the HFC proposal on emissions accounts for the substitution of hydrochlorofluorocarbons (HCFCs) by HFCs, as was prescribed in the Amendment. The historic HCFCs emission levels are based on EPA (2013a).

The objective of the **Global Methane Initiative** (GMI) is to mitigate climate change by advancing cost-effective near-term methane recovery from fossil-fuel production, transport, agriculture, agricultural waste, landfills, and wastewater. Currently 42 countries are member of the initiative, including large such as Brazil, China, European Union, India, and the United States. Although the GMI does not specify a final year, it published a fact sheet which included cost-effective reductions until 2020 (Global Methane Initiative, 2011). In our assessment, we made use of US-EPA cost curves (EPA, 2013a) to identify cost-effective reductions per emission source for 2030. It was assumed that cost-effective reductions take place at US$15/t$CO_2$e, since this is considered a realistic cost level for all sources (Global Methane Initiative, 2011).. The Climate and Clean Air Coalition (CCAC) also aims at reducing CH4 emissions. As the CCAC only specifies a reduction potential and has large overlap with GMI, this was not included in our analysis.

The **New York Declaration of Forests** (NYDF) aims at reducing emissions from deforestation and forest degradation (REDD) and has set quantified reduction targets. With the declaration, 26 national governments, 23 large multinationals and more than 50 civil society and indigenous organizations endorse a global timeline to halve natural forest loss by 2020, and strive to end it by 2030 (New York Declaration of Forests, 2014). In addition, the declaration calls for restoring 150 million hectares of forests and croplands by 2020 and an additional 200 million hectares by 2030 (ibid). The participants in the NYDF represented 20% of global CO_2 deforestation emissions in 2010. It was assumed that ending forest loss implies zero emissions from biomass burning. The impact of reforestation and restoration was assessed on the basis of IMAGE regrowth dynamics, which determine the carbon uptake until 2020 and 2030, given the staged restoration of 350 million hectares of land in the initiative.

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The **International Maritime Organization** (IMO) adopted mandatory measures to improve energy efficiency and to reduce GHG emissions from international shipping. These measures have entered into force on 1 January 2013 and address the largest and most energy-intensive ship types responsible for about 70% of GHG emissions from international shipping (IMO, 2011). As almost all countries in the world are participating in the IMO, it was assumed they all implement the mandatory measures. The projected reductions were derived by applying the reduction percentages from the IMO study to the IMAGE baseline. The range depends on the degree of implementation of cost-effective activities and baseline fleet growth assumptions as described in IMO (2011).

In 2010, the **International Civil Aviation Organization** (ICAO) adopted a resolution in which reference was made to commitments announced by the *International Air Transport Association* (IATA) and other sectoral organisations on behalf of the international air transport industry. These commitments are to improve CO_2 efficiency by an average of 1.5% per year from 2009 until 2020 and a long-term goal of reducing carbon emissions by 50% by 2050 compared to 2005 levels (ICAO, 2010). The latter was translated into a global fuel efficiency improvement rate of 2% per year from 2021 to 2050, based on the basis of volume of fuel used per revenue kilometre performed (IATA, 2009b). Emission reductions for international aviation have been excluded from the commitments made within the UNFCCC as it appeared difficult to allocate emissions to specific countries. The participants in the ICAO that are expected to take measures, represent 50% of global international aviation emissions. IATA estimates a reduction of 21% in CO_2 emissions from international aviation due to the expected fleet renewal compared to a scenario without fleet renewal with 2020 emissions of about 0.9 $GtCO_2eq$ (IATA, 2009a).

The **Zero Routine Flaring by 2030** initiative was introduced by the Word Bank and brings together oil companies, national governments, and development institutions to agree on eliminating CO_2 emissions from gas flaring by 2030 (World Bank, 2015b). Currently 10 governments endorsed the principle of the initiative.

6.4 RESULTS OF TERI ASSESSMENT ON GLOBAL GHG EMISSIONS

6.4.1 Impacts of the TERIs

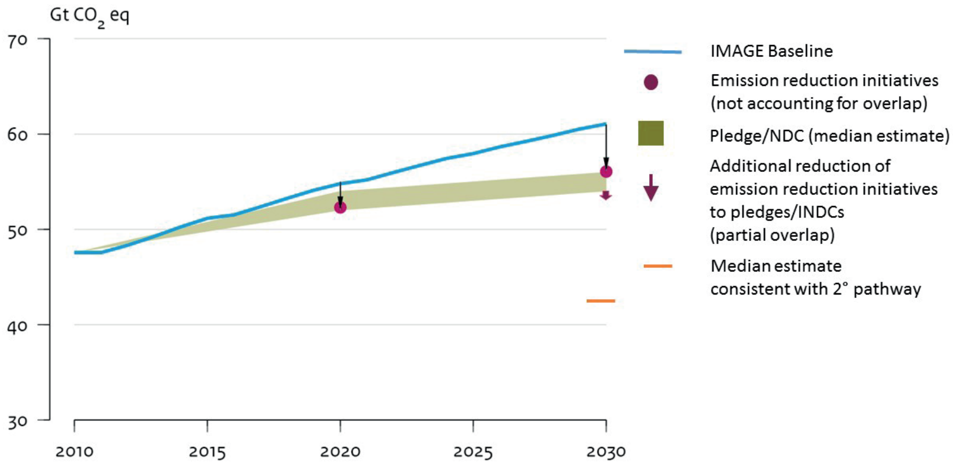
The selected initiatives cover almost all energy and AFOLU sectors, except for the freight transport and rural residential sector (see Supplementary Information). Table 6-1 shows the estimated emission reductions of the various TERIs. The largest absolute reductions are expected from company, city, the NYDF, the Kigali Amendment, and the Global Methane Initiative (see Table 6-1). Except for the HFC proposal, these TERIs represent a large part of global emissions in 2010. Together, these initiatives with the largest impact are projected to decrease emissions by 4.1 $GtCO_2eq$ by 2030. The initiatives with the largest relative reductions include NYDF, the Kigali Amendment, and the Global Fuel Initiative – all of which are expected to have reductions of 50% or more by 2030 relative to baseline.

The CDP companies are projected to reduce 0.7 $GtCO_2eq$ GHG emissions from a baseline level of 3.8 $GtCO_2eq$ by 2020, which is extrapolated to 0.8 $GtCO_2eq$ reductions relative to a baseline level of 4.2 $GtCO_2eq$ for 2030. The city initiatives cover the C40 Cities initiative and the Covenant of Mayors initiative. The reductions for the C40 initiative are projected at respectively 0.4 $GtCO_2eq$ emissions from a baseline level of 3.5 $GtCO_2eq$ by 2020 and 0.5 $GtCO_2eq$ emissions from a level of 4.1 $GtCO_2eq$ by 2030. For the Covenant of Mayors, the projected reductions are 0.3 $MtCO_2eq$ by 2020 from a baseline level of 1.4 $GtCO_2eq$ and 0.3 $GtCO_2eq$ by 2030 from a level of 1.7 $GtCO_2eq$. The overlap between the two TERIs is projected to be approximately 0.2 $GtCO_2eq$ by 2020 and 2030. All countries participating in the Kigali Amendment are projected to reduce GHG emissions by 0.7 $GtCO_2eq$ from a baseline level of 1.3 $GtCO_2eq$, and even more reductions are expected after 2030, as the proposal runs until 2043.The baseline emissions for the New York Declaration of Forests from deforestation are already projected to decrease from 1.0 $GtCO_2eq$ in 2010 to 0.4 $GtCO_2eq$ in 2030 for the countries that participate in this initiative. On top of that, the emission reduction from the NYDF is estimated at 0.7 $GtCO_2$ in 2030, of which 0.5 $GtCO_2$ is the result of ending natural forest loss, and 0.2 $GtCO_2$ is the result of reforestation and restoration. The Global Methane Initiative largely overlaps with the Climate and Clean Air coalition, and the latter is therefore not analysed, but could also reduce emissions from the non-Kyoto gases black carbon and organic carbon. See Table 6-1 for all results.

Table 6-1 Global baseline emissions and emission reductions for individual international initiatives

	Target year	Baseline (GtCO2eq)			Reduction (GtCO2eq)		Overlap with above initiatives
		2010	**2020**	**2030**	**2020**	**2030**	
Actor							
Carbon Disclosure Project	2020	3.2	3.8	4.2	0.7	0,8	
C40 Cities and Covenant of Mayors	2020-2050	3.5	4.6	5.3	0.6	0.7	25%
Sector							
Cement Sustainability Initiative	2050	0.5	0.6	0.7	0.1	0.1	10%
Global Fuel Economy Initiative	2020/2050	0.5	0.8	1.0	0.2	0.5	4%
Kigali Amendment	2043	0.5	1.0	1.3	0.0	0.7	0%
Global Methane Initiative	2022	4.1	5.1	5.9	0.5	1.2	0%
New York Declaration of forests	2020/2030	1.0	0.5	0.4	0.3	0.7	0%
International Maritime Organization	2020/2050	0.6	0.6	0.7	0.1	0.2	0%
International Civil Aviation Organization	2020/2050	0.5	0.6	0.9	0.1	0.3	0%
Zero Routine Flaring by 2030	2030	0.1	0.1	0.1	0.0	0.1	70%
Overlap					0.2	0.3	
Total*					2.5	5.0	

In the IMAGE implementation, the total projected reductions of all TERIs add up to 2.5 $GtCO_2eq$ by 2020 and 5.0 $GtCO_2eq$ by 2030, leading to projected emission levels of 51.2 $GtCO_2eq$ by 2020 and 56.1 $GtCO_2eq$ by 2030 (see Figure 6-1). It is assumed that all selected TERI targets are fully achieved. This number includes an assessment of the overlap between TERIs, as some TERIs act in the same countries and sectors. The overlap between TERIs, however, is expected to be relatively small; approximately 0.2 $GtCO_2eq$ by 2020 and 0.3 $GtCO_2eq$ by 2030 (see Table 6-1), not including the overlap between the two city initiatives. Note that overlap for cities was calculated at two stages: 1) overlap between city initiatives and 2) overlap between cities and companies, both at the global level using the fraction of emissions that are emitted in the same region (excluding China for companies) and sector.



Source: PBL; UNEP 2014

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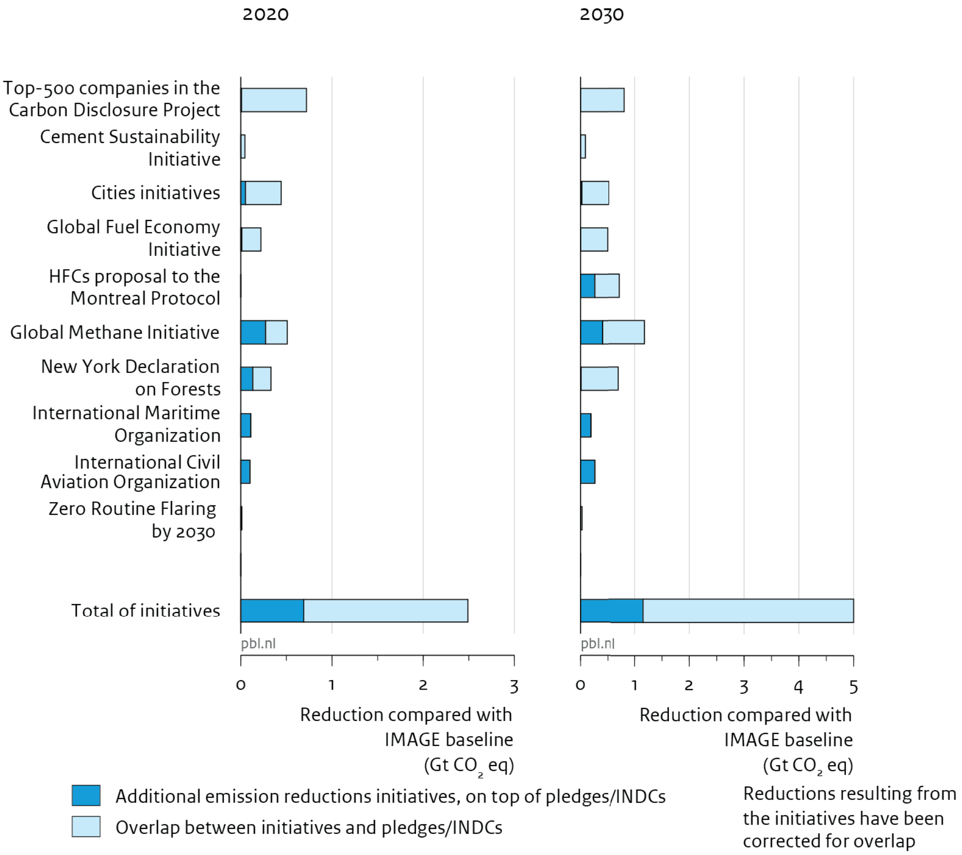
Figure 6-1 GHG emission levels after implementation of transnational emission reduction initiatives; The red dot represents reductions not considering overlap with pledges/NDCs, and the red arrow represents additional reductions to pledges/NDCs when overlap is taken into account. These emission levels are compared with the pledge/NDC scenario and median estimate consistent with 2°C pathway, based on the UNEP Gap reports from 2014 (pre-2020 pledges) and 2015 (post-2020 NDCs)

6.4.2 Comparison of the TERIs and the impact of the pledges and NDCs

Earlier assessments have shown that the 2020 pledges of national governments are projected to lead to (median) global emission levels between 52 GtCO_2eq and 54 GtCO_2eq by 2020 (UNEP, 2014) and 2030 NDCs to a (median) level between 54 GtCO_2eq and 56 GtCO_2eq by 2030 (UNEP, 2015f). The global reductions of the selected TERIs, if they are fully achieved, could be of a similar order of magnitude as the global reductions as pledged by the Parties under the umbrella of the UNFCCC (Figure 6-1). But, this estimate does not consider possible overlap between TERIs and pledges/NDCs. Overlap was calculated by making the conservative assumption, that full overlap exists between TERIs and the pledges/NDCs, if they target the same Kyoto gases in the same countries and sectors (see Discussion). The part that does not overlap, can be considered as additional GHG reduction to pledges/NDCs.

Obviously, the TERIs targeting the international shipping and aviation sectors are additional to pledges/NDCs (see Figure 6-2). The Global Methane Initiative and the HFC amendment to the Montreal protocol also have relatively low overlap as these TERIs partly act in countries without pledges or in sectors that are not included in pledges made by specific countries (i.e.

non-CO_2 gases for China and India). Overall, the overlap could amount to 70% to 80%, equal to 1.8 $GtCO_2eq$ by 2020 and 3.9 $GtCO_2eq$ by 2030 (see Figure 6-2). Therefore, a conservative projection is that the additional reductions relative to the pledge/NDC scenario is 0.7 $GtCO_2eq$ by 2020 and 1.2 $GtCO_2eq$ by 2030 (see Figure 6-1). Note that overlap between TERIs, representing overlap in membership or in sector (see Table 6-1), was applied before calculating overlap between pledges/NDCs and TERIs.



Source: PBL

Figure 6-2 Additional emission reductions in 2020 and 2030 from international cooperative initiatives to pledge/NDC scenario from UNEP Gap reports from 2014 and 2015

Assuming a maximum overlap, the combined effect of pledges/NDCs and TERIs leads to a projected emission level of 51-53 $GtCO_2eq$ by 2020 and to 5355 $GtCO_2eq$ by 2030 (see Figure 6-1). The median emission level in 2030 to stay on track to meet the 2°C goal, based on cost-effective implementation of climate policy from 2020 onwards, is 42 $GtCO_2eq$ (UNEP, 2015f).

Due to the large potential overlap, the combined effect is only slightly larger than the effect of pledges/NDCs alone, and therefore TERIs contribute only slightly to reducing the gap with emission levels necessary to stay on track to meet the 2°C goal (see Figure 6-1).

A comparison of our study with those of UNEP (2015a) and Hsu et al. (2015) shows that the studies included different TERIs in their analysis, but that many of the TERIs aim to reduce emissions in the same sectors. For instance, the Global Methane Initiative included in our study aims at reducing methane emissions from, among others, agriculture and oil & gas systems, which are treated as separate initiatives in the UNEP (2015a) study. The comparison also shows that the definition of TERIs differs between the studies. This study includes international climate action outside the UNFCCC, while UNEP considers initiatives initiated by non-state actors only. Hsu et al. (2015) only takes into account initiatives that submitted action plans to the New York Climate Summit that was held in 2014. Despite these differences, it can be concluded that the different studies arrive at total reductions by 2020 which are in the same order of magnitude. UBA (2016) estimates much larger additional reductions to NDCs by 2030, which is, among others, caused by different assumptions on overlap with pledges and NDCs, as will be discussed in Section 5.1.

6.4.3 Assumptions on overlap between TERIs and pledges/NDCs

Our assessment showed that the potential for overlap with pledges and INCDs is large, as TERIs often target the same countries and sectors that are covered by pledges/NDCs. UNEP (2015a) concluded that the overlap is much lower (about a third) than the 70% to 80% of potential overlap we have found. The most significant difference in estimating the potential overlap between our methodology and the method of UNEP is that the latter included domestic policies that could result in achieving pledge/NDC targets, and assumed no overlap between TERIs and reductions achieved from domestic climate policies already in place. In other words, UNEP assumed that all TERIs lead to reductions additional to existing domestic policies. The question is, whether this is really the case. It would not be difficult to think of a domestic climate policy which leads to achievement of the same goals set in an TERI. Therefore, these reductions will also help to achieve the targets set by the two city initiatives included in our assessment. In addition, the UBA (2016) study assesses the impact of non-state actors compared to NDCs, assuming both non-state targets and NDC targets are reached. It is not fully clear how they assess overlap, especially whether reductions in one specific sector or for one specific greenhouse gas are compared to NDC reductions that apply economy-wide. It is also relevant whether additional reductions are determined in absolute or relative terms compared to NDC targets. If the latter is assumed, this implicitly assumes that all non-state actors without GHG emission reduction commitments will reduce emissions in line with NDCs, which may not be the case. Moreover, not having a reduction commitment could indicate that these non-state actors have no climate policy in place and therefore might be more inclined to follow a business-as-usual pathway. Our study implicitly assumes that non-state actors without climate policy at least will not offset the commitments made by other non-state actors. But it does make the conservative estimate, that only additional reductions occur in those sectors and countries that are not covered by NDCs.

More in-depth assessments of overlaps on country level are necessary to determine if non-state action will be additional to NDCs. This should include explicit assumptions on climate policy by non-state actors without commitments. In addition, including domestic climate policies would enable assessment beyond NDC reduction commitments and therefore could provide better insight into the interaction and projected overlap between national governments and non-state actors (at sector level), which is important for further research.

6.5 DISCUSSION AND CONCLUSION

One of the expectations of TERIs is that they can realise additional emission reductions beyond those proposed by national governments under the UNFCCC (Blok et al., 2012), but Widerberg and Pattberg (2015) raise the question whether this is really the case. In order to assess this, we have selected those TERIs that have set quantified emission- or energy reduction targets. However, the purpose of TERIs in climate policy implementation is broader then bringing mere additional reduction to pledges and NDCs. For example, Michaelowa and Michaelowa (2017) assess four criteria necessary, but not sufficient, for effective mitigation. They show that about half of the initiatives do not meet any of the criteria, giving rise to the conclusion that other objectives play a role. This is confirmed by Chan et al. (2016), showing that most quantitative targets did not relate directly to GHG emission reductions by initiatives launched at the UN Climate Summit in 2014. But, these initiatives are shown to link organisations (domestic and international) beyond those that participate in TERIs, thereby presenting the possibility of diffusion of policy and learning (Cao and Ward, 2017). In addition, national policies and transnational governance could mutually reinforce each other (Roger et al., 2017), increasing effectiveness, certainty of implementation and accelerating implementation. Thus, many initiatives that were not included in our assessment, seem less focused on a singular outcome, resulting in more experimental forms of climate governance, but could create important opportunities and have the ability to effectively respond to climate change (Hoffmann, 2011). Moreover, as many of the initiatives are still small at this moment, they could have significant potential to scale up. Some TERIs with potential to scale up are listed in the Supplementary Information.

Assessing the impact and effectiveness of TERIs and measuring progress in terms of absolute emission reductions is a challenge, among others caused by the lack of common baselines and multiple measures to record emission reductions (Bulkeley and Newell, 2015). This also holds for potential future impact. Therefore, the analysis of this paper should be regarded as a first attempt to assess the impact of climate action outside the UNFCCC, using an integrated assessment model. No global models are available (yet) that account for non-state actor climate policy, and data on individual non-state actors is not publicly and readily available. Together with the calculation of overlap, these are important challenges for the research community.

6.5.1 Limitations of Integrated Assessment Models

Although IAMs are very suitable to assess the impact of TERIs on a global level and for large emitting countries, they have limitations with regard to modelling all details of non-state actions. Most IAMs only represent large countries and aggregate others to regions. Therefore, reduction commitments of smaller countries need to be aggregated. The IMAGE model has the advantage that approximately 65% of global GHG emissions by 2010 represent individual large countries.

Policy instruments, such as feed-in-tariffs, are in general not well represented in IAMs, making it difficult to explicitly model interactions between national governments and none-state actors. Actor-based models would be better able to translate the mental models of policymakers with respect to the assumed behaviour of important economic actors into quantitative numerical simulation models including the response of actors to the proposed policies (Hasselman et al., 2015), but most of these models focus on relatively small regions or only cover parts of the energy system (De Cian et al., 2017).

In addition, actors are not explicitly modelled in IAMs. However, GHG commitments from different actors can be aggregated at country level (outside the model), if national GHG inventories and those of non-state actors can be linked on sector level. This is under the condition that commitments, especially for companies, can be broken down to country and sector level. If Monitoring, Reporting, Verification (MRV) of non-state action is improved, more information will be available, which could improve the representation of TERIs in the IMAGE model.

6.5.2 Sensitivity analysis

For the largest individual TERI calculations, we have conducted a sensitivity analysis on the most important assumptions. For the CDP initiative, we have analysed the effect of 20% lower/higher annual reductions, which would change total GHG emissions by 2030 by ±35 $MtCO_2eq$. For the C40 initiative we have scaled baseline emissions on the basis of population to include the newly joined 16 cities. This could be improved by using other drivers, such as population density or heating degree days of urban areas (Singh and Kennedy, 2015). If we assume that the scaling factor is ±10% lower or higher, the emission level after implementation of city targets would be approximately 0.35 $GtCO_2eq$ lower or higher. For the Global Methane Initiative, we have assessed the sensitivity of the carbon price ($10 or $30 instead of $15), and found that the reduction relative to baseline changes by ±100 $MtCO_2eq$ by 2030. For the NY Declaration of forests calculations, sensitivity was not assessed, because only the assumption on scaling to GHG emissions was a possible candidate, but no applicable FAOSTAT (2017) data was available.

6.5.3 Uncertainty of selection and progress made by TERIs

One of the main assumptions for selecting the TERIs was that they cover the most important sectors. After the Paris Agreement, especially many international cooperative initiatives seem to have emerged or progressed. If they include more individual actors or pledge higher ambitions, our estimate of impact on GHG emissions could change. Therefore, our estimate is a first step, taking into account some of the largest initiatives, but the analysis could be extended and improved.

It is difficult to assess whether TERIs will deliver what they have promised, as the commitments that are put forward are voluntary and often aspirational. MRV is a possible instrument to enforce accountability and compliance, but now this is mostly lacking for TERIs (IVM, 2015). Data gaps especially exist around emerging and developing economies in many northern-led initiatives. To some degree this is also true for national policies, although MRV is already much more advanced here. Currently some TERIs have started publishing databases with information on progress of cities and companies, such as the CDP Open Data Portal (CDP, 2015a) and the Carbon Climate Registry (ICLEI, 2015). For example, the Carbon Action Initiative, a CDP initiative, found that 80% of the companies correctly reported all details necessary to accurately assess the achievability and ambition of reduction targets. For other initiatives, we have not found any such databases. The NAZCA UNFCCC database could fill this gap in the future.

Climate action by TERIs could increase fragmented action and this assessment did not account for positive and negative spillover (leakage) effects. The impact of carbon leakage on frontrunner countries in the energy sector is estimated to be below 16% of additional emission reductions to the currently implemented national policies and does not provide a strong counter-argument against adoption of more stringent mitigation action by pioneering regions (Arroyo-Currás et al., 2015), and therefore possibly also not to pioneering TERIs. This estimate is within the range of most ex-ante modelling studies that conclude to leakage rates in the range of 5-20% (Branger and Quirion, 2013).

Despite these uncertainties, our analysis gives a valid (first attempt) order of magnitude estimate of committed TERI impact on global GHG reductions, based on a consistent set of sectoral baseline emission projections.

6.5.4 Conclusion

TERIs can be an important to international climate policy as they could ensure and accelerate implementation of mitigation measures, but also add additional reductions to international pledges/NDCs made by national governments. These TERIs have formulated a wide set of measures that could reduce emissions. In some cases, these measures are additional to those formulated by governments in the UNFCCC framework, but often there is an overlap.

The selected set of large TERIs are projected to deliver annual emission reductions of 2.5 GtCO2eq by 2020 from a no-policy baseline emission level of 53.7 GtCO2eq and 5.0 GtCO2eq by 2030 from a no-policy baseline emission level of 61.1 GtCO2eq, provided that they are fully achieved. The largest reductions are expected from company, city, NYDF, and the Kigali amendment to the Montreal Protocol and the Global Methane Initiative. Together, these largest TERIs are projected to decrease emissions by 3.9 $GtCO_2eq$ by 2030. Overlap between all selected TERIs is estimated to be small. At a global level, the projected emission levels achieved by implementation of measures put forward by TERIs are roughly similar to what may be expected based on pledges and NDCs for 2020 and 2030.

Our conservative assessment is that the potential overlap in reductions between the TERIs assessed and pledges/NDCs is large and could amount to 70% by 2020 and 80% by 2030. This is a maximum estimate, based on the assumption that emission reductions from TERIs will not lead to additional reductions where these occur in those countries that made pledges and NDCs, provided that they occur in sectors included in such pledges/NDCs. In order to exactly determine the degree of overlap an exact and detailed analysis of all measures taken needs to be made. Given that is not possible at the moment, transparent assumptions are needed.

The combined effect of TERIs and pledges/NDCs, assuming the maximum overlap of 70-80%, would lead to emission levels of between 53 and 55 GtCO2eq by 2030, compared to an emission range based on the impact of NDCs alone of 54 to 56 GtCO2eq (UNEP, 2015f). Although insufficient to close the emission gap between pledges/NDCs and the emission level necessary to remain on track to stay below the 2°C limit, it could bring us closer to meeting this goal.

Setting up and improving Monitoring, Reporting and Verification is an important pre-condition for showing TERI progress and assess effectiveness of implementation. This would also be an important pre-condition to improve integration and assessment of TERIs into Integrated Assessment Models such as the IMAGE model.

This research resulted in important lessons learned for future impact assessments. Aggregation of non-state actors' emissions and targets is necessary for Integrated Assessment Models, and for this they need to be more publicly and readily available. In addition, overlap between emissions and targets of non-state actors and national governments then needs to be accounted for, but policy interaction at more instrumental level would be difficult.

CHAPTER 7

Beyond national climate action: the impact of region, city, and business commitments on global greenhouse gas emissions

Kuramochi, T., Roelfsema, M., Hsu, A., Lui, S., Weinfurter, A., Chan, S., Hale, T., Clapper, A., Chang, A., Höhne, N., 2020. Beyond national climate action: the impact of region, city, and business commitments on global greenhouse gas emissions. Climate Policy 20, 275–291. https://doi.org/10.1080/14693062.2020.1740150

ABSTRACT

This article quantifies the net aggregate impact in 2030 of commitments by individual non-state and subnational actors (e.g. regions, cities and businesses, collectively referred to as "NSAs") to reduce greenhouse gas (GHG) emissions. The analysis was conducted for NSAs operating within ten major emitting economies that together accounted for roughly two-thirds of global GHG emissions in 2016. Our assessment includes 79 regions (e.g., subnational states and provinces), approximately 6,000 cities, and nearly 1,600 companies with a net emissions coverage of 8.1 $GtCO_2e$/year, or a quarter of the ten economies' total GHG emissions in 2016. The analysis reflects a proposed methodology to aggregate commitments from different subnational (i.e., city and regional government) and non-state (i.e., business) actors, accounting for overlaps.

If individual commitments by NSAs in the ten high-emitting economies studied are fully implemented and do not change the pace of action elsewhere, projected GHG emissions in 2030 for the ten economies would be 1.2–2.0 $GtCO_2e$/year lower compared to scenario projections for current national policies (31.6–36.8 $GtCO_2e$/year). On a country level, we find that the full implementation of these individual commitments alone could result in the European Union and Japan overachieving their nationally determined contributions (NDCs), while India could further overachieve its unconditional NDC target. In the United States, where the national government has rolled back climate policies, NSAs could become a potential driving force for climate action.

Key policy insights

- Full implementation of reported and quantifiable individual commitments by regions, cities and businesses (NSAs) in ten major economies could reduce emissions by 1.2–2.0 $GtCO_2e$/year in 2030 below current national policies scenario projections.
- National governments' mitigation targets could be more ambitious if they would take NSA commitments into account. With such action, the European Union and Japan would overachieve their NDC targets. For the United States such action could help meeting its original 2025 NDC target in spite of rollbacks in national climate policies.
- The full universe of NSA climate action expands far beyond the subset of commitments analysed in this study; NSAs could become a strong driving force for enhanced action towards the Paris climate goals.

Keywords

non-state actors; local government, climate change mitigation; mitigation scenarios, bottom-up approaches

7.1 INTRODUCTION

The role of non-state and subnational actors (hereinafter referred to as “NSAs”), such as regions, cities and businesses, in climate change mitigation has become critical to achieving global climate goals. With the inadequacy of current national government policies to keep global emissions in line with 1.5°C/2°C pathways (UNEP, 2018), the Intergovernmental Panel on Climate Change (IPCC) has emphasized the need for all actors to reduce greenhouse gas (GHG) emissions in a strengthened and timely manner, while cooperating with national governments, in order to limit global warming to 1.5°C (IPCC, 2018b).

Climate action by NSAs, however, is not a substitute for national government climate action; rather, it is largely complementary to national policies (Andonova et al., 2017; Roger et al., 2017). Nevertheless, understanding NSA climate action alongside national governments is critical because the mitigation potential of such action can be significant. NSAs are also increasingly responding to calls for deeper and more ambitious climate action; for example, the 2018 Global Climate Action Summit triggered over 500 new NSA commitments to strengthen global action (UNFCCC, 2018b), some of which in countries where national governments are rolling back climate policies.

These NSA climate commitments will become even more crucial within the Paris Agreement’s “ratchet” mechanism, where countries are requested to update their nationally determined contributions (NDCs) with more ambitious targets by 2020 and every five years afterwards. Although NSAs could become key ambition drivers in these review cycles of country-level climate action, national governments overall have yet to leverage NSAs’ potential in the first round of NDCs, with many failing to mention these actors’ contributions altogether (Hsu et al., 2019a). Providing national governments with evidence of NSA climate action’s potential impact is necessary to support more ambitious NDC revisions in the future.

Only limited assessments of NSA climate action’s net aggregate impact on GHG emissions exist, however. Most analyses have focused on international initiatives, which represent coalitions of actors in diverse constellations, sometimes involving national governments. Blok et al. (2012) formulated the concept of aggregating large-scale initiatives of NSAs, finding that 21 of these initiatives could lower global emissions by 10 $GtCO_2e$/year in 2020 with approximated estimates on overlaps between initiatives; Wouters (2013) conducted a more detailed assessment of overlaps for the 10 initiatives covered in Blok et al. (2012). Hsu et al. (2015) found that the 29 commitments pledged at the 2014 UN Summit would result in 2.5 $GtCO_2e$/year emission reductions by 2020, taking into account geographical and sectoral overlap between initiatives. Höhne et al. (2015b), UNEP (2015b) and Graichen et al. (2017)

aggregated the potential GHG impact of selected international cooperative initiatives; these applied a more systematic approach to quantifying overlaps by developing a sector-based overlap matrix across initiatives and considering different types of intra- and inter-sectoral overlaps. Roelfsema et al. (2018b) used an integrated assessment model and estimated that 11 selected transnational emission reduction initiatives could –if fully implemented– deliver annual GHG emission reductions of 5.0 $GtCO_2e$/year by 2030; overlaps across initiatives were based on literature estimates.

Hsu *et al.* (2019b) presented a research roadmap for quantifying individual-scale non-state and subnational climate mitigation action. Methods to quantify overlaps across commitments applied in the literature differ from those applied for the aggregation of international cooperative initiatives because of the differences in the types and levels of data available. Kuramochi et al. (2017) provided a first estimate for the United States (US); a step-wise approach addressing, in order, regions, cities, energy end-use companies and then electricity-generating companies, was taken to quantify overlaps between commitments. America's Pledge's report (2018) explored three different policy scenarios for the US, using an integrated assessment model combined with bottom-up analyses on the impact of NSA climate action in the US. Kona et al. (2018) examined the aggregated effort of the European Covenant of Mayors signatories in terms of geographical distribution, mitigation ambition and achievements, as well as whether projected emissions reductions are consistent with limiting warming to 2°C or 1.5°C. To the authors' knowledge, however, there is no peer-reviewed publication to date that has quantified the GHG mitigation potential of existing individual city, region and company climate commitments for a range of major emitting economies.

This article responds to this gap in the peer-reviewed literature by quantifying the potential aggregate impact of quantifiable climate change mitigation commitments by individual regions, cities, and companies on global GHG emissions in 2030. The analysis was conducted for ten major emitting economies: Brazil, Canada, China, the European Union (EU28), India, Indonesia, Japan, Mexico, South Africa, and the US. These ten economies together accounted for 67% of global GHG emissions (excluding land use, land-use change and forestry) in 2016 (Olivier and Peters, 2018).

The world of climate action is vast and heterogenous. This study uses the best available current data, looking at NSA climate action that is reported to selected global databases and networks. Therefore, the scale and scope of climate commitments presented in this study is likely to systematically underrepresent smaller scale actions, such as those that are not formally institutionalised or those not described or presented in English or other major languages. In a similar context, this study also does not quantify the potentially significant synergistic or catalytic impacts that NSA climate action may generate. Notwithstanding these limitations, this study is one of the first in the academic literature that attempts to quantify the potential aggregate contributions of global NSA climate action towards the achievement of the Paris Agreement climate goals.

7.2 DEFINITIONS, DATA AND METHODS

The assessment presented in this paper consists of:

1. a methodology to aggregate cities' commitments to the country and global levels;
2. projections of GHG emissions reductions that would result from the implementation of these commitments, including estimating the overlap between different NSAs; and
3. a quantification of reductions additional to national government policies.

For the purposes of this study, cities are local governments that are administrative units of a specific geographical territory, and include towns, urban communities, districts, and counties. Regions are subnational administrative units that are generally broader in population and in scope, and often are the first administrative level below the national government.

All GHG emissions figures presented in this article are presented in terms of aggregated 100-year global warming potential (GWP) values of the IPCC Fourth Assessment Report (AR4). Global and national GHG emissions totals include LULUCF emissions, unless otherwise noted. Businesses are defined as private or publicly-traded for-profit entities that operate within or have emissions impact in one or more of the 10 countries we analyse in this study. We distinguish between energy-end use companies that consume energy and electricity and electric utilities that generate electricity for other actors' consumption.

7.2.1 Scenarios investigated

We use the following scenarios showing emissions pathways for different actors' climate policy implementation:

1. The **"Current national policies" (CNP) scenario** considers the likely path of emissions under currently implemented national policies. This scenario assumes that no additional mitigation action is taken beyond climate policies implemented as of

mid-2018. Whenever possible, current policy trajectories reflect all adopted and implemented policies, which are defined here as legislative decisions, executive orders, and their equivalent. This scenario excludes announced plans and future strategies, yet policy instruments to implement such plans or strategies would qualify. We do not assume that policy targets will be achieved even when they are codified in a law or a strategy document. These classifications of policy type are often subject to interpretation and sometimes require informed judgement calls. These current national policies scenario criteria are consistent with those applied in den Elzen et al. (den Elzen et al., 2019). For our analysis we took two current national policies scenario projections based on distinct modelling approaches: the PBL IMAGE model (Stehfest et al., 2014) bottom-up policy impact analysis using existing external baseline scenario projections, and land-use sector modelling by IIASA using the global land-use model GLOBIOM (Havlík et al., 2014) global forest model G4M (Fricko et al., 2017), presented in Kuramochi et al. (Kuramochi et al., 2018a).

2. The **“Current national policies plus individual actors’ commitments” (CNP+NSA) scenario** models the potential impact of both currently implemented national policies as well as recorded and individual, quantifiable city, region, and company commitments. This approach accounts for overlaps between and within the jurisdictions of NSAs to avoid double-counting of potential emission reductions. The main assumptions are that all commitments are fully implemented and that the pace of action elsewhere is not impacted. At this moment, we believe the latter is a valid assumption, as there is limited coordination on policy implementation between national governments and other actors (Chan et al., 2018). Therefore, we did not quantify the coordination effects between national governments and other actors, nor the interaction between policy instruments at different scales. Instead, we assume that additional reductions take place for each actor group (e.g., regions, cities, companies), if their aggregated reductions (relative to 2016) are larger than those that would result from the (geographically evenly distributed) implementation of national policies. We also assume that both national governments and other actors do not change (i.e., roll back or increase) existing climate policies and actions in response to these NSA efforts.

This study uses the current national policies scenario as the baseline, rather than an NDC achievement scenario that considers national-level Paris Agreement climate change mitigation commitments (i.e., NDCs), for several reasons. For all countries analysed in this article, it is useful to inform policymakers of the extent to which NSAs could potentially help national governments to achieve their NDC targets. For countries that are projected to (over)achieve their NDC targets with existing national policies, such as China, EU28, India, Japan and Mexico (Kuramochi et al., 2018a; den Elzen et al., 2019), it is useful to inform policymakers of the extent to which they could raise their mitigation ambition by considering NSA commitments within their territory. For countries where national governments are rolling back climate policies, such as Brazil and the US, it is useful to inform stakeholders of the extent to which NSA commitments could collectively make up for regressive policies at the national level.

7.2.2 Dataset preparation

We first collected the available current data on individual commitments, drawing from NSA climate action that is reported to global databases and networks, and selected those appropriate for our analysis.

For each commitment by regions, cities and companies (per country location), we developed GHG emissions time series for the period 2016–2030. When an actor had multiple targets, we always prioritized the use of absolute economy-wide (for cities) or operations-wide (for companies) GHG emissions reduction targets over intensity-based targets or targets that covered limited sectors or scopes. For companies, we analysed absolute targets and intensity targets. We did not include renewable energy targets in our analysis due to inconsistencies in how these targets were reported and limited available information on underlying energy mixes.

GHG emissions are categorised into scopes that indicate where emissions are physically emitted (Greenhouse Gas Protocol, 2004, 2014). This analysis considered scope 1 emissions –GHG emissions emitted directly by the actors– and scope 2 emissions, which result from the actors' electricity consumption. The impacts of commitments on supply chain emissions (scope 3 emissions) are excluded from the analysis, even though they are significant for some companies, because it was not possible to quantify the overlaps between scope 1 and 2 emissions and scope 3 emissions across actors, nor to localize these emissions to specific geographies given current data gaps.

Our dataset on NSA commitments is primarily based on those that are reported by the actors themselves to international networks and/or data providers. This analysis therefore excludes a large portion of actions that are (i) not (self-)identified as climate change mitigation-related, (ii) not linked to international networks with English as working language, although we estimate that these exclusions are likely minimal.

7.2.2.1 Regions and cities

Data for subnational climate actions was collected from a variety of climate action registries and platforms, including the Alliance of Pioneer Peaking Cities, Global Covenant of Mayors for Climate and Energy, Global Covenant of Mayors for Climate and Energy (EU Secretariat), Compact of States and Regions, CDP Cities, ICLEI carbon*n*® Climate Registry, C40 Cities Climate Leadership Network, Under2 Coalition, United States Climate Mayors, United States Climate Alliance and We Are Still In. We supplemented data on subnational actors from a range of external sources for the ten analysed countries.

In other cases when city-level GHG emissions data was missing, cities' emission values were estimated by multiplying per capita provincial-level emissions by the cities' population. For example, the emissions inventory value of Semarang, a city in Indonesia, was calculated by multiplying per capita emissions of Central Java Province, where Semarang is located (WRI, 2016), by Semarang's population.

Further details on the preparation of the subnational actors' dataset can be found in section S1 of the supplemental online material (SOM).

7.2.2.2 Companies

The country-specific corporate GHG emissions and climate action dataset used in this analysis was based on responses to CDP's 2018 climate change questionnaire (CDP, 2019b). Dataset preparation involved data cleaning and processing of the raw response data provided about company and supply chain (scope 3) emissions and climate actions, including statistical examination of the internal consistency of companies' responses and additional consistency checks using responses in previous years. Our analysis specifically draws on the relationship between companies' actions and the reported amount of GHG emissions generated in each country's jurisdiction per emissions scope, by a company operating worldwide (CDP, 2018). Detailed description of the dataset preparation can be found in section S2 of the SOM.

The analysis divided the companies' actions into two groups based on the target type and the data availability in the CDP dataset: (1) energy end-use companies with GHG targets, and (2) electricity-generating companies with commitments. Targets aiming at exclusively reducing scope 3 emissions were removed from the dataset since we were unable to quantify probable overlaps. For targets that include scope 3 emissions together with scope 1 and/or scope 2 emissions, we excluded the scope 3 part, and assumed the same scope 3 emissions share in the target year as the target base year (or most recent data year); such targets comprised about 1% of the number of total company commitments and 13% of total GHG emissions in the companies' commitments dataset.

Only one target was selected for each company branch, and the aggregated emission pathway for companies per country was calculated by summing up interpolated individual historical and target year emissions for each year, assuming emissions growth at the CNP scenario rate after the target year.

7.2.3 Calculation of net aggregate GHG impact of commitments

7.2.3.1 General approach

Quantifying subnational non-state actor commitment impact in the context of national-level policies included three steps:

- First, aggregated emission pathways per actor group (regions, cities, and companies) were calculated based on the assumption that NSAs fully achieve their commitments in the target year.
- Second, the emissions pathways from the CNP scenario were divided into two separate parts. The first part begins from the share of current national emissions covered by regions, cities and companies that have targets. We then calculated the aggregated reductions per actor group by comparing their emission growth between 2016 and 2030 with the growth from the CNP scenario. The second part originates from the share of current emissions that are not covered by city, region and company targets and follows the CNP scenario.
- Third, for the share of emissions covered by targets, geographical and supply chain (only scope 2) overlaps of GHG emissions between actor groups were determined. Then, for overlapping targets, only the additional reductions compared to other actor groups were calculated. Finally, the combined mitigation reductions of all actor groups were determined.

7

Total GHG emissions under the CNP+NSA scenario in a country in year *t* under (E_{tot}(t)) and is given by (Eqs. (1) and (2)):

$$E_{\text{tot,CNP+NSA}}(\text{t}) = E_{\text{tot,CNP}}(\text{t}) * \frac{E_{\text{tot}}(2016) - E_{\text{NSA}}(2016)}{E_{\text{tot}}(2016)} + E_{\text{NSA}}(\text{t}) \qquad (1)$$

where

$E_{\text{tot,CNP+NSA}}$(t): total GHG emissions under CNP+NSA scenario in year *t*;
$E_{\text{tot,CNP}}$(t): total GHG emissions under the CNP scenario in year *t*;
E_{NSA}(t): total GHG emissions from non-state and subnational actors in year 2015 as a result of achieving pledged commitments, accounting for overlap between non-state and subnational actors.

We assume that those GHG emissions in Eq. (1) not covered by existing NSA commitments, based on the 2016 emissions data, will grow proportionally to the current policies scenario projections. The quantification of GHG mitigation impact overlaps between commitments is based on Hsu et al. (2019b). Details are described in the following sections and the derivation of E_{NSA}(t) is elaborated in section S3.1 of the SOM.

7.2.3.2 Quantification of emissions overlaps between actor commitments

Multiple actors have commitments that target the same geographic area or the same subset of emissions. To avoid the double counting of emission reductions, we first determined to what extent the commitments target the same set of emissions (i.e., overlap, as described in this section) and then, in cases of overlap, we compared the stringency of various actions. The determination of the overlap was conducted in three steps (see Figure 7-1).

First, **geographic overlap between region and city commitments** was quantified based on whether or not a city with a target is located within a region with a target. After identifying these cities, the net GHG emissions coverage of subnational actors with commitments (overlap (C-R) in the top panel of Figure 7-1) was calculated. We have assumed that all electricity consumed by cities is generated in regions where the cities are located.

Second, **geographic overlaps between energy end-use companies and subnational actor commitments** were quantified (overlap (B-RC) in the middle panel of Figure 7-1). Energy end-use companies are companies that are not electric utilities. We assumed that energy end-use companies with commitments are geographically evenly spread over subnational actors with and without commitments. We therefore applied the same GHG emissions percentage for the overlap between energy end-use companies with commitments and subnational actors with commitments as the share of sub-national actors with commitments in national total GHG emissions. This simplified approach was taken because there was no data available on which subnational jurisdictions the companies' emissions were generated, as the CDP dataset provides only country-specific emissions data per company. As companies within a geographical area with an ambitious commitment might be more likely to adopt commitments themselves, stringent thresholds were applied to estimate the impact of companies that is unambiguously additional to the impact of the commitments of the regions or cities in which the companies (or company operations) are located (see section 7.2.3.3 for details).

Third, **overlaps between electricity-generating companies and all other NSA commitments** (overlap (P-RCB) in the bottom panel of Figure 7-1) was quantified. This overlap is calculated to avoid double counting of emissions from electricity production by electric and gas utilities (scope 1), and the use of electricity by other sectors (scope 2).

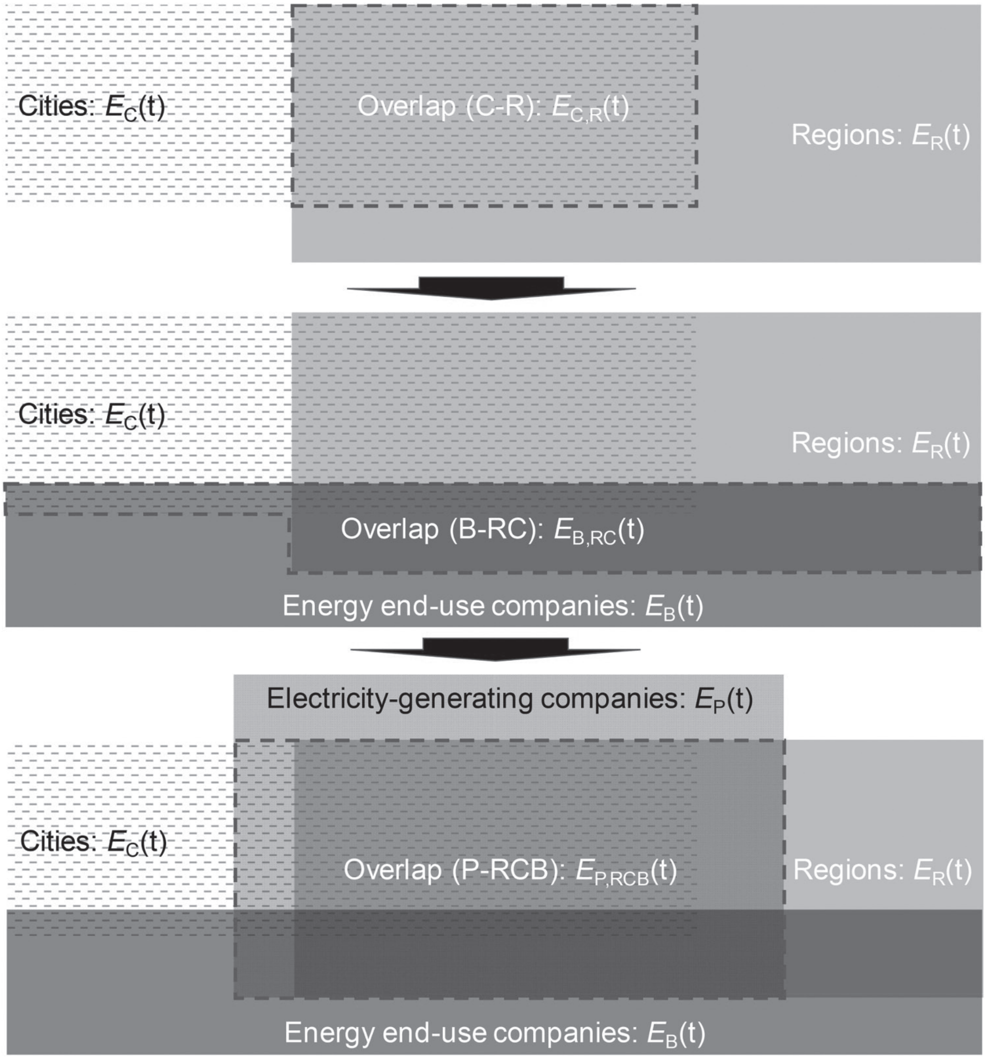


Figure 7-1 Step-by-step quantification of overlaps between actor groups.

We assumed that electricity-generating companies with commitments are geographically evenly spread over regions/cities. The overlap rate for electricity-generating companies is therefore equal to the net coverage rate of electricity-related GHG emissions by subnational actors and energy end-use companies. For the calculations, the share of electricity-related GHG emissions in total emissions of a region is assumed to equal the national average. The shares of scope 2 emissions in energy end-use companies' total scope 1 plus scope 2 emissions were often not available, so we mainly used the median values for companies with available data (Supplementary Table 7-2). Country-level total GHG emissions from electricity generation in 2016 were estimated based on IEA statistics (IEA, 2018, 2020).

The quantification of overlaps was done in the following order: regions, cities, energy end-use companies then electricity-generating companies. This order implies starting from the largest emissions scope to the smallest, but it is important to note that this order was taken only to maximize the transparency of the calculation methods and does not imply the relative importance of different actor groups.

7.2.3.3 Comparing ambition when targets are overlapping

In the previous section, we identified emissions that overlap between regions, cities and companies, i.e. overlap areas (C-R), (B-RC) and (P-RCB) from Figure 7-1. For these emissions, we assessed which of the actor group's targets is more ambitious compared to others.

To determine additional reductions, two extreme assumptions could be taken: 1) emission reductions by actors with commitments are fully counterbalanced by actors that do not act on climate change; and 2) action by actors with commitments is fully additional to other actor's commitments. In the first case, the additional emissions reduction impact of city A's commitment compared to the commitment of region B, in which the city is located, could possibly be zero, even if city A's emissions are reducing at a faster rate than region B's. In the second case, city A's action would lead to significant emission reductions, as the reduction effort is not reversed by inaction elsewhere within region B.

Our analysis makes use of the average result of two different approaches that present the middle ground between those described above:

- The first is the **"partial effect" method**, which uses 2°Cconsistent emission levels based on a range of effort-sharing approaches calculated by Höhne, den Elzen and Escalante (2014) as threshold values to quantify the additional emissions reductions. Compared to current ambition and effort levels observed in most countries as well as NSAs, stringent threshold values were applied to identify and quantify only the commitments that are unambiguously more ambitious than the overlapping commitments compared (in the above example, city A compared to region B).
- The second is the **"partial conservative effect" method**, which assumes that the NSAs' actions are partially offset by a group with "laggard" sub-national actors and companies that do not implement any climate action (Hsu et al., 2019b). This "laggard" group is assumed to follow a no policy, business-as-usual scenario projection, which is derived from the TIMER model (for details, see S3.3 in the SOM).

7.3 RESULTS

7.3.1 GHG emissions coverage

Our assessment included 79 regions accountable for at least 3.7 $GtCO_2e$/year in 2016, approximately 6,000 cities accountable for at least 4.4 $GtCO_2e$/year, and nearly 1,600 companies accountable for 2.6 $GtCO_2e$/year (Supplementary Table 7-1). Altogether, individual commitments from the ten economies cover 8.1 $GtCO_2e$/year in 2016 after subtracting the overlaps, a total larger than the US' 2016 emissions and accounting for 25% to 26% of total GHG emissions including LULUCF from the ten economies in the same year. The combined revenue of the companies with commitments assessed here totals over 21 trillion US Dollars (USD), roughly the size of US GDP (World Bank, 2019a). China, EU28 and the US together accounted for more than 80% of the total GHG emissions covered by the dataset used for the assessment. The emissions coverage rates were close to 40% in Canada, whereas they were generally in the order of 10% to 20% for emerging countries. S4 of the SOM presents the population coverage of city and region commitments, the number of commitments by target year, and the number of company commitments per sector.

7.3.2 GHG emission reductions in 2030

This analysis estimates significant emission reductions from city, region, and business climate commitments. Total GHG emissions in 2030 for the ten major-emitting economies would be 1.2 to 2.0 $GtCO_2e$/year lower than the current national policies scenario projections (31.6 to 36.8 $GtCO_2e$/year), if recorded and quantified commitments by individual regions, cities and companies are fully implemented (see Table 7-2). The range for the quantified projected emissions reductions is nearly entirely attributable to the uncertainty in the CNP scenario projections; the difference in results due to the methodological choice to compare ambition in case of overlapping commitments (i.e. partial effect method versus the partial conservative effect method) is very small.

The highest global reductions relative to the CNP scenario are estimated to be contributed by regions, while the lowest contribution is from electric utilities (Figure 7-2a). Individual commitments from regions, cities and energy end-use companies could result in 0% (China) to 14.3% (US) lower GHG emission levels below CNP scenario projections in the ten major emitting economies (see Table 7-2). Only electricity-producing companies have not made sizeable commitments that go beyond current national policies; a possible explanation is that national climate policies in the economies concerned have so far focused on the power sector.

Table 7-1 2016 greenhouse gas (GHG) emissions covered by quantifiable non-state and subnational actor commitments

Country	2016 GHG emissions coverage by subnational and non-state actors (unit: MtCO2e/year)			
	Regions	**Cities**	**Companies**	**Net total (share in national total emissions including LULUCF)**
Brazil	127 (n=1)	35.5 (n=7)	60.3 (n=361)	199 (12%)
Canada	147 (n=5)	112 (n=24)	114 (n=371)	256 (38%)
China	313 (n=2)	2,170 (n=27)	129 (n=607)	2,510 (20%)*
European Union (EU28)	801 (n=33)	808 (n=5,707)	729 (n=4,572)	1,500 (38%)
India	15.6 (n=1)	3.54 (n=3)	218 (n=392)	235 (9%)*
Indonesia	0	234 (n=7)	22 (n=183)	244 (12%)*
Japan	283 (n=15)	265 (n=56)	347 (n=445)	559 (45%)
Mexico	46.6 (n=2)	50.9 (n=9)	37.6 (n=323)	93.1 (14%)*
South Africa	0	85.3 (n=7)	98.9 (n=194)	118 (21%)*
United States	1,940 (n=20)	657 (n=156)	884 (n=837)	2,610 (45%)
Total of ten economies	3,670 (n=79)	4,430 (n=6003)	2,640 (n=8285)	8,080 (26%)

7.3.2.1 Summary of country findings

The extent to which sub-national and non-state actors are found to contribute to or exceed current national policies varies by country and is certainly dependent on data availability, as our analysis only includes actions that are recorded through voluntary climate action reporting initiatives and platforms. In the US and Brazil, where national governments have retreated from their Paris pledges (Friedman, 2019), sub-national and non-state climate action, if fully implemented, could recover a significant portion of the emission reductions potentially lost. For the US, a surge of sub-national and non-state actors representing almost half (45%) of 2016 national emissions could yield 21% to 24% below 2005 levels in 2025, nearly constituting the country's original NDC of 26% to 28%. The largest impact is expected from 20 US states, including California and New York (Figure 7-2g). The impact in Brazil, however, is not as substantial, as the scope of NSAs recording climate actions is still limited (12% of total national emissions including LULUCF) (Figure 7-2b).

Table 7-2 Projected greenhouse gas (GHG) emissions in 2030 for non-state and subnational climate commitments in ten major-emitting economies under the current national policies (CNP) scenario and CNP plus individual actors' commitments scenario. Emission projections for unconditional NDC scenario are also presented for comparison. The CNP scenario projections do not account for subnational and non-state climate action

Country	2016 GHG emissions including LULUCF (MtCO2e/year)	2030 GHG emissions projections including LULUCF (MtCO2e/year)		
		Current national policies (CNP) scenario*	CNP plus individual actors' commitments scenario (%-reduction to CNP scenario)	[For comparison] Unconditional NDC scenario*
Brazil	1,720	1,560-1,800	1,520-1,720 (2.3%-4.5%)	1,180
Canada	676	610-744	558-663 (8.5%-11.0%)	498
China	12,100-12,600	12,200-14,600	12,200-14,500 (0%-0.7%)	13,200-16,200
European Union (EU28)	3,990	2,920-3,540	2,810-3,220 (3.8%-9.2%)	3,100
India	2,510-2,620	4,050-4,450	3,830-4,210 (5.5%)	4,980-6,130
Indonesia	1,990-2,030	2,820-3,170	2,730-2,990 (3.5%-5.5%)	2,100
Japan	1,250	1,040-1,150	953-1,010 (8.2%-11.5%)	1,020
Mexico	640-701	686-834	664-791 (3.2%-5.1%)	750
South Africa	560-574	640-747	622-715 (2.9%-4.3%)	404-623
United States	5,790	5,050-5,760	4,510-4,940 (10.7%-14.3%)	4,740
Total of ten economies	**31,200-31,900**	**31,600-36,800**	**30,400-34,800 (3.8% - 5.5%)**	**32,000-36,300**

* Based on Kuramochi et al. (2018).

In a few of the countries analysed, NSAs' commitments allow national governments to even over-achieve their existing NDCs. For instance, in the EU, the full implementation of recorded and quantified individual commitments by regions, cities and companies could lead to an emissions reduction of up to 48% by 2030 from 1990 levels — a 20% increase from the EU's current goal of at least 40% reduction by 2030. In India, commitments would add a 5.5% reduction to the current national policy projections for 2030, which would deepen the ambition of India's current national policy that is expected to exceed its NDC by 1,100 to 1,900 $MtCO_2e$/year. A large majority of this expected impact is from companies (Figure 7-2e). Japan also demonstrates significant contributions from city, region and business commitments, which would lower emissions by up to 70 $MtCO_2e$/year below the country's NDC by 2030. The results for both the EU and Japan show comparatively more balanced contributions from NSAs than in other countries ((Figure 7-2d and f). Other countries, such as China and Canada, may have a sizeable representation of NSAs taking action, but their marginal additional impact, compared to current national policies, demonstrates the high degree of overlap in their actions. One reason for China's seemingly relatively low impact from cities and provinces could be due to the top-down manner in which national climate policies are set and implemented (Figure 7-2c). In others, such as Indonesia and South Africa, non-state and subnational climate action data are quite limited, a challenge that is further elaborated in the discussion section.

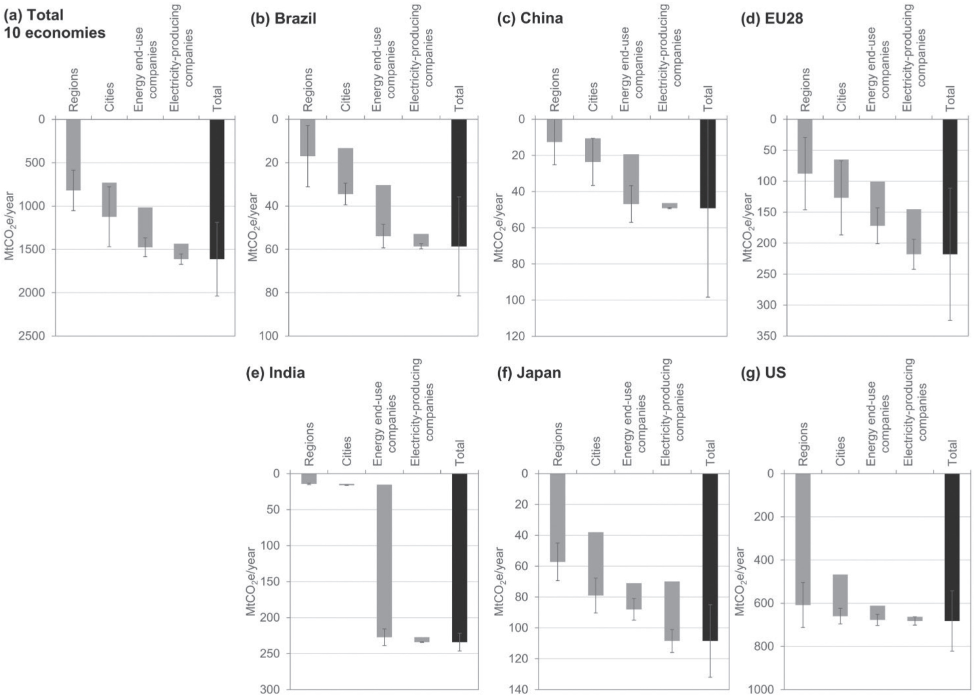


Figure 7-2 Impact of fully implemented, recorded and quantified region, city and business commitments on global greenhouse gas (GHG) emissions by actor group for the total of ten major-emitting economies and selected individual economies (Brazil, China, EU28, India

7.3.3 Sensitivity analysis

We examined the sensitivity of our results to a few key assumptions. The first assumption is the emissions trend under the CNP scenario in 2030 for NSA groups with commitments. In the results presented above, we applied the average national emissions trend compared to a historical base year to all NSAs. For these actors, however, higher autonomous improvements might already be expected independent of their commitments, as they might foresee declining emissions trends under their jurisdiction even without policies or are frontrunners within their country on climate action with more measures implemented than in regions, cities and companies without commitments.

Therefore, we conducted a sensitivity calculation by assuming a 10% lower emissions change by 2030 compared to a historical base year. Table 7-3 shows this assumption equals to approximately 0.7%/year lower emissions growth compared to the national averages between 2016 and 2030, which is more than double the uncertainty assumed for cities in UNEP (UNEP, 2015b) (+/-0.3%/year) and is consistent with the range observed across nine US regions for 2030 (90% to 108% of the national average) under the reference scenario in the US Annual Energy Outlook 2019 (U.S. Energy Information Administration, 2019). The estimated GHG emissions reductions for the ten major-emitting economies then reduce by roughly 35% (upper bound) to 45% (lower bound). Similar sensitivity levels were observed also at the individual country levels.

Table 7-3 Sensitivity of the 2030 GHG emissions reductions to counterfactual emission levels for the non-state and subnational actors with commitments under the current national policies (CNP) scenario. Values are rounded to the nearest five.

	GHG emissions reductions in 2030 (MtCO2e/year)	
Country	**2030 counterfactual emissions (relative to 2010 levels) same as the national average under CNP scenario**	**2030 counterfactual emissions (relative to 2010 levels) 10% lower than the national average under CNP scenario**
China	0-100	0
EU28	110-325	0-190
India	220-245	185-205
Japan	85-130	35-80
US	545-820	315-565
Total of ten major emitting economies	1,185-1,985	650-1,325

We also assessed the sensitivity of our findings to the threshold values used to determine ambitious city and company commitments (Supplementary Table 7-3applied to quantify the net additional impact of cities and companies in cases where they are in geographical locations that also have commitments. We found that total GHG emissions reductions changed by 5% when the threshold values were changed by +/-30%.

7.3.4 Comparison of results with earlier studies

On a global level, there are few studies that have aggregated the GHG mitigation potential of individual NSA commitments. Roelfsema et al. (Roelfsema et al., 2018b) projected that the commitments reported to CDP, C40 Cities and Covenant of Mayors (the present Global Covenant of Mayors) would together lead to a reduction of about 1.3 $GtCO_2e$/year compared to a no-policy baseline by 2030. While Roelfsema et al. (2018) and our analysis used different baselines, we find the calculated GHG mitigation potential values to be comparable to our results (1.2 to 2.0 $GtCO_2e$/year by 2030). The Global Covenant of Mayors estimates a 1.4 $GtCO_2e$/year emissions reduction by 2030, compared to a current policy baseline with a modelling start year of 2010 (GCoM, 2018).

On country-level assessments, our findings for Japan are consistent with a study by E-konzal and Kiko Network (2016). For the US, our projection range for 2030 is similar to the range indicated by the “Climate Action Strategies” scenario (reflecting 10 high-impact, near-term and readily available opportunities) and “Enhanced Engagement” scenario (broader set of ambitious undertakings by regions, cities and companies) projections in the America’s Pledge (2018) report. Our result is higher than an earlier similar analysis (Kuramochi et al., 2017), as the number of actors and commitments have increased significantly in the US since then.

7.4 DISCUSSION

7.4.1 Significance and policy implications of this study

This study represents, to the authors’ knowledge, the most comprehensive analysis to date of the aggregated impact of individual NSA commitments on climate change mitigation. While not comprehensive of all actors and climate actions globally, the data evaluated for this study provides a detailed window into bottom-up mitigation efforts, identifying trends, patterns, and gaps in cities, companies and state and regions’ responses to climate change. These results have three important implications. First, while many national governments do not seem to fully acknowledge subnational non-state climate action in their NDC formulation (Hsu et al., 2019a), they could help many countries achieve or over-achieve their NDCs. Second, many countries could raise their NDC ambition by considering existing city, region, and company commitments in their national climate policy formulation process. Third, for those countries where national governments withdraw from ambitious climate policy, bottom-up climate action can partly make up for backtracking.

7.4.2 Limitations of this study

We identify a number of limitations of this study related to: (1) incomplete coverage of existing non-state and subnational climate action, particularly in developing countries and major energy economies, (2) assumptions applied for the preparation of the dataset and for the aggregation of commitments, (3) assumption that climate action efforts are not displaced elsewhere, (4) the likelihood of commitments being fulfilled. These limitations work in opposite directions (i.e., (1) would lead to an underestimation of the impact, (3) and (4) to an overestimation).

7.4.2.1 Incomplete coverage of existing sub-national and non-state climate action

Our analysis only included actors from 10 high-emitting countries, while in reality sub-national and non-state climate actions take place globally. Studies have shown that the full extent of climate action often goes unreported, particularly among actors from the Global South (Chan and Hale, 2015; Hsu et al., 2016; Widerberg and Stripple, 2016; Chan et al., 2018; UNFCCC, 2018b) and varies across economic, geographic, and national contexts. For businesses, not all companies are willing to make their climate action commitments public. For example, companies can choose not to allow public access to their survey responses in the CDP questionnaire (CDP, 2019b). Actors that do not participate in a voluntary, public reporting platform are also excluded in this analysis. Unquantifiable NSA climate actions can still result in indirect emissions reductions through catalytic effects (Hsu et al., 2019b).

7.4.2.2 Uncertainties related to the assumptions used for dataset preparation and aggregation

In the process of preparing and validating data used for this analysis, there were certain exclusions and decisions made that may affect the overall assessment, although we deem them to be *de minimis.* For example, we excluded companies' scope 3 emissions by applying their scope 3 share in total emissions covered per target estimated from the most recent historical data throughout the assessment period. This simplified assumption was made due to a lack of information and the complexity of quantifying overlaps with other emissions resulting from the diversity of scope 3 emissions (e.g., upstream, downstream and boundary considerations). While this assumption would not considerably affect our country-level findings because scope 3 emissions accounted for only 13% of total corporate GHG emissions reported to CDP in our dataset, value chain and/or life cycle GHG emissions included in scope 3 are important emissions sources, and future research is needed to understand the net impact of scope 3 emissions-related targets.

The assumption that all NSAs under the CNP scenario would show future emissions trends equal to the national average may also have affected the obtained results. In the uncertainty analysis, we found that a 10% lower counterfactual baseline emission level would lead to 40% or larger decrease in the potential GHG emissions reductions. We conclude that our results are more robust for economies with comparatively higher coverage of national total GHG emissions by NSA commitments—as the emissions coverage becomes larger, the counterfactual baseline under the CNP scenario would become closer to the national average. For country-specific assessments, subnational region-specific baselines would ideally be used (America's Pledge, 2018).

7.4.2.3 No displacement of climate action elsewhere

Another major assumption of the mitigation potential achieved is that city, region, and company climate actions do not replace existing climate efforts embedded in the current policy scenario, for example by other subnational, non-state actors or national governments where the actions take place. This phenomenon, where carbon emissions increase despite actions being taken by some actors, can be compared to carbon leakage (van Asselt and Brewer, 2010) that may occur if a country implements an ambitious climate policy but emissions rise in other countries. For such action displacement to occur, however, actors must have full knowledge of each other's climate actions and legal enforcement of emission reduction policies. Additionally, studies note that almost no coordination between national government and regions, cities and companies on climate action actually occurs (Hsu et al., 2019a). Therefore, we conclude that NSA climate action does not, at this moment, replace efforts elsewhere, although there are open questions that remain as to the future of sub-national and non-state climate action. For instance, if increased coordination with national government occurs, particularly in the context of the Paris Agreement's five-year review cycle, this may subsume sub-national and non-state climate actions into NDCs or national climate policy.

7.4.2.4 Likelihood of non-state and subnational commitments being fulfilled

This study estimates the GHG emissions reductions of full implementation of NSA commitments, but does not assess the likelihood of this given the current status of progress. Data on progress towards climate action goals is scarce, although a few studies have assessed performance by tracking the production of tangible and attributable outputs by climate initiatives (Chan et al., 2016; Chan and Amling, 2019). A lack of quality progress data, however, makes it difficult to assess the likelihood of implementation. The challenges of monitoring climate policy implementation have been significant at both national and subnational levels even in the EU, where the bottom-up monitoring system is among the most advanced (Kona et al., 2018; Schoenefeld et al., 2018, 2019). While some climate action networks offer ways for their members to report on their progress, often only a fraction of participating actors share this information (Hsu et al., 2018). Additionally, companies provide information about the percentage of an emissions reduction or renewable energy target that has been achieved to date in their responses to CDP, but there remain challenges to analysing this information from year to year and understanding how it relates to a company's overall emissions inventory. Collection of additional and more streamlined information, including anticipated progress pathways (e.g., linear, exponential, logarithmic, variable, etc.), could improve progress tracking in future datasets.

A better understanding of progress towards meeting goals will be vital for accurately assessing the contributions that NSAs can make towards national and global mitigation goals – and help unlock and direct the support and resources needed to ensure their success. For instance, surveys of cities have flagged shortfalls in funding, technical know-how, or shifts in political priorities or leadership as potential obstacles to progress (C40 Cities, 2016). More detailed implementation data could power expanded analysis that explores drivers and obstacles to climate action in different contexts, insights that would enable the global community to better support these efforts.

Several initiatives to more closely track progress are underway. From 2019 onwards, the Corporate Climate Action Benchmark (CCAB), developed by CDP and the World Benchmarking Alliance, will measure the climate action performance of high emitting companies on a yearly basis, allowing stakeholders to monitor their progress (Hsu et al., 2018). Efforts to streamline the reporting processes could also make it easier to track progress by lowering actors' reporting burden and consolidating existing data. In April 2019, ICLEI's carbon*n*® Climate Registry and CDP streamlined their data platforms – local and regional governments can report just once, on CDP's platform, and their data will automatically be shared with ICLEI (van Staden and Appleby, 2019). The common reporting framework of the Global Covenant of Mayors for Climate & Energy (GCoM), which took effect in January 2019, is designed to enable cities to report data in a standardised way, provide flexibility to meet specific local or regional circumstances, and unambiguously track progress (GCoM). These changes in the reporting pipeline have the potential to make it easier for analysts, policymakers, and the reporting regions, cities and companies to track individual and collective progress towards climate action commitments.

In this context, it is also of critical importance that ex-post assessments of NSA actions be conducted, by both the actors themselves as well as by independent research groups. As there are many NSAs that set targets for 2020, critical assessment of their results is an important area for future research. To date there are limited assessments of NSA climate action implementation, and those that do exist are limited in sample size (e.g. Khan and Sovacool (2016) evaluate 25 cities' emissions reductions reported to Carbon*n*® Climate Registry) or by sector (e.g. Steffen, Schmidt and Tautorat (2019) evaluate the impact of transnational municipal networks on city investment in utility-scale solar photovoltaics). With the next decade marking a crucial period for the achievement of global climate goals, ex-post evaluation of whether and how NSA climate actions achieve their stated goals will be a critical area for further research.

7.5 CONCLUSIONS

This study quantified the aggregate potential of recorded and quantified city, region, and company GHG mitigation commitments covering 8.1 $GtCO_2e$/year in 2016 in ten major-emitting economies. We found that these efforts could lower emissions by 1.2 to 2.0 $GtCO_2e$/year compared to current national policies scenario projections in 2030, if these commitments are fully implemented and if such efforts do not change the pace of action elsewhere. These results may be an overestimation, given a range of assumptions we make in developing our data and models to assess impact of NSA action, but they could also be underestimated as not all NSA action is recorded and/or could be quantified.

On a country level, NSAs are estimated to reduce emissions relative to current national policies from 0% to 14.3%. In some cases, such as the EU, India, and Japan, these actions could help national governments overachieve their NDC targets by extending ambitious actions beyond national policies. In other cases, such as the U.S. and Brazil, sub-national and non-state action could help recover emissions reductions lost through national government rollbacks in climate policies.

To realize the potential quantified in this article, however, efforts for implementation will be required at all levels – from the international community, to national and local governments – to ensure a supportive policy environment that recognises the valuable contributions of all actors to global climate mitigation. Critical assessment of whether and how NSAs would achieve their stated climate action goals is an important area for future research.

ACKNOWLEDGEMENTS

This work was funded by ClimateWorks Foundation (grant no.19-1383). T.K., M.R., S.L., and N.H. received additional support from the European Union's Horizon 2020 research and innovation program under grant agreement No 821471 (ENGAGE). S.C. and T.H. received additional support from German Development Institute/Deutsches Institut für Entwicklungspolitik's "Klimalog" project, generously funded by the German Federal Ministry of Economic Cooperation and Development (BMZ). A.H. and A.W. received support from the 2018 National University of Singapore Early Career Award awarded to A.H.

This work draws on data provided by CDP, Global Covenant of Mayors for Climate & Energy, Global Covenant of Mayors (EU Secretariat), Compact of States and Regions Annual disclosure to CDP, in partnership with The Climate Group, and ICLEI carbonn® Climate Registry.

Zhi Yi Yeo, Yunsoo Kim, Mia Raghavan, Claire Inciong Krummenacher, Yihao Xie of Yale-NUS College contributed to cleaning and preparing the dataset of NSAs' commitments, and Xiyao Fu (Yale-NUS College) and James Sun (Yale University) helped gather data on Chinese cities' climate commitments.

Authors would like to thank experts in the UNFCCC Climate Action Methodologies Data and Analysis (CAMDA) community for their feedback in various stages of the analysis.

CHAPTER 8

Summary and conclusions

8.1 INTRODUCTION

8.1.1 International climate policy in the last 30 years

The international climate negotiations have a long history and have experienced some noticeable failures and successes. A few important markers were the first World Climate Conference in 1979 (Geneva, Switzerland), the International Conference on the Assessment of the Role of Carbon Dioxide in 1985 (Villach, Austria), and the first ministerial conference on climate change in 1989 (Noordwijk, the Netherlands). The establishment of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 (Rio de Janeiro, Brazil) gave the negotiations a clear status. It included the objective to stabilise greenhouse gas concentrations at a level that would prevent dangerous interference with the climate system. After the formation of the UNFCCC, the Kyoto Protocol was the first concrete step to put this objective into practice and reduce emissions. Industrialised (Annex I) countries agreed to reduce greenhouse gas emissions between 2008 and 2012 by (on average) 5.2% relative to 1990. The potential impact of the Protocol was significantly reduced shortly after, as the USA decided not to ratify the Protocol. Some years later, Canada, Russia, New Zealand and Japan decided not to enter a second Kyoto commitment period. Although the protocol officially existed until 2020, the focus shifted to the negotiations that had already started in parallel to reach a more comprehensive global agreement secured in the Bali action plan. Much like the Kyoto Protocol, the idea was to establish a set of binding targets, including a wider range of counties and themes. This attempt, however, failed in Copenhagen in 2009 as no agreement could be reached on binding targets, and the agreement on the table, including the limit to hold temperature below 2 °C relative to pre-industrial levels, was only taken note of by the parties of the UNFCCC. The negotiations were resumed one year later in Cancun, where some agreements from the previous year were secured, and progress could be made again. This was the starting point of a new hybrid approach to international climate policy where countries pledge voluntary bottom-up reductions to reach a globally agreed, common goal and were the blueprint for the Paris Agreement.

The Paris Agreement in 2015 formalised the long-term goal to keep temperature increase since pre-industrial levels well below 2 °C and the effort to pursue keeping it below 1.5 °C and introduced a process to implement this. As climate policies need to be implemented at the national level, the agreement requires countries to submit Nationally Determined Contributions (NDCs), including mitigation pledges and actions. These are meant to result in the domestic implementation of climate policy. It should be noted that the Paris Agreement does not include binding targets for countries – but instead foresees a so-called stocktaking process in which countries progressively align their national pledges and implementation with the long-term climate goals. The collective action assessed in this process also includes the efforts and support actions of non-Party stakeholders such as cities and companies who are encouraged to contribute to the implementation of the Paris Agreement (UNFCCC, 2015g). This group, including companies, cities, regions and provinces, has also been asked to contribute to emission reductions – although, at this point, it is not clear what the potential contribution is and whether this is additional to the action of national governments.

8.1.2 Integrated assessment models support climate policy

A unique aspect of the climate negotiations is the strong involvement of scientific knowledge. This includes information on climate science, climate policy, impacts and mitigation pathways. Although scientific information sometimes finds a direct route into the negotiations, the more official route is via assessment reports – most noteworthy, those of the IPCC and the Emissions Gap report from the UN Environment Programme (UNEP). For mitigation, the results of Integrated Assessment Models (IAMs) play a crucial role in these reports. IAMs evaluate the impact of climate mitigation strategies by developing scenarios or emission pathways that typically cover this century. They can show different emission routes to stabilise greenhouse gas concentrations and keep global mean temperature well below 2 °C or 1.5 °C. In addition, they can also identify the so-called emissions gap between global emissions needed to meet the Paris climate goal and projected emissions based on fully implemented NDCs.

Around 2010, most IAMs only included stylised policy scenarios often developed by applying a regional or global carbon price. However, since the adoption of the Paris Agreement and the increasing number of domestic climate policies being implemented, climate policy is moving from policy formulation and decision making (‘where do we go’) to the policy implementation phase (‘how do we get there’). Therefore, more detailed policy pathways incorporating domestic climate policies would improve the analysis of mitigation pathways. Primarily to assess the critical question of how to close the emissions gap and if effective policies are implemented to achieve NDC’s.

To assess the impact of climate policy on global and domestic greenhouse gas emissions, climate policy scenarios in this thesis were developed and implemented in integrated assessment models. These scenarios describe different levels of policy stringency, time horizons and geography (specific details for each scenario differ per chapter):

- **Baseline**. Scenario representing extrapolation of current trends and includes past implemented policies up to a certain historical date (e.g. 2010).

- Current (national) policies (**CNP**). Scenario representing climate policies that have been approved by parliament or through executive orders until a certain cut-off data (e.g. 2017).
- International targets. Domestic emission targets pledged in the context of the international negotiations (Cancun Agreement, Paris Agreement)
    - **Pledges** (for the year 2020)
    - **NDC** (for the year 2030[24]) submitted to the UNFCCC until a certain cut-off date (e.g. 2017).
- Current (national) policies and non-state actions (**CNP+NSA**). Scenario representing current implemented policies and additional reductions expected from individual subnational and non-state actors such as regions, cities and companies.
- International Cooperative Initiatives **(ICI)**. Scenario representing current implemented policies and additional reductions expected from subnational and non-state actions from international cooperative initiatives.
- Good practice policies (**GPP).** Scenario representing the worldwide replication of successful sector examples from exemplary countries.
- Paris goals. Temperature goals secured in the Paris Agreement
    - **2 °C** scenario: global least-cost emissions scenario consistent with keeping global temperature increase below 2 °C throughout the 21st century and starts long-term reductions from 2020.
    - **1.5 °C** scenario: global least-cost emissions scenario consistent with keeping global temperature increase below 1.5 °C by 2100 and starts long-term reductions from 2020.

8.1.3 The research question of this dissertation

Official international climate negotiations have by now lasted for about 30 years. During this period, global greenhouse gas emissions have continued to rise. Meanwhile, ambitious global goals have been acknowledged in the Cancun Agreements to keep global temperature below 2 °C, while the Paris Agreement secured the global goal to keep global mean temperature increase to stay well below 2 °C or even 1.5 °C, and in addition to reach global peaking of greenhouse gas emissions as soon as possible and to achieve net-zero emissions in the second half of the century. However, the global goals need to be implemented through climate policies and measures at the national level. The critical question is thus whether the world is on track with the current implementation of mitigation policies and measures to ensure a transition

[24] 2025 targets are translated to 2030

towards a zero-carbon world? Integrated assessment models are used to assess this question as it asks for a global picture. These insights guide the research questions of this dissertation:

What is the impact on greenhouse gas emissions of implemented climate policy, climate actions and potential enhancements towards limiting global temperature change to below 2 °C and 1.5 °C above pre-industrial levels?

This raises the following four sub-questions:

1. How can integrated assessment models evaluate current domestic climate policy in the context of long-term temperature goals? (Chapter 2)
2. Are countries on track to meet their 2020 pledges and 2030 NDCs with current policies? (Chapter 3 and 4)
3. How can countries tighten the 2030 emissions gap between NDCs and the well below 2 °C temperature targets and scale up their domestic climate action? (Chapter 5)
4. To what extend can sub-national and business actors contribute to closing the global gap, and how much are actions from these actors additional to national government implementation? (Chapter 6 and 7)

These questions revolve around the agreements made in Paris and the earlier bottom-up pledges that resulted from the Copenhagen Accord. Therefore, the focus is on 2020 and 2030 targets, with the main focus on the latter. Several chapters introduced new topics in scientific literature involving global assessments and integrated assessment models, such as domestic policies in the context of long-term goals, international cooperative initiatives, and good practice policies. However, often these were part of research in a larger context. As the author also contributed to other scientific articles in this period that add to the insights presented in this dissertation, important insights from this other work are presented in boxes in several chapters.

8.2 HOW CAN INTEGRATED ASSESSMENT MODELS EVALUATE CURRENT DOMESTIC CLIMATE POLICY IN THE CONTEXT OF LONG-TERM TEMPERATURE GOALS?

Climate policy assessments based on IAMs play an important role in supporting the international negotiation process. These models contribute by showing scenarios and emission pathways that represent different types of policy implementation with different stringency, time horizons and geography. In this context, the exact meaning of the concept 'climate policy' is not always clear.

It is important to establish a coherent framework for climate policy analysis with clear definitions to develop a common language across different disciplines. Such a framework defines key terms, concepts, and scenarios applicable to the assessment of climate policy in IAMs. Besides being helpful for IAM implementation, insights from this framework can help policymakers understand and interpret the results of model studies and function as a dictionary and also help other scholars understand the results of IAMs, given the different use of terms across disciplines. Here, a climate policy framework is presented based on the public policy framework of Howlett (2009).

The climate policy framework used in this dissertation is divided into two dimensions: policy components and policy stages (see Figure 8-1). The framework defines climate policy as ''*the result of agenda setting, formulation, decision-making and implementation by (groups of) governments considering actions to mitigate climate change at the international and economy-wide level that encompasses (aspirational) objectives and goals not necessarily secured by legislation, national targets secured by legislation, and policy instruments and targets designed and calibrated to implement these goals and objectives'.* Accordingly, climate policy is enacted at different policy stages and consists of different policy components. The policy stages are derived from the policy cycle: agenda setting, policy formulation, decision-making, policy implementation; problems come to the attention of governments, policy options are formulated, governments adopt a particular course of action, and policies are put into effect (Howlett, 2011; Lasswell, 1956). The policy components are divided into policy aims and means defining where the policy is heading and how this will be achieved (tools or instruments).

Climate policy is captured by policy objectives, secured by policy goals and implemented through policy targets and measures (see Figure 8-1). The policy aims occur at different stages of the policy cycle and consist of objectives and goals which are secured in different forms of (legal) documents such as agreements, protocols and legislation, and implemented through policy instruments translated to (technical) measures that install technologies and infrastructure in the physical world that result in changes in energy and land use and a reduction of greenhouse gas emissions.

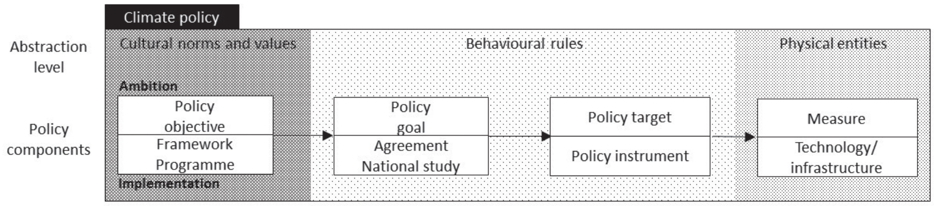


Figure 8-1 The concept 'climate policy' represented by decreasing abstraction levels and divided into policy components (ambition/implementation

The framework used in this dissertation is applicable to current international and national policymaking (see Table 8-1). The UNFCCC **objective** to 'stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous interference with the climate system' (UNFCCC, 1992) is translated in the Paris Agreement to the **goal** to keep the increase in global average temperature to well below 2 °C, and to pursue efforts to keep it below 1.5 °C (UNFCCC, 2015g). Implementation of climate policy is done at the national level: countries need to communicate their emissions reduction pledges and climate policies to the international community in Nationally Determined Contributions (NDCs). The NDC that each country should prepare, communicate and maintain (UNFCCC, 2015g) is instrumental to the Paris agreement and the lowest level of implementation at the international level. In addition to NDCs, countries are requested to submit a Long-Term Strategy (LTS) for 2050. These objectives, goals and targets are secured in the UNFCCC framework, Paris Agreement and NDCs.

At the national or economy level, policies are secured by programs or other high-level policy ensembles, such as the EU objective to cut greenhouse gas emissions by taking the most environmentally and cost-effective policies and measures (European Commission, 2000). More specific policy goals can be specified in terms of aspirational emission reductions or energy use reported in climate strategies, plans or roadmaps, for example, the EU 2030 climate and energy framework (Commission, 2014), and sometimes secured by climate legislation, such as the European Climate law (European Commission, 2020a). Also, the climate neutrality goal from the Green Deal roadmap is such a policy goal (European Commission, 2019). These goals are achieved by implementing policy instruments such as the EU Emission Trading System and the Effort Sharing mechanism. Often, these instruments are part of a policy mix that includes an overarching reduction target. The implementation of policy instruments finally results in physical or infrastructural changes, such as solar PV installations installed on residential roofs or hydrogen pipelines.

Table 8-1 Climate policy framework applied to UNFCCC and EU climate policy

Climate policy	Components/stages	Agenda setting	Policy formulation	Decision making	Implementation
International (UNFCCC)	Policy aims	**Policy objective** Article 2: Stabilise greenhouse gas concentrations in the atmosphere at a level that 'would prevent dangerous interference with the climate system'	**Policy goals** Hold the increase in global average temperature to well below 2 °C above pre-industrial levels; and to pursue efforts to limit the increase to 1.5 °C Reach global peaking of greenhouse gas emissions as soon as possible To achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century	**Policy targets** Targets in NDCs (submitted to Paris Agreement): Emission reduction targets (e.g. EU: 55% reduction relative to 1990 by 2030) non-fossil targets (e.g. China: 20% non-fossil share by 2030) afforestation (e.g. India: additional carbon sink of 2.5-3 $GtCO_2eq$ by 2030) Targets in LTS (submitted to Paris Agreement): (e.g. EU: net-zero emissions by 2050)	
	Policy means	**Framework, Programme** UNFCCC	**Agreement, Protocol, Accord, Treaty** Paris Agreement	**Articles of the Paris Agreement (instruments)** Article 4.2: NDC Article 6: internationally Transferred Mitigation Outcomes (ITMOs)	
Economy-wide (EU)	Policy aims	**Policy objectives** EU: cut greenhouse gas emissions by taking the most environmentally and cost-effective policies and measures	**Policy goal** EU: Climate neutral through net zero greenhouse emissions by 2050	**Policy targets** EU: (current) economy-wide emission reduction target: 40% reduction relative to 1990 (current) ETS emission reduction target: 43% reduction relative to 2005 (current) effort sharing reduction target: 30% reduction relative to 2005 (planned) emissions target of 55% below 1990 levels by 2030	

Climate policy	Components/stages	Agenda setting	Policy formulation	Decision making	Implementation
	Policy means	**Programme** European Climate Change Programme	**Legislation** European Climate law **Climate strategies, roadmap** Green Deal	**Policy instrument (mix)** 2030 climate & energy framework with ETS and effort sharing as main policy instruments	**Measure** Installation of renewable energy (e.g. solar PV), insulation of residential buildings, reforestation

8

The elements from the policy framework are the building blocks for developing climate policy scenarios in the IMAGE model. The climate policy scenarios are implemented to evaluate the aggregate impact of domestic climate policies in the context of the Paris Agreement. For this, five scenarios are introduced: no-new policies baseline, current policies scenario, NDC scenario, and scenarios implementing the 2 °C and 1.5 °C target of the Paris Agreement (see Table 8-2).

Table 8-2 Climate policy scenarios

Climate policy	Policy formulation	Decision-making
Policy aims at international level (UNFCCC)	**2 °C/1.5 °C scenario** By 2100: translation to W/m^2, CO_2 budget, ppm	**NDC/LTS scenario** Carbon price to implement (pledged/ calculated) LTS/NDC targets Carbon price to implement CO_2/GHG intensity target Non-fossil target by adding minimum requirement to non-fossil technologies in investment decision
Policy means at economy level	**(not modelled)** Aspirational goals are checked afterwards and need to be achieved by implemented policy targets	**Current policies scenario** Carbon price or energy tax (e.g. Canada carbon tax) Change model input parameter to enforce target (e.g. Appliance standard) Translate policy target to appropriate model input parameter (e.g. net-zero emissions buildings to 0 GJ/m^2) Use aspirational goal from climate strategy (e.g. renewable auctions in Brazil) **Planned policies scenario** (not modelled)
No new climate policy		**No new policies scenario**
Climate policy	**Components/levels**	**Policy formulation Decision-making**

Temperature goals from the **2 °C and 1.5 °C scenarios** are translated to radiative forcing levels as input to the FAIR model, where 2.6 and 1.9 W/m2 correspond to a 66% chance of staying below 2 °C and 1.5 °C by 2100 (with possible overshoot). It is assumed that climate policy is implemented cost-effectively on a global level after a certain start year (e.g. 2020). The **NDC scenario** describes the impact of fully implementing the international pledged domestic targets. NDC targets in terms of emission reduction targets relative to a base year are settings in the FAIR model, and renewable and forestry targets are implemented in the TIMER and

IMAGE land-use model. The same holds for the long-term targets from the **LTS** scenario. The **current policies scenario** describes the impact of domestic policies: i.e. implemented policy targets and instruments. The policy targets and instruments are collected from the Climate Policy Database (NewClimate Institute, 2015). To implement these scenarios, the targets and policy instruments need to be translated to model parameters and involves changing settings in the TIMER energy model, IMAGE land-use model and FAIR policy model. There are different ways to implement policies in the IMAGE model; 1) sometimes the policy instruments are directly available such as a carbon-, or energy tax, 2) in other cases, the policy target linked to the policy instrument can be implemented by changing model settings, such as the efficiency level of appliance standards, 3) finally, if no explicit target exists, the impact can be estimated by using aspirational policy targets reported in national studies for which the policy instrument has been implemented, or from impacts reported in the literature. The **no new policies scenario** is a baseline scenario representing an extrapolation of current trends without assuming newly implemented policies after a certain historical date.

8.3 ARE COUNTRIES ON TRACK TO MEET THEIR 2020 PLEDGES AND 2030 NDCS WITH CURRENT POLICIES?

The Copenhagen summit and the subsequent Cancun Agreements introduced the 2 °C limit and the process of bottom-up country pledges. This process was a useful experience and input to the design of the Paris Agreement that recycled elements such as the implementation of pledges included in NDCs and the adoption of long-term temperature goals. The methods developed in this thesis to assess the impact of policies and the resulting emissions gap started around the Cancun Agreements (UNEP, 2016a). Therefore, we present some of the work that was done in the context of the Cancun Agreements for 2020 next to the assessment of the Paris Agreement goals and targets.

8.3.1 2020 Cancun pledges

The assessment of domestic policies concerning Cancun pledges (done in 2012) was based on two methods. The first was based on the IMAGE baseline projections developed for the OECD Environmental Outlook (OECD, 2012) combined with additional calculations to estimate policy reductions. The second method uses projections from national studies, supplemented with World Energy Outlook (IEA, 2011b) and US EPA (EPA, 2006) projections. For both methods, reductions were calculated for each policy individually, accounting for overlap between policies (e.g. reductions from renewable and efficiency policies). In addition, the impact of conditional or unconditional Cancun pledges on greenhouse gas emissions was calculated. In this context, conditionality means that countries will implement the pledges conditional on finance or implementation by other countries.

The 2012 analysis of the Cancun implementation showed a mixed picture of whether countries were estimated to achieve their pledges. In the analysis of Chapter 3, some countries were likely to overachieve (India, China, Russia, Ukraine) their pledges, while other countries were projected only to overachieve their conditional pledges (EU, Australia). Yet, other countries were projected not to achieve their targets (Canada, USA, Mexico). For Japan, South Korea, Brazil and Indonesia, it was uncertain whether the target would be reached. Meanwhile, parallel or in response to the pledges, many countries were implementing renewable electricity policies. Some also implemented efficiency standards for car and emission trading systems were emerging. Note that the achievement of national targets does not say anything on ambition of a country. These occurrences of policy implementation are in line with Iacobuta et al. (2018), who conclude that key shifts in national policies coincide with landmark international events such as the Copenhagen Climate conference.

The largest uncertainty of the outcomes resulted from uncertainty in baseline emissions. The estimated emissions range resulting from policy implementation is large and mainly depends on the range of baseline emissions from the two models included (see Figure 8-2). Due to the implementation of Cancun pledges, the emissions range is smaller as the underlying targets are more clearly defined relative to a base year or national baseline and therefore independent of the model baselines used. In addition, the uncertainty in emission levels from the China and India pledges is reasonably large as it is formulated as an intensity that depends on uncertain GDP growth. Furthermore, estimates of historical emissions from China and for LULUCF, in general, are uncertain. Figure 8-2 also includes results from Den Elzen et al. (2011) and Hof et al. (2013) to show the emissions gap by 2020 with the scenario that limits temperature change to 2 °C this century (see Box 8-1).

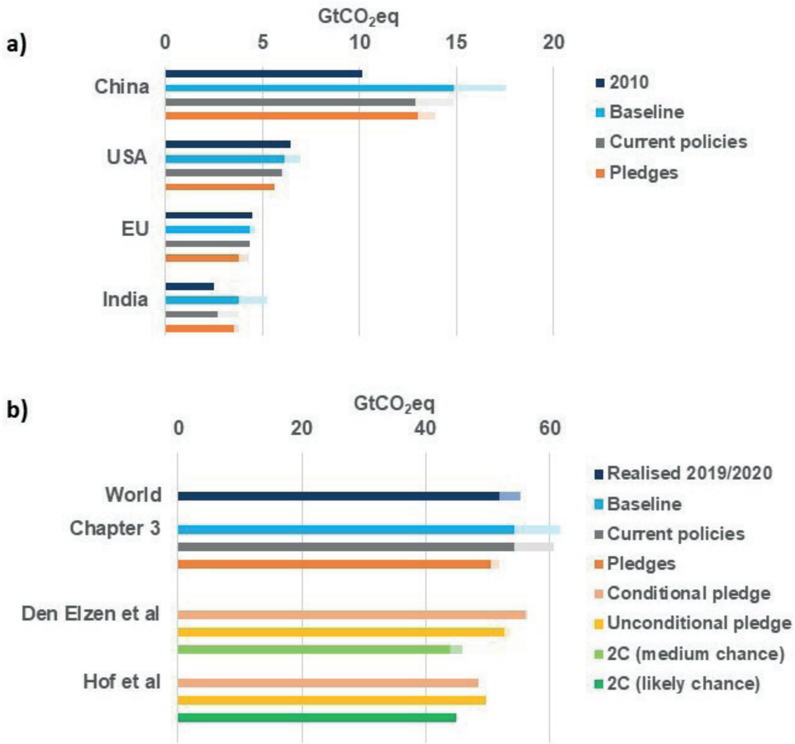


Figure 8-2 Impact of current policies on GHG emissions on a global level and for China, USA, EU and India relative to baseline, pledge and 2° C scenarios:
a) 2010 emission levels, and 2020 baseline, current policies and pledged emission levels for China, USA, EU and India
b) Comparison of realised 2019/2020 emission levels with estimated emissions levels (in 2012) due to the impact of domestic policies, conditional/unconditional Cancun pledges and 2 °C pathways with cost-effective implementation after 2010, from Chapter 3 and Den Elzen et al. (2011), Hof et al. (2013) (see Box 8-1 Assessment of Cancun pledges in the context of the 2 °C limit
c). The global level presented for Chapter 3 consists of country results supplemented with IMAGE baseline projections.
Source 2019/2020 emissions: (Friedlingstein et al., 2020) *for historical CO2 fossil, industry and land use.* (Gütschow et al., 2016) *for historical non-CO2 fossil, industry and waste.* (FAO, 2020) *for historical non-CO2 land use and agriculture.*
Source other: Chapter 3, den Elzen et al (2011), Hof et al (2013)

Other related work on the assessment of Cancun pledges in the context of the 2 °C temperature limit

Chapter 3 looked into the impact of domestic policies that have been implemented in 14 large economies. The author of this dissertation contributed to papers from Den Elzen et al. (2011) and Hof et al. (2013), which were the starting point for research from Chapter 3. These studies add additional insights as they explored the conditional and unconditional Cancun pledges and evaluated their ambition in the context of the 2 °C temperature limit.

The emissions gap between pledges and optimal 2 °C pathways by 2020 were estimated to amount to 2.6-7.7 $GtCO_2eq$ (Den Elzen et al., 2011) and 8.7-12.6 $GtCO_2eq$ (Hof et al., 2013), see Figure 8-2. The latter study was an update of the former. The difference could be explained by updated national baseline projections, new and updated pledges, and more clarity on accounting rules. It shows that the absolute global emission level was 4 $GtCO_2eq$ higher in the latter analysis due to updates of historical emissions (from 2005 to 2010), more clarification of the baseline used in the Brazilian pledge, and changes in the methodology for estimating intensity targets. The gap range results from the distinction between conditional and unconditional pledges and the different interpretations of accounting rules.

A key uncertainty forms the accounting rules for GHG emissions discussed in the UNFCCC negotiations. First, countries could sell their Kyoto surplus credits from the 2008-2012 period and dilute the effect of the pledges. Second, this could also happen because of the low agreed stringency of land-use credits allowed to use by countries (possibly changing natural disturbances to anthropogenic disturbances). Third, this is also possible with double counting of CDM (Clean Development Mechanism) credits.

Kuramochi et al. (2019) evaluate the outcome of the 2020 pledges and expects one year before the final target year of the Cancun pledges, eleven economies to meet their pledges (Brazil, Chile, China, EU28, India, Japan, Mexico, Russian Federation, South Africa, Thailand, Ukraine), while six economies are expected not to achieve them (Australia, Canada, Indonesia, Kazakhstan, Republic of Korea, USA).

Box 8-1 Assessment of Cancun pledges in the context of the 2 °C limit

8.3.2 2030 Nationally Determined Contributions (NDCs)

The NDCs and current policies for 2030 (Chapter 4) were assessed with nine IAMs that included explicit representation of implemented climate policies for G20 countries. This is based on an extensive collection of climate,- energy,- and land-use policies implemented until the end of 2016 and stored in an online database (NewClimate Institute, 2015). This suite of models adds to the robustness of the assessment compared to single-model studies. Although these models differ in country and sector representation and how they mimic decisions on climate policy, they all implemented the same list of effective high impact policies for G20 countries.

Current policy implementation is projected to leave a global implementation gap by 2030 with NDCs, and an ambition gap with agreed global temperature goals (see Figure 8-3). Implementation of current policies is projected to increase emissions until 2030 and reduce greenhouse gas emissions by 3.5 $GtCO_2eq$ (2.3;5.2[25]) or 5.3% (3.8;7.9%) relative to the baseline that represents the hypothetical situation where no policies would have been implemented after 2010. This leaves a median implementation gap with NDCs of 7.7 $GtCO_2eq$ (5.3;9.7) and a median gap of 22.4 (13.6;29.6) and 28.2 (19.8;42.2) $GtCO_2eq$ with pathways that start with cost-effective implementation in 2020 to keep global temperature below 2 °C and 1.5 °C. To keep the world on track on the pathway to the Paris goals cost-effectively, (median) global emission levels need to decrease between 36% and 45% in 2030 relative to the current policies scenario. If conditional NDCs were fully implemented, the emissions gap would reduce by 1/3. The Kaya identity is used to indicate to what extend efficiency (TPES[26]/GDP) or CO_2 reduction measures (CO_2/TPES) need to be implemented. The emissions gap between current policies and (cost-effective) 2 °C pathways by 2030 can be closed by the implementation of policies that would need to increase the (median) low carbon share by 2.8pp and decrease (median) energy intensity by 12.7% relative to the current policies scenario.

[25] 10-90% percentiles

[26] Total Primary Energy Supply

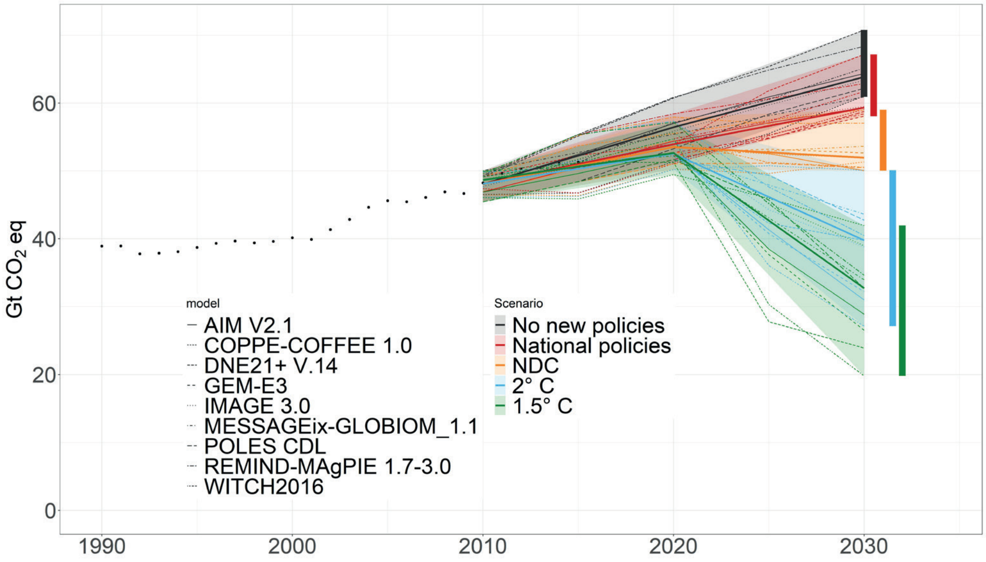


Figure 8-3 Greenhouse gas emissions on a global level under different scenarios for the 1990-2030 period based on nine IAMs.

The mutual policies of all countries analysed fail to achieve an emission level consistent with the cost-optimal 2°C or 1.5 °C scenarios due to a lack of national ambition and/or implementation. The seven included G20 countries (China, USA, EU, India, Brazil, Japan, Russian Federation) are shown to reduce GHG emissions in 2030 by 0-9% if they would implement current policies. The reductions mainly occur in the energy supply and transport sector. Domestic policy implementation leaves a small implementation gap between current policies and NDCs for China, India, Japan, and Russia. This is not the case for the European Union, the United States and Brazil, but their ambition gap between NDCs and 2 °C or 1.5 °C pathways is smaller. It should be noted that taking the 2016 point as reference means that the analysis did not capture some US policies that were withdrawn and newly announced policies by the EU.

From four drivers of uncertainty in global emission levels that were analysed, the difference in baseline assumptions on socio-economic factors is the largest. The analyses decomposed the emission growth between 2015 and 2030 in the current policies scenario into 1) differences in historical emissions, 2) differences into baseline assumptions on population and economic growth, 3) impact of policy implementation, and 4) other such as model form. The impact of socio-economic factors is shown to be the largest, historical calibration relatively small, and policy impact represents around one third.

Other related work on the assessment of NDCs

Den Elzen et al. (2016), including the author of this dissertation, assessed also smaller countries compared to Chapter 4. That paper assessed NDCs covering 105 countries but focussed on the results of G20 countries and shows that on a global level by 2030, the NDCs lack 4-6 GtCO2eq reduction efforts relative to current policies implementation. In addition, emissions from Brazil, Indonesia, Mexico and South Korea are expected to peak before 2025, while 2030 or later for China, India and South Africa. Brazil, China, the EU28 and the USA represent 50% of global GHG emissions but account for 80% of the projected 2030 reductions.

Box 8-2 Assessment of NDCs

8.4 HOW CAN COUNTRIES TIGHTEN THE GAP BETWEEN NDCS AND THE WELL BELOW 2 °C TEMPERATURE LIMIT AND SCALE UP THEIR DOMESTIC CLIMATE ACTION?

Countries could learn from past and current successes in policy implementation from other countries. While successful policy implementation can provide a guiding example for implementation in other countries, it should be noted that the country context matters and can sometimes form a barrier to replication such as different legislative systems or institutional settings. Still, also in those cases collecting sufficient background information to determine success factors and allow for experimentation could help translate policy instruments' implementation to other countries.

To show the potential of replicating 'good practice policies', we have estimated the impact of replicating nine successful sector examples in all countries worldwide. The assessment starts with selecting successful sector examples from a shortlist of effective policies for each sector. Based on historical impact or future policy target levels, the most successful policy was selected, such as the German feed-in-tariff and UK renewable portfolio standard, EU fuel economy standards, and Brazilian regulations and enforcement in the forestry sector (see Table 8-3). Germany and the UK showed on average 1.35% growth in renewable electricity production between 2004 and 2012. The annual fuel efficiency of EU cars decreased by 1.8% between 1990 and 2015. The Forestry Code in Brazil successfully decreased deforestation in the Amazon from 1.95 Mha/y to 0.58 Mha/y between 1996 and 2014 until the policy was reversed. These policies were translated to appropriate sector indicators for which the 2030 levels could be replicated in the models, such as annual growth in renewable generation

(%), fuel efficiency (km/l) and deforestation rates relative to 2010 (%) (see Table 8-3). This was implemented in the IMAGE energy (TIMER) and GLOBIOM/G4M land-use models to determine the global impact on greenhouse gas emissions.

Table 8-3 Successful sector examples and translation to policy impact

Main sector	Policy action	Successful policy instrument	Policy impact indicator
Energy supply	Increase renewables in electricity production	Renewable portfolio standard, feed-in-tariff in the UK and Germany	+1.35% growth in the share of RE generation per year
	Reduce flaring and venting in oil and gas production	Regulation and carbon tax in Norway	4.4% annual reduction of oil/gas intensity ($ktCO_2eq$/Mtoe) until 2030
Industry	Enhance energy efficiency of industrial production	Energy agreements in Ireland	1% annual energy savings improvement above current efforts until 2030
	Reduce fluorinated emissions	International agreement	70% reductions below 2010 F-gas emissions
Buildings	Enhance the efficiency of the residential building envelope	EU regulation	Energy intensity of 0 kWh/m² by 2030 (space heating)
	Set efficiency standards for appliances and lighting	Appliance standards in EU countries	Average efficiency improvement of 1.8% per year until 2030
Transport	Improve fuel efficiency of cars	Fuel economy standard in the EU	Fuel economy standard of 26 km/l in 2030
	Increase number of electric cars (charged with renewable electricity)	Tax levies and investments in infrastructure in Norway	25% share of new electric vehicles in 2020, 50% in 2030
LULUCF	Reduce deforestations in forests	Regulations and enforcement in Brazil	Decreasing deforestation rate relative to 2010 by 22% in 2020, 44% in 2030.

Replicating nine successful sector policy examples from the energy supply, industry buildings, transport, and LULUCF sectors in countries across the world between 2015 and 2030 is projected to reduce global GHG emissions in 2030 by 10 GtCO2eq, which is 17% below the current policies scenario, and is close to 2010 levels. This would significantly reduce the emissions gap by 2030 with a 2 °C pathway. The largest reductions were the results of replicating the policy impact of renewable electricity, reduction of f-gas, decrease flaring and venting, and industry efficiency policies.

This approach is an alternative to the traditional method of determining the potential for international climate policy with models by developing 2 °C or 1.5 °C pathways based

on a global carbon price. The most common practice to explore pathways towards the 1.5 and well below 2 °C target with IAMs is implementing a global uniform carbon price, leading to a cost-optimal pathway towards the climate goal. At the same time, however, the likelihood that such a universal price can be implemented is small. One can even ask whether this is attractive, as specific policy measures might have more social support and/or co-benefits. Thus, instead of merely applying a global carbon price, an approach based on concrete measures, including successful examples of policies implemented elsewhere, presents a more realistic method to represent climate policy in IAMS and explore ways to implement ambitious goals. Such scenarios could even account for local circumstances – such as specific preferences for measures (e.g. regarding nuclear power) or instruments (e.g. financial instruments versus standards). One challenge is to align the choice of parameters to national priorities and local circumstances that affect implementation success.

Other related work on the assessment good practice policies

Fekete et al. (2021) have updated the analysis of good practice policies from Chapter 5 by adding more sectors resulting in thirteen successful sector examples for which global replication is projected to result in a peak of global GHG emissions by 2020 and a reduction of global emissions by 20% relative to the current policies scenario by 2030. The assessment was done with a bottom-up model and the IMAGE model, and results are presented for ten large emitting economies and the world. Sectors added are agriculture and freight transport. Most selected policies were identified in OECD countries as more information on policy performance was available and often also showed higher historical performance. Also, information was difficult to obtain in hard-to-abate sectors such as industry and buildings.

The largest reductions are expected from the power sector, LULUCF sector, and industry sector. The NDCs of all countries analysed would be overachieved by replicating the successful sector examples. However, results are uncertain due to the dependency of NDC targets on economic growth in India and uncertainty in projected land-use emissions in Brazil.

Box 8-3 Update of good practice policies

8.5 TO WHAT EXTENT CAN SUBNATIONAL AND BUSINESS ACTORS CONTRIBUTE TO CLOSING THE GLOBAL GAP, AND HOW MUCH ARE ACTIONS FROM THESE ACTORS ADDITIONAL TO NATIONAL GOVERNMENT IMPLEMENTATION?

Non-party stakeholders are invited in the Paris Agreement to scale up their efforts and support actions to reduce emissions and demonstrate this in the Non-state Actor Zone for Climate Action (NAZCA) (UNFCCC, 2015b). These Non-Party stakeholders are non-state and subnational actors (cities, regions and businesses) that could ensure and accelerate national implementation or tighten the emission gap. The non-state and subnational actors can pledge actions as part of International Cooperative Initiatives (ICIs) or individually.

International cooperative initiatives are international activities outside the UNFCCC driven by non-state actors or coalitions of national governments committed to reducing greenhouse gas emissions. Such initiatives often operate in specific sectors. Besides non-state and subnational actors, we also included coalitions of national governments outside the UNFCCC context, such as the Kigali Agreement and the International Maritime Organisation (see Table 8-5). Most initiatives set overarching goals that apply to all members, although they also motivate members to set individual commitments in some cases. Interestingly, ICIs often set aspirational goals, but enforcement is more complicated as they lack the power to change their members' behaviour.

The assessment of the contribution of non-state actors is complex. In addition to estimating the direct impact of their actions relative to a reference level, one also needs to estimate the additionality to actions already covered by governments in their NDCs or current policies. As the countries report progress on all domestic emissions, the action by non-state actors cannot simply be added to the NDCs as this would easily lead to double-counting. Here, we assume that coordinated actions by ICIs can lead to additional reductions in countries that submitted NDCs, provided that their measures do not cover emissions and sectors included in the NDCs (e.g. methane measures in China are not covered by the CO_2-intensity target for 2020). The estimated additional effect in this analysis is a conservative estimate (*no additional effect,* see Box 8-5), as ICI actions that are more ambitious and overlap with national targets are assumed to be fully counteracted by less action in the economy elsewhere. However, other assumptions are possible, see hereafter.

Table 8-4 Global reductions from individual non-state and subnational actions and International Cooperative Initiatives (ICI) by 2030 with lenient/strict rules for additionality. Comparison between Chapter 6, 7 and Lui et al. (2021).

	Additionality rules	
	Strict	**Lenient**
Individual		(*Chapter 6*) 1.2 - 2 $GtCO_2eq$ (relative to current policy scenario)
Cooperative initiatives	(*Chapter 7*) 5 $GtCO_2eq$ (11 ICIs) (relative to no-policy baseline)	(*Lui et al, 2021*) 18-21 $GtCO_2eq$ (17 ICIs) (relative to current policy scenario

A selection of eleven ICIs covering most energy and AFOLU sectors is projected to reduce global GHG emissions by 2.5 GtCO2eq in 2020 and by 5.0 GtCO2eq in 2030 relative to a counterfactual scenario without climate policies (see Table 8-4 and Figure 8-4), and 30% of reductions is considered additional to 2030 NDC targets. These calculations show how much ICI actions could reduce emissions and how much they are additional to national NDC targets. The estimates include the overlap between different ICI actions that occurs if they target the same sectors and emissions, and was estimated to be small, 0.3 $GtCO_2eq$ by 2030.

8

Note that reductions would increase to much higher levels of 1821 $GtCO_2eq$ relative to the current policies scenario (Lui et al., 2021) (see Box 8-4) if a few more ICIs were added and especially if it were assumed that (part of the) more ambitious action is not replaced elsewhere (see Table 8-4 and Figure 8-4). This shows that assumptions on additionality are crucial for interpreting results on non-state and subnational actor reductions (see Box 8-5).

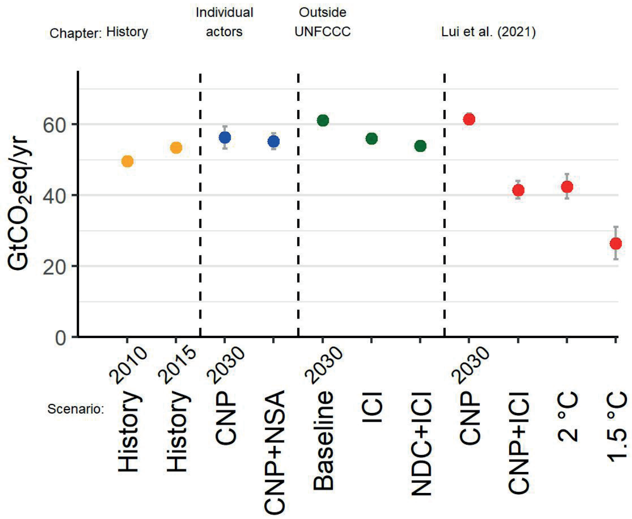


Figure 8-4 2030 emission levels for different non-state and subnational actor scenarios. Comparison of chapters 6, and 7 Lui et al. (2021) with historical emissions. CNP=Current National Policies, NSA=(individual) non-state actors, ICI=International Cooperative Initiatives

Other related work on the impact of international cooperative initiatives, assuming actions do not replace actions elsewhere

Lui et al. (2021) use the same methodology as Chapter 7 to determine the impact of ICIs on global greenhouse gas emissions, different from the assumptions made in the assessment from Chapter 6. It is estimated that a selection of 17 large ICIs together could reduce GHG emissions by 18-21 $GtCO_2eq$ by 2030, which is in the range of a 2 °C pathway**.** The largest global reductions are expected to come from the business, forestry sector and cities and regions. The ICIs were selected from a list of 300 (see Table 8-5). Like in chapter 6, it is assumed that all ICIs achieve their stated targets, but in contrast to Chapter 6 it is assumed that non-state and subnational actions do not displace actions elsewhere.

The reductions are larger than those estimated for individual actors due to the ambitious mitigation goals, the pursuit of sectoral transformational change, and large geographical coverage. However, it is important to understand that these reductions can only materialise if governments adopt and integrate the voluntary ICI ambitions and coordinate effectively. For this, monitoring and tracking are essential.

Box 8-4 Impact of international cooperative initiatives, assuming actions do not replace actions elsewhere

Table 8-5 International cooperative initiatives included in Chapter 6 and Lui et al (2020). ICIs with a large overlap in members are put on the same row

Sector	ICIs (Chapter 6)	ICIs (Lui et al, 2020)
Energy efficiency		United for Energy Efficiency
		Super-efficient Equipment and Appliance Deployment Initiative
Transport	Global Fuel Economy Initiative	Global Fuel Economy Initiative
	International Civil Aviation Organisation	Collaborative Climate Action Across the Air Transport World
	International Maritime Organisation	
		Lean and Green
Renewable Energy		European Technology & Innovation Platform forPhotovoltaics
		Africa Renewable Energy Initiative
		Global Geothermal Alliance
Business & Industry		RE100
	Carbon Disclosure Project	Science-Based Targets initiative (SBTi)
	Cement Sustainability Initiative	
	Zero Routine Flaring by 2030	
Forestry	New York Declaration of Forests	Bonn Challenge / New York Declaration on Forests (NYDF) / Governors' Climate and Forests Task Force
Non-CO2 gases	Global Methane Initiative	Climate & Clean Air Coalition
	Kigali Amendment	
Cities and regions	EU Covenant of Mayors	Global Covenant of Mayors for Climate & Energy
	C40 Cities Climate Leadership Group	C40 Cities Climate Leadership Group
		Under2 Coalition

Regions, cities and companies that have put forward individual commitments are projected to reduce global GHG emissions by 1.2-2.0 GtCO2eq (3.8-5.5%) in 2030 relative to the current policies scenario (see Table 8-4 and Figure 8-4) if they realise their often more ambitious targets than brought forward by national governments, assuming their actions do not decrease the pace of action elsewhere. Next to committing to climate action in cooperative initiatives, non-state and subnational actors also commit to climate actions individually or register their individual commitments as part of these cooperative initiatives. These actions are registered by international databases such as CDP (CDP, 2019a), Global Climate Action Portal (UNFCCC, 2020), or the Global Covenant of Mayors (GCOM, 2021). The analysis of individual commitments was based on 79 regions/provinces, 6,000 cities and 1,600 companies that together account for 8.1 $GtCO_2eq$ emissions after subtracting overlaps. It shows that especially pledges from power companies were not very ambitious. The additional reductions for the ten economies included in the analysis were calculated relative to two existing current policies scenarios and range from 0-0.7% for China to 10.7-14.3% for the United States. This shows that the most significant impact is expected from the USA.

It is essential to understand the crucial assumptions on overlap and additionality made in assessments of non-state and subnational actor climate actions (see Table 8-6). Overlap and additionality are critically important in estimating the impact of non-state actors. Overlap occurs if actors target the same emissions and sectors, e.g., emissions from companies located in a city that both have reduction targets. The overlap between the two actors is the amount of total emissions they both cover with their commitments. Additionality occurs if non-state and subnational actors targets overlap with national targets but aim for higher reductions than imposed by these national targets. This is an important factor in the assessments because these assumptions on additionality greatly influence the results, and no consensus is reached (see Box 8-5). In Chapter 6, we applied the conservative approach from Box 8-5, assuming that action from non-state and subnational actors that are more ambitious than anticipated from national policies will be counteracted with less ambitious action elsewhere. This resembles the concept of leakage of emission reductions between countries. On the other hand, there is currently limited coordination between national governments and these actors on climate policy and ambition. Also, national governments are not capturing region, city or company commitments to establish their national goals (Hsu and Rauber, 2021). In the latter case, reductions can be assumed to be (partly) additional if they are more ambitious than nationally pledged or implemented. This was assumed in Chapter 7 for the assessment of individual commitments. We identified two ways of accounting for partial additionality are: 1) only those reductions that are very ambitious (e.g. in line with 2 °C pathways) are assumed to be additional, or 2) assume that a portion of the actors are laggards that only follow baseline emissions (see Table 8-6).

Table 8-6 Overlap and additionality in assessments of chapter 6 and 7

	Chapter 6	**Chapter 7**
Overlap	Calculated between subnational actors and businesses	Calculated between regions, cities and companies
Additionality	Only if actions take place in sectors or for GHG emissions not covered by NDCs	National - regions → full accounting Regions - cities and cities-companies ➔Only if the city/company target is very ambitious. ➔Include accounting for laggards.

International cooperative ambition is high but not reflected yet in strong, individual actions. The estimated reductions from ICIs are relatively high (from Chapter 7 and Lui et al. (2021))

compared to those from individual actions by non-state and subnational actors (Chapter 6). These ICI reductions could bring the world close to the pathway limiting global mean temperature increase to below 2 °C (Lui et al. (2021)). However, these cooperative initiatives put forward ambitious goals, often assuming increasing memberships but not always backed by concrete plans and targets from individual actors. Transparency on achieved results from ICIs could help in separating real ambitious actions from those that are not delivering.

Other related work on the assessment of non-state and subnational actors' climate actions

Based on a few existing publications (including Roelfsema et al. (2015), which was the basis for Chapter 6), Hsu et al. (2019b) discuss existing issues on the research agenda for assessment of non-state and subnational actors, such as differences in characteristics of set goals and additionality. This article aims to give clear and consistent definitions of concepts used, an overview of existing methodologies, and recommendations on how to best approach these assessments.

To quantify the impact of non-state and subnational climate action, more clarity on assumptions and methodology is needed. Goals set by these actors vary in different aspects. One important observation is that ICIs vary with respect to set goals and climate action statements, where some initiatives only require an overall commitment, whereas others require specific target setting, monitoring and evaluation. Another observation is that existing analyses are inconsistent concerning the scope of emissions covered by different actors (Scope 1,2, and/or 3), target and base years, and counterfactuals or scenarios used in the assessments. In addition, one barrier for assessment is the availability of information about non-state and subnational actors' baseline emissions, targets and growth assumptions which is often scarce and non-transparent and drafted with multiple accounting methodologies.

To assess the impact of non-state and subnational actors at the national level, it is essential to be clear on the assumptions on additionality**.** Additionality occurs if one actor has a more ambitious commitment in case of overlap. Four different assumptions to calculate this additionality were identified in the literature: 1) the *No additional effect* is assumed in case of full overlap, 2) the *Partial conservative effect* assumes the actions to be partly additional and accounts for laggards that underperform, 3) the *Partial effect* only accounts for additionality if the target in line with the Paris goals and 4) the *full effect* assumes that all reductions beyond the commitment of the larger geographical area that it is part of, is additional.

Box 8-5 A roadmap for the assessment of non-state and subnational climate actions

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8.6 WHAT IS THE IMPACT ON GREENHOUSE GAS EMISSIONS OF IMPLEMENTED POLICY, CLIMATE ACTIONS, AND POTENTIAL ENHANCEMENTS TOWARDS LIMITING GLOBAL TEMPERATURE CHANGE TO BELOW 2 °C AND 1.5 °C ABOVE PRE-INDUSTRIAL LEVELS?

The scenario results and insights from the evaluated research questions on current policies, NDCs and potential enhancements from good practice policies and climate actions from non-state and subnational actors give a clear picture of the current status of climate policy towards meeting the long-term temperature targets.

The climate negotiations from the last decade have resulted in increasingly clear global ambitions. However, this has not led to sufficient ambition or action by countries or other actors to stay on track to achieve global temperature goals or even reach a global peak of emissions. This dissertation presented several estimates of the impact of currently implemented policies in the context of global goals and internationally pledged domestic targets, covering various points of time, focussing on the Cancun pledges (2020) and the Paris Agreement contributions (2030). Figure 8-5 puts the results of the different chapters in the larger perspective of some important milestones since 1971, representing different international climate conferences and agreements.

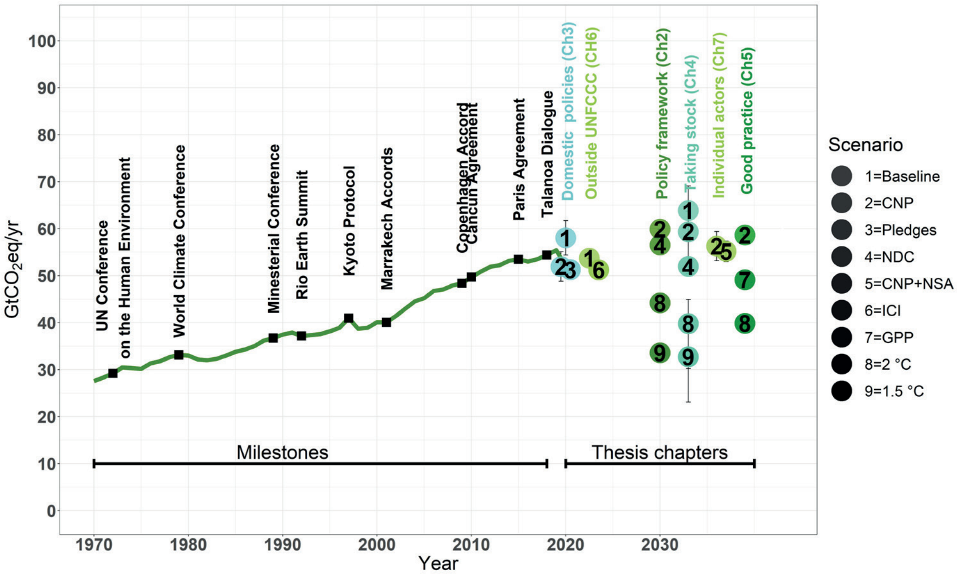


Figure 8-5 Summary of dissertation results per chapter. Global greenhouse gas emissions level estimates (including LULUCF) from dissertation chapters in the context of milestones from the international climate

negotiation conferences. Milestones are linked to global historical emissions between 1970 and 2020. Chapter titles to global greenhouse gas emissions projections from chapters 2-7 supplemented with IMAGE projections for LULUCF emissions and 'Rest of the world '(OECD, 2012) *for Chapters 3 and 7. CNP=current (national) policy scenario, CNP+NSA=current policies and non-state climate action scenario, ICI=international cooperative initiatives scenario, GPP=good practice policies scenario. Error bars show minimum and maximum emission levels from different models for scenarios, except for the 'Taking stock' chapter, where they represent the 10th and 90th percentile. The ranges are based on 1 (Ch2), 2 (Ch3), 9 (Ch4), 1 (Ch5), 1 (Ch6), 2 (Ch7) model(s). Historical greenhouse gas emissions are based on CO2 fossil, industry and land use* (Friedlingstein et al., 2020)*. non-CO2 fossil, industry and waste* (Gütschow et al., 2016) *and non-CO2 land use and agriculture* (FAO, 2020)*.* (OECD, 2012) *is used in Ch1 for baseline emissions from countries not included in assessment.*

Implementation of current implemented policies has significantly fallen behind the overall ambitions in the past three decades. The scenarios exploring emission trajectories without new climate policy project increases in line with historical growth rates (see Figure 8-5). Implementation of current policies is expected to lead to some reductions but still results in a net increase of global emissions compared to 2010 levels. Also, the 2020 pledges and 2030 NDCs merely stabilise emissions and are insufficient to bring the world on a cost-efficient 2 °C or 1.5 °C pathway.

8

The projected 2030 emission levels in the context of the Paris Agreement show both an ambition gap and an implementation gap (see Figure 8-6). In all assessments, the emissions gap is considerable. Currently, the estimated total gap by 2030 between current implemented policies and optimal pathways towards 2 °C and 1.5 °C is between 22-28 $GtCO_2eq$. This is equal to an additional 36-45% reduction relative to the current policies scenario. This can be divided into an *implementation gap* by 2030 between projected current policies and globally aggregated NDCs and an even larger *ambition gap* between projected NDCs and cost-effective pathways that keep the world on track to keep temperature increase well below 2 °C or 1.5 °C.

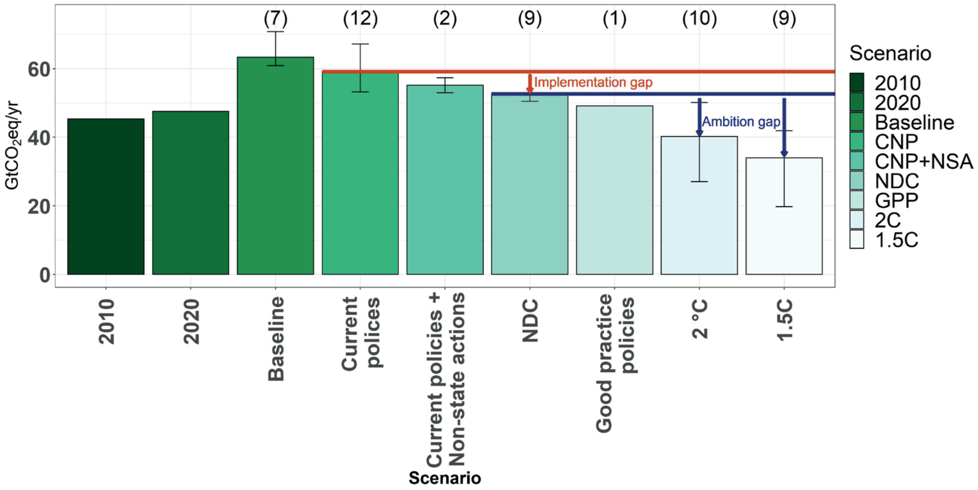


Figure 8-6 Global (median) greenhouse gas emission projections for 2030 for different climate policy scenarios developed in this dissertation compared to historical 2010 and 2020 total Kyoto greenhouse gas emissions. Scenario results from different chapters (and models_ have been combined. Error bars give minimum and maximum emission levels for specific scenarios from the assessments. The number of models that participated in the assessments and produced results for a specific scenario are shown in brackets. Emissions are in GWP AR4.

Actions from non-state and subnational actors could contribute to tightening the emissions gap, but this would need a clear translation of ambition to concrete plans together with improved transparency. This dissertation contributed to the international policy environment by broadening the scope of climate actions to cities, regions and businesses, where the interaction between actors and geographical scales is important (Jordan et al., 2015). The aggregated ambitions of non-state and subnational actors could tighten the emissions gap as it is projected to decrease emissions relative to the current policy scenario by 2 $GtCO_2eq$.

Worldwide implementation of good practice examples could close half the emissions gap between current policies and 2 °C pathways. A possible route forward for climate policy is to promote a process of international policy learning and the 'emergence of a global marketplace of ideas' (Hadjiisky et al., 2017). Countries could learn from each other and replicate successful sector policies from other countries, adjusted to local circumstances. Implementing ten successful examples in all countries globally would reduce global GHG emissions by 10 $GtCO_2eq$ relative to a current policy scenario by 2030.

The research in this dissertation has contributed to the improvement of realism of integrated assessment models. Integrated assessment models have been called upon to improve some of the realism of mitigation pathways. This is especially important when assessing whether the world is on track to achieve the temperature goals with current implemented (domestic) policies. The research in this dissertation contributed to climate policy assessment by developing a methodology to incorporate real implemented (sector) climate policies instead of a general carbon tax. This resulted in an improved representation of short-term sector and technology trends that affect long-term emission reductions.

However, to achieve the complex transformative systemic changes needed to keep the global temperature change well below 2 °C or even 1.5 °C, more aspects are important besides implementation of effective policy instruments. Policy learning and multi-level governance are other important components (de Coninck et al., 2018). The model-based mitigation pathways as developed in this thesis addressed these topics by addressing international policy learning and good practice policies to bring the world closer to a 2 °C or 1.5 °C scenario. In addition, this dissertation responded to the call to address the polycentric governance structure of climate policy by including different actors. It examined the role of non-state and subnational actors by assessing their impact on global greenhouse gas emissions partly based on IMAGE mitigation pathways. For this purpose, it gave insights to what extend bottom-up reductions are taking place to support or go beyond national climate policy and what could be achieved if actors work together in international cooperative initiatives.

8.7 RECOMMENDATIONS FOR FURTHER RESEARCH

Informing the international climate policy community and the wider community requires regular updates and insights into the progress of historical emissions, policies and NDC targets. Although this dissertation showed how current domestic policies could be implemented in IAMs, and IMAGE specifically, informing the international climate policy community requires regular updates and insights into the progress of historical emissions, policies and NDC targets. For some IAM models, it is still important to include more details on current policies and follow the example of the IMAGE model. In general, however, it is essential to accelerate and automate the update of this information in these models. Although not straightforward, smart developments are needed, as IAMs are often complex models that consist of several interlinked sub-models. The development of open-source software based on the IAMC format (Gidden and Huppmann, 2019) could broaden the IAM community and cooperation between different models teams is already a good starting point. However, further automation would support reporting the current status of implementation.

Although this dissertation contributed to increasing realism of IAM mitigation pathways, more model changes would be needed to assess the different 'how do we get there' questions that stand out after the Paris Agreement. Examples are incorporating local circumstances, improve representation of policy instruments and include social science insights. However, as IAMs describe key processes between the human and natural environment, a balance between too much detail and including important factors must always be considered.

As all actors are needed to implement the global goals from the Paris Agreement, IAMs would need to include the ambition and commitments from non-state and subnational actors. This can be done by linking to more detailed models or downscaling and attributing IAM results to actor geographies. One option to include more actors is developing global agent-based models (ABMs) that provide heterogeneous decision-making. However, a global ABM model does not (yet) exist, and these types of models generally focus on specific regions or parts of the energy system (De Cian et al., 2017). Nevertheless, these models could be calibrated to more high-level IAM results. In addition, it would be insightful to present mitigation pathways on lower aggregation levels by downscaling emissions and energy output to regions, cities, and companies. This could be done based on available grid data such as city boundaries, roads and industrial locations. New developments such as satellite imagery data (Yang et al., 2020) and open climate data using blockchain (Wainstein, 2021) are accommodating in this context.

The introduction in this dissertation of explicit current policies and good practice policies until 2030 in IAMs could be extrapolated to 2 °C, 1.5 °C or net-zero emission scenarios to include an explicit representation of policy targets and instruments until the end of this century instead of one global carbon tax after 2030. The starting point for these scenarios is the existing policy mix translated to model parameters from Chapter 4 and retrieved from the Climate Policy Database (NewClimate Institute, 2015). Subsequently, based on insights from the successful sector examples from Chapter 5 or Fekete et al. (2021), implementation mechanisms could be developed to determine the underlying policy targets and meet the long-term temperature goals. It will result in a 'second-best' portfolio of instruments that combines country-wide economic and different types of sectoral instruments (Bertram et al., 2015). The main challenge is the choice of policy targets in the absence of the minimising cost criterium.

An important topic for policy implementation that would need to be addressed by IAMs researchers and the broader research community is combining social science insights and

IAM results on mitigation. Other scientific disciplines such as social and political science are crucial in directing the world to transformative systemic changes. We need to understand which solutions are feasible or preferable, as also pointed out in the 'climate-policy models debated' article by Anderson and Jewell (2019) or even link these models to political feasibility (Jewell and Cherp, 2020). Important topics to be addressed in the context of mitigation pathways are multi-level governance, institutional capacities, behavioural change, and finance (de Coninck et al., 2018). Insights into multi-level governance, as described above, could expose the interaction between actors and geographical scales (Jordan et al., 2015) and identify catalytic effects. Institutions and human behaviour influence the decision-making process for effective policy implementation (De Cian et al., 2017). The financial system is crucial for supplying the large investments necessary for mitigation. However, insights are missing on the interdependence between investors' risk perceptions, depending on the credibility of climate policies and allocation of investments in the economy (Battiston et al., 2021).

Factors that affect social change are expected to have large impacts and need to be linked to IAM results by either bridging or integration. Bridging encompasses sequential and interactive approaches. The sequential approach invites social scientists to provide feedback on climate policy scenarios from IAMs resulting in revised model implementations based on boundary conditions that favour or hinder certain mitigation measures (Geels et al., 2016). The integration approach maps and assesses societal assumptions in existing models by integrating generalisable and quantifiable social patterns (Trutnevyte et al., 2019).

CHAPTER

9

Chapter 9 Samenvatting en conclusies

9.1 INTRODUCTIE

9.1.1 Internationaal klimaatbeleid in de afgelopen 30 jaar

De internationale klimaatonderhandelingen hebben een lange geschiedenis met zowel mislukkingen als successen. Enkele belangrijke mijlpalen waren de eerste Wereldklimaatconferentie in 1979 (Genève, Zwitserland), de Internationale Conferentie over de beoordeling van de rol van kooldioxide in 1985 (Villach, Oostenrijk) en de eerste ministeriële conferentie over klimaatverandering in 1989 (Noordwijk, Nederland). De oprichting van United Nations Framework Convention on Climate Change (UNFCCC) in 1992 (Rio de Janeiro, Brazilië) gaf de onderhandelingen een duidelijke status. Een belangrijk onderdeel was de doelstelling om de broeikasgasconcentraties te stabiliseren op een niveau dat gevaarlijke verstoring van het klimaatsysteem zou voorkomen. Na de oprichting van de UNFCCC was het Kyoto-protocol de eerste concrete stap om deze doelstelling in de praktijk te brengen en zo de mondiale uitstoot te verminderen. Geïndustrialiseerde (Annex I) landen kwamen overeen om de uitstoot van broeikasgassen tussen 2008 en 2012 met (gemiddeld) 5,2% te verminderen ten opzichte van 1990. De potentiële impact van het protocol werd kort daarna aanzienlijk verminderd door het besluit van de VS om het protocol niet te ratificeren. Enkele jaren later besloten Canada, Rusland, Nieuw-Zeeland en Japan niet mee te doen aan de tweede Kyoto-periode van 2012 tot 2020. Hoewel het protocol officieel tot 2020 in werking was, verschoof de focus naar een parallelle onderhandeling met als doel een overeenkomst te maken met alle landen. Dit voornemen werd vastgelegd in het Bali actieplan. Net als bij het Kyoto-protocol was het de bedoeling om een reeks bindende doelstellingen af te spreken met landen en een breder palet aan thema's. Deze poging mislukte echter in 2009 in Kopenhagen omdat er geen overeenstemming kon worden bereikt over bindende doelstellingen. Het akkoord dat op tafel lag bevatte de limiet om de temperatuur onder 2 °C te houden ten opzichte van het pre-industriële niveau, maar werd niet volledig ondertekend door de partijen van het UNFCCC. De onderhandelingen werden een jaar later hervat in Cancun waar tot enkele afspraken werd gekomen en er weer vooruitgang kon worden geboekt. Dit was het startpunt van een nieuwe hybride benadering van het internationale klimaatbeleid, waarbij landen vrijwillige bottom-up reducties beloven met gezamenlijk wereldwijde doelstelling wat de blauwdruk was voor het Akkoord van Parijs.

Het akkoord van Parijs in 2015 formaliseerde de lange termijn doelstelling om de temperatuurstijging sinds het pre-industriële niveau ruim onder 2 °C te houden en de inspanning om deze onder 1,5 °C te houden. Tegelijkertijd introduceerde het akkoord een proces om dit te implementeren. Aangezien het klimaatbeleid op nationaal niveau moet worden geïmplementeerd, vereist de overeenkomst dat landen hun bijdrage in de vorm van Nationally Determined Contributions (NDC's) indienen, inclusief mitigatietoezeggingen en te ondernemen acties. Deze bijdrages moeten leiden tot de binnenlandse uitvoering van het klimaatbeleid. Het Akkoord van Parijs bevat echter geen bindende doelstellingen voor landen, maar in plaats daarvan voorziet het in een inventarisatieproces waarin landen hun nationale toezeggingen en uitvoering geleidelijk afstemmen op de klimaatdoelstellingen voor de lange termijn. De gezamelijke actie die in dit proces wordt beoordeeld, omvat ook de inspanningen en maatregelen van partijen buiten de UNFCCC, zoals steden en bedrijven. Zij worden aangemoedigd om bij te dragen aan de uitvoering van het Parijs-Akkoord (UNFCCC, 2015b). Deze groep is ook gevraagd om bij te dragen aan emissiereducties. Het is op dit moment niet duidelijk wat de potentiële bijdrage is en of dit een aanvulling is op het optreden van nationale overheden.

9.1.2 Integrated Assessment modellen ondersteunen klimaatbeleid

Een uniek aspect van de klimaatonderhandelingen is de sterke betrokkenheid van wetenschappelijke kennis. Dit bestaat onder andere uit informatie over klimaatwetenschap, klimaatbeleid, effecten en mitigatiepaden. Hoewel wetenschappelijke informatie soms een directe weg naar de onderhandelingen vindt, is de meer officiële route via officiële rapporten zoals het IPCC- en het Emissions Gap-rapport van het VN-milieuprogramma (UNEP). Voor de informatie over mitigatie spelen de resultaten van Integrated Assessment Modellen (IAM's) een cruciale rol in deze rapporten. IAM's evalueren de impact van klimaatmitigatiestrategieën door scenario's of emissiepaden te ontwikkelen die meestal deze eeuw bestrijken. Ze kunnen verschillende emissiepaden laten zien die de broeikasgasconcentraties stabiliseren en de wereldwijde gemiddelde temperatuur ruim onder 2 °C of 1,5 °C te houden. Daarnaast kunnen ze ook de zogenaamde emissiekloof identificeren tussen de mondiale emissies die nodig zijn om de klimaatdoelstelling van Parijs te halen en de verwachte emissies op basis van volledig geïmplementeerde NDC doelstellingen.

Rond 2010 bevatten de meeste IAM's alleen gestileerde beleidsscenario's die meestal werden ontwikkeld door toepassing van een regionale of wereldwijde koolstofprijs. Sinds de goedkeuring van het Akkoord van Parijs en het toenemende aantal binnenlandse klimaatbeleidsmaatregelen verplaatst het klimaatbeleid zich echter van beleidsformulering en besluitvorming ('waar gaan we naartoe') naar de beleids-uitvoeringsfase ('hoe komen we daar'). Daarom zouden meer gedetailleerde beleidspaden waarin binnenlands klimaatbeleid is meegenomen de analyse van mitigatiepaden verbeteren. In de eerste plaats om de vraag te beoordelen hoe de emissiekloof kan worden gedicht en ten tweede om te zien of het huidige beleid voldoende is om de NDC doelstellingen te halen.

Om de impact van klimaatbeleid op de wereldwijde en binnenlandse uitstoot van broeikasgassen te beoordelen zijn klimaatbeleidsscenario's in dit proefschrift ontwikkeld en geïmplementeerd in Integrated Assessment modellen. Deze scenario's beschrijven verschillende niveaus van voorgenomen of vastgesteld beleid voor verschillende tijdshorizonnen en (groepen van) landen (specifieke details voor elk scenario verschillen per hoofdstuk):

- **Baseline**. Scenario dat huidige trends extrapoleert en historisch geïmplementeerd beleid omvat tot weergeeft een bepaalde datum (bijv. 2010).
- Huidig (nationaal) beleid (**CNP**). Scenario met klimaatbeleid tot een bepaald jaar (bijv. 2017) dat is goedgekeurd door het parlement of via een uitvoeringsbevel is uitgevaardigd.
- Internationale doelen. Binnenlandse emissiedoelstellingen die zijn toegezegd in het kader van de internationale klimaatonderhandelingen (Overeenkomsten van Cancun, Akkoord van Parijs)
    - **Pledges** (voor het jaar 2020)
    - **NDC** (voor het jaar 2030) ingediend bij het UNFCCC tot een bepaalde datum (bv. 2017).[27]
- Huidig (nationaal) beleid en niet-statelijke maatregelen (**CNP+NSA**). Scenario met het huidige geïmplementeerde beleid en aanvullende reducties die worden verwacht van individuele lagere overheden en niet-overheidsactoren zoals regio's, steden en bedrijven.
- Internationale samenwerkingsinitiatieven **(ICI)**. Scenario met het huidige geïmplementeerde beleid en aanvullende reducties die worden verwacht van lagere overheden en niet-statelijke maatregelen van internationale samenwerkingsinitiatieven.
- Beleid inzake beproefde toepassingen (**GPP).** Scenario dat de wereldwijde replicatie van succesvolle sectorvoorbeelden uit voorbeeldlanden vertegenwoordigt.
- Parijs-doelen. Temperatuurdoelstellingen vastgelegd in het Akkoord van Parijs
    - **2°** C-scenario: wereldwijd emissiescenario met de laagste implementatiekosten dat consistent is met het houden van de wereldwijde temperatuurstijging onder de 2 °C gedurende de 21e° eeuw en begint met lange-termijnreducties vanaf 2020.
    - **1,5°** C-scenario: wereldwijd emissiescenario met de laagste implementatiekosten dat consistent is met het handhaven van de wereldwijde temperatuurstijging onder 1,5 C tegen 2100 en begint met lange-termijnreducties vanaf 2020.°

[27] Doelstellingen voor 2025 worden vertaald naar 2030

9.1.3 De onderzoeksvraag van dit proefschrift

De officiële internationale klimaatonderhandelingen vinden inmiddels al zo'n 30 jaar plaats. Maar in deze periode is de mondiale uitstoot van broeikasgassen blijven stijgen. Ondertussen zijn ambitieuze mondiale doelen afgesproken in de Cancun-overeenkomsten om de wereldwijde temperatuur onder de 2 °C te houden, terwijl het Akkoord van Parijs het wereldwijde doel heeft vastgelegd om de wereldwijde gemiddelde temperatuurstijging ruim onder 2 °C of zelfs 1,5 °C te houden. Het Parijs Akkoord stelt bovendien dat zo snel mogelijk een wereldwijde piek van broeikasgasemissies en netto-nulemissies in de tweede helft van de eeuw bereikt moeten worden. De mondiale doelstellingen moeten echter worden uitgevoerd door middel van klimaatbeleid en -maatregelen op nationaal niveau. De cruciale vraag is dus of de wereld op schema ligt met de huidige implementatie van mitigatiebeleid en -maatregelen om een overgang naar een koolstofvrije wereld te garanderen. Integrated Assessment modellen worden gebruikt om deze vraag te beoordelen, omdat deze om een mondiaal beeld kunnen geven. De bovenstaande inzichten bepalen de onderzoeksvragen van dit proefschrift:

Wat is de impact op de uitstoot van broeikasgassen van geïmplementeerd klimaatbeleid, klimaatmaatregelen en mogelijke verbeteringen om de wereldwijde temperatuurverandering te beperken tot minder dan 2 °C en 1,5 °C boven pre-industriële niveaus?

Dit roept de volgende vier deelvragen op:

1. Hoe kunnen Integrated Assessment modellen het huidige binnenlandse klimaatbeleid evalueren in de context van de temperatuurdoelen op lange termijn? (Hoofdstuk 2)
2. Liggen landen op schema om hun toezeggingen voor 2020 en 2030 NDC's na te komen met het huidige beleid? (Hoofdstuk 3 en 4)
3. Hoe kunnen landen de emissiekloof voor 2030 tussen NDC's en de temperaturen van ruim onder de 2 °C aanscherpen en hun binnenlandse maatregelen opschalen? (Hoofdstuk 5)
4. In hoeverre kunnen lokale overheden en bedrijven bijdragen aan het dichten van de wereldwijde kloof, en in hoeverre zijn maatregelen van deze actoren een aanvulling op de implementatie door de nationale overheid? (Hoofdstuk 6 en 7)

Deze vragen draaien om de afspraken die in Parijs zijn gemaakt en de eerdere bottom-up toezeggingen die voortvloeiden uit het Akkoord van Kopenhagen. Daarom ligt de focus op de doelstellingen voor 2020 en 2030, met de nadruk op de laatste. Verschillende hoofdstukken introduceerden nieuwe onderwerpen in de wetenschappelijke literatuur rondom mondiale analyses en integrated assessment zoals binnenlands beleid in de context van lange-termijn doelen, internationale samenwerkingsinitiatieven en beleid inzake beproefde toepassingen. Vaak maakten deze echter deel uit van onderzoek in een grotere context. Omdat de auteur ook heeft bijgedragen aan andere wetenschappelijke artikelen in dezelfde tijd die bijdragen aan de inzichten die in dit proefschrift worden gepresenteerd, worden belangrijke inzichten uit dit andere werk gepresenteerd in tekstvakken in verschillende hoofdstukken.

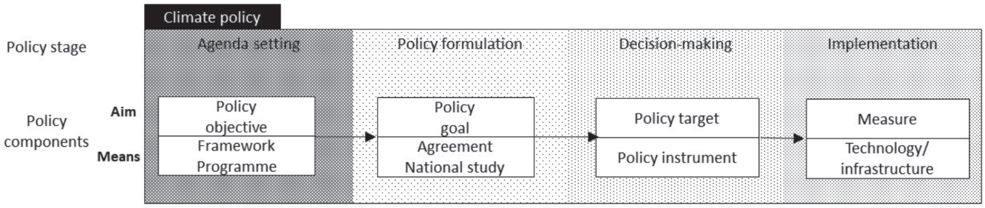
9.2 HOE KUNNEN INTEGRATED ASSESSMENT MODELLEN HET HUIDIGE BINNENLANDSE KLIMAATBELEID EVALUEREN IN DE CONTEXT VAN LANGE TERMIJN TEMPERATUURDOELEN?

Klimaatbeleidsanalyses op basis van IAM's spelen een belangrijke rol bij het ondersteunen van het internationale onderhandelingsproces. Deze modellen dragen bij door scenario's en emissiepaden te geven die verschillende soorten beleidsimplementatie vertegenwoordigen met verschillende striktheid van beleid, tijdshorizonnen en (groepen van) landen. In deze context is de precieze betekenis van het begrip 'klimaatbeleid' niet altijd duidelijk.

Het is belangrijk om een samenhangend raamwerk voor klimaatbeleidsanalyse te ontwikkelen met duidelijke definities om zo een gemeenschappelijke taal te ontwikkelen in verschillende disciplines. Een dergelijk raamwerk definieert belangrijke termen, concepten en scenario's die van toepassing zijn op de beoordeling van klimaatbeleid in IAMs. Naast het feit dat dit raamwerk nuttig kan zijn voor ontwikkeling van scenario's in IAMs, kan het beleidsmakers helpen de resultaten van modelstudies te begrijpen, en functioneren als een woordenboek om zowel beleidsmakers als andere wetenschappers te helpen de resultaten van IAM's te interpreteren. Hier wordt een klimaatbeleidsraamwerk gepresenteerd op basis van het beleidsraamwerk van Howlett (2009).

Het klimaatbeleidsraamwerk dat in dit proefschrift wordt gebruikt is onderverdeeld in twee dimensies: beleidscomponenten en beleidsfasen (zie Figuur 91).' Het raamwerk definieert klimaatbeleid als '*het resultaat van het vaststellen, formuleren, besluiten en uitvoeren van agenda's door (groepen van) overheden die maatregelen overwegen om klimaatverandering op internationaal en binnenlands niveau te beperken en die (ambitieuze) doelstellingen en doelen hebben die niet noodzakelijkerwijs door wetgeving worden gewaarborgd, of nationale doelstellingen die wel door wetgeving wordt gewaarborgd, en beleidsinstrumenten en -doelen die zijn ontworpen en gekalibreerd om deze voornemens en doelstellingen te verwezenlijken".* Het gehele klimaatbeleid wordt dan ook in verschillende beleidsstadia vastgesteld en bestaat uit verschillende beleidscomponenten. De beleidsfasen zijn afgeleid van de beleidscyclus: agendering, beleidsformulering, besluitvorming, beleidsuitvoering: problemen komen onder de aandacht van overheden, beleidsopties worden geformuleerd, overheden leggen een bepaalde beleidskoers vast en het beleid wordt uitgevoerd (Howlett, 2011; Lasswell, 1956). De beleidscomponenten zijn onderverdeeld in beleidsintenties en -middelen die bepalen waar het beleid naartoe gaat en hoe dit zal worden bereikt (instrumenten).

Klimaatbeleid wordt vastgelegd door beleidsvoornemens, geborgd door beleidsdoelstellingen en uitgevoerd door middel van beleidsdoelstelen en -maatregelen (zie Figuur 91). De beleidsdoelstellingen komen voor in verschillende stadia van de beleidscyclus en bestaan uit voornemens, doelstellingen en doelen die worden geborgd in verschillende vormen van (juridische) documenten zoals overeenkomsten, protocollen en wetgeving, en uitgevoerd door middel van beleidsinstrumenten vertaald naar (technische) maatregelen die technologieën en infrastructuur in de fysieke wereld installeren die resulteren in veranderingen in energie- en landgebruik en een vermindering van de uitstoot van broeikasgassen.



Figuur 9-1 Het begrip 'klimaatbeleid' wordt weergegeven door dalende abstractieniveaus en onderverdeeld in beleidscomponenten (ambitie/uitvoering)

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Het in dit proefschrift gehanteerde raamwerk is van toepassing op de huidige internationale en nationale beleidsvorming (zie Tabel 9-1). In de Engelse taal zijn de woorden 'objective', 'goal' en 'target' verwant en worden in dit hoofdstuk als minder to meer specifiek gebruikt. We vertalen deze woorden in het Nederlands als 'voornemen, 'doelstelling' en 'doel'. Het voornemen van de UNFCCC is om de concentraties van broeikasgassen in de atmosfeer te stabiliseren op een niveau dat gevaarlijke verstoring van het klimaatsysteem zou voorkomen (UNFCCC, 1992). Dit wordt in het Akkoord van Parijs vertaald naar de **doelstelling** om de stijging van de mondiale gemiddelde temperatuur ruim onder de 2 °C te houden en inspanningen te blijven leveren om deze onder de 1,5 °C te houden (UNFCCC, 2015b). Implementatie van klimaatbeleid gebeurt op nationaal niveau: landen moeten hun emissiereductiedoelstellingen en klimaatbeleid communiceren naar de internationale gemeenschap in zogenaamde Nationally Determined Contributinos (NDC's). De NDC die elk land moet voorbereiden, communiceren en onderhouden (UNFCCC, 2015b) is instrumenteel voor het Parijs-Akkoord. Naast NDC's worden landen verzocht een Langetermijnstrategie (LTS) voor 2050 in te dienen. Deze voornemens, doelstellingen, en doelen zijn vastgelegd in het UNFCCC-raamwerk, het Akkoord van Parijs en de NDC's.

Tabel 9-1 Klimaatbeleidsraamwerk toegepast op UNFCCC en EU-klimaatbeleid

Klimaatbeleid	Componenten/fasen	Agenda-instelling	Beleidsformulering	Besluitvorming	Implementatie
Internationaal (UNFCCC)	Beleidsintenties	**Beleidsvoornemen** Artikel 2: Stabiliseer de concentraties van broeikasgassen in de atmosfeer op een niveau dat 'gevaarlijke verstoring van het klimaatsysteem zou voorkomen'	**Beleidsdoelstellingen** • De stijging van de wereldwijde gemiddelde temperatuur ruim onder 2 °C boven het pre-industriële niveau houden en inspanningen blijven leveren om de stijging tot 1,5 °C te beperken • Bereik zo snel mogelijk een wereldwijde piek van de uitstoot van broeikasgassen • Het bereiken van een evenwicht tussen antropogene emissies per bron en verwijderingen per put van broeikasgassen in de tweede helft van deze eeuw	**Beleidsdoelen** Doelstellingen in NDC's (ingediend bij de Overeenkomst van Parijs): Emissiereductiedoelstellingen (bv. EU: 55% reductie ten opzichte van 1990 tegen 2030) niet-fossiele doelwitten (bijv. China: 20% niet-fossiel aandeel in 2030) bebossing (bijv. India: extra koolstofput van 2,5-3 $GtCO_2eq$ tegen 2030) Doelstellingen in LTS (ingediend bij de Overeenkomst van Parijs): (bv. EU: netto-nulemissies tegen 2050)	
	Beleidsmiddelen	**Raamwerkprogramma** UNFCCC	**Overeenkomst, Protocol, Akkoord, Verdrag** Overeenkomst van Parijs	**Artikelen van de Overeenkomst van Parijs (instrumenten)** Artikel 4.2: NDC Artikel 6: internationaal overgedragen mitigatieresultaten (ITMO's)	

Klimaatbeleid	Componenten/fasen	Agenda-instelling	Beleidsformulering	Besluitvorming	Implementatie
Economie-breed (EU)	Beleidsintenties	**Beleidsvoornemen** EU: de uitstoot van broeikasgassen verminderen door de meest milieuvriendelijke en kosteneffectieve beleidslijnen en maatregelen te nemen	**Beleidsdoelstellingen** EU: Klimaatneutraal door netto nul broeikasgasemissies tegen 2050	**Beleidsdoelen** EU: • (huidige) emissiereductiedoelstelling voor de gehele economie: 40% reductie ten opzichte van 1990 • (huidig) ETS-emissiereductiedoelstelling: 43% reductie ten opzichte van 2005 • (huidige) reductiedoelstelling voor de verdeling van de inspanningen: 30% reductie ten opzichte van 2005 • (geplande) emissiedoelstelling van 55% onder het niveau van 1990 tegen 2030	
	Beleidsmiddelen	**Programma** Europees programma inzake klimaatverandering	**Wetgeving** Europese klimaatwetgeving **Klimaatstrategieën, routekaart** Green Deal	**Beleidsinstrument (mix)** Klimaat- en energieraamwerk 2030 met ETS en het delen van inspanningen als belangrijkste beleidsinstrumenten	**Meten** Installatie van hernieuwbare energie (bijv. zonne-PV), isolatie van woongebouwen, herbebossing

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Op nationaal niveau wordt het beleid gewaarborgd door programma's of andere beleidskaders zoals de EU-doelstelling om de uitstoot van broeikasgassen te verminderen door de meest milieuvriendelijke en kosteneffectieve beleidslijnen en maatregelen te nemen (Europese Commissie, 2000)." Meer specifieke beleidsdoelstellingen kunnen worden gespecificeerd in termen van ambitieuze emissiereducties of energieverbruik die worden gerapporteerd in klimaatstrategieën, plannen of routekaarten, bijvoorbeeld het EU-klimaat- en energiekader voor 2030 (Commissie, 2014), en worden soms gewaarborgd door klimaatwetgeving zoals de Europese klimaatwet (Europese Commissie, 2020a). Ook de klimaatneutraliteitsdoelstelling van de Green Deal roadmap is zo'n beleidsdoelstelling (Europese Commissie, 2019). Deze doelstellingen worden bereikt door de implementatie van beleidsinstrumenten zoals de EU-regeling voor de handel in emissierechten en het Effort-sharing Mechanism. Vaak maken deze instrumenten deel uit van een beleidsmix die een overkoepelende reductiedoelstelling omvat. De implementatie van beleidsinstrumenten leidt uiteindelijk tot fysieke en infrastructurele veranderingen zoals pv-installaties op woondaken of waterstofpijpleidingen.

De elementen uit het beleidsraamwerk zijn de bouwstenen voor het ontwikkelen van klimaatbeleidsscenario's in het IMAGE-model. De klimaatbeleidsscenario's worden geïmplementeerd om de geaggregeerde impact van binnenlands klimaatbeleid in de context van het Parijs-Akkkoord te evalueren. Hiervoor worden vijf scenario's geïntroduceerd: geen nieuw beleid, huidig beleidsscenario, NDC-scenario en de 2 C- en 1,5 C scenario's die de Parijs vertegenwoordigen (zie Tabel 9-2).

Tabel 9-2 Klimaatbeleidsscenario's

Klimaatbeleid	Beleidsformulering	Besluitvorming
Beleidsdoelstellingen op internationaal niveau (UNFCCC)	**2 C/1,5 C scenario** 2100: vertaling naar W/m², CO_2 budget, ppm	**NDC/LTS-scenario** • Koolstofprijs om (toegezegde/berekende) LTS/NDC-doelstellingen te implementeren • Koolstofprijs om CO_2 of broeikasgas-intensiteitsdoelstelling te implementeren • Niet-fossiele doelstelling door minimumvereisten te stellen niet-fossiele technologieën
Beleidsmiddelen op economisch niveau	**(niet gemodelleerd)** Doelstellingen worden achteraf gecontroleerd en moeten worden bereikt door geïmplementeerde beleidsdoelen	**Huidig beleidsscenario** • Koolstofprijs of energiebelasting (bijv. Canadese koolstofbelasting) • Invoerparameter van model wijzigen om doel af te dwingen (bijv. toestelstandaard) • Vertaal beleidsdoelstelling naar geschikte invoerparameters voor model (bijv. gebouwen met netto-nulemissies tot 0 GJ/m²)

Klimaatbeleid	Beleidsformulering	Besluitvorming
		• Gebruik ambitieuze doelen uit de klimaatstrategie (bijv. hernieuwbare veilingen in Brazilië)
		Gepland beleidsscenario (niet gemodelleerd)
Geen nieuw klimaatbeleid		**Geen nieuw beleidsscenario**
Klimaatbeleid	**Componenten/ niveaus**	**Beleidsformulering Besluitvorming**

Temperatuurdoelen uit de **2 °C- en 1,5 °C-scenario's** worden vertaald naar stralingsforceringsniveaus (in W/m^2) als input voor het FAIR-model, waarbij 2,6 en 1,9 W/m^2 overeenkomen met een kans van 66% om in 2100 onder de 2 °C en 1,5 °C te blijven (met mogelijke overschrijding). Er wordt vanuit gegaan dat klimaatbeleid na een bepaald startjaar (bijvoorbeeld 2020) op mondiaal niveau kosteneffectief wordt uitgevoerd. Het **NDC-scenario** beschrijft de impact van de volledige uitvoering van de internationaal toegezegde binnenlandse doelstellingen. NDC-doelstellingen in termen van emissiereductiedoelstellingen ten opzichte van een basisjaar kunnen in het FAIR-model worden geïmplementeerd en doelstellingen voor hernieuwbare energie en bosbouw in het TIMER- en IMAGE-landgebruiksmodel. Hetzelfde geldt voor de lange-termijndoelen uit het **LTS-scenario**. Het **huidige beleidsscenario** beschrijft de impact van binnenlands beleid, d.w.z. uitgevoerde beleidsdoelstellingen en -instrumenten. De beleidsdoelstellingen en -instrumenten zijn verzameld in de Climate Policy Database (NewClimate Institute, 2015). Om deze scenario's te implementeren moeten de doelstellingen en beleidsinstrumenten worden vertaald naar modelparameters en voor het TIMER-energiemodel, IMAGE-landgebruiksmodel en FAIR-beleidsmodel. Er zijn verschillende manieren om beleid in het IMAGE-model te implementeren; 1) soms zijn de beleidsinstrumenten direct beschikbaar, zoals een koolstof- of energiebelasting, 2) in andere gevallen kan de beleidsdoelstelling dat gekoppeld is aan een beleidsinstrument worden gebruikt, zoals de normen voor efficiëntie van huishoudelijke apparaten, 3) en ten slotte als er geen expliciete doelstelling bestaat kan het effect kan worden geschat aan de hand van beleidsdoelstellingen die zijn gerapporteerd in nationale studies of aan de hand van effecten die in de literatuur zijn gerapporteerd. Het **scenario zonder nieuw beleid** is een basisscenario dat een extrapolatie van de huidige trends weergeeft zonder uit te gaan van nieuw geïmplementeerd beleid na een bepaalde historische datum.

9.3 LIGGEN LANDEN OP SCHEMA OM HUN 2020 CANCUN BELOFTES EN 2030-NDC DOELSTELLINGEN MET HET HUIDIGE BELEID NA TE KOMEN?

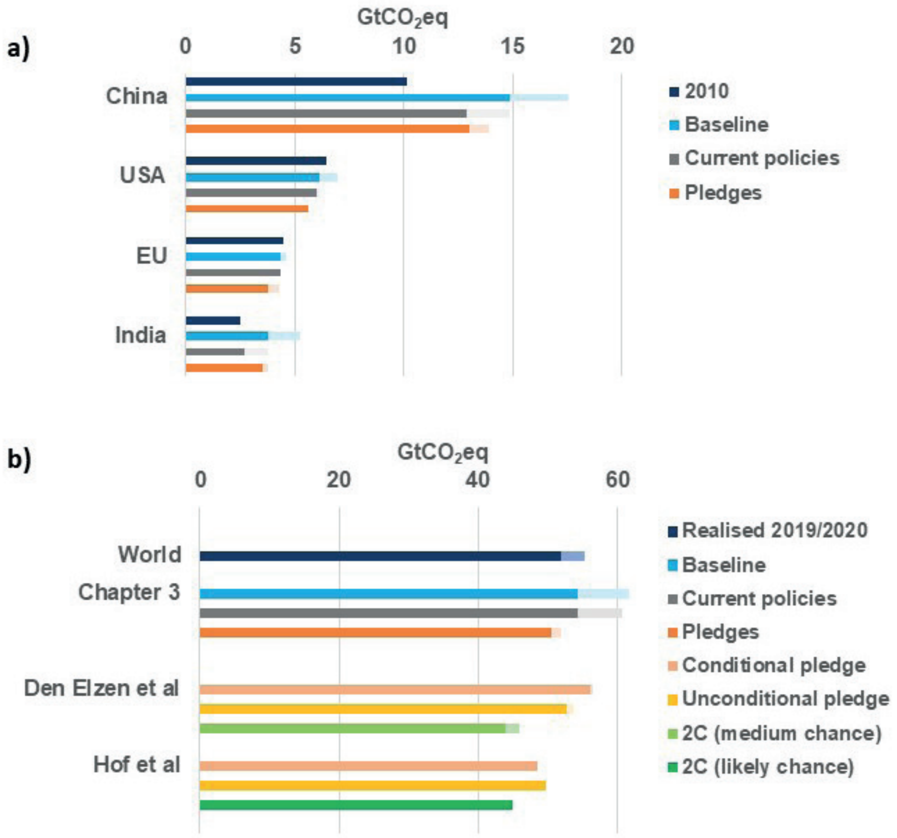
De klimaattop van Kopenhagen en de daaropvolgende akkoorden van Cancún hebben de 2 °C-limiet en het proces van bottom-up toezeggingen van landen ingevoerd. Dit proces was een nuttige ervaring en input voor het ontwerp van het Parijs-Akkoord waarbij elementen werden gerecycleerd zoals de beloftes in NDC's en de vaststelling van temperatuurdoelstellingen voor de lange termijn. De ontwikkeling van de methoden die in dit proefschrift zijn ontwikkeld om de impact van beleid en de daaruit voortvloeiende emissiekloof te beoordelen is gestart rond de Cancun-overeenkomsten (UNEP, 2016a). Daarom presenteren we een deel van het werk dat is gedaan in de context van de Cancun-overeenkomsten voor 2020 en daarna de beoordeling van de doelstellingen en nationale doelen vastgelegd in het Parijs-Akkoord.

9.3.1 2020 Cancun beloftes

De analyse van het binnenlandse beleid in de context van de Cancun beloftes (gedaan in 2012) was gebaseerd op twee methodes. De eerste methode was gebaseerd op de IMAGE baseline-projecties die zijn ontwikkeld voor de Environmental Outlook (OESO, 2012) van de OESO, gecombineerd met aanvullende berekeningen om beleidsreducties te schatten. De tweede methode maakt gebruik van projecties uit nationale studies, aangevuld met World Energy Outlook (IEA, 2011) en US EPA (EPA, 2006) projecties. Voor beide methoden werden de reducties voor elk beleid afzonderlijk berekend, en werd er een inschatting gemaakt van de overlap tussen beleidsmaatregelen (bv. verminderingen van hernieuwbare en efficiëntiebeleidsmaatregelen). Daarnaast werd de impact van voorwaardelijke of onvoorwaardelijke Cancún-toezeggingen berekend op de uitstoot van broeikasgassen. In deze context betekent conditionaliteit dat landen de toezeggingen zullen uitvoeren op voorwaarde van financiering of uitvoering door andere landen.

De analyse van de Cancún beloftes in 2012 liet een gemengd beeld zien van de vraag of landen hun toezeggingen zouden nakomen. In de analyse van hoofdstuk 3 bleken sommige landen waarschijnlijk hun toezeggingen ruim te halen (India, China, Rusland, Oekraïne), terwijl andere landen naar verwachting alleen hun voorwaardelijke toezeggingen zouden overtreffen (EU, Australië). Tegelijkertijd werd verwacht dat andere landen hun doelen niet zouden bereiken (Canada, VS, Mexico). Voor Japan, Zuid-Korea, Brazilië en Indonesië was het onzeker of het doel gehaald zou worden. Ondertussen hadden veel landen parallel aan of in reactie op de toezeggingen een beleid voor hernieuwbare elektriciteit. Sommigen implementeerden ook efficiëntienormen voor auto's en emissiehandelssystemen. Het wel of niet halen van nationale beloftes zegt overigens niets over de klimaatambitie van een land. Deze timing van beleidsuitvoering zijn in lijn met Iacobuta et al. (2018) die concluderen dat belangrijke verschuivingen in het nationale beleid samenvallen met historische internationale evenementen zoals de klimaatconferentie van Kopenhagen.

De grootste onzekerheid in de uitkomsten was het gevolg van onzekerheid in de baseline-emissies. Het geschatte interval van mogelijke emissies als gevolg van de uitvoering van binnenlands beleid is groot en hangt voornamelijk af van het niveau van de emissies in de baselines van de twee gebruikte modellen (zie Figuur 92). Het interval als gevolg van de implementatie van de Cancun toezeggingen is kleiner omdat de onderliggende doelstellingen duidelijker zijn gedefinieerd ten opzichte van een referentiejaar of nationale baseline en zijn daarom onafhankelijk van de gebruikte model baselines. Voor de beloftes is de onzekerheid in emissieniveaus van doelen van China en India redelijk groot omdat deze zijn geformuleerd als een intensiteit die afhankelijk is van een onzekere BBP-groei. Bovendien zijn schattingen van historische emissies uit China en voor LULUCF in het algemeen onzeker. Figuur 92 bevat ook resultaten van Den Elzen et al. (2011) en Hof et al. (2013) zodat de emissiekloof in 2020 met het scenario dat de temperatuurverandering deze eeuw beperkt tot 2 °C getoond kan worden (zie Tekstvak 9-1)



Figuur 92 De impact van het huidige beleid op mondiale broeikasgasemissies en voor China, de VS, de EU en India ten opzichte van basisscenario's, toezeggingen en 2 °C-scenario's: a) emissieniveaus voor 2010 en baseline voor 2020, huidig beleid en toegezegde emissieniveaus voor China, de VS, de EU en India b) vergelijking van gerealiseerde emissieniveaus voor 2019/2020 met geschatte emissieniveaus (in 2012) als gevolg van de impact van binnenlands beleid, voorwaardelijke/ onvoorwaardelijke Cancun-toezeggingen en 2 °C-trajecten met kosteneffectieve implementatie na 2010, van hoofdstuk 3 en Den Elzen et al. (2011), Hof et al. (2013). Het mondiale niveau dat voor hoofdstuk 3 wordt gepresenteerd bestaat uit landenresultaten aangevuld met IMAGE-basisprojecties. Bron 2019/2020 emissies: (Friedlingstein et al., 2020) *voor historisch CO2 fossiel, industrie en landgebruik.* (Gütschow et al., 2016) *voor historisch niet-CO2 fossiel, industrie en afval.* (FAO, 2020) *voor historisch niet-CO2 landgebruik en landbouw. Bron overig: Hoofdstuk 3, den Elzen et al (2011), Hof et al (2013)*

Andere gerelateerde werkzaamheden met betrekking tot de beoordeling van de Cancun beloftes in het kader van de 2 C° temperatuurlimiet

In hoofdstuk 3 werd de impact van binnenlands beleid onderzocht dat in 14 grote economieën is geïmplementeerd. De auteur van dit proefschrift heeft bijgedragen aan artikelen van Den Elzen et al. (2011) en Hof et al. (2013) die het uitgangspunt waren voor onderzoek vanaf hoofdstuk 3. Deze studies evalueerden de voorwaardelijke en onvoorwaardelijke Cancun-beloften en hun ambitie in de context van de 2 °C-temperatuurlimiet.

De emissiekloof tussen toezeggingen en optimale 2 °C-trajecten in 2020 werd geschat op 2,6-7,7 $GtCO^{\circ}_2eq$ (Den Elzen et al., 2011) en 8,7-12,6 $GtCO_2eq$ (Hof et al., 2013), zie Figuur 92. De laatste studie was een update van de eerste. Het verschil kan worden verklaard door geactualiseerde nationale baseline projecties, nieuwe en geactualiseerde toezeggingen en meer duidelijkheid over boekhoudregels voor broeikasgassen. Hieruit blijkt dat het absolute mondiale emissieniveau in de laatste analyse 4 $GtCO_2eq$ hoger was als gevolg van updates van historische emissies (van 2005 tot 2010), meer verduidelijking van de baseline die in de Braziliaanse belofte werd gebruikt en wijzigingen in de methodologie voor het schatten van intensiteitsdoelstellingen. De kloof vloeit voort uit het onderscheid tussen voorwaardelijke en onvoorwaardelijke toezeggingen en de verschillende interpretaties van boekhoudregels.

Een belangrijke onzekerheid is de boekhoudregels voor broeikasgassen die in de UNFCCC-onderhandelingen zijn besproken. Ten eerste zouden landen hun credits voor Kyoto-overschoten uit de periode 2008-2012 kunnen verkopen en het effect van de toezeggingen kunnen afzwakken. Ten tweede zou dit ook kunnen gebeuren vanwege de ruime mogelijkheid van het gebruik van credits voor landgebruik. Ten derde is dit ook mogelijk met dubbeltelling van CDM-credits (Clean Development Mechanism).

Kuramochi et al. (2019) analyseert de uitkomst van de 2020 beloftes en verwacht één jaar voor 2020 dat de elf economieën hun toezeggingen waarschijnlijk na komen (Brazilië, Chili, China, EU28, India, Japan, Mexico, Russische Federatie, Zuid-Afrika, Thailand, Oekraïne) en zes economieën ze naar verwachting niet zullen halen (Australië, Canada, Indonesië, Kazachstan, Republiek Korea, VS).

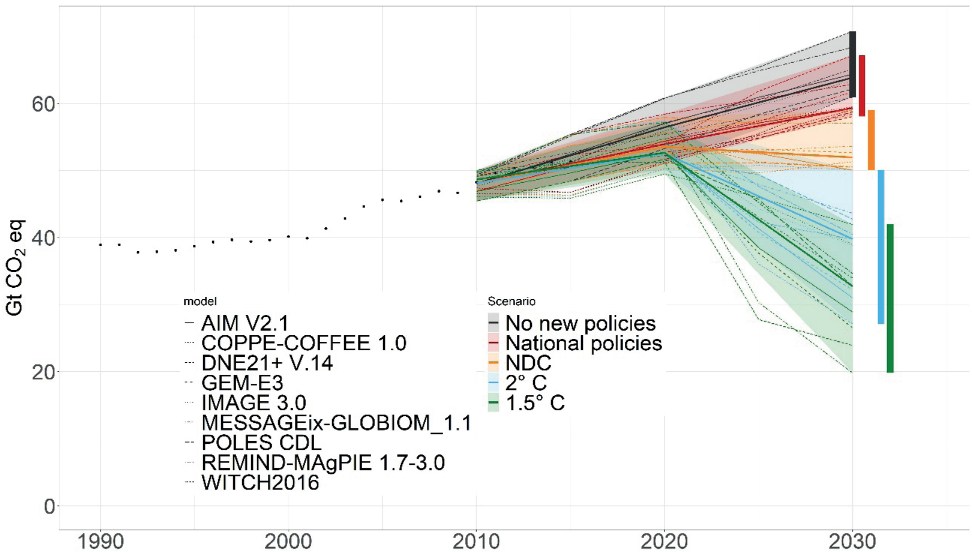
Tekstvak 9-1 Beoordeling van de toezeggingen van Cancun in het kader van de 2 C-limiet°

9.3.2 2030 Nationale beloftes in NDC's

De NDC's en het huidige beleid voor 2030 (hoofdstuk 4) werden beoordeeld aan de hand van negen IAMs met expliciete representatie van het geïmplementeerde klimaatbeleid voor de G20-landen. Dit is gebaseerd op een uitgebreide verzameling van klimaat-, energie- en landgebruiks-beleidsmaatregelen die tot einde 2016 zijn geïmplementeerd en opgeslagen in een online database (NewClimate Institute, 2015). Deze modellen dragen bij aan de robuustheid van de beoordeling in vergelijking met studies met één model. Hoewel deze modellen verschillen in representatie van landen en sectoren en hoe ze beslissingen over klimaatbeleid nabootsen, hebben ze allemaal dezelfde lijst met effectief beleid voor G20-landen geïmplementeerd.

De huidige beleidsmaatregen zullen naar verwachting tegen 2030 een wereldwijde implementatiekloof laten zien met NDC's en een ambitiekloof met de mondiaal afgesproken temperatuurdoelstellingen (zie Figuur 93). Ondanks de uitvoering van het huidige beleid zullen naar verwachting de emissies tot 2030 nog verder stijgen, maar zal de uitstoot van broeikasgassen verminderen met 3,5 $GtCO_2eq$ (2,3;5,2) of 5,3% (3,8;7,9%) ten opzichte van de baseline welke de hypothetische situatie vertegenwoordigt waarin na 2010 geen beleid zou zijn uitgevoerd. Dit laat een mediane implementatiekloof zien met NDC's van 7,7 GtCO[28]$_2$eq (5,3;9,7) en een mediane gap van 22,4 (13,6;29,6) en 28,2 (19,8;42,2) $GtCO_2eq$ met trajecten die beginnen met kosteneffectieve implementatie in 2020 om de wereldwijde temperatuur onder de 2 °C en 1,5 °C te houden. Om de wereld op koers te houden op weg naar een kosten-efficiënte implementatie van de Parijs doelstellingen moeten de (mediane) wereldwijde emissieniveaus in 2030 tussen 36% en 45% dalen ten opzichte van het huidige beleidsscenario. Als de voorwaardelijke NDC's volledig zouden worden geïmplementeerd zou de emissiekloof met 1/3 verminderen. De Kaya-identiteit wordt gebruikt om inzicht te geven in hoeverre efficiëntie (TPES/GDP) of CO_2-reductiemaatregelen (CO_2/TPES) moeten worden geïmplementeerd. De emissiekloof tussen het huidige beleid en de (kosteneffectieve) 2 °C-trajecten tegen 2030 kan worden gedicht door de uitvoering van beleidsmaatregelen die het (mediane) koolstofarme aandeel met 2,8 procentpunt moeten verhogen en de (mediane) energie-intensiteit met 12,7% moeten verlagen ten opzichte van het huidige beleidsscenario.

[28] 10-90% percentielen



Figuur 9-3 Broeikasgasemissies op mondiaal niveau in verschillende scenario's voor de periode 1990-2030 op basis van negen IAM's.

Het gezamenlijke beleid van alle geanalyseerde landen slaagt er niet in een emissieniveau te bereiken dat consistent is met de kost-efficiëntie 2 °C of 1.5 °C scenario's vanwege een gebrek aan ambitie en/of uitvoering van landen. De zeven G20-landen (China, vs, EU, India, Brazilië, Japan, Russische Federatie) blijken de uitstoot van broeikasgassen in 2030 met 0% to 9% te verminderen als ze het huidige beleid zouden implementeren. De reducties doen zich vooral voor in de elektriciteits- en de transportsector. De uitvoering van binnenlands beleid laat een kleine implementatiekloof zien tussen het huidige beleid en de NDC's voor China, India, Japan en Rusland. Dit is niet het geval voor de Europese Unie, de Verenigde Staten en Brazilië, maar hun ambitiekloof tussen NDC's en 2 °C- of 1,5 °C-trajecten is kleiner. Opgemerkt moet worden dat het nemen van het punt van 2016 als referentie betekent dat de analyse geen rekening heeft gehouden met sommige Amerikaanse beleidsmaatregelen die zijn ingetrokken en nieuw aangekondigd beleid in de EU.

Van de vier geanalyseerde oorzaken van onzekerheid in wereldwijde emissieniveaus is het verschil in baselines door sociaal-economische factoren het grootst. De analyses splitsten de emissiegroei tussen 2015 en 2030 in het huidige beleidsscenario in 1) verschillen in historische emissies, 2) verschillen in aannames over bevolking en economische groei, 3) impact van beleidsmaatregelen en 4) andere zoals modeltype. De impact van sociaal-economische factoren blijkt het grootst, terwijl die van historische kalibratie relatief klein is en de impact van beleidsmaatregelen vertegenwoordigt ongeveer een derde.

Andere gerelateerde werkzaamheden op het gebied van de beoordeling van NDC's

Den Elzen et al. (2016), inclusief de auteur van dit proefschrift analyseerden ook kleinere landen in vergelijking met hoofdstuk 4. Dit artikel beoordeelde NDC's die 105 landen bestrijken, maar concentreerde zich op de resultaten van de G20-landen en toont aan dat de NDC's in 2030 op mondiaal niveau 4-6 GtCO2eq meer reductie-inspanningen beogen ten opzichte van de huidige beleidsuitvoering. Daarnaast wordt verwacht dat de uitstoot van Brazilië, Indonesië, Mexico en Zuid-Korea vóór 2025 zal pieken, terwijl 2030 of later voor China, India en Zuid-Afrika. Brazilië, China, de EU28 en de VS vertegenwoordigen 50% van de wereldwijde broeikasgasemissies, maar zijn goed voor 80% van de verwachte reducties in 2030.

Tekstvak 9-2 Beoordeling van NDC's

9.4 HOE KUNNEN LANDEN DE KLOOF TUSSEN NDC'S EN DE TEMPERATUURGRENS VAN RUIM ONDER DE 2 °C AANSCHERPEN EN HUN BINNENLANDSE KLIMAATMAATREGELEN OPSCHALEN?°

Landen zouden kunnen leren van eerdere en huidige successen bij de uitvoering van beleid in andere landen. Hoewel een succesvolle beleidsimplementatie een leidend voorbeeld kan zijn voor implementatie in andere landen moet als eerste worden opgemerkt dat de context van het land van belang is zoals verschillende wetgevingssystemen of institutionele instellingen en soms een belemmering kan vormen voor replicatie van beleid. Toch kan ook in die gevallen het verzamelen van voldoende achtergrondinformatie om succesfactoren te bepalen en experimenten mogelijk te maken helpen bij het vertalen van de implementatie van beleidsinstrumenten naar andere landen.

Om het potentieel van het repliceren van 'good practice-beleid' te laten zien hebben we de impact geschat van het repliceren van negen succesvolle sectorvoorbeelden in alle landen wereldwijd. De beoordeling begint met het selecteren van succesvolle sectorvoorbeelden uit een shortlist van effectief beleid voor elke sector. Op basis van de historische impact of toekomstige beleidsdoelstellingen werd het meest succesvolle beleid geselecteerd. Voorbeelden zijn het Duitse feed-in-tariff en de Britse standaard voor hernieuwbare technologieën, de EU-normen voor het brandstofverbruik en de Braziliaanse regelgeving en handhaving in de bosbouwsector (zie Tabel 93). Duitsland en de UK lieten tussen 2004 en 2012 een gemiddelde groei van 1,35% zien in de productie van hernieuwbare elektriciteit. De brandstofefficiëntie van auto's in de EU is tussen 1990 en 2015 gemiddeld jaarlijks met

1,8 % gedaald. De bosbouwcode in Brazilië heeft de ontbossing in de Amazone tussen 1996 en 2014 met succes verminderd van 1,95 Mha per jaar naar 0,58 Mha per jaar totdat het beleid werd teruggedraaid. Dit beleid werd vertaald in passende sectorindicatoren waarvoor de niveaus van 2030 in de modellen konden worden gerepliceerd, zoals de jaarlijkse groei van hernieuwbare opwekking (%), brandstofefficiëntie (km/l) en ontbossingspercentages ten opzichte van 2010 (%) (zie Tabel 93). Dit werd geïmplementeerd in de IMAGE energy (TIMER) en GLOBIOM/G4M landgebruiksmodellen om de wereldwijde impact op de uitstoot van broeikasgassen te bepalen.

Tabel 9-3 Succesvolle sectorvoorbeelden en vertaling naar beleidsimpact

Belangrijkste sector	**Beleidsmaatregelen**	**Succesvol beleidsinstrument**	**Beleidseffectindicator**
Energievoorziening	Verhoging van hernieuwbare energiebronnen in elektriciteitsproductie	Hernieuwbare portfolio standaard, feed-in-tarief in het Verenigd Koninkrijk en Duitsland	+1,35% groei van het aandeel re-opwekking per jaar
	Verminder affakkelen en uitlagen bij olie- en gasproductie	Regelgeving en koolstofbelasting in Noorwegen	4,4% jaarlijkse vermindering van de olie-/gasintensiteit ($ktCO_2eq$/Mtoe) tot 2030
Industrie	Verbeter de energie-efficiëntie van industriële productie	Energieovereenkomsten in Ierland	1% jaarlijkse verbetering van de energiebesparing ten opzichte van de huidige inspanningen tot 2030
	Verminder emissies van fluorhoudende gassen	Internationale overeenkomst	70% reductie onder 2010 F-gasemissies
Gebouwen	Verbeter de efficiëntie van de schil van het woongebouw	EU-regelgeving	Energie-intensiteit van 0 kWh/m^2 tegen 2030 (ruimteverwarming)
	Stel efficiëntienormen voor apparaten en verlichting	Toestelnormen in EU-landen	Gemiddelde efficiëntieverbetering van 1,8% per jaar tot 2030
Vervoer	Verbeter de brandstofefficiëntie van auto’s	Brandstofbesparingsnorm in de EU	Brandstofbesparingsnorm van 26 km/l in 2030
	Toename aantal elektrische auto’s (opgeladen met hernieuwbare elektriciteit)	Belastingen en investeringen in infrastructuur in Noorwegen	25% aandeel nieuwe elektrische voertuigen in 2020, 50% in 2030
LULUCF	Verminder ontbossing in bossen	Regelgeving en handhaving in Brazilië	Afnemende ontbossing ten opzichte van 2010 met 22% in 2020, 44% in 2030.

Het repliceren van negen succesvolle voorbeelden van sectorbeleid uit de sectoren energievoorziening, industrie, gebouwde omgeving, transport en landgebruik (LULUCF) in landen over de hele wereld tussen 2015 en 2030 zal naar verwachting de wereldwijde broeikasgasemissies in 2030 met 10 GtCO2-eq verminderen, wat 17% onder het huidige beleidsscenario ligt en dicht bij het niveau van 2010. Dit zou de emissiekloof met een 2 °C-pad tegen 2030 aanzienlijk verkleinen. De grootste reducties waren het resultaat van het repliceren van de beleidsimpact van hernieuwbare elektriciteit, reductie van f-gassen, verminderen van affakkelen en uitlaten en industrie-beleid.°

Deze aanpak is een alternatief voor de traditionele methode om het potentieel voor internationaal klimaatbeleid met modellen te bepalen door 2 °C- of 1,5 °C-paden te ontwikkelen op basis van een wereldwijde koolstofprijs. De meest gebruikelijke manier om paden naar de 1,5 en ruim onder 2 °C-doelstelling met IAM's te verkennen is het implementeren van een wereldwijde uniforme koolstofprijs die leidt tot een kostenefficient pad naar het klimaatdoel. Tegelijkertijd is de kans echter klein dat een dergelijke universele prijs kan worden geïmplementeerd. Men kan zich zelfs afvragen of dit aantrekkelijk is omdat specifieke beleidsmaatregelen meer sociale steun en/of bijkomende voordelen kunnen hebben. In plaats van alleen een wereldwijde koolstofprijs toe te passen biedt een aanpak op basis van concrete maatregelen, waaronder succesvolle voorbeelden van beleid dat elders is geïmplementeerd, dus een meer realistische methode om het klimaatbeleid in IAMS weer te geven en manieren te verkennen om ambitieuze doelen te implementeren. Dergelijke scenario's kunnen zelfs rekening houden met lokale omstandigheden zoals specifieke voorkeuren voor maatregelen (bijvoorbeeld met betrekking tot kernenergie) of instrumenten (bijvoorbeeld financiële instrumenten versus normen). Een uitdaging is om de keuze van parameters af te stemmen op nationale prioriteiten en lokale omstandigheden die van invloed zijn op het succes van de uitvoering.

Andere gerelateerde werkzaamheden met betrekking tot het beleid inzake goede praktijken op het gebied van beoordeling

Fekete et al. (2021) hebben de analyse van het 'good practice' beleid uit hoofdstuk 5 bijgewerkt door meer sectoren toe te voegen wat resulteert in dertien succesvolle sectorvoorbeelden waarvoor wereldwijde replicatie naar verwachting zal resulteren in een piek van de wereldwijde broeikasgasemissies tegen 2020 en een vermindering van de wereldwijde emissies met 20% ten opzichte van het huidige beleidsscenario tegen 2030. De beoordeling is gedaan met een bottom-up model en het IMAGE-model, en de resultaten worden gepresenteerd voor tien grote uitstotende economieën en de wereld. Sectoren die zijn toegevoegd zijn landbouw en goederenvervoer. De meeste geselecteerde beleidsmaatregelen werden in OESO-landen geïdentificeerd omdat er meer informatie over beleidsprestaties beschikbaar was en vaak ook hogere historische prestaties lieten zien. Ook was informatie moeilijk te verkrijgen in 'hard-to-abate' sectoren zoals industrie en gebouwde omgeving.

De grootste reducties worden verwacht van de energiesector, LULUCF-sector en industriesector. De NDC-doelstellingen van alle geanalyseerde landen zouden worden bereikt door de succesvolle sectorvoorbeelden te repliceren. De resultaten zijn echter onzeker vanwege de afhankelijkheid van de NDC-doelstellingen van de economische groei in India en de onzekerheid over de verwachte emissies van landgebruik in Brazilië.

Tekstvak 9-3 Actualisering van het beleid inzake goede praktijken

9.5 IN HOEVERRE KUNNEN LOKALE OVERHEDEN EN BEDRIJVEN BIJDRAGEN AAN HET DICHTEN VAN DE MONDIALE KLOOF EN IN HOEVERRE IS DE IMPACT VAN DE MAATREGELEN VAN DEZE ACTOREN EXTRA TEN OPZICHTE VAN HET BELEID DOOR DE NATIONALE OVERHEID?

Partijen die niet onderdeel van de UNFCCC zijn worden in het Parijs-Akkoord uitgenodigd om hun inspanningen m.b.t. klimaat op te schalen en maatregelen te nemen om emissies te verminderen en dit aan te tonen in de Non-state Actor Zone for Climate Action (NAZCA) (UNFCCC, 2015a). Deze niet-partijgebonden belanghebbenden zijn niet-statelijke actoren (o.a. bedrijven) en lokale overheden (steden, regio's/provincies) die de uitvoering van nationaal beleid kunnen waarborgen en versnellen of zelfs de emissiekloof kunnen verkleinen. In hoofdstuk 6 en 7 worden lokale overheden en bedrijven geanalyseerd. Deze actoren kunnen maatregelen toezeggen als onderdeel van internationale samenwerkingsinitiatieven (ICI's) of individueel.

Internationale samenwerkingsinitiatieven (ICI's) zijn internationale activiteiten buiten de UNFCCC, aangestuurd door niet-statelijke actoren of coalities van nationale regeringen die zich inzetten voor het verminderen van de uitstoot van broeikasgassen. Dergelijke initiatieven zijn vaak actief in specifieke sectoren. Naast lokale overheden en bedrijven bestaan ook coalities van nationale regeringen die buiten de UNFCCC-context zijn opgesteld zoals de Kigali-overeenkomst en de afspraken binnen de International Maritime Organization (zie Tabel

95). De meeste initiatieven stellen overkoepelende doelen die voor alle leden gelden, hoewel ze leden in sommige gevallen ook motiveren om individuele verplichtingen aan te gaan. Interessant is dat ICI's vaak ambitieuze doelen stellen maar dat handhaving vaak ingewikkelder is omdat ze niet het volle vermogen hebben om het gedrag van hun leden te veranderen.

De beoordeling van de bijdrage van niet-overheidsactoren is complex. Naast het schatten van de directe impact van hun acties ten opzichte van een referentieniveau moet men ook de additionaliteit schatten ten opzichte van het beleid dat al door overheden in hun NDC's of huidig beleid wordt gedekt. Aangezien de landen vooruitgang rapporteren over alle binnenlandse emissies, kan de impact van maatregelen van lokale overheden en bedrijven niet eenvoudigweg aan de impact van NDC's worden toegevoegd omdat dit gemakkelijk tot dubbeltelling zou kunnen leiden. Hier gaan we ervan uit dat gecoördineerde acties van ICI's kunnen leiden tot extra reducties in landen die NDC's hebben ingediend op voorwaarde dat hun maatregelen geen betrekking hebben op emissies en sectoren die zijn opgenomen in de NDC's (methaanmaatregelen in China vallen bijvoorbeeld niet onder de CO_2-intensiteitsdoelstelling voor 2020). Het geschatte extra effect in deze analyse is een conservatieve schatting (*geen bijkomend effect,* zie Tekstvak 9-5) aangezien verondersteld wordt dat de maatregelen van ICI's die ambitieuzer zijn maar overlappen met nationale doelstellingen volledig worden gecompenseerd door minder actie van niet-statelijke actoren elders. Maar andere aannames zijn mogelijk, zie verderop in de tekst.

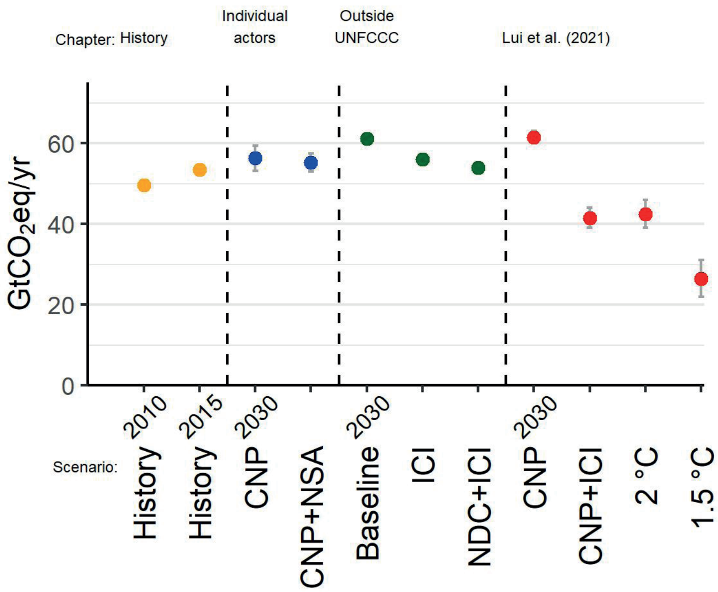
Tabel 9-4 Wereldwijde reducties van maatregelen van individuele niet-statelijke actoren en lokale overheden en internationale samenwerkingsinitiatieven (ICI's) in 2030 met soepele/strikte regels voor additionaliteit. Vergelijking tussen hoofdstuk 6, 7 en Lui et al. (2021).

	Aannames rondom additionaliteit	
	Streng	**Lankmoedig**
Individueel		(*Hoofdstuk 6*) 1,2 - 2 $GtCO_2eq$ (ten opzichte van het huidige beleidsscenario)
Samenwerkingsinitiatieven	(*Hoofdstuk 7*) 5 $GtCO_2eq$ (11 ICI's) (ten opzichte van de uitgangssituatie zonder beleid)	(*Lui et al, 2021*) 18-21 $GtCO_2eq$ (17 ICI's) (ten opzichte van het huidige beleidsscenario)

Een selectie van elf ICI's die de meeste energie- en AFOLU-sectoren bestrijken zal naar verwachting de wereldwijde broeikasgasemissies in 2020 met 2,5 GtCO2-eq en in 2030 met

5,0 GtCO2-eq verminderen ten opzichte van een referentiescenario zonder klimaatbeleid (zie Tabel 94) en Figuur 9-4 Figure 8-4) waarbij 30% van de reducties wordt beschouwd als een aanvulling op de NDC-doelstellingen voor 2030. Deze berekeningen laten zien hoeveel de ICI-maatregelen de emissies kunnen verminderen en hoeveel ze een aanvulling vormen op de nationale NDC-doelstellingen. De schattingen houden rekening met de overlap tussen verschillende ICI-maatregelen welke optreedt als ze gericht zijn op dezelfde sectoren en emissies. Deze overlap werd geschat op slechts 0,3 $GtCO_2$-eq in 2030.

Merk op dat de reducties zouden toenemen tot de veel hogere niveaus van 18-21 $GtCO_2$eq ten opzichte van het huidige beleidsscenario (Lui et al., 2021) (zie) als er nog enkele ICI's zouden worden toegevoegd en vooral als zou worden aangenomen dat de ambitieuzere maatregelen niet elders (volledig) worden gecompenseerd (zie Tabel 9-4 Table 8-4 en Figuur 9-4). Hieruit blijkt dat aannames over additionaliteit van cruciaal belang zijn voor de interpretatie van de resultaten gezamenlijke reducties van nationale, lokale overheden en bedrijven (zie Tekstvak 9-5).



Figuur 9-4 Emissieniveaus in 2030 voor verschillende scenario's van niet-statelijke actoren en lokale overheden. Vergelijking van de hoofdstukken 6 en 7 Lui et al. (2021) met historische emissies. CNP= Huidig nationaal beleid, NSA = (individuele) niet-statelijke actoren, ICI = Internationaal coöperatieve initiatieven

Ander gerelateerd werk over de impact van internationale samenwerkingsinitiatieven, ervan uitgaande dat de impact van maatregelen niet elders gecompenseerd wordt

Lui et al. (2021) gebruiken dezelfde methodologie als in hoofdstuk 7 om de impact van ICI's op de mondiale broeikasgasemissies te bepalen welke anders zijn dan de aannames in de analyse van hoofdstuk 6. Geschat wordt dat een selectie van 17 grote ICI's samen de broeikasgasemissies tegen 2030 met 18-21 $GtCO_2eq$ zou kunnen verminderen, wat in het bereik van een 2 °C-pad ligt. De grootste wereldwijde reducties zullen naar verwachting afkomstig zijn van het bedrijfsleven, de bosbouwsector en steden en regio's. De ICI's werden geselecteerd uit een lijst van 300 initiatieven (zie Tabel 95). Net als in hoofdstuk 6 wordt ervan uitgegaan dat alle ICI's hun gestelde doelen bereiken maar in tegenstelling tot hoofdstuk 6 wordt aangenomen dat maatregelen lokale overheden en bedrijven niet maatregelen elders verdringen.

De reducties zijn groter dan die voor individuele actoren wordt geschat als gevolg van de ambitieuze mitigatiedoelstellingen. Deze initiatieven streven in het algemeen naar sectorale transformationele veranderingen en hebben grote geografische dekking. Het is echter belangrijk om te begrijpen dat deze reducties alleen kunnen worden gerealiseerd als regeringen de vrijwillige ICI-maatregelen overnemen, integreren in hun beleid en effectief coördineren. Hiervoor zijn monitoring en tracking essentieel.

Box 9-4 Impact van internationale initiatieven ervan uitgaande dat maatregelen niet andere maatregelen elders vervangen

Tabel 9-5 Internationale samenwerkingsinitiatieven opgenomen in hoofdstuk 6 en Lui et al (2020). ICI's met een grote overlap in leden worden op dezelfde rij geplaatst

Sector	ICI's (hoofdstuk 6)	ICI's (Lui et al, 2020)
Energie-efficiëntie		United for Energy Efficiency
		Super-efficient Equipment and Appliance Deployment Initiative
Vervoer	Global Fuel Economy Initiative	Global Fuel Economy Initiative
	International Civil Aviation Organisation	Collaborative Climate Action Across the Air Transport World
	International Maritime Organisation	
		Lean and Green

Sector	ICI’s (hoofdstuk 6)	ICI’s (Lui et al, 2020)
Hernieuwbare energie		European Technology & Innovation Platform for
		Photovoltaics
		Africa Renewable Energy Initiative
		Global Geothermal Alliance
Bedrijfsleven & Industrie		RE100
	Carbon Disclosure Project	Science-Based Targets initiative (SBTi)
	Cement Sustainability Initiative	
	Zero Routine Flaring by 2030	
Bosbouw	New York Declaration of Forests	Bonn Challenge / New York Declaration on Forests (NYDF) / Governors’ Climate
		and Forests Task Force
Niet-CO2-gassen	Global Methane Initiative	Climate & Clean Air Coalition
	Kigali Amendment	
Steden en regio’s	EU Covenant of Mayors	Global Covenant of Mayors for
		Climate & Energy
	C40 Cities Climate Leadership Group	C40 Cities Climate Leadership
		Group
		Under2 Coalition

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Regio’s, steden en bedrijven die individuele toezeggingen hebben gedaan zullen naar verwachting de wereldwijde broeikasgasemissies in 2030 met 1,2-2,0 GtCO2-eq (3,8-5,5%) verminderen ten opzichte van het huidige beleidsscenario (zie Tabel 94 en Figuur 94) als zij hun doelstellingen realiseren ervan uitgaande dat hun maatregelen het tempo van maatregelen elders niet verminderen. Naast het inzetten op klimaatmaatregelen in samenwerkingsinitiatieven stellen lokale overheden en bedrijven ook individuele doelen of registreren ze hun individuele doelen als onderdeel van deze samenwerkingsinitiatieven. Deze acties worden geregistreerd door internationale databases zoals CDP (CDP, 2019a), Global Climate Action Portal (UNFCCC, 2020) of het Global Covenant of Mayors (GCOM, 2021). De analyse van individuele toezeggingen in Hoofdstuk 7 was gebaseerd op 79 regio’s/provincies, 6.000 steden en 1.600 bedrijven die samen goed zijn voor 8,1 $GtCO_2$eq-emissies na aftrek van overlap. Het laat zien dat toezeggingen van energiebedrijven niet erg ambitieus waren. De extra reducties voor de tien economieën die in de analyse zijn opgenomen zijn berekend ten opzichte van twee bestaande huidige beleidsscenario’s en variëren van 0-0,7% voor China tot 10,7-14,3% voor de Verenigde Staten. Hieruit blijkt dat de grootste impact wordt verwacht van de VS.

Het is van essentieel belang om de cruciale aannames over overlap en additionaliteit te begrijpen die worden gemaakt bij beoordelingen van klimaatmaatregelen van lokale overheden en bedrijven (zie Tabel 96**).** Overlap en additionaliteit zijn van cruciaal belang bij het inschatten van de impact van maatregelen van lokale overheden en bedrijven. Overlap treedt op als actoren zich richten op dezelfde emissies en sectoren, bijvoorbeeld emissies van bedrijven in een stad die beide reductiedoelstellingen hebben. De overlap tussen de twee actoren is de hoeveelheid totale emissies die zij beiden dekken met hun maatregelen. Additionaliteit treedt op als de doelstellingen van lokale overheden en bedrijven overlappen met nationale doelstellingen maar streven naar hogere reducties dan opgelegd door deze nationale doelstellingen. Dit is een belangrijke factor bij de beoordelingen omdat deze aannames over additionaliteit van grote invloed zijn op de resultaten en er geen consensus bereikt is in de literatuur (zie Tekstvak 9-5). In hoofdstuk 6 werd de conservatieve benadering uit Tekstvak 9-5, ervan uitgaande dat maatregelen van lokale overheden en bedrijven die ambitieuzer zijn dan verwacht op grond van nationaal beleid zullen worden gecompenseerd met minder ambitieuze maatregelen elders. Dit lijkt op het concept van het weglekken van emissiereducties tussen landen. Aan de andere kant is er momenteel beperkte coördinatie tussen nationale overheden en deze actoren over klimaatbeleid en -ambitie. Ook leggen nationale overheden geen toezeggingen van regio's, steden of bedrijven vast om hun nationale doelen vast te stellen (Hsu en Rauber, 2021). In het laatste geval kan worden aangenomen dat reducties (deels) aanvullend zijn als ze ambitieuzer zijn dan nationaal toegezegd of uitgevoerd. Dit werd in hoofdstuk7 verondersteld voor de analyse van individuele verplichtingen. We identificeerden twee manieren om rekening te houden met gedeeltelijke additionaliteit: 1) alleen die reducties die zeer ambitieus zijn worden verondersteld aanvullend te zijn (bijvoorbeeld in overeenstemming met 2 °C-paden), of 2) ervan uitgaan dat een deel van de actoren achterblijvers zijn die alleen de baseline emissies volgen (zie Tabel 9-6).

Tabel 9-6 Overlap en additionaliteit bij de analyses van hoofdstuk 6 en 7

	Hoofdstuk 6	**Hoofdstuk 7**
Overlappen	Berekend tussen lokale overheden en bedrijven	Berekend tussen regio's, steden en bedrijven
Additionaliteit	Alleen als er maatregelen genomen worden in sectoren of voor broeikasgasemissies die niet onder NDC's vallen	Nationaal - regio's→ full accounting Regio's - steden en steden-bedrijven ➔Alleen als de doelstelling van de stad/het bedrijf erg ambitieus is. ➔Rekening houdend met achterblijvers.

De ambitie van International Cooperative Initiatives is hoog maar komt nog niet tot uiting in duidelijke individuele maatregelen. De geschatte reducties van ICI's zijn relatief hoog (uit hoofdstuk 7 en Lui et al. (2021)) vergeleken met die van individuele maatregelen van bedrijven en lokale overheden (hoofdstuk 6). Deze ICI-reducties zouden de wereld dicht bij een pad kunnen brengen die de wereldwijde gemiddelde temperatuurstijging beperkt tot minder dan 2 °C (Lui et al. (2021)). Deze samenwerkingsinitiatieven stelden echter ambitieuze doelen, vaak uitgaande van toenemende ledenaantallen, maar niet altijd ondersteund door concrete plannen en doelstellingen van individuele actoren. Transparantie over de bereikte resultaten van ICI's kan helpen om echte ambitieuze acties te scheiden van acties die niet worden uitgevoerd.

Andere gerelateerde werkzaamheden op het gebied van de beoordeling van klimaatacties van lokale overheden en bedrijven

Op basis van enkele bestaande publicaties (waaronder Roelfsema et al. (2015), die de basis vormden voor hoofdstuk 6) bespreekt Hsu et al. (2019) openstaande punten op de onderzoeksagenda van klimaatbeleid van bedrijven en lokale overheden zoals verschillen in kenmerken van gestelde doelen en additionaliteit. Dit artikel is bedoeld om duidelijke en consistente definities te geven van gebruikte concepten, een overzicht van bestaande methodologieën en aanbevelingen over hoe deze beoordelingen het beste kunnen worden benaderd.

Om de impact maatregelen van lokale overheden en bedrijven te kwantificeren is meer duidelijkheid nodig over aannames en methodologie. De doelen die door deze actoren worden gesteld variëren op verschillende manieren. Een belangrijke observatie is dat ICI's variëren met betrekking tot gestelde doelen en verklaringen waarbij sommige initiatieven alleen een algemene inzet vereisen terwijl andere specifieke doelen, monitoring en evaluatie vereisen. Een andere vaststelling is dat de bestaande analyses inconsistent zijn met betrekking tot de scope van de emissies die door verschillende actoren worden bestreken (scope 1,2 en/of 3), streef- en basisjaren en referentie-scenario's die in de beoordelingen worden gebruikt. Daarnaast is een belemmering voor de analyse de beschikbaarheid van informatie over de baseline-emissies, -doelstellingen en groeiveronderstellingen van lokale overheden en bedrijven die vaak schaars en ondoorzichtig zijn en vastgesteld met meerdere accounting methoden.

Om de impact van lokale overheden en bedrijven op nationaal niveau te beoordelen is het van essentieel belang om duidelijk te zijn over de aannames over additionaliteit.

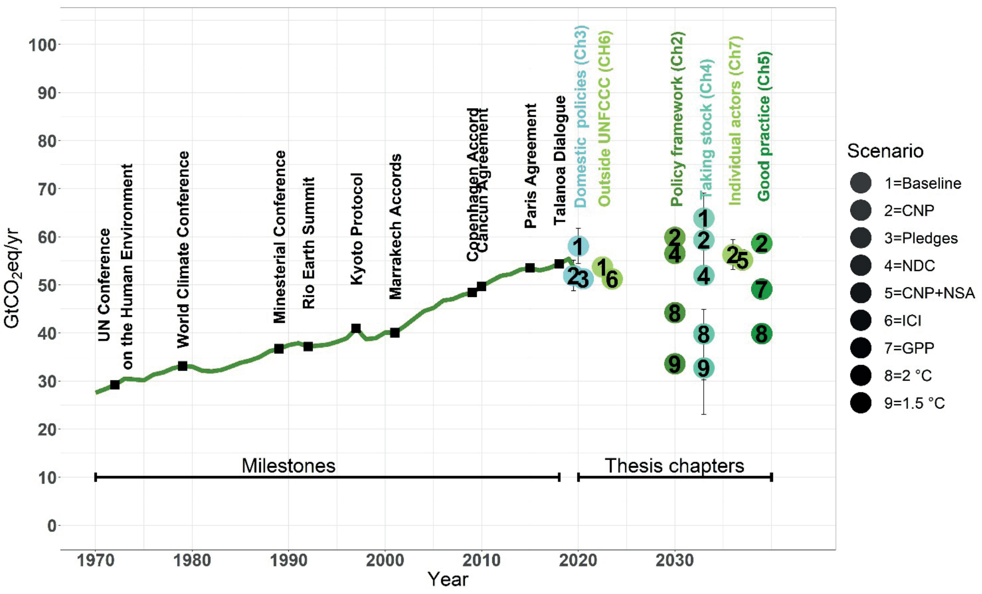
Additionaliteit treedt op als een actor een ambitieuzer doel heeft en volledige overlap heeft met een andere actor (bijvoorbeeld overheid). Vier verschillende aannames om deze additionaliteit te berekenen werden in de literatuur geïdentificeerd: 1) het *Geen bijkomend effect* wordt verondersteld in geval van volledige overlap, 2) het *Partieel conservatief effect* gaat ervan uit dat de acties gedeeltelijk aanvullend zijn en rekening houdt met achterblijvers die ondermaats presteren, 3) het *Gedeeltelijke effect* houdt alleen rekening met additionaliteit als het doel in overeenstemming is met de doelstellingen van Parijs en 4) het *volledige effect* gaat ervan uit dat alle reducties buiten de inzet van het grotere geografische gebied waarvan het deel uitmaakt, aanvullend zijn.

Tekstvak 9-5 Een routekaart voor de analyse van maatregelen van lokale overheden en bedrijven

9.6 WAT IS DE IMPACT OP DE UITSTOOT VAN BROEIKASGASSEN VAN GEÏMPLEMENTEERD BELEID, KLIMAATMAATREGELEN EN MOGELIJKE BELEIDSVERBETERINGEN OM DE WERELDWIJDE TEMPERATUURVERANDERING TE BEPERKEN TOT MINDER DAN 2 °C OF 1,5° C BOVEN HET PRE-INDUSTRIËLE NIVEAU?

De scenarioresultaten en inzichten uit de beschouwde onderzoeksvragen over huidig beleid, NDC's, mogelijke verbeteringen van good practice-beleid en klimaatacties van lokale overheden en bedrijven geven een duidelijk beeld van de huidige status van het klimaatbeleid om de temperatuur-doelstellingen op lange termijn te halen.

De klimaatonderhandelingen van de afgelopen tien jaar hebben geleid tot steeds duidelijkere mondiale ambities. Dit heeft echter niet geleid tot voldoende ambitie of maatregelen van landen of andere actoren om op koers te blijven om de mondiale temperatuurdoelstellingen te beperken of zelfs een wereldwijde piek van emissies te bereiken. Dit proefschrift presenteerde verschillende schattingen van de impact van het huidig geïmplementeerde beleid in de context van mondiale doelen en internationaal toegezegde binnenlandse doelen, die verschillende tijdstippen bestrijken met de nadruk op de toezeggingen van Cancun (2020) en de bijdragen van het Akkoord van Parijs (2030). Figuur 95 plaatst de resultaten van de verschillende hoofdstukken in het grotere perspectief van enkele belangrijke mijlpalen sinds 1971 die verschillende internationale klimaatconferenties en -overeenkomsten vertegenwoordigen.



Figuur 95 Samenvatting van de resultaten van het proefschrift per hoofdstuk. Schattingen van het wereldwijde broeikasgasemissieniveau (inclusief LULUCF) uit de verschillende hoofdstukken van het proefschrift in de context van mijlpalen van de internationale klimaatonderhandelingen. Mijlpalen zijn gekoppeld aan wereldwijde historische emissies tussen 1970 en 2020. De hoofdstuktitels van de wereldwijde broeikasgasemissieprognoses uit de hoofdstukken 2-7 zijn aangevuld met IMAGE-projecties voor LULUCF-emissies en 'Rest van de wereld' (OESO, 2012) *voor de hoofdstukken 3 en 7. CNP=huidig (nationaal) beleidsscenario, CNP+NSA=huidig beleid en niet-statelijk klimaatactiescenario, ICI=scenario internationale samenwerkingsinitiatieven, GPP='good practice' policies scenario. Foutbalken tonen minimale en maximale emissieniveaus van verschillende modellen voor scenario's, behalve in hoofdstuk 3, waar ze het 10e en 90e percentiel vertegenwoordigen. De reeksen zijn gebaseerd op 1 (Ch2), 2 (Ch3), 9 (Ch4), 1 (Ch5), 1 (Ch6), 2 (Ch7) model(en). Historische broeikasgasemissies zijn gebaseerd op CO2-fossiel, industrie en landgebruik niet-CO2-fossiel, industrie en afval* (Gütschow et al., 2016) *en niet-CO2-landgebruik en landbouw* (FAO, 2020). (OESO, 2012) *wordt in Ch1 gebruikt voor referentie-emissies van landen die niet in de beoordeling zijn opgenomen.*

De uitvoering van het huidige gevoerde beleid is de afgelopen drie decennia aanzienlijk achtergebleven bij de algemene ambities. De scenario's waarin emissiepaden zonder nieuw klimaatbeleidsbeleid worden verkend nemen proportioneel toe met de historische groeicijfers (zie Figuur 95). De uitvoering van het huidige beleid tot 2030 zal naar verwachting leiden tot enige verminderingen, maar zal nog steeds leiden tot een netto toename van de wereldwijde emissies ten opzichte van het niveau van 2010. Ook de 2020-beloftes en de mitigatiedoelstellingen in de NDC's voor 2030 stabiliseren alleen de emissies en zijn onvoldoende om de wereld op een kosten-efficiënt 2 °C- of 1,5 °C-pad te brengen.

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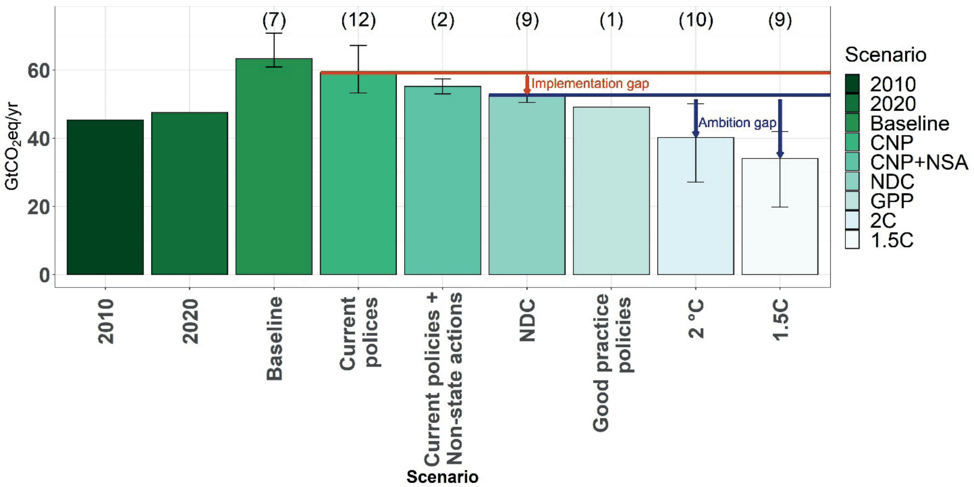
De verwachte emissieniveaus voor 2030 in het kader van de het Parijs-Akkoord laten zowel een ambitiekloof als een uitvoeringskloof zien (zie Figuur 96**).** In alle beoordelingen is de emissiekloof aanzienlijk. Momenteel ligt de geschatte totale kloof tegen 2030 tussen het huidige geïmplementeerde beleid en optimale trajecten naar 2 °C en 1,5 °C tussen 22-28 $GtCO_2eq$. Dit komt overeen met een extra reductie van 36-45% ten opzichte van het huidige beleidsscenario. Deze reductie kan worden onderverdeeld in een *implementatiekloof* in 2030 tussen het verwachte huidige beleid en de wereldwijd geaggregeerde NDC's en een nog grotere *ambitiekloof* tussen geprojecteerde NDC's en kosteneffectieve paden die de wereld op koers houden om de temperatuurstijging ruim onder 2 °C of 1,5 °C te houden.



Figuur 96 Wereldwijde (mediane) broeikasgasemissieprognoses voor 2030 voor verschillende klimaatbeleidsscenario's die in dit proefschrift zijn ontwikkeld in vergelijking met de historische totale kyoto-uitstoot van broeikasgassen in 2010 en 2020. Scenarioresultaten uit verschillende hoofdstukken (en modellen) zijn gecombineerd. Foutbalken geven minimale en maximale emissieniveaus voor specifieke scenario's uit de beoordelingen. Het aantal modellen dat heeft deelgenomen aan de beoordelingen en resultaten heeft opgeleverd voor een specifiek scenario wordt tussen haakjes weergegeven. De emissies zijn in GWP AR4.

Maatregelen van lokale overheden en bedrijven kunnen bijdragen aan het verkleinen van de emissiekloof, maar dit vereist een duidelijke vertaling van ambitie naar concrete plannen tezamen met meer transparantie. Deze dissertatie heeft bijgedragen aan de internationale beleidsomgeving door de reikwijdte van klimaatregelen in Integrated Assessment models te verbreden naar steden, regio's en bedrijven, waar de interactie tussen actoren en geografische schalen belangrijk is (Jordan et al., 2015). De geaggregeerde ambities lokale overheden en bedrijven kunnen de emissiekloof verkleinen aangezien deze naar verwachting de emissies ten opzichte van het huidige beleidsscenario met 2 $GtCO_2eq$ kunnen verminderen.

De wereldwijde toepassing van voorbeelden van beproefde toepassingen (good practice) zou de helft van de emissiekloof tussen het huidige beleid en 2 °C-paden kunnen dichten. Een mogelijke route voorwaarts voor klimaatbeleid is het bevorderen van een internationaal proces van wederzijds leren van beleidsmaatregelen en het ‘ontstaan van een wereldwijde marktplaats van ideeën’ (Hadjiisky et al., 2017). Landen zouden van elkaar kunnen leren en succesvol sectoraal beleid van andere landen kunnen herhalen, aangepast aan de lokale omstandigheden. Het implementeren van tien succesvolle voorbeelden in alle landen wereldwijd zou de wereldwijde uitstoot van broeikasgassen tegen 2030 met 10 $GtCO_2eq$ kunnen verminderen ten opzichte van een huidig beleidsscenario.

Het onderzoek in dit proefschrift heeft bijgedragen aan de verbetering van het realisme van Integrated Assessment modellen. Er is een beroep gedaan op Integrated Assessment modellen om een deel van het realisme van mitigatiepaden te verbeteren. Dit is vooral van belang bij het beoordelen of de wereld op koers ligt om de temperatuurdoelen te bereiken met het huidige geïmplementeerde (binnenlandse) beleid. Het onderzoek in dit proefschrift heeft bijgedragen aan de beoordeling van het klimaatbeleid door een methodologie te ontwikkelen om echt geïmplementeerd (sector)klimaatbeleid op te nemen in plaats van een algemene koolstofbelasting. Dit resulteerde in een betere weergave van sector- en technologietrends op korte termijn die van invloed zijn op emissiereducties op lange termijn.

Om echter de complexe transformatieve systeemveranderingen te bereiken die nodig zijn om de wereldwijde temperatuurverandering ruim onder 2 °C of zelfs 1,5 °C te houden zijn naast de implementatie van effectieve beleidsinstrumenten meer aspecten van belang. Beleidsleren en multi-level governance zijn andere belangrijke componenten (de Coninck et al., 2018). De modelgebaseerde mitigatiepaden zoals ontwikkeld in dit proefschrift behandelden deze onderwerpen door zich bezig te houden met internationaal beleidsleren en beleid voor goede praktijken om de wereld dichter bij een 2 °C- of 1,5 °C-emissiepad te brengen. Daarnaast beantwoordt dit proefschrift aan de oproep om de polycentrische governance van klimaatbeleid mee te nemen door verschillende actoren te betrekken. De dissertatie onderzocht de rol van niet-statelijke actoren en lokale overheden door hun impact op de wereldwijde uitstoot van broeikasgassen te analyseren, deels op basis van IMAGE-mitigatiepaden. Daartoe gaf het inzicht in de mate waarin bottom-up reducties plaatsvinden om het nationale klimaatbeleid te ondersteunen of te overstijgen en wat kan worden bereikt als actoren samenwerken in internationale samenwerkingsinitiatieven.

9.7 AANBEVELINGEN VOOR VERDER ONDERZOEK

Het informeren van de internationale klimaatbeleidsgemeenschap en het grotere publiek vereist regelmatige updates en inzichten in de voortgang van historische emissies, beleid en NDC-doelstellingen. Hoewel dit proefschrift liet zien hoe het huidige binnenlandse beleid kan worden geïmplementeerd in IAM's, en IMAGE in het bijzonder, vereist het informeren van de internationale klimaatbeleidsgemeenschap regelmatige updates en inzichten in de voortgang van historische emissies, beleid en NDC-doelen. Voor sommige IAM-modellen is het nog steeds belangrijk om meer details over het huidige beleid op te nemen en het voorbeeld van het IMAGE-model te volgen. Over het algemeen is het echter essentieel om de update van deze informatie in deze modellen te versnellen en te automatiseren. Omdat dit niet eenvoudig is zijn slimme ontwikkelingen nodig daar IAM's vaak complexe modellen zijn die bestaan uit verschillende onderling verbonden sub-modellen. De ontwikkeling van open-source software op basis van het IAMC-formaat (Gidden en Huppmann, 2019) zou de IAM-community kunnen verbreden en de huidige samenwerking tussen verschillende modelteams is al een goed startpunt. Verdere automatisering zou echter de rapportage van de huidige status van de implementatie ondersteunen.

Hoewel dit proefschrift heeft bijgedragen aan het toenemende realisme van IAM-mitigatiepaden, zouden er meer modelwijzigingen nodig zijn om de verschillende 'hoe komen we daar' vragen te beoordelen die opvallen na het Parijs-Akkoord. Voorbeelden zijn het opnemen van lokale omstandigheden, het verbeteren van de representatie van beleidsinstrumenten en het opnemen van sociaalwetenschappelijke inzichten. Aangezien IAM's echter belangrijke processen tussen de menselijke en natuurlijke omgeving beschrijven, moet altijd rekening worden gehouden met een evenwicht tussen te veel details en het opnemen van belangrijke factoren.

Aangezien alle actoren nodig zijn om de mondiale doelstellingen van het Parijs-Akkoord uit te voeren zouden de IAM's de ambitie en toezeggingen van niet-statelijke actoren en lokale overheden moeten omvatten. Dit kan worden gedaan door te linken naar meer gedetailleerde modellen of door IAM-resultaten te downschalen en toe te schrijven aan de lokaties waar actoren zich bevinden. Een optie om meer actoren op te nemen is het ontwikkelen van global agent-based modellen (ABM's) die heterogene besluitvorming meeneemt. Een mondiaal ABM-model bestaat echter (nog) niet, maar dit soort modellen richten zich over het algemeen op specifieke regio's of delen van het energiesysteem (De Cian et al., 2017). Niettemin kunnen deze modellen worden gekalibreerd voor meer IAM-resultaten op hoog niveau. Bovendien zou het inzichtelijk zijn om mitigatiepaden op lagere aggregatieniveaus te presenteren door emissies en energie-output naar regio's, steden en bedrijven te downscalen. Dit kan op basis van beschikbare rasterdata zoals stadsgrenzen, wegen en industriële locaties. Nieuwe ontwikkelingen zoals satellietbeeldgegevens (Yang et al., 2020) en open klimaatdata met behulp van blockchain (Wainstein, 2021) zijn in dit verband versterkend.

De introductie in dit proefschrift van expliciet huidig beleid en good practice-beleid tot 2030 in IAM's zou kunnen worden geëxtrapoleerd naar 2 °C, 1,5 °C of netto-nul-emissiescenario's om een expliciete weergave van beleidsdoelen en -instrumenten tot het einde van deze eeuw op te nemen in plaats van één wereldwijde koolstofbelasting na 2030. Het uitgangspunt voor deze scenario's zou de bestaande beleidsmix kunnen zijn op basis van de Climate Policy Database (NewClimate Institute, 2015) en vertaald naar modelparameters uit hoofdstuk 4. Vervolgens zouden op basis van inzichten uit de succesvolle sectorvoorbeelden uit Hoofdstuk 5 of Fekete et al. (2021) uitvoeringsmechanismen kunnen worden ontwikkeld om de onderliggende beleidsdoelen te bepalen en de langetermijntemperatuurdoelen te halen. Het zal resulteren in een 'second-best' portfolio van instrumenten die landelijke economische en verschillende soorten sectorale instrumenten combineert (Bertram et al., 2015). De belangrijkste uitdaging is de keuze van de beleidsdoelen door de complexiteit van beslissingscriteria die kostenefficiënctie zouden moeten vervangen.

Een belangrijk onderwerp voor beleidsimplementatie dat zou moeten worden aangepakt door IAMs-onderzoekers en de bredere gemeenschap van onderzoekers is het combineren van sociaalwetenschappelijke inzichten en IAM-resultaten over mitigatie. Andere wetenschappelijke disciplines zoals sociale en politieke wetenschappen zijn cruciaal in het leiden van de wereld naar transformatieve systeemveranderingen. We moeten begrijpen welke oplossingen haalbaar of beter zijn zoals ook wordt aangegeven in het artikel 'climate-policy models debated' van Anderson en Jewell (2019), of deze modellen zelfs koppelen aan politieke haalbaarheid (Jewell en Cherp, 2020). Belangrijke onderwerpen die in het kader van mitigatietrajecten aan bod moeten komen, zijn multi-level governance, institutionele capaciteiten, gedragsverandering en financiën (de Coninck et al., 2018). Inzichten in multi-level governance, zoals hierboven beschreven, kunnen de interactie tussen actoren en geografische schalen blootleggen (Jordan et al., 2015) en katalytische effecten identificeren. Instituties en menselijk gedrag beïnvloeden het besluitvormingsproces voor effectieve beleidsuitvoering (De Cian et al., 2017). Het financiële systeem is cruciaal voor het leveren van de grote investeringen die nodig zijn voor mitigatie. Er ontbreken echter inzichten over de onderlinge afhankelijkheid tussen de risicopercepties van beleggers, afhankelijk van de geloofwaardigheid van het klimaatbeleid en de allocatie van investeringen in de economie (Battiston et al., 2021).

Factoren die van invloed zijn op sociale verandering zullen naar verwachting grote gevolgen hebben en moeten worden gekoppeld aan IAM-resultaten door ze samen te brengen of te integreren. Samenbrengen omvat sequentiële en interactieve benaderingen. De sequentiële aanpak nodigt sociale wetenschappers uit om feedback te geven op klimaatbeleidsscenario's van IAM's die resulteren in herziene modelimplementaties op basis van randvoorwaarden die bepaalde mitigerende maatregelen begunstigen of belemmeren (Geels et al., 2016). De integratiebenadering brengt maatschappelijke aannames in bestaande modellen in kaart en beoordeelt deze door generaliseerbare en kwantificeerbare sociale patronen te integreren (Trutnevyte et al., 2019). (Geels et al., 2016).

9

SUPPLEMENTARY INFORMATION

Chapter numbers in the supplementary information correspond to the chapter numbers in the main text

SUPPLEMENTARY 2 A CLIMATE POLICY FRAMEWORK FOR DEVELOPING SCENARIOS IN THE CONTEXT OF THE PARIS AGREEMENT AND APPLICATION IN THE INTEGRATED ASSESSMENT MODEL IMAGE

S2.1 Author contributions

Mark Roelfsema (MR): conceptualization, methodology, software, validation, formal analysis, investigation, writing - original draft, writing - review & editing, project coordination

Heleen van Soest (HvS): Methodology, software, validation, formal analysis, investigation, writing - Review & Editing

Michel den Elzen (MdE): Methodology, writing - review & editing, supervision

Heleen de Coninck (HdC): Methodology, conceptualization, supervision, writing - review & editing

Takeshi Kuramochi (TK): Methodology, investigation, writing - review & editing

Mathijs Harmsen (MH): Software, validation, formal analysis

Ioannis Dafnomilis (ID): Software, validation, formal analysis

Niklas Höhne (NH): Methodology, conceptualization, supervision, funding acquisition

Detlef P. van Vuuren (DPvV): Methodology, conceptualization, writing - original draft, supervision, project coordination, funding acquisition

MR and DPvV. have received funding from the European Union's Horizon 2020 research and innovation programme (Grant agreement 837089, SENTINEL project).

S2.2 Supplementary data

Roelfsema, Mark (2022), "A decade of climate policy", Mendeley Data, V1, doi: 10.17632/krxvpxn8b9.1

2.s.1 - Supplementary Information – IMAGE implementation.xlsx

S2.3 References to IPCC reports

Supplementary Table 2-1 Used references for climate policy terms from IPCC reports

Term	Report		Page
Policies	Technologies, Policies and Measures for Mitigating Climate Change	IPCC, 1996	84
Policies	Annexes: In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, U	IPCC, 2014	1286
Objectives	*Climate Change 2001: Mitigation. Contribution of Working Group III to the third assessment report of the Intergovernmental Panel on Cimate Change*. Cambridge University	IPCC, 2001	401, 461, 567
Objectives	IPCC. (2007). *Climate change 2007: Mitigation of climate change. Working group III contribution to the fourth assessment report of the Intergovernmental Panel on Climate Change*. Cambridge University Press	IPCC, 2007	306, 677
Policy goals	IPCC (2014). *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*	IPCC, 2014	ix (preface), 1020
Policy targets	IPCC (2014). *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*	IPCC, 2014	1020
Policy instruments	Policies, instruments and cooperative arrangements: . In Climate change 2007: Mitigation of climate change (pp. 747-807)	Gupta et al 2007, IPCC 2007	750
Policy instruments	Climate change 1995: Economic and social dimensions of climate change. Contribution of Working Group III to the second assessment report of the intergovernmental panel on climate change	IPCC, 1995	15
Measures	Annexes: In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, U	IPCC 2014	1266 (Annex I)

SUPPLEMENTARY 3 ARE MAJOR ECONOMIES ON TRACK TO ACHIEVE THEIR PLEDGES FOR 2020? AN ASSESSMENT OF DOMESTIC CLIMATE AND ENERGY POLICIES

S3.1 Introduction

This Supplementary Information describes the methodology used to calculate the impact of the major climate and energy policies on emissions for major emitting countries (see Table 3-1, main text). Before describing the methods in more detail, we first explain the terms Primary energy supply and Target year, as these are used throughout the document.

Primary energy supply. Primary energy supply refers to the direct supply of energy at the source, or supply of crude energy which has not been subjected to any conversion or transformation process**29**. For generating electricity, either combustible sources, such as fossil fuels and biomass, or non-combustible sources, such as wind, solar, and nuclear, can be used. Primary energy supply can be directly measured for combustible sources, but for non-combustible sources it depends on the accounting method. In literature, there are two major accounting methods for determining the primary energy supply of non-combustible sources: the physical energy content method (IEA method) and the substitution method (BP method), see IPCC (Moomaw et al., 2011), , IEA for more details. The IEA method counts the electricity produced from the renewables as primary energy supply, while the BP method calculates an equivalent primary energy supply that would have been necessary to produce this electricity in a fossil-fuel power plant. The difference between the methods is the (virtual) energy loss (Martinot et al., 2007). In this study, PBL uses the IEA method, whereas Ecofys uses the method that is assumed in the underlying study.

Target year. Most policies have a target year of 2020. If the target year of a policy is after 2020, the target is linearly interpolated between 2010 and the target year. For example, the renewable mix target for Mexico that holds for 2023 is linearly interpolated between 2023 and 2010. The resulting target for 2020 is used as a starting point for the calculations to assess the effect of the policy. If the target year is before 2020, the target scenario that is constructed is divided into two parts. The first part contains emissions and energy projections until the target year, taking into account the target level. In the second part, we assume a business-as-usual (BAU) trend between the target year and 2020. For example, the effect of the energy intensity target for China that holds for 2015 is calculated by constructing a target scenario that meets the energy intensity target in 2015 and follows energy intensity

[29] http://www.iea.org/aboutus/faqs/energyefficiency/

trends from BAU between 2015 and 2020. The 2020 level of the target scenario can then be compared to BAU energy and emission projections.

S3.2 Renewable targets

Renewable targets aim for a certain amount of renewable energy supply in the target year. There are two types of renewable targets: (i) a *renewable mix target*, which aims for a certain share of renewable energy supply in the total energy mix, and (ii) a *renewable capacity target*, which aims for a certain amount of installed renewable power capacity, specified per type of renewable technology (e.g. solar, wind). A renewable capacity target only covers the electricity sector, but a renewable mix target can cover all sectors.

S3.2.1 Renewable mix targets

The effect of renewable mix targets is calculated based on the difference in the share of energy use from renewable resources between the BAU projection and a projection of a scenario in which the renewable target is achieved, using emission factors per unit of primary energy supply. If the target applies to electricity generation, a similar method is used.

A *renewable mix target* aims for a certain share of renewable energy in the target year. The share of renewable energy is either measured in terms of primary energy supply or electricity generation (which is a form of secondary energy supply). The difference between the two is that primary energy supply also includes energy use outside the electricity sector and that it accounts for energy losses in power plants within the electricity sector. Of the countries included in our study, Australia, Brazil, China, EU, India, Indonesia, Mexico, Russia, South Korea, and USA States have renewable mix targets.

The first step in the calculations is to determine the energy mix in the target scenario, in which the renewable target is achieved. If a country does not explicitly specify which non-renewable resources are replaced (e.g. coal, oil, gas) by which renewable resources (e.g. wind, solar), we have assumed that the weight of each renewable energy resource within the renewable mix is the same as in the BAU scenario. This also holds for the non-renewable resources within the non-renewable energy mix. In the second and final step, the emission level after implementation of the target is calculated for each energy carrier using emission factors per unit of primary energy supply. The emission factors for renewables are assumed to be zero. In the calculations we do not consider nuclear energy as a renewable energy source, except if countries have specified this (China, for instance, has defined its renewable target as a non-fossil target, which implies that nuclear energy is included).

There are three differences between the PBL and Ecofys calculations. The first difference is in the accounting method for primary energy supply. The PBL calculations are based on PBL TIMER projections, which are based on the IEA accounting method for primary energy supply. The only difference between the IEA and PBL TIMER accounting method is in the conversion ratio for nuclear energy: IEA assumes a ratio of 33% based on heat loss, whereas the PBL TIMER model assumes a ratio of 100% based on (the absence of) electricity loss. The Ecofys calculations use primary energy supply projections from national plans or the WEO 2011, and thus use the primary energy accounting method underlying these projections. The second difference is in the change in nuclear energy use between the BAU scenario and the target scenario. The PBL calculations assume substitution of nuclear energy by renewable energy, whereas the Ecofys calculations assume that the use of nuclear energy does not change between the two scenarios. Finally, if the target is defined in terms of electricity generation, the PBL calculations first determine the primary energy supply for each energy resource using the appropriate accounting method of primary energy supply before applying emission factors per unit of primary energy supply. The Ecofys calculations directly use emission factors per unit of electricity generation.

S3.2.2 Renewable capacity targets

The effect of renewable capacity targets is calculated by estimating the reduction in primary energy supply coming from fossil fuel resources compared to BAU developments, by replacing the fossil fuel resources with renewables resources, using emission factors per unit of primary energy supply.

A *renewable capacity target* aims for a certain amount of installed renewable power capacity in a specific year, specified per type of renewable resource (e.g. solar, wind). Brazil, China, India, and South Africa have renewable capacity targets.

In the PBL calculations, we first calculate the additional installed capacity per type of renewable resources compared to BAU projections. The electricity production from this additional renewable capacity is calculated by using load factors per renewable technology from the TIMER model. The load factor is defined as the annual generated electricity divided by the generated electricity that would have been achieved if the power plant would have functioned at maximum capacity for a full year (Blok, 2007). It is assumed that these additional installed renewable capacities replace coal-fired power plants. Then, the reduction in the primary energy supply of coal is calculated by using the efficiency of coal-fired power plants. Finally, the emission reduction is calculated based on the emission factors per unit of primary energy supply of coal.

The Ecofys calculations are based on a slightly different method. This method first determines the new energy mix in the target scenario, based on the electricity generation from the additional renewable capacities, using information on load factors from national studies or Beurskens et al. (2011). This method implies that renewable technologies replace different types of fossil-fuel power plants (whereas PBL calculations assume that only coal-fired plants are replaced – see above). The emission reduction is calculated based on emission factors per unit of electricity generation.

S3.3 Intensity targets

Two types of intensity targets can be distinguished: emission intensity targets and energy intensity targets. The calculations assume that the GDP trend is not affected by meeting the intensity targets.

S3.3.1 Emission intensity targets

Greenhouse gas emission intensity targets aim for reductions in emissions per unit of economic output (real GDP), in a specific year, compared to a base year.

Some countries (e.g. China, India[30]) have an emission intensity target, i.e. reduction in greenhouse gas emissions per unit of GDP. Hence, the effect of intensity targets on the emission level depends on future GDP growth: higher economic growth would imply a higher target emission level. The effect of this target is determined by calculating the emission level corresponding to the emission intensity target, assuming that GDP is not affected by the intensity target. This level can be compared to BAU emission projections to determine the expected emission reductions.

S3.3.2 Energy intensity targets

Energy intensity targets aim for reductions in primary energy supply per unit of economic output (real GDP), in a specific year, compared to a base year. The effect of energy intensity targets is calculated based on GDP projections, BAU trends in primary energy use and emission factors per unit of primary energy supply.

China, Russia, and Ukraine have energy intensity targets. The effect of these targets is determined by first calculating the primary energy supply level in a scenario in which the energy intensity target is achieved, again assuming that GDP is not affected by the target.

[30] India pledged an intensity target, but this is not included in the domestic policies

The emission target level is calculated using emission factors per unit of primary energy supply. This level can be compared to BAU projections to determine the expected emission reductions.

S3.4 Power plant standards

Power plant standards are usually set at the level of best available technology and are stated in terms of CO_2 emissions per unit generated electricity. The effect of power plant standards is estimated by calculating the difference in emissions per unit generated electricity of the new installed or replaced power plants between BAU projection and the projection in which all new plants meet the standards.

Power plant standards set a limit on CO_2 emissions per unit of generated electricity within a certain period. This performance standard is usually based on the best system of emission reduction that has been adequately demonstrated (Lashof Yeh et al., 2012); the so-called best available technology (BAT). The USA and Canada have set power plant standards based on natural gas combined-cycle (NGCC) plants or power plants capable of carbon capture storage. Power plant standards can apply for new (USA, Canada) or existing (Australia) fossil fuel power plants.

The effect of power plant standards is estimated by calculating the difference in emissions of the installed or existing power plants in the BAU projection and the projection in which these plants are replaced by new plants that meet or exceed the standards.

In the PBL calculations with the TIMER energy model, existing or new coal fired power plants under the BAU projections are replaced by power plants that satisfy the specified BAT standards. Assuming that the same amount of electricity is generated, the primary energy supply for the new power plants in the target scenario is calculated by applying the efficiencies of the specified BAT power plants. The emission reductions are calculated using emission factors per unit of primary energy supply.

Ecofys calculations are based on the assumption that with the power plant standard no additional coal-fired power plants are built; these are replaced by gas-fired power plants. Therefore, first the expected capacity increase of coal-fired power plants under the BAU projections needs to be determined. Subsequently, the electricity generated by these plants is calculated using an average load factor for coal-fired power plants of 7,500 hours/year[31].

[31] This can be converted to the load factor as defined in Section 2.2, given that a (non-leap) year has 8760 hours (see Blok (2006))

Emissions from the new coal-fired plants are calculated using coal emission factors per unit of generated electricity. For estimating the effect of the standard, we compare these emissions with the emissions that would be emitted if all the additional coal-fired plants were to be replaced by gas-fired power plants.

S3.5 Feed-in-tariff

The impact of feed-in-tariffs on installed renewable capacity is calculated based on the relationship between the level of the subsidy and growth of installed renewable capacity, estimated from historic data for Germany and Spain, and accounting for barriers such as difficult grid access, missing long-term perspectives and lack of clear regulations. The calculation of the effect on emissions of the resulting installed renewable capacities is the same as for renewable capacity targets.

A *feed-in-tariff* (FIT) is an energy-supply policy focused on supporting the development of new renewable power generation . The most common FIT policy provides a fixed rate per kilowatt hour (US$/kWh) for the electricity produced for a guaranteed period of time (Blok, 2007). The rate is usually based on the generation cost of each specific technology and is in general higher than expected electricity prices. South Africa and Ukraine introduced feed-in-tariffs.

The impact of feed-in-tariff policies is calculated by first estimating the impact of feed-in-tariffs on the growth of installed renewable capacity, and then by calculating the emission reduction resulting from this growth in the same way as is done for renewable capacity targets.

A calculation tool was developed by Ecofys to estimate the growth of installed renewable capacity resulting from a FIT scheme. The tool includes two main calculation steps. First the FIT is compared with the generation costs found in literature. Based on an analysis of the relationship between the level of the FIT and growth of installed renewable capacity from historic data for Germany and Spain, the annual growth rate is estimated to be equal to

$$g = \frac{\left(\frac{F}{C} - 1\right) - 0.1}{0.9}$$

where

g = annual growth rate of installed capacity
F = Feed-in-tariff of technology (per kWh)
C = Average costs per technology found in literature (per kWh)

This relationship assumes that a policy starts to be effective if the feed-in-tariff is more than 10% above average costs. If this is the case, the annual growth rate of installed capacity is proportional to the level of support above 1.1 times the costs. If the support is twice the costs, the annual growth rate is 100%. Then second, a barrier factor is determined through expert judgement and based on the following considerations that are weighted differently:

- Is grid access 100% assured?
- What is the long-term perspective (20 years)?
- Are clear regulations available for the guaranteed purchase price?

If there are no barriers in place, the annual growth rate is unaffected. Otherwise the resulting barrier factor will multiplied with the growth factor. Then the estimated growth factor will be multiplied with installed capacity values from WEO 2011 for the starting year and extrapolated to 2020.

S3.6 Emission trading system

Emission levels resulting from the implementation of an emission trading system (ETS) are determined by applying the proposed emission caps to emissions of the sectors that are covered by the ETS, also taking into account implementation barriers. The difference with BAU emissions determines the reductions.

In an *emission trading system* (ETS), allowances to emit GHG emissions are issued or auctioned to companies. Companies are required to hold a number of allowances equivalent to their emissions. In this way an emission cap is set. The national cap is set as a percentage reduction compared to a historical year or BAU level. Australia, the EU, South Korea and USA have set up emission trading systems.

Emission levels resulting from the implementation of an ETS are determined by applying the emission cap to the sectors that are covered under the ETS. The difference with BAU emissions determines the reductions. Based on expert opinion, a barrier factor is introduced to take into account expectations about reaching the target, for example because flaws in measurement, reporting or verification exist or lack of enforcement of the system. It is assumed that the ETS does not affect emissions of sectors not covered under the ETS.

S3.7 Fuel efficiency car standard

The effect of fuel efficiency standards for cars is calculated by two methods. The first is based on replacing cars that do not satisfy the new efficiency standards for cars that do, where the replacement rate is based on the average life time of cars. The other method makes use of the TIMER transport model; the effect on emissions is calculated by running a scenario with improved car standards, taking into account the higher purchase costs for such cars.

A *fuel efficiency car standard* aims to achieve a certain fuel efficiency for new cars within a specific period.

The effect of fuel efficiency standards for cars is calculated by two methods: the Ecofys method, which is based on the replacement rate of cars, and the PBL method, based on the TIMER transport model. Of the analysed countries, the USA and Canada have set fuel efficiency standards.

Ecofys calculations are based on BAU projections for travel distance and emissions from national studies or literature. An assumption is made for the expected life time of cars. This implies an average annual replacement rate for cars. It is assumed that this rate also applies to distance travelled. The calculation starts in the first year of the period that the car standard will come into effect. The car stock in terms of travel distance is decreased by applying the replacement rate, assuming a homogeneous age structure of existing cars. The removed cars are replaced with new cars that are built in that year and satisfy the car standard. The fuel efficiency for these cars follows a linear development until the standard that applies in the final year. These new cars remain in the car stock for a period equal to the expected life time. The emissions of old cars, that are built before the starting year, are calculated with an average emission factor per kilometre that applies in the BAU projections. The emissions for new cars are based on the new car standard. These steps are repeated for all the following years until the final year of the policy period.

The PBL calculations are based on running a target scenario in the TIMER transport model (Girod et al., 2012). Compared to the BAU scenario, two settings are changed (for details, see Deetman et al. (2012)). First, the efficiency for gasoline cars and trucks is set equal to the fuel efficiency standard. Second, the purchase costs of these cars is adjusted, based on costs found in literature. These adjustments lead to different car technologies under the scenario with efficiency standards compared to BAU projections, resulting in different transport emissions. The reduction from implementation of the fuel efficiency standard can be calculated by comparing these emissions to BAU projections.

S3.8 Biofuel targets

The effect of biofuel targets is calculated by two methods. For the first method the PBL TIMER transport model is used. The second method of Ecofys is based on substituting energy use from gasoline or diesel cars by biofuels, using different emission factors from literature.

A *biofuel target* sets a mandatory minimum volume or share of biofuels to be used in the total transportation fuel supply. The effect of biofuel targets is calculated by two methods. The first method of Ecofys is based on substituting energy use from gasoline or diesel cars by biofuels, using different emission factors from literature. For the second method the PBL TIMER transport model is used. Of the countries included in our study, only Indonesia has set biofuel targets.

Ecofys calculations are based on national projections. The additional energy use for biofuels is calculated by comparing the share of biofuels to the transport mix in the BAU projections. It is assumed that the additional biofuels replace gasoline and diesel. The emissions based on gasoline and diesel cars are compared with emissions from biofuels, calculated using IPCC emission factors (IPCC, 2006). Two different emission factor for biofuels are used, first it is assumed that biofuels do not lead to emissions and second that they do lead to indirect emissions, e.g. through land-use change and deforestation.

PBL calculations are based on running a target scenario using the TIMER transport model (Girod et al., 2012). Deetman et al. (2012) presents a more detailed description of the method. A biofuel target specifies the share of biofuels in the fuel mix, in terms of secondary energy use. We assume that the biofuel target is set for passenger cars only. In the biofuel target scenario, the model finds different share of fuels per vehicle type, leading to different emissions compared to BAU projections.

S3.9 Energy efficiency targets

Energy efficiency targets aim for reductions in primary energy supply or electricity consumption in a specific year, compared to either the level in a historic base year or BAU projections. The effect of energy efficiency targets that aim at reducing primary energy supply is calculated by applying the targeted reduction on historical levels or BAU trends in primary energy supply and emission factors per unit of primary energy supply. If the target applies to electricity generation, a similar method is used, in which first the primary energy supply is calculated using the appropriate accounting method.

Energy efficiency targets are similar as energy intensity targets, but instead of reduction per unit of GDP, absolute reduction is targeted. Of the countries included in our assessment, the EU is the only one that has set energy efficiency targets. Calculations are similar to those for energy intensity targets (see section 3.2). PBL and Ecofys calculations differ only for energy efficiency targets defined in terms of electricity consumption, and is the same as difference (iii) as described in section 2.1.

SUPPLEMENTARY 4 TAKING STOCK OF NATIONAL CLIMATE POLICIES TO EVALUATE IMPLEMENTATION OF THE PARIS AGREEMENT

S4.1 Author contributions

MR, DV wrote the paper, and all authors contributed to the analysis and article review. Figures were created by HvS and MR. MR, HvS, DvV, MdE and FU coordinated the analysis for this paper. The policy inventory and database was created by NH, GI, MR, HvS and DvV. The CD-LINKS project was supervised by KR and VK, and advised by JE. MH, EK, GL, KR, MR, HvS and DvV coordinated the global modelling exercise, and CB, DH, VK, EK, GL, KR, RS, HvS, FU and DvV coordinated the national modelling exercise. DvV and NH supervised the collection of policies, and DvV and MR the protocol for model runs. The scenario database was coordinated by DH and VK. Global model runs (incl. documentation) were accomplished by MH, MR, HvS (IMAGE), CB, FH, EK, GL, FU (REMIND), SF, OF, MG, VK (MESSAGE), LD, JE, LAR (WITCH), ZV, KF (GEM-E3), JD, KK (POLES), RS, PR (COPPE-COFFEE), AK (BLUES), SF, KO (AIM/CGE, AIM Enduse Japan), KG (DNE21+), WC (China TIMES), GI (GCAM-USA), MK (PRIMES), GS (RU-TIMES), SSV (AIM-India), JK (IPAC China), RM (MARKAL India).

S4.2 Source data Data Figures

Roelfsema, Mark (2022), "A decade of climate policy", Mendeley Data, V1, doi: 10.17632/krxvpxn8b9.1

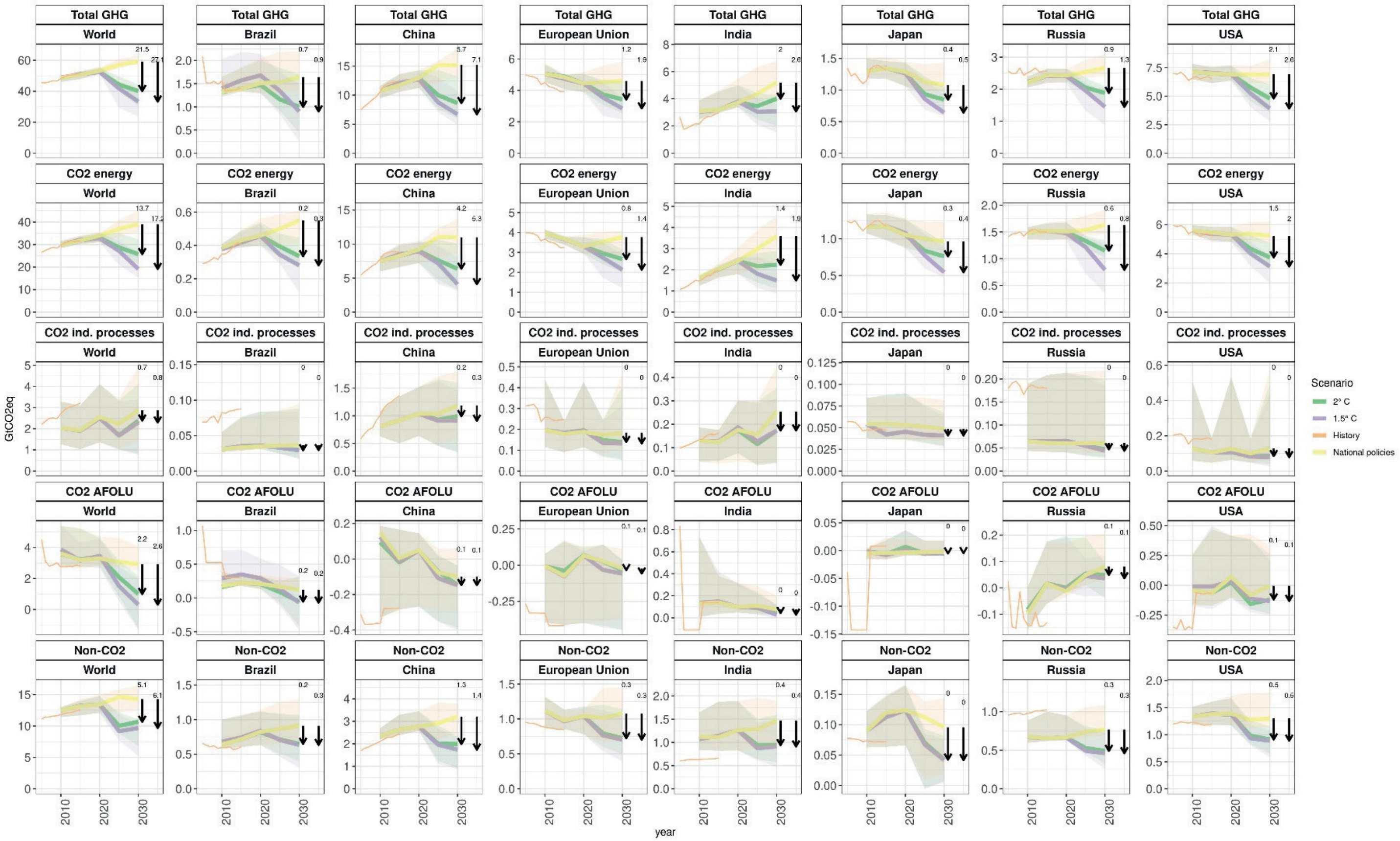
4.s2a Source Data 1 – Data Figures.xls

S4.3 Source data IAM protocol

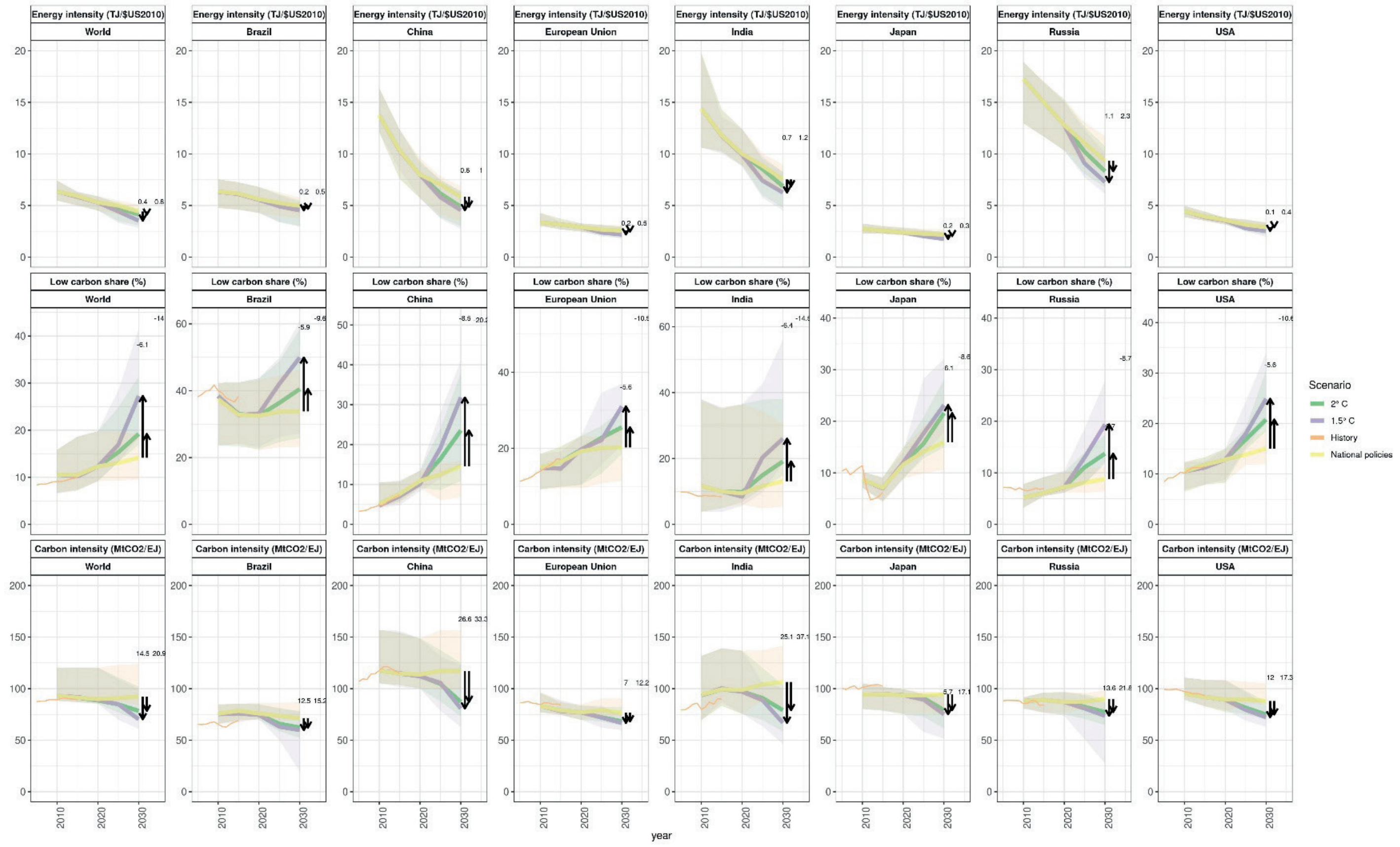
Roelfsema, Mark (2022), "A decade of climate policy", Mendeley Data, V1, doi: 10.17632/krxvpxn8b9.1

4.s2b Source Data 1 – IAM protocol_CD_LINKS.xls

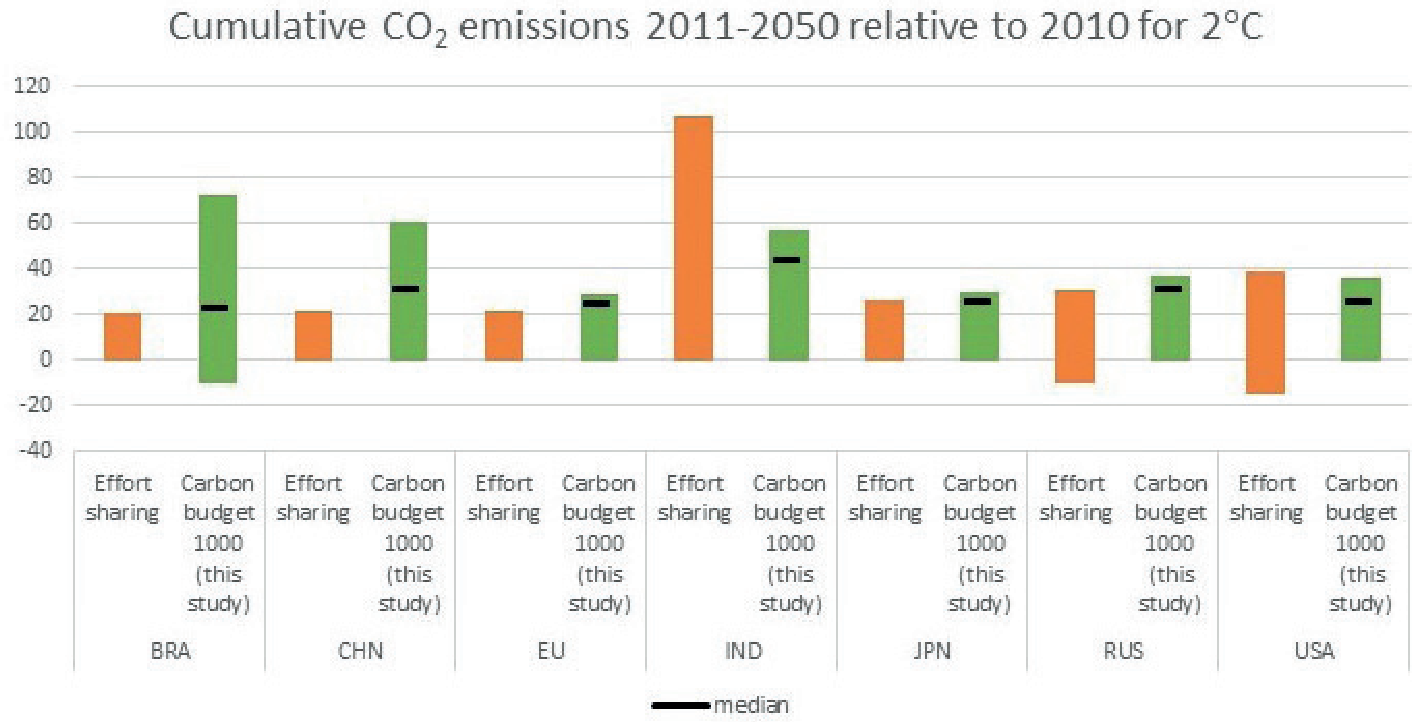
S4.4 Supplementary Figures



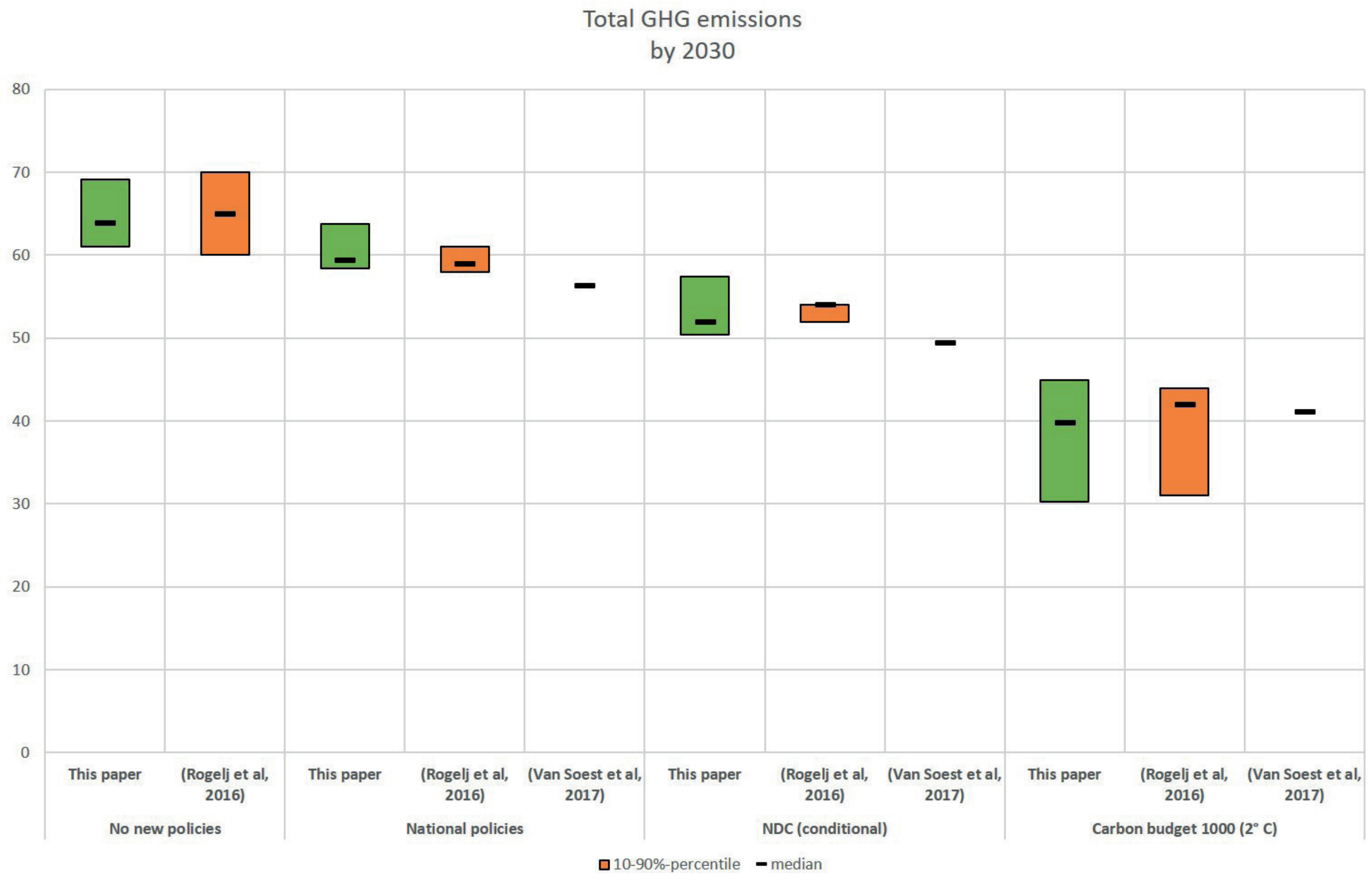
Supplementary Figure 4-1 Decomposition of total greenhouse gas emissions into CO2 energy, CO2 industrial processes, CO2 Agriculturze and other land use (AFOLU) and non-CO2 emissions. Arrows with number a on top show the emissions gap in GtCO2eq.



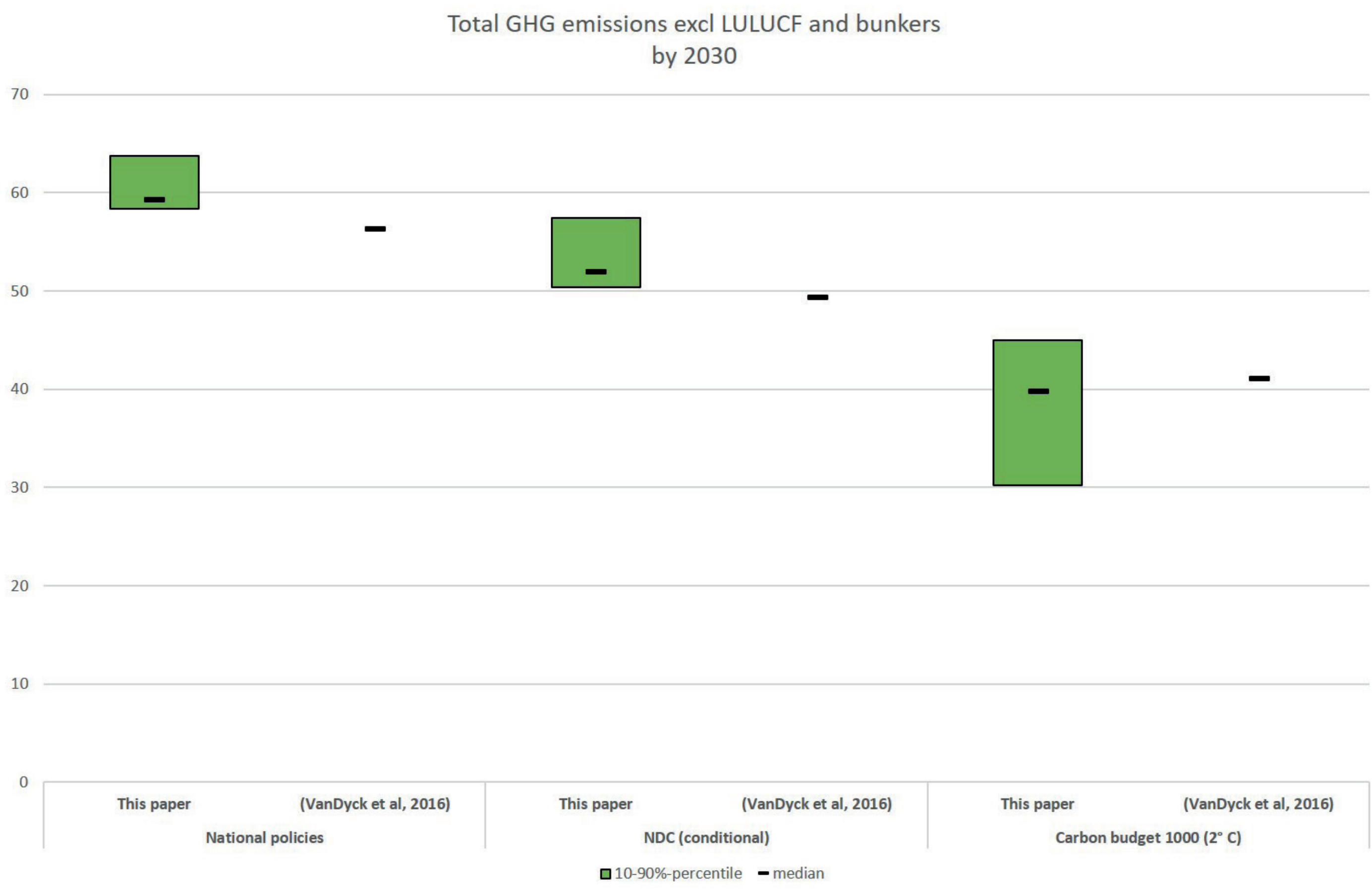
Supplementary Figure 4-2 Decomposition of CO2 emissions using Kaya identity into energy intensity (final energy/GDP), low carbon share of final energy and CO2 intensity of fossil final energy



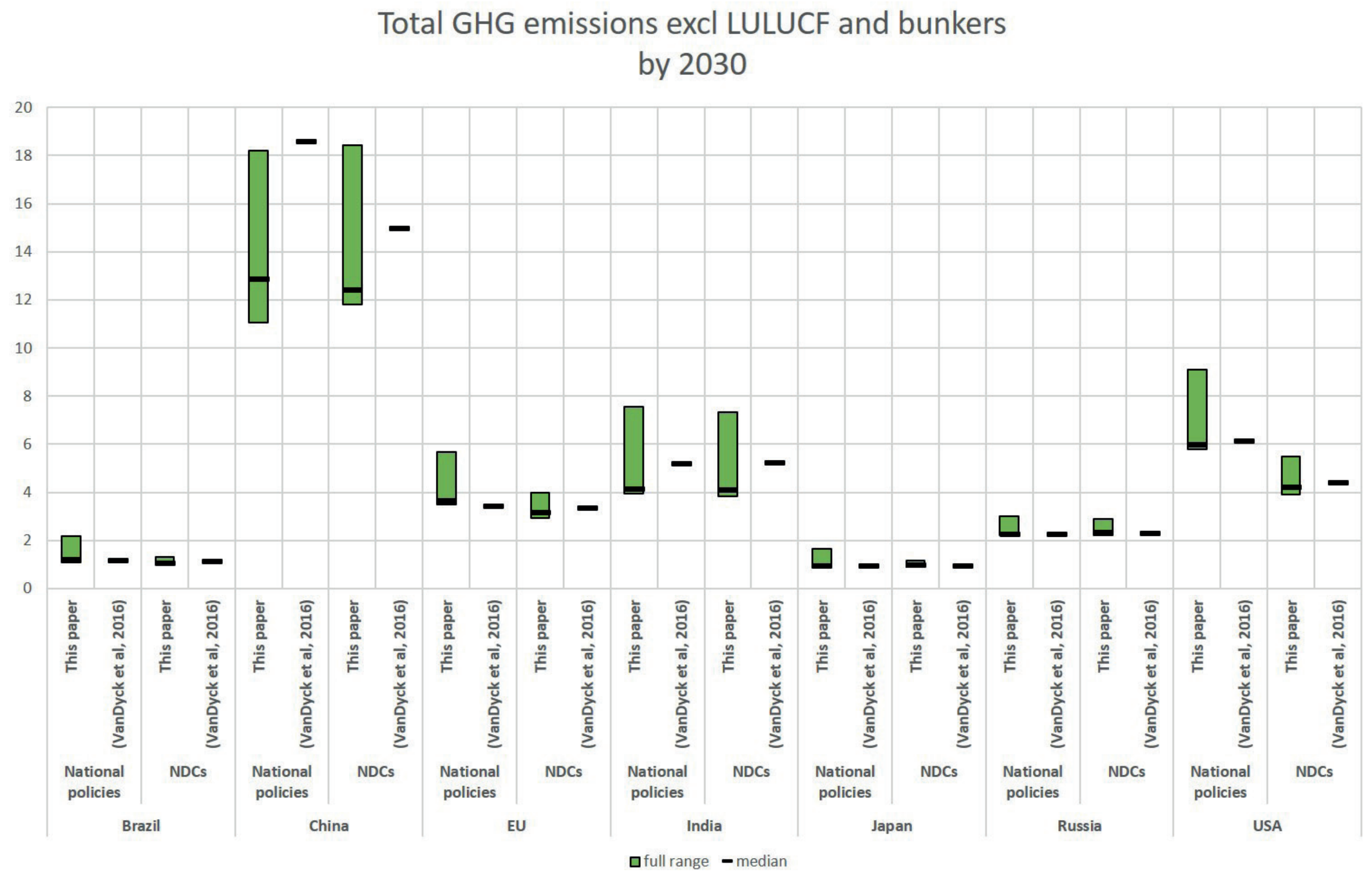
Supplementary Figure 4-3 Comparison of G20 country emission years (cumulative emissions 2011-2050 relative to 2010) with effort sharing range for carbon budget 1000 GtCO2 from CD-LINKS project. The effort sharing ranges are calculated by only one model, the FAIR model (Stehfest et al., 2014)



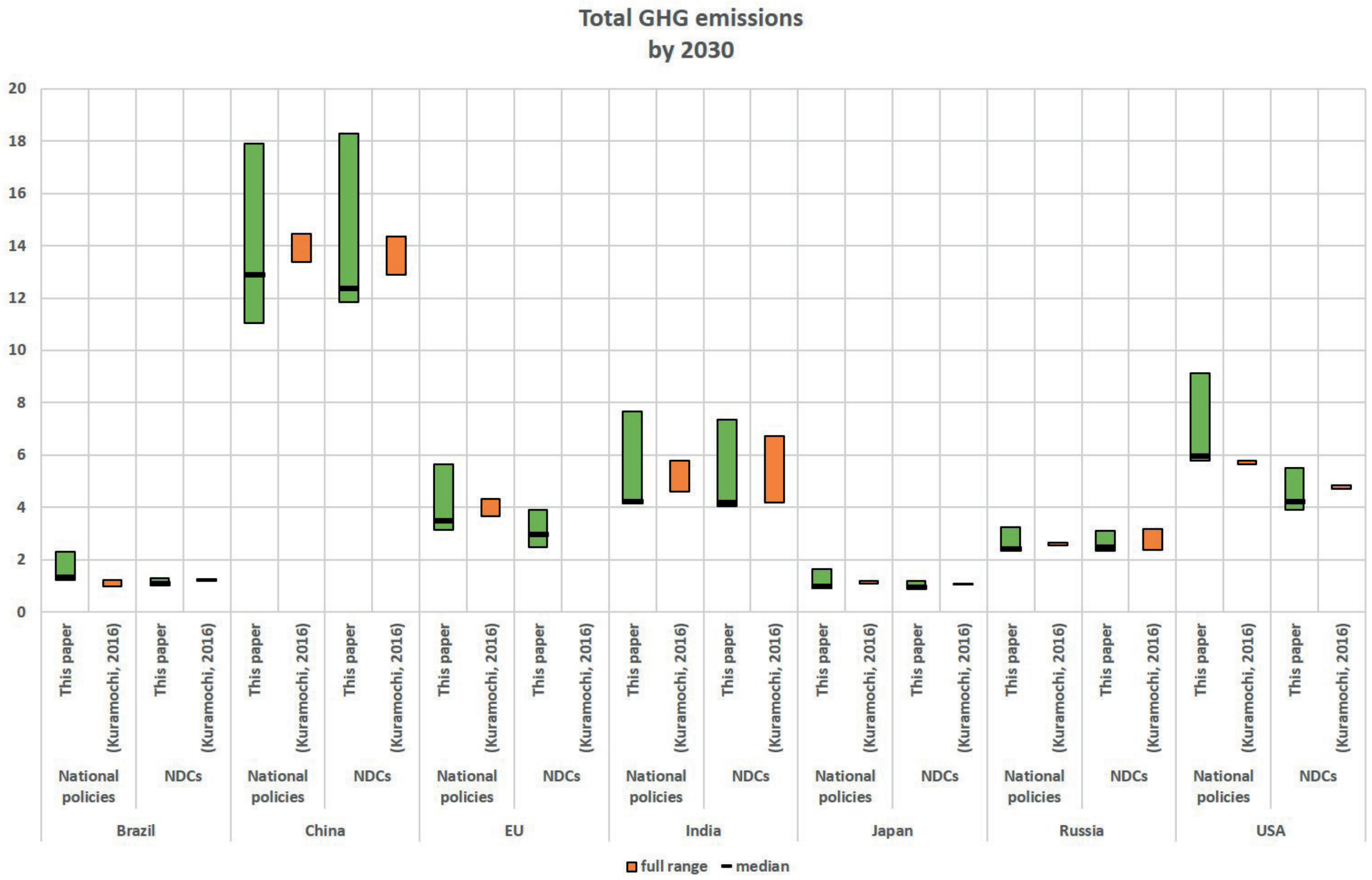
Supplementary Figure 4-4: Comparison of total GHG emissions on a global level for the No new policies, National policies, NDC (conditional) and Carbon budget 1000 scenario between this study and Rogelj et al. (2016) *and van Soest et al.* (2017).



Supplementary Figure 4-5 Comparison of National policies, NDC and carbon budget 1000 scenario on global level with VanDyck et al. (2016). *Total emissions exclude LULUCF and bunkers*



Supplementary Figure 4-6 Comparison of National policies, NDC and carbon budget 1000 scenario on global level with VanDyck et al. (2016). *Total emissions exclude LULUCF and bunkers*



Supplementary Figure 4-7 Comparison of National policies and NDCs of seven large G20 countries with (Kuramochi et al., 2016b). *Total emissions exclude LULUCF and bunkers*

S4.5 Supplementary Tables

Supplementary Table 4-1 Total GHG emissions in 2010 for G20 countries and countries with implemented climate policies, but not included in assessment

	Country	ISO	Total Kyoto emissions (2010)
	World	EARTH	47,100,000
Included	Argentina	ARG	450,000
	Australia	AUS	554,000
	Brazil	BRA	1,550,000
	Canada	CAN	880,000
	China	CHN	10,600,000
	France	FRA	473,000
	Germany	DEU	932,000
	India	IND	2,140,000
	Indonesia	IDN	2,140,000
	Italy	ITA	474,000
	Japan	JPN	1,150,000
	Mexico	MEX	690,000
	Republic of Korea	KOR	625,000
	Russia	RUS	2,510,000
	Saudi Arabia	SAU	533,000
	South Africa	ZAF	525,000
	Turkey	TUR	357,000
	the United Kingdom	GBR	608,000
	the United States	USA	6,580,000
	European Union	EU28	4,490,000
	G20 countries		35,774,000
	Seven large emitting countries		29,020,000
Not included	Bhutan	BTN	(801)
(with implemented policies)[32]	Chile	CHL	90,600
	Costa Rica	CRI	6,890
	Ethiopia	ETH	135,000
	Gambia	GMB	2,100
	Kazakhstan	KAZ	305,000
	Mororcco	MAR	102,000
	New Zealand	NZL	62,400
	Norway	NOR	33,500
	Peru	PER	174,000
	Philippines	PHL	202,000
	Singapore	SGP	52,700
	Switerzland	CHE	51,100
	UAE	ARE	233,000
	Ukraine	UKR	394,000
	Total with policies, not included		1,843,489
	World	EARTH	47,100,000

[32] https://climateactiontracker.org/countries/, retrieved October 2019

Supplementary Table 4-2 Consulted sources for setting up Climate Policy Database

Name	**Sectors covered**	**Countries**	**Report/ Database**	**Website**
Climate Policy Database	All	All	Database	http://climatepolicydatabase.org/
IEA Addressing Climate Change	All, including Adaptation	50 countries including all IEA countries	Database	http://www.iea.org/policiesandmeasures/climatechange/
IEA Global Renewable Energy	Renewables	126 countries including all IEA countries	Database	http://www.iea.org/policiesandmeasures/renewableenergy/
IEA Energy Efficiency	Energy Efficiency - All	66 countries including all IEA countries	Database	http://www.iea.org/policiesandmeasures/energyefficiency/
Climate Action Tracker	All	30 countries	Country Profiles	http://climateactiontracker.org/countries.html
UNFCCC National Communications	All	Worldwide	Country Reports	http://unfccc.int/national_reports/items/1408.php
LSE Global Climate Legislation DB	All	Worldwide	Database	http://www.lse.ac.uk/GranthamInstitute/legislation/the-global-climate-legislation-database/
OECD Fossil Fuel Support	All	OECD countries	Database	http://stats.oecd.org/Index.aspx?DataSetCode=FFS_AUS
Columbia Law School Database	All	Worldwide	Country Profiles	http://web.law.columbia.edu/climate-change/resources/climate-change-laws-world#http://web.law.columbia.edu/climate-cha
INDCs – UNFCCC	All	Worldwide	Country sheets	http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx
ECOLEX	All	Worldwide	Database	https://www.ecolex.org/
REN21	RE and EE	Worldwide	Database	Data download: http://www.ren21.net/status-of-renewables/ren21-interactive-map/; Report: http://www.ren21.net/future-of-renewables/global-futures-report/
Kevin Boulder Thesis	Climate Strategies	Worldwide	Database	Excel file provided
Enerdata	Building standards	A few countries	Database	Export excel: https://www.wec-policies.enerdata.eu/world-overview.php#BC-residential
Industrial Efficiency Policy Database (IEPD)	Industrial efficiency	15 countries	Country profiles	http://iepd.iipnetwork.org/
Transport policy	Vehicle and fuel energy and emissions standards	10 countries	Country profiles	Transportpolicy.net

Name	Sectors covered	Countries	Report/ Database	Website
Dieselnet	Emissions standards	A few countries	Country profiles	https://www.dieselnet.com/standards/
REEGLE	RE and EE	All?	Country profiles	http://www.reegle.info/countries/a
RES Legal	Renewables	EU members	Country profiles	http://www.res-legal.eu/
OECD Policy Instruments for the Environment	Fiscal/ Financial/ Regulatory	OECD and 38 others	Database	http://www2.oecd.org/ecoinst/queries/Default.aspx#
OECD Environmental country data	Not policies!! Indicators.	OECD + others	Database	https://stats.oecd.org/Index.aspx?DataSetCode=EPS
OECD Science, technology and industry outlook		OECD	Country surveys	http://qdd.oecd.org/DATA/STIOb_COUNTRY_ITEM_TOPIC_POLICY_SOURCE/.SVN..STIO_2012?Page=1
Investment and R&D	R&D	All	Country profiles	https://www.innovationpolicyplatform.org/content/statistics-ipp?l=G_XGDP;v3;s;;IND
World Bank INDC data	INDCs	All	Database	http://spappssecext.worldbank.org/sites/indc/Pages/mitigation.aspx
WTO Environmental Database	Trade-relevant env. policies	All	Database	https://www.wto.org/english/tratop_e/envir_e/envdb_e.htm
State incentives of RE & EE	RE and EE	US	State list	http://www.dsireusa.org/
State Energy Efficiency Policy	EE all	US	Database	http://database.aceee.org/
IEA Clean Coal Database	Emissions standards	All		http://www.iea-coal.org.uk/site/2010/database-section/emission-standards?
Industrial Efficiency Programs	Industry	All		http://www.iipnetwork.org/databases/programs
GBPN - Building Policies for a Better World	Buildings	A few EU & US states		http://www.gbpn.org/databases-tools
APEC Energy Standards	Appliances	21 countries		http://apec-esis.org/
ICAP Emissions Trading Schemes	Industry (?)	All National and Regional		https://icapcarbonaction.com/ets-map
EU Climate Change Mitigation Policies and Measures	All, including Adaptation	EU		http://www.eea.europa.eu/data-and-maps/data/climate-change-mitigation-policies-and-measures-1
Deutsche Bank Global Climate Policy Tracker	All	All	Report	https://www.db.com/cr/en/docs/Global_Policy_Tracker_20120424.pdf
Asia Regional Integration Centre	All	Asia	Database	https://aric.adb.org/climatechange?seltab=3

Supplementary Table 4-3 Selected number of high impact policies for G20 countries

Policy type	Brazil	China	European Union	India	Japan	Russian Federation	United States of America	Other G20 countries	Total
Renewable electricity policies	6	9	0	8	1	4	1	33	62
Other policies	1	0	0	0	0	0	1	2	4
Transport biofuel blending	4	2	0	4	0	0	3	10	23
Forestry policies	4	3	0	2	2	0	0	8	19
F-gas emission reduction policies	0	0	1	0	1	0	0	1	3
Transport fuel tax	0	0	0	0	0	0	0	2	2
Economy-wide policy targets	0	7	6	0	2	1	0	6	22
Renewable policies in demand sectors	2	2	3	0	0	0	0	1	8
Buildings policies	1	0	0	0	0	0	0	0	1
Transport fuel efficiency standards	1	4	2	4	1	0	2	8	22
New power plant standards	0	0	0	1	0	0	1	2	4
Building standards	0	0	0	0	0	0	0	2	2
Existing power plant standards	0	1	0	0	0	0	0	0	1
Industry policies	0	3	0	4	1	0	0	1	9
Building codes	0	1	2	0	1	0	4	2	10
Electric vehicle policies	0	4	0	1	1	0	0	0	6
Carbon taxes, emission trading	0	0	1	0	0	0	0	1	2
Energy tax/ subsidies	0	0	0	0	6	0	0	0	6
Fossil-fuel production policies	0	0	0	0	0	2	1	2	5
Other buildings policies	0	0	0	0	0	1	2	0	3
Agricultural policies	0	0	0	0	0	0	1	0	1
	19	36	15	24	16	8	16	81	215

Supplementary Table 4-4 Selected number of high impact policies for G20 countries

Model/policy	AIM V2.1	IMAGE 3.0	MESSAGEix-GLOBIOM_1.0	POLES CDL	REMIND-MAgPIE 1.7-3.0
Carbon tax, emission trading	A carbon tax on region level is the main policy instrument of the model, increasing the cost of fossil energy carriers and increasing the cost-effectiveness of energy savings measures. The carbon tax is endogenously determined by emissions constraints parameters.	A carbon tax on region and sector level is the main policy instrument of the model, increasing the cost of fossil energy carriers and increasing the cost-effectiveness of energy savings measures. The carbon tax is an input parameter of the model. Emissions trading is implemented through imposing a carbon tax on GHG emissions and sectors covered, such that the emission reduction target (or cap on GHG emissions) is met.	*not implemented*	The carbon value is the main mitigation instrument across the entire economy. It is different according to the region and sector. It is an input of the modeller used to reach a given carbon emission budget. No explicit carbon trading; the EU ETS is modelled as a single carbon price for participating countries and sectors.	Regional carbon taxes that apply for all GHG emissions are the main policy instrument in the policy scenarios. In the NDC scenario, they are iteratively adjusted, such that the regional 2025/2030 emissions target is met, with exogeneous assumptions on the temporal profile of the tax. For scenarios with global emissions budgets, similarly the harmonized global tax rate is adjusted iteratively so as to meet the budget.
Renewable electricity policy	Renewable share and capacity targets are exogenously input as the share in the total electricity. The capacity targets are translated into the power generation and shares accordingly by assuming capacity factors. To realize these targets, logit parameters are endogenized.	Renewable share: first the share of technologies used for electricity production is determined in the usual way (multinomial logit function, see general description of IMAGE policy implementation). Then, if the annual increase would reach a renewables share lower than the imposed target, the ratio of renewable to fossil technologies is increased until the total renewable share is achieved, keeping the ratio between the renewable technologies,	Renewable share: Share targets in general can be applied for different energy levels. As MESSAGE models 11 global regions, national targets are re-calculated, based on historical data, into regional targets. Should multiple national targets within a model region exist, then these are aggregated. If these multiple national targets within a single model region differ in	Renewable capacities are in competition with non-renewable technologies through a multinomial logit function while taking into account the non-dispatchable nature of wind and solar energy sources. The decreasing value of wind and solar with their penetration is included. Feed-in tariffs modify the competitiveness of renewables, by technology. A non-cost factor representing the technological maturity	Short term targets for absolute renewable deployment (in GW) or renewable shares (in %) are implemented in all regions. For the former, country targets are summed up, while the latter is only used for native model regions (i.e. EU28, Japan, USA, China, India)

Model/policy	AIM V2.1	IMAGE 3.0	MESSAGEix-GLOBIOM_1.0	POLES CDL	REMIND-MAgPIE 1.7-3.0
		and also between the non-renewable technologies, the same. Renewable capacity targets: these are input parameters of the model, and enforce installation of specific capacities in addition to the outcome of the multinomial logit function in the same way as for renewable electricity targets.	their definition (e.g. non-fossils as a share of primary energy and renewables as a share of electricity generation), then these are recalculated to a single type of share constraint in order to obtain the aggregated impact within a single region. Renewable capacity targets: renewable capacity targets are recalculated into (powerplant) activity which is used as direct lower bound in the model.	and choice preferences between technologies can be altered to represent regulatory measures, non-cost policies or non-market-related consumer choice.	
Renewable policy in demand sectors	Renewable targets in demand sectors are not implemented.	Renewable targets in demand sectors can only be implemented iteratively by implementation of individual measures (e.g. car renewable electricity targets, efficiency standards, subsidies of electric cars, biofuel standards and fuel tax in the transport sector) such that the renewable target is achieved. If possible, the policy mix should be based on existing country climate- and energy plans.	Renewable targets in demand sectors Here only biofuel targets or renewable share targets are directly implemented as constraints in the model. As MESSAGE models 11 global regions, national targets are re-calculated, based on historical (2010) data, into regional targets. Should multiple national targets within a model region	Renewables adoption in demand sectors is triggered by the carbon value in these sectors, which will favour low-carbon options in the multinomial logit function.	The share targets for biofuels in transport are implemented on the level of secondary energy liquids, with a lower share to account for non-transport liquids use in buildings and industry.

Model/policy	AIM V2.1	IMAGE 3.0	MESSAGEix-GLOBIOM_1.0	POLES CDL	REMIND-MAgPIE 1.7-3.0
			exist, then these are aggregated. If these multiple national targets within a single model region differ in their definition (e.g. non-fossils as a share of primary energy and renewables as a share of electricity generation), then these are recalculated to a single type of share constraint in order to obtain the aggregated impact within a single region.		
Existing power plant standard	Existing power plant standards are implemented by changing the input coefficient of fuel.	Existing power plant standards can be implemented through changing the efficiency of existing power plants starting after a specific year, which are both input parameters of the electricity model.	Existing power plant standards have not been directly implemented. The model is calibrated to IEA energy production/ generation statistics and certain technology transitions are already assumed as part of the overall scenario design, e.g. once unabated coal power plant capacity has reached the end of its life time a shift to newer, cleaner technologies is assumed.	Power plant standards are input parameters for historical plants.	No standards on existing power plants are implemented.

Model/policy	AIM V2.1	IMAGE 3.0	MESSAGEix-GLOBIOM_1.0	POLES CDL	REMIND-MAgPIE 1.7-3.0
New power plant standard	New power plant standards are not explicitly considered.	New power plant standards are implemented by specifying a maximum efficiency or CO2-intensity for new power plants (input parameter), which prevents installation of less efficiency power plants even if this is cost-effective (allocation is done with multinomial logit function).	New power plant standards have not been directly implemented. The model is calibrated to IEA energy production/generation statistics and certain technology transitions are already assumed as part of the overall scenario design, e.g. once unabated coal power plant capacity has reached the end of its life time a shift to newer, cleaner technologies is assumed.	The standards of new power plants can be adjusted by the evolution of efficiency in the future.	In the case of the US, this is implemented by disabling new construction of coal power plants without CCS.
Model/policy	**WITCH2016**	**COPPE-COFFEE 1.0**		**DNE21+ V.14**	**GEM-E3**

Model/policy	AIM V2.1	IMAGE 3.0	MESSAGEix-GLOBIOM_1.0	POLES CDL	REMIND-MAgPIE 1.7-3.0
Carbon tax, emission trading	Carbon taxes can be implemented globally or regionally, and on a generic sector such energy or land use or on a specific fuel. Similarly, a global or coalition specific emission trading market can be implemented for the energy system, based on a per-specified GHG emission cap.	In mitigation scenarios the model can use a combination of carbon tax and/or carbon budgets. When using carbon budgets, the cost of limiting carbon emissions is the shadow price (dual value). Emissions trading is available in the model, and it is used to achieve the global minimum cost. In the basic form of the model, there is no constraint on emissions traded (regions can trade freely).		A carbon tax on region is an input parameter of the model.	Carbon taxes and the energy system soft linkage with energy system models or IAMs (PRIMES for the EU28 and IMAGE for non-EU regions in these scenarios) are the main enablers of the low-carbon transition in this scenario set-up for GEM-E3. Following the transformation of the energy system via the soft linkage, a carbon tax is applied to all unabated emissions so as to ensure the achievement of the emission target and/or the emissions trajectory. For the NDC scenarios this corresponds to a carbon tax on the economic sectors and GHG gases that are mentioned in the original INDC communication of the Parties to UNFCCC so as to achieve the NDCs in 2025/2030. The carbon tax is endogenous and estimated as the dual variable of the emission constraint. It thus serves so as to abate the remaining emissions and meet the 2025/2030 target in the NDC case or the 2010-2050 emission pathway for the budget scenarios. For this application, there is no initial allocation of permits and

Model/policy	AIM V2.1	IMAGE 3.0	MESSAGEix-GLOBIOM_1.0	POLES CDL	REMIND-MAgPIE 1.7-3.0
					no emission trading takes place. Nevertheless, GEM-E3 features several structures of emission trading schemes, not used in this analysis. Carbon tax revenues are then recycled back to the economy through either i) a reduction of social security contributions, ii) the reduction of indirect taxation or iii) a lump-sum transfer to the households.
Renewable electricity policy	Both renewable shares and capacity targets, can be directly implemented in WITCH constraining the model to meet at least the specified target. The shadow price yields the marginal cost of the policy.	The user defines what technologies are a part of the renewable share or capacity (hydro, wind, solar, geothermal, biomass, etc). Renewable share: shares are generally added by user-defined constraints, for each region, which are composed of inequalities equations in the LP. Renewable capacity targets: there are two ways to implement capacity targets: minimum constraint of absolute capacity (unit: MW) or capacity additions (MW/year).		Renewable share targets in electricity generation by region by time point are represented by additional constraints which total renewable generation (e.g. total renewables including hydro) divided by total power generation is equal to an input parameter of the model. Renewable capacity targets are input parameters of the model. For solar and wind, capacity targets are converted to generation targets by using annual capacity factor by region.	GEM-E3 power supply system features 10 power technologies. The power supply mix is exogenously defined via a one-way soft-linkage with other energy system models (PRIMES for the EU28 and IMAGE for the non-EU regions in this case). We thus follow the power mix and RES targets defined in the implementation of scenarios by IMAGE model. In particular, to achieve the soft link for the power mix, GEM-E3 features a Leontief production function for power supply, whose parameters are set equal to the shares of each technology in the power mix of the energy system model.

Model/policy	AIM V2.1	IMAGE 3.0	MESSAGEix-GLOBIOM_1.0	POLES CDL	REMIND-MAgPIE 1.7-3.0
Renewable policy in demand sectors	Renewable targets in demand sectors can only be implemented in 2 generic sectors (electric and non-electric(except road transport)) and in road transport. Similarly to the electricity targets this can be implemented directly as constraints to the model. The shadow price yields the marginal cost of the policy.	Renewable targets in demand sectors can be achieved in different ways. The main approach is through implementation of individual measures (e.g. electrification targets, efficiency standards, biofuel standards and fuel tax). Nonetheless, user-defined constraint (such as for renewable share) can also be applied.		Renewable targets in demand sectors are represented by additional constraints which total renewable energy consumption (e.g. biofuels in transport) divided by total final energy consumption by sector is equal to an input parameter of the model.	Similarly to the power supply sector, for this analysis, the fuel mix of the GEM-E3 for the energy demand sectors is exogenously taken via a one-way soft-linkage. For this purpose, we adjust the fuel mix of private transportation, the fuel mix of public transport modes, the fuel mix of freight transportation, the fuel mix of households, industry and service sectors, including data for the level of electrification and the penetration of biofuels by end-user category.
Existing power plant standard	Existing power plant standards can be implemented through changing the efficiency of existing power plants starting after a specific year, which are both input parameters of the electricity model.	Existing power plant standards are modelled by changing the input parameters (such as efficiency) of the set of technologies available in the model.		Existing power plant standards are represented by excluding specific power plant options (e.g. low-efficiency coal) by region by time point which does not meet the standards.	No standards on existing power plants are implemented.

Model/policy	AIM V2.1	IMAGE 3.0	MESSAGEix-GLOBIOM_1.0	POLES CDL	REMIND-MAgPIE 1.7-3.0
New power plant standard	New power plant standards are implemented by specifying the efficiency for new power plants (input parameter).	New power plant standards are implemented by limiting the options of technology expansion of the model, preventing certain technologies (available in the model) to be chosen. When a specific standard is not within the range of the current set of technologies available, new technologies were added to represent the new standard.		New power plant standards are represented by excluding specific power plant options (e.g. low-efficiency coal) by region by time point which does not meet the standards.	No standards on new power plants are implemented, but implictly this is taken into consideration through the exogenous input of power supply mix (please refer to the responses of the IMAGE model)

Model/policy	AIM V2.1	IMAGE 3.0	MESSAGEix-GLOBIOM_1.0	POLES CDL	REMIND-MAgPIE 1.7-3.0
Transport fuel efficiency standard	The fuel efficiency of total road energy consumption is an input parameter of the model, which is represented by changing the efficiency parameter. Actual model results are affected by the price effects and therefore we changed the parameter manually roughly meet the corresponding target.	The fuel efficiency of new cars and trucks is an input parameter of the model, which is fixed for the target year, and interpolated between the current and target year. Non-fuel costs of cars are changed accordingly.	The effect of fuel efficiency standards of new cars and trucks was implemented via adjusting the autonomous energy efficiency improvement (AEEI) indicators of the MACRO model (linked to MESSAGE) based on the total final energy savings as estimated by the IMAGE model.	The fuel efficiency of vehicles can be defined as input parameter if the modelling does not otherwise reach the policy objective (via price-induced technical change with fuel prices and carbon prices, and via autonomous technical improvements).	REMIND does not differentiate different vehicle efficiency classes. Therefore, these policies are represented by implementing an upper bound on final energy use in transport, informed by results from the IMAGE modelling.
Transport biofuel standard	Transport biofuel targets is assumed to be in the share of biofuel consumption in the total road energy consumption. We change the logit parameter to hit the target share.	Transport biofuel targets consist of either a mandatory minimum volume of biofuels in the total fuel supply, or sets a minimal share of biofuels. As the TIMER model only includes vehicles that drive on one fuel, biofuel blending is modelled by fixing the share of new biofuel cars and fossil fuelled cars in a specific year. This share is an input parameter to the model, and works in the same way as for the renewable electricity share (by changing the result of the multinomial logit function).	As MESSAGE models 11 global regions, national targets are re-calculated, based on historical (2010) data, into regional targets. Should multiple national targets within a model region exist, then these are aggregated. The constraint is applied to the transport sector.	The share of biofuels used in conventional engines is determined by the relative costs of fuels. An evolving maximum blend is included.	The share targets for biofuels in transport are implemented on the level of secondary energy liquids, with a lower share to account for non-transport liquids use in buildings and industry.

Model/policy	AIM V2.1	IMAGE 3.0	MESSAGEix-GLOBIOM_1.0	POLES CDL	REMIND-MAgPIE 1.7-3.0
Electric vehicle policy	Electric vehicle targets, in terms of share of new electric car energy usage in the total road energy consumption, is implemented in the same way as is done for biofuel standards.	Electric vehicle targets, in terms of share of new electric cars in the total fleet, is implemented in the same way as is done for biofuel standards.	Share targets in general can be applied for different energy levels. As MESSAGE models 11 global regions, national targets are re-calculated, based on historical (2010)data, into regional targets. Should multiple national targets within a model region exist, then these are aggregated. The constraint is applied specifically to the transport sector.	EVs develop based on a multinomial logit function (with elasticities) according to the relative total cost of all vehicles, including their fuel costs (which are impacted by the carbon value).	Absolute target for number of electric vehicles in stock are directly implemented as lower bound.
Building standard	Building codes (standards) are implemented by changing the energy efficiency parameter in the building sector.	Building codes (standards), in terms of maximum energy use per m2, is implemented by specifying the heating efficiency (MJ/m2/HDD) for the target year, inducing use of more efficient heating technologies and increased insulation. The model interpolates this efficiency between the current and target year. Other services such as cooling and appliances are not targeted (yet).	The effect of building codes (and other efficiency measures in the building sector such as standards for appliances and lighting) was implemented via adjusting the autonomous energy efficiency improvement (AEEI) indicators of the MACRO model (linked to MESSAGE) based on the total final energy savings as estimated by the IMAGE model.	The building stock is defined with low consumption, medium consumption and standard buildings. The development of low and medium consumption buildings is linked to a return on investment taking into account energy prices and technological development (maturity of new technologies).	In this version, building standards are not represented.

Model/policy	AIM V2.1	IMAGE 3.0	MESSAGEix-GLOBIOM_1.0	POLES CDL	REMIND-MAgPIE 1.7-3.0
F-gas emission reduction targets	F-gas emissions reduction policies are not implemented.	F-gas emission reduction targets are implemented by applying a carbon tax only to F-gases such that the required emission level is achieved.	*not implemented*	SF6, PFCs: emissions follow MACCs considering the economy-wide carbon price. HFCs: the Kigali agreement was considered reached (exogenous trajectories of emissions per country/region).	F-Gas emissions are an exogeneous parameter in the scenarios, and different pathways are used for the different policy scenarios.
Fossil-fuel production policies	Fossil fuel production intensity targets are not implemented.	Fossil fuel production intensity targets are defined in terms of CO2/CH4 per energy used (GJ). It is assumed that the oil and gas production for each region remains at the same level as in the baseline scenario. As this is an end of pipe measure, additional flaring/venting measures are implemented that decrease GHG emissions to the level that would achieve the annual reduction target of the oil/gas emission intensity.	*not implemented*	The emission factor of CH4 for gas, coal and oil production follow MACCs considering the economy-wide carbon price, on top of the underlying activity evolution (gas, coal, oil production).	Not represented, as emissions intensity of fuels is exogeneous parameter in the model.
Other	Fossil fuel taxes are set as polices targeting. Industrial and economy wide energy efficiencies are controlled by changing autonomous energy efficiency parameter.	The model allows for setting other taxes or subsidies in addition to carbon tax, such as oil tax and car subsidies resulting in a different allocation of fossil and non-fossil energy carriers or technologies.	The effect of efficiency measures in the industry sector was implemented via adjusting the autonomous energy efficiency improvement (AEEI) indicators of the MACRO model (linked to MESSAGE) based on the total final energy savings as estimated by the IMAGE model.	Energy taxes or subsidies are kept constant in volume; renewable support mechanisms (e.g. feed-in tariffs) are progressively phased-out.	NA

Model/policy	WITCH2016	COPPE-COFFEE 1.0	DNE21+ V.14	GEM-E3
Transport fuel efficiency standard	This can be done only for road transport of passenger and freight vehicles. Similarly to the electricity targets, it can be specified directly as a constrain in the model. The shadow price yields the marginal cost of the policy.	The fuel efficiency of new vehicles (cars, busses, trucks, etc) is an input parameter of the model. COFFEE uses the same approach as for new power plant standard: by limiting the available options of fleet expansion (through sales of new vehicles) of the available range of technologies (cars, busses, trucks, etc). Therefore, an specific target is met by allowing a combination of vehicles.	The fuel efficiency of new cars and trucks is represented by excluding specific vehicle options (e.g. small low-efficiency internal combustion engine passenger vehicle) by region by time point which does not meet the standard.	The fuel efficiency of new cars and trucks is an input parameter of the model, calibrated to detailed energy system models
Transport biofuel standard	This can be done only for road transport of passenger and freight vehicles. Similarly to the electricity targets, it can be specified directly as a constrain in the model. The shadow price yields the marginal cost of the policy.	Transport biofuel targets are modelled by the combination of three approaches: i) the model has the options of blending biofuels with fossil fuels up to a given range (e.g. from 0% to 50%); ii) there are several technology options for producing advanced biofuels, which replaces conventional fuels (diesel, gasoline, kerosene and bunker); iii) There are vehicles options that can use blended biofuels, conventional or advanced fuels. There are also a few options of flex-fuel vehicles (e.g. gasoline/ethanol).	Transport biofuel targets are represented by additional constraints which total biofuel consumption divided by total final energy consumption in transport sector by region by time point is equal to an input parameter of the model.	See column D. Biofuel shares are specified through the one-way soft-link with energy system models (IMAGE)
Electric vehicle policy	This can be done only for road transport of passenger and freight vehicles. Similarly to the electricity targets, it can be specified directly as a constrain in the model. The shadow price yields the marginal cost of the policy.	Electric vehicle targets can be achieved the same way as renewable capacity targets: by share of the fleet or through share of sales of new vehicles.	Electric vehicle target, in terms of the number of electric vehicles is an input parameter of the model.	See column D. Electric vehicles shares are specified through the one-way soft-link with energy system models (IMAGE), in particular apart from the fuel mix for passenger transport, we also adjust the share of new electric, plug-in-hybrid and conventional vehicles

Model/policy	WITCH2016	COPPE-COFFEE 1.0	DNE21+ V.14	GEM-E3
				taking stock of the input from PRIMES model and other available input from IAM models and adjusting accordingly for non-EU regions.
Building standard	Currently the model cannot represent the building sector.	Building codes (standards) are simplified in COFFEE. There assumptions of parameters (heating and cooling efficiency) for the determination of the specific demands of the residential sector, which are not completely endogenous at this time. The model has limited options of energy efficiency for all energy services included in the model.	Building standard, in terms of energy savings in building sector is represented by additional constraints which total final energy consumption in building sector in policy scenarios is smaller than that in baseline by specific amount that is an input parameter of the model.	Not represented
F-gas emission reduction targets	F-gas emission reduction targets are implemented by applying a carbon tax only to F-gases such that the required emission level is achieved or by applying a generic carbon tax.	The model does not include F-gas at this time, therefore there are no mitigation options.		F-gases are mitigated through the imposition of the carbon tax. GEM-E3 features a MAC curve for non-CO2 GHGs which has been estimated from input taken by the GAINS model.
Fossil-fuel production policies		Fossil fuel production intensity targets are defined by adjusting the use of mitigation options for the oil and gas sector. For instance, there flaring, venting and gas recuperating options for each region and type of oil/gas reservoir (e.g. onshore and offshore). There are also options of recuperating methane in some coal reservoirs. Energy efficiency options for fossil fuel production are not included at this time.		Fossil fuel production intensity targets are remain the same as in the baseline scenario. MAC curves for CH4 emissions imply end of pipe abatement measures for the scenarios, depending on the carbon tax level.

Model/policy	WITCH2016	COPPE-COFFEE 1.0	DNE21+ V.14	GEM-E3
Other	The model allows for setting other taxes or subsidies and coalition emission trading markets in addition to carbon tax, such as oil tax and car subsidies resulting in a different allocation of fossil and non-fossil energy carriers or technologies.		CO2 intensity targets (CO2/TPES), energy intensity targets (TPES/GDP), energy consumption targets (TPES and total energy consumption in industry sector relative to those in baseline), primary energy consumption and coal consumption targets (cap), and gas and oil import targets (share) are represented by additional constraints which are input parameters of the model.	

Model/policy	*AIM/Enduse[Japan]	*BLUES
Carbon taxes, emission trading	Carbon tax trajectory (based on the national carbon budget in each scenario)	The model takes either carbon pricing or an emissions budget. No emissions trading implemented.
Renewable electricity targets	Renewable capacity targets (Calculated from generation share target according to the NDC: 22% in 2030) by 2020 and 2030 in the NPi and NDC scenarios, respectively.	Shares of renewable sources in power generation are implemented via constraints on activity, capacity or both.
Renewable targets in demand sectors	N/A	Transport biofuel targets are modelled by the combination of three approaches: i) the model has the options of blending biofuels with fossil fuels up to a given range (e.g. from 0% to 50%); ii) there are several technology options for producing advanced biofuels, which replaces conventional fuels (diesel, gasoline, kerosene and bunker); iii) There are vehicles options that can use blended biofuels, conventional or advanced fuels. There are also a few options of flex-fuel vehicles (e.g. gasoline/ethanol). Agriculture sector technological options include solar and biomass driers, biofuel machines. Industrial options also include fuel switching through technologies delivering the same end service but utilizing renewable sources. The fuel efficiency of new vehicles (cars, busses, trucks, etc) is an input parameter of the model. COPPE-MSB uses the same approach as for new power plant standard: by limiting the available options of fleet expansion (through sales of new vehicles) of the available range of technologies (cars, busses, trucks, etc). Therefore, a specific target is met by allowing a combination of vehicles.
Existing power plant standards	N/A	Existing power plant standards are fixed to current values. These plants can be replaced by new ones with higher efficiency or, in some cases, refurbished to either extend their lifetime (hydro_repot) or improved their efficiencies (bagasse-fired boilers in the sugarcane sector).
New power plant standards	N/A	New power plants have better standards than vintage ones, but their efficiencies do not improve over time.

Model/policy	*AIM/Enduse[Japan]	*BLUES
Transport fuel efficiency standards	National fuel economy standards	The fuel efficiency of new vehicles (cars, busses, trucks, etc) is an input parameter of the model. BLUES uses the same approach as for new power plant standard: by limiting the available options of fleet expansion (through sales of new vehicles) of the available range of technologies (cars, busses, trucks, etc). Therefore, a specific target is met by allowing a combination of vehicles.
Transport biofuel targets	N/A	Transport biofuel targets are modelled by the combination of three approaches: i) the model has the options of blending biofuels with fossil fuels up to a given range (e.g. from 0% to 50%); ii) there are several technology options for producing advanced biofuels, which replaces conventional fuels (diesel, gasoline, kerosene and bunker); iii) There are vehicles options that can use blended biofuels, conventional or advanced fuels. There are also a few options of flex-fuel vehicles (e.g. gasoline/ethanol).
Electric vehicle targets	N/A	Electric vehicle targets can be achieved the same way as renewable capacity targets: by share of the fleet or through share of sales of new vehicles.
Building Standards	Building energy standards for new constructions (the 1999 standard for residential and commercial buildings)	Building codes (standards) are not explicitly modelled in BLUES. However, appliances sued in buildings can be chosen from a diverse portfolio of options including CFLs and LEDs for lighting, high efficiency appliances for cooling, PV and solar water heating. There are assumptions of parameters (heating and cooling efficiency) for the determination of the specific demands of the residential and commercial sectors, which are not completely endogenous at this time.
F-gas emission reduction targets	N/A	The model does not include F-gas at this time, therefore there are no mitigation options.
Fossil-fuel production intensity targets	N/A	Land use and agriculture are explicitly model at technology level, with various options in land use conversion, crop and livestock production technologies. Intensification of crop and livestock production is explicitly modelled. Mitigation measures such as nitrification inhibitors are not modelled in the version used in this project but has been implemented in a new version being calibrated and tested currently.
Other	Nuclear capacity targets (Lifetime extension to 60 years and new construction based on the NDC)	

Supplementary Table 4-5 Overview of policy implementation per integrated assessment model

	%-of policies implemented (in 7 large countries)		Reduction relative to No new policies scenario
	# policies	% impact of IMAGE reductions	
IMAGE 3.0	94%	100%	-3.8%
DNE21+ V.14	64%	81%	-11.2%
WITCH2016	62%	63%	-3.8%
REMIND-MAgPIE 1.7-3.0	42%	71%	-4.0%
MESSAGEix-GLOBIOM_1.0	43%	81%	-5.7%
POLES CDL	49%	56%	-3.0%
COPPE-COFFEE 1.0	51%	50%	-0.6%
AIM V2.1	55%	64%	-4.6%
GEM-E3	40%	58%	NA

Supplementary Table 4-6 Overview of policy implementation per integrated assessment model

Party (target year)	Base Year emissions (incl LULUCF)	Base Year emissions (excl LULUCF)	LULUCF emissions Target Year	LULUCF credits	Emissions "conditional" vs 2010 (incl LULUCF)	Emissions "conditional" vs 2010 (excl LULUCF)	Emissions "conditional" at target year (incl LULUCF)	Emissions "conditional" at target year (excl LULUCF)
EU (2030)	5,368	5,626	-283		68%	69%	3,093	3,376
Canada (2030)	789	736	-28	-30	56%	74%	517	545
Mexico (2030)	973	x	0		85%	87%	623	623
USA (2025)	6,223	7,228	-970		68%	79%	4,543	5,513
Argentina (2030)	670	x	115		110%	107%	469	354
Brazil (2030)	2,100	x	0		80%	117%	1,300	1,300
Australia (2030)	548	523	34		70%	64%	400	367
Japan (2030)		1,408	-76	-37	89%	85%	1,003	1,079
Korea (Republic) (2030)		851				84%		536
China (2030)		5,976	-250					
India (2030)		1,433	-325					
Indonesia (2030)	2,881	1,918	439		79%	148%	1,700	1,261
Russian Federation (2030)	3,532	3,368	-468	-468	106%	119%	2,357	2,826
Saudi Arabia (2030)	1,160	1,160				162%		1,030
Turkey (2030)	1,175	1,230	59		254%	207%	928	870
South Africa (2030)			-26		97%	103%	506	532

Supplementary Table 4-7 NDC policies in CD-LINKS protocol

Party	Target year	Policy (includes only countries >0.15 of global 2010 emissions)
China	2030	20% non-fossil fuels in primary energy consumption
	2030	increase the forest stock volume by around 4.5 billion cubic meters on the 2005 level
India	2030	40% cumulative electric power installed capacity from non-fossil fuel based energy sources
	2030	create additional carbon sink of 2.5 to 3 billion tCO2eq through additional forest and tree cover

Supplementary Table 4-8 NDC policies in CD-LINKS protocol

Country	Source for LULUCF 2030 projections target year	Assumptions for LULUCF 2030 projections	Source for LULUCF credits
EU	(den Elzen et al., 2016)		We assume the EU has zero LULUCF credits in 2030
Canada	(den Elzen et al., 2016)		(Grassi and Dentener, 2015)
Mexico	(den Elzen et al., 2016)	Estimate from Fifth National Communication is used (Den Elzen et al. include range)	
USA	(Grassi and Dentener, 2015)		
Argentina	(UNFCCC, 2015d)	Assumption: 2010 emissions are kept constant until 2030	
Brazil	(Grassi and Dentener, 2015)		
Australia	(den Elzen et al., 2016)		
Japan	(den Elzen et al., 2016)		INDC Japan
Republic of Korea			
China	(Grassi and Dentener, 2015)		
India	(Grassi and Dentener, 2015)		
Indonesia	(UNFCCC, 2015e)	National baseline from BAPPENAS presentation (Government of Indonesia, 2015)	
Russian Federation	(den Elzen et al., 2016)		(Grassi and Dentener, 2015)
Saudi Arabia		It is assumed that the INDC is excluding LULUCF	
Turkey	(UNFCCC, 2015c)	No LULUCF credits estimates available, so we assume full accounting. For this 2013 emissions from BUR are kept constant	
South Africa	(National government of South Africa, 2015)	Assumption: 2010 emissions are kept constant until 2030	

Supplementary Table 4-9 Individual impact of most effective policies based on IMAGE model calculations and an overview whether these were implemented in the other eight participating models (1=implemented, 0=not implemented)

Country	**Policy target type**	**GHG Reductions (MT CO2eq)**	**IMAGE 3.0**	**DNE21+ V.14**	**WITCH2016**	**REMIND-MAgPIE 1.7-3.0**	**MESSAGEix-GLOBIOM_1.0**	**POLES CDL**	**COPPE-COFFEE 1.0**	**AIM V2.1**	**GEM-E3**
China	Renewable electricity	409	1	1	1	1	1	1	1	1	1
USA	Power plant standard	366	1	1	0	1	1	0	1	0	1
US A	Fuel efficiency standard cars	242	1	1	1	1	1	1	0	1	0
EU	Building standard	218	1	0	0	0	0	0	0	0	0
EU	Emissions trading	195	1	1	1	1	1	1	0	1	1
China	Fuel efficiency standard cars	160	1	1	1	1	1	1	1	1	0
USA	Flaring and venting regulation	103	1	0	0	0	0	0	0	0	0
EU	Fuel efficiency standard cars	96	1	1	1	0	1	0	0	1	1
India	Fuel efficiency standard cars	90	1	1	1	1	1	1	0	1	0
India	Energy efficiency policy	76	1	1	0	0	1	0	0	1	0
Japan	F-gas policy	64	1	0	1	0	0	0	0	0	1

Country	Policy target type	GHG Reductions (MT CO2eq)	IMAGE 3.0	DNE21+ V.14	WITCH2016	REMIND-MAgPIE 1.7-3.0	MESSAGEix-GLOBIOM_1.0	POLES CDL	COPPE-COFFEE 1.0	AIM V2.1	GEM-E3
India	Renewable electricity	37	1	1	1	1	1	1	1	1	1
Brazil	Fuel efficiency standard cars	29	1	1	0	0	1	1	1	1	0
Brazil	Biofuel mandate	23	1	1	1	0	1	1	1	1	1
India	Biofuel mandate	20	1	0	1	0	1	0	1	0	1
Japan	Renewable electricity	18	1	1	1	1	0	1	1	1	1
Brazil	Renewable electricity	11	1	1	1	1	1	1	1	1	1
USA	Biofuel mandate	5	1	1	1	0	1	1	1	1	1

Supplementary Table 4-10 Online model documentation

Model	Coverage IAM model	Documentation
AIM V2.1	Global	http://www-iam.nies.go.jp/aim/data_tools/enduse_model/aim_enduse_manual.pdf
COPPE-COFFEE 1.0	Global/national	https://www.iamcdocumentation.eu/index.php/Model_Documentation_-_COFFEE-TEA (under review)
DNE21+ V.14	Global/national	https://www.rite.or.jp/system/en/global-warming-ouyou/modeltodata/overviewdne21/
GEM-E3	Global/national	https://ec.europa.eu/jrc/en/gem-e3
IMAGE 3.0	Global	https://models.pbl.nl/image/index.php/Welcome_to_IMAGE_3.0_Documentation (including visualization tool)
MESSAGEix-GLOBIOM_1.0	Global	https://message.iiasa.ac.at/en/stable/ (including installation version)
POLES CDL	Global	https://ec.europa.eu/jrc/en/poles
REMIND-MAgPIE 1.7-3.0	Global	REMIND: https://www.pik-potsdam.de/research/transformation-pathways/models/remind MAGPIE : https://www.pik-potsdam.de/research/projects/activities/land-use-modelling/magpie (both including source code)
WITCH2016	Global	https://doc.witchmodel.org/

S4.6 Supplementary Note: Scenario protocol for the model comparison

All scenarios and input parameters used in our analysis are described in the global modelling protocol (CD-LINKS, 2017b) and accompanying list of high impact policies and policy indicators. A summary of most important assumptions and a short description of scenarios is given in this section. The following scenarios have been used

- No new policies scenario
- National policies scenario
- NDC scenario
- 2 °C scenario
- 1.5 °C scenario

S4.6.1 Country and region definitions

The analysis described here addresses the impact of climate policies of the G20 economies Brazil, China, European Union, India, Russia and the USA. However, the results for Argentina, Australia, Canada, Indonesia, Mexico, Republic of Korea, Saudi Arabia, and South Africa are based on explicit policies also, but were only included in the global results. The Rest of the World (RoW) region that is presented in the paper includes all remaining G20 economies, except for the seven G20 countries that were explicitly addressed. The G20 countries cover approximately 75% of global GHG emissions, and countries with implemented climate policies (according to Climate Tracker) represent approximately 5%.

S4.6.2 Climate policy database and selection of high impact climate policies

To inform the Integrated Assessment Models, a climate policy inventory was developed for the G20 countries (CD-LINKS, 2017a). The consulted sources for this were country NDCs that often include a description of policies that are being implemented to meet the NDC reduction targets, literature, national experts and existing policy databases (see Supplementary Table 4-2). Based on this database, a selection of high impact policies was made, which were secured in the CD-LINKS protocol, and can be found in Supplementary S4.2. Supplementary Table 4-3 categorises the policies into different policy types. A selection of around ten high impact policies for each G20 country was made with the help of national climate policy experts participating in the CD-LINKS project, but also from outside the project (see worksheet 'high impact policies'). To replicate the impact on GHG emissions, energy and land use, the policies were translated into policy indicators that can be implemented in integrated assessment models (see worksheet 'protocol reference (numerical)'), which is described in the Methods section. The tables in this worksheet show the policy indicators for G20 countries for each sector: economy-wide, energy supply, transport, buildings, industry and AFOLU. These policy targets are classified as ‘ target, ‘alternate interpretation’ or ‘planned’. The ‘target’ policies are included in the national policies scenario (NPi), while the planned policies scenario (NPip in protocol) also includes those classified as ‘planned’. The latter was not assessed in this report. The ‘alternate interpretation’ can be used as alternative to the ‘target’ if this better connects with the model structure.

The spreadsheet also includes NDC emission reduction targets for G20 countries, and many other countries (worksheet ‘NDC emission targets’). Note, that some NDCs include additional policy targets besides emission reduction targets (e.g. non-fossil target) (worksheet ‘NDC policies’). The NDC information is based on the protocol used in the ADVANCE (Luderer et al., 2018; Vrontisi et al., 2018) project, but was updated with additional information and guidance.

S4.6.3 Nationally Determined Contributions

The Nationally Determined Contributions (NDCs) were included in the NDC. This scenario starts from the National policies scenario, and additionally implements individual G20 country NDC targets (see Supplementary Table 4-5), but also NDCs from other countries. In general, these additional emission reductions above national domestic policies were implemented with a carbon tax, resulting in cost-optimal implementation. In addition, China and India also specified renewable energy and forestry targets (see Supplementary Table 4-6). Sources for the assumptions on AFOLU CO_2 (i.e. LULUCF CO_2) are specified in Supplementary Table 4-7.

S4.7 Supplementary Note: Kaya indicator framework and uncertainty

S4.7.1 Kaya indicator framework

Based on the Kaya identity (Equation 1.1) we have analysed the future estimated progress of national climate policies towards the Paris goals of limiting temperature increase relative to pre-industrial levels to well below 2° C by. This was done by designing pathways that keep cumulative emissions between 2011 and 2100 within 1,000 $GtCO_2$ (below 2° C pathway, with high probability) and within 400 $GtCO_2$ (below 1.5° C pathway, with high probability).

(1.1) $$CO_2 = POP * \frac{GDP}{POP} * \frac{CO_2}{GDP}$$

(1.2) $$\frac{CO_2}{GDP} = \frac{TPES}{GDP} * \frac{CO_2}{TPES} = \frac{TPES}{GDP} * \frac{FE}{TPES} * \frac{CO_2}{FE}$$

(1.3) $$\frac{CO_2}{GDP} = \frac{TPES}{GDP} * \frac{FE}{TPES} * \frac{FE_{fossil}}{FE} * \frac{CO_2}{FE_{fossil}} = \frac{TPES}{GDP} * \frac{FE}{TPES} * \left(1 - \frac{FE_{non-fossil}}{FE}\right) * \frac{CO_2}{FE_{fossil}}$$

where
POP = Population
GDP = Gross domestic product
FE = Final energy

The Kaya indicators can support tracking progress of climate policies, both at a global level and for individual countries. At the same time they give guidance on the efforts necessary to enhance ambition in terms of increasing the share of renewable energy technologies and extending the range of efficiency measures. The Kaya identity component CO_2/GDP can be rewritten (see Equation 1.3) to include final energy intensity (FE/TPES), non-fossil share ($FE_{non\text{-}fossil}$/FE) and CO_2 intensity of fossil fuels (CO_2/FE_{fossil}) which were used in the analysis.

Instead of looking at CO_2 emissions only, we considered total GHG emissions and broke this down into CO_2-energy, CO_2-industrial processes, CO_2-AFOLU and non-CO_2 GHG emissions (see Figure 4-1). It shows that CO_2-energy gives a similar picture as total GHG (Kyoto) emissions, except for Brazil. For this reason we have chosen to use total GHG emissions as indicator in our analysis. For the other indicators from Equation 1.3, we have used GDP in terms of Market Exchange Rates (MER). Non-fossil energy in ours assessment includes renewable resources such as solar, wind and biomass, but also nuclear power and electricity generated with fossil fuels together with carbon capture and storage. Total primary energy (TPES) was not included in this analysis as the level depends on the primary energy accounting method used, which differs between models (Moomaw et al., 2011). Figure 4-2 shows that the gap in terms of low carbon share is high for all countries, and differences in energy intensity between countries are most pronounced. These two indicators were used in our analysis.

S4.7.2 Uncertainty

One of the main results of our study is the range of GHG emissions by 2030 representing the impact of climate policy implementation. The uncertainty was decomposed into four drivers: 1) historical calibration, 2) socio-economic growth assumptions, 3) policy impact on GHG emissions and 4) real uncertainty (see Figure 4-5 in methods section), and is described in this section. Although this covers most uncertainty, unknown uncertainty due to limited knowledge (van Asselt and Rotmans, 2002) is not represented as this is difficult to quantify.

The impact of national policies is shown by comparing the national policies scenario with scenarios that have not included new climate policies after 2010. These scenario comparisons were made with nine integrated assessment models (see sections S4.9 for more details).

Historical emissions are uncertain as they are in general not directly measured, but estimated based on other indicators (e.g. fuel use in transport). In our analysis, the difference between model emissions and the PRIMAP (Gütschow et al., 2016) dataset (version 1.2) is used to give an indication. In addition, the models ensemble represents uncertainty in socio-economic growth rates, as they differ in socio-economic assumptions on GDP, population and energy demand. This uncertainty is represented by the range of GHG emissions in the No new policies scenario.

Then, the uncertainty of policy impact is given by the range of emission reductions between the No new policies scenario and the national policies scenario. This range is the result of the uncertain impact of policies, but also partly due to some models not being able to implement all high impact policies. Supplementary Table 4-1 shows that between 42% and 94% of all policies have been implemented by the models. But this does not say much about the impact on GHG emissions. Therefore, we have made an order of magnitude estimate of the impact on GHG emissions of policies not covered by specific models. This was done by first calculating the individual impact of each policy with the IMAGE model (not accounting for overlap between policies), as this model was able to implement most of the high impact policies[33]. Based on the overview of policies that were implemented by each model (see Supplementary Table 4-2), we calculated the emissions reductions covered by each model in terms of IMAGE emission reductions. Of course the impact would differ for different models, but this gives the best available order of magnitude estimate of policy impact. The result is an estimate of emissions reductions covered by each model, which is between 50% and 100% (see Supplementary Table 4-1), which is equal to 0.4 and 1.3 $GtCO_2eq$. These estimates were used in Figure 4-5 of the Methods section, that also includes uncertainty ranges for historical calibration, emission growth in the no new policies scenario, policy impact and real uncertainties. The latter uncertainty is represented by the difference in structural form, representing for example different technological learning, and behaviour on price signals or regulation.

S4.8 Supplementary Note: Assessment of policy impact on GHG emissions in the context of other literature sources

S4.8.1 Effort sharing

The cost-optimal budget scenarios from our study were compared to effort sharing ranges based on Van den Berg et al (van den Berg et al., 2019b) (see Supplementary Figure 3). We

[33] Except the building standard for China, medium-trucks efficiency standard in the USA, Electric vehicle production goals for China

have used the results from this paper using the following effort sharing approaches (default settings)

- Ability to pay
- Equal cumulative per capita emissions
- Per capita convergence
- Immediate per capita convergence
- Grandfathering

For most countries, the median of the cost optimal carbon budgets for the period 2011-2050 is close to, but above the maximum of the effort sharing ranges, except for India and the USA. The Indian cost-optimal budget is on the lower side of the effort sharing range, while the median of the US cost-optimal range falls on the higher side of the effort sharing range. Note, that the picture for the period 2011-2100 could be different.

S4.8.2 National policies and carbon budgets

The scenario results on a global and G20 economy level for the national policies, NDCs and 2 °C scenarios were compared with literature outcomes from

- Rogelj et al. (2016) (global level)
- Van Soest et al. (2017) (global level)
- VanDyck et al. (2016) (global and country level)
- Kuramochi et al. (2016b) (country level)

The results are shown in Supplementary Figures 4-7. In general the GHG emission level by 2030 for the *national policies* scenario are somewhat higher compared to those from Rogelj, et al. (2016), van Soest, et al. (2016) and Vandyck, et al. (2016), while GHG emission levels for the 2 °C scenario in line. The result is a larger emissions gap between national policies and emission levels by 2030 consistent with cost-optimal 2°C scenarios. At G20 economy level, this study is similar (especially median estimates) to national policies scenarios from Kuramochi et al. (2016b) and Vandyck, et al. (2016), except for the EU and USA for which GHG emissions in this study are slightly higher. The large range of emission levels for China representing national policy implementation is consistent with the outcomes from Kuramochi et al. (2016b) and Vandyck, et al. (2016) that also differ significantly.

S4.9 Supplementary Note: Model documentation and policy implementation

The model exercise in this paper was done by nine IAMs that have global coverage, and the results for total GHG emissions and final energy were compared with national models that represent one specific G20 economy. Each model implemented the suite of policies discussed in this paper: 1) No new policies, 2) national policies 3) NDC, 4) 2 °C target (carbon budget 1000) and 5) 1.5 °C (carbon budget 400).

The 'National policies' scenario includes implemented policies for G20 countries. The starting point for this scenario is the no-policy scenario, which is based on the SSP2 scenario (Fricko et al., 2017)and describes a middle-of-the-road scenario in terms of economic and population growth and other long-term trends such as technology development. The main drivers of this scenario for the energy and industry sectors are: population, gross domestic product (GDP), lifestyle and technology change from Riahi et al. (2017), Van Vuuren et al. (2017a) and for the LULUCF sector: agricultural productivity, bioenergy and wood demand from Fricko et al (2017). Integrated assessment models can differ in their interpretation of SSP2 storyline concerning GDP growth (three versions).

The policies included in the national policies scenario were selected from a policy database, and resulted in a list of high impact policies. These policies were translated into policy indicators, which is described in the Methods section. How each policy indicator is implemented in each participating integrated assessment model is described in this chapter of the supplementary material. For each integrated assessment model, first a general description of the model structure and main assumptions are given, and second, a general description of climate policy. A more detailed description per policy type (e.g. fuel efficiency standard, emission trading) is provided in Section 2 of this chapter.

IMAGE 3.0 (GLOBAL)

Model description

IMAGE 3.0 is a comprehensive integrated assessment framework, modelling interacting human and natural systems (Stehfest et. All, 2014) The IMAGE framework is well suited for assessing interactions between human development and the natural environment, including a range of sectors, ecosystems and indicators. The model allows to assess the impacts of human activities on the natural systems and natural resources and how such impacts hamper the provision of ecosystem services to sustain human development. The model framework is suited to a large geographical (usually global) and temporal scale (up to the year 2100).

The IMAGE framework identifies socio-economic pathways, and projects the consequences for energy, land, water and other natural resources, subject to resource availability and quality. Impacts such as air, water and soil emissions, climatic change, and depletion and degradation of remaining stocks (fossil fuels, forests), are calculated and taken into account in future projections. Within the IAM group, different types of models exist, and IMAGE is characterised by relatively detailed biophysical processes and a wide range of environmental indicators.

The IMAGE Energy Regional model (TIMER) has been developed to explore scenarios for the energy system in the broader context of the IMAGE framework. Similar to other IMAGE components, TIMER is a simulation model. The results obtained depend on a single set of deterministic algorithms, according to which the system state in any future year is derived entirely from previous system states. TIMER includes 12 primary energy carriers in 26 world regions and is used to simulate long-term trends in energy use, issues related to depletion, energy-related greenhouse gas and other air polluting emissions, together with land-use demand for energy crops. The focus is on dynamic relationships in the energy system, such as inertia and learning-by-doing in capital stocks, depletion of the resource base and trade between regions.

Policy implementation

Population and GPD (Dellink et al, 2017) projections from the SSP2 scenario are exogenous input to the model (Van Vuuren et al, 2017) and do not change in the National policies scenario.

The IMAGE 3.0 model consists of several components, of which the TIMER energy model analyses long-term trends in energy demand and supply in the context of the sustainable development challenges (Van Vuuren et al, 2017). Another component enables the long-term trends for agriculture and land use. The carbon tax is the main policy instrument in the TIMER model, but also regulations or (implicit) policy targets can be imposed by changing model input parameters. Policy targets that cover multiple sectors (e.g. intensity targets and renewable shares of final energy) cannot be directly implemented into the model, and are checked the implementation of other policies. If these multiple-sector targets are not met, sector carbon taxes or regulations are imposed iteratively.

A carbon tax is imposed at region or sector (energy supply, industry, transport, buildings) level, and with small model adjustments also specific sub-sectors can be targeted (e.g. F-gas emission reduction targets). An increase in the carbon tax increases the costs of fossil energy carriers relative to the baseline. This induces a response of the energy system and results in an increased allocation of investments into different non-fossil energy technologies. This allocation is calculated by a multinomial logit function that accounts for relative differences in costs and preferences (technologies with lower costs gain larger market shares). It is also possible to impose other taxes or subsidies on for example fossil fuels (e.g. oil tax) or cars (e.g. subsidy for electric cars) that also change the relative costs of technologies.

Regulations (e.g. standards) are implemented into the model by changing input parameters (e.g. car efficiencies, building insulation rate) or by enforcing larger allocation of investments (e.g. in renewable electricity) than calculated by the multinomial logit function in the baseline. For example, car efficiencies and corresponding costs are model input parameters that can be changed to enforce fuel efficiency standards, and minimal renewable electricity targets are input parameters to the model and result in larger proliferation of renewables compared to baseline. This is also used for those policy instruments that were translated into policy indicators (see CD-LINKS protocol), such as feed-in-tariffs that were translated to renewable electricity targets.

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MESSAGEIX-GLOBIOM_1.0 (GLOBAL)

Model description

MESSAGE*ix*-GLOBIOM 1.0 integrates the energy engineering model MESSAGE with the land-use model GLOBIOM via soft-linkage into a global integrated assessment modelling framework (Fricko et al., 2017; Krey et al., 2016). It utilizes the ix platform for integrated and cross-sectoral modelling (Huppmann et al., in preparation).

MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environmental Impact) is a linear programming (LP) energy engineering model with global coverage (Riahi et al., 2012; Riahi, Grübler, & Nakicenovic, 2007). As a systems engineering optimization model, MESSAGE is primarily used for medium- to long-term energy system planning, energy policy analysis, and scenario development. The model provides a framework for representing an energy system with all its interdependencies from resource extraction, imports and exports, conversion, transport, and distribution, to the provision of energy end-use services such as light, space conditioning, industrial production processes, and transportation. MESSAGE-Access (Cameron et al., 2016) is a standalone residential cooking energy choice and demand model that can be applied jointly with MESSAGE*ix*-GLOBIOM to estimate implications of energy and climate policies on access to clean cooking fuels. To assess economic implications and to capture economic feedbacks of climate and energy policies, MESSAGE is linked to the aggregated macro-economic model MACRO (Messner & Schrattenholzer, 2000).

Land-use dynamics are modelled with the GLOBIOM (GLobal BIOsphere Management) model, which is a partial-equilibrium model (Havlík et al., 2011; P. Havlík et al., 2014). GLOBIOM represents the competition between different land-use based activities. It includes a detailed representation of the agricultural, forestry and bio-energy sector, which allows for the inclusion of detailed grid-cell information on biophysical constraints and technological costs, as well as a rich set of environmental parameters, incl. comprehensive AFOLU (agriculture, forestry and other land use) GHG emission accounts and irrigation water use. For spatially explicit projections of the change in afforestation, deforestation, forest management, and their related CO_2 emissions, GLOBIOM is coupled with the G4M (Global FORest Model) model (Gusti, 2010; Kindermann, Obersteiner, Rametsteiner, & McCallum, 2006). As outputs, G4M provides estimates of forest area change, carbon uptake and release by forests, and supply of biomass for bioenergy and timber.

MESSAGE*ix*-GLOBIOM covers all greenhouse gas (GHG)-emitting sectors, including energy, industrial processes as well as agriculture and forestry. The emissions of the full basket of greenhouse gases including CO2, CH4, N2O and F-gases (CF4, C2F6, HFC125, HFC134a, HFC143a, HFC227ea, HFC245ca and SF6) as well as other radiatively active substances, such as NOx, volatile organic compounds (VOCs), CO, SO2, and BC/OC is represented in the model. Air pollution implications of the energy system are accounted for in MESSAGE*ix*-

GLOBIOM by a linkage to the GAINS (Greenhouse gas and Air pollution INteractions and Synergies) model (Amann et al., 2011). MESSAGE*ix*-GLOBIOM is used in conjunction with MAGICC (Model for Greenhouse gas Induced Climate Change) version 6.8 (Meinshausen, Raper, & Wigley, 2011) for calculating atmospheric concentrations, radiative forcing, and annual-mean global surface air temperature increase.

Policy implementation

The starting point for the national policy scenarios are the MESSAGE-GLOBIOM implementations of the Shared Socio-economic Pathways (Riahi et al., 2017; Fricko et al., 2017)). The (no-policy) baseline scenario, which does not include any policies, is calibrated up until 2010 and is used as a basis for implementing policies, which do not provide specific values for given target years or change relative to a historical base year, but are expressed relative to a business-as-usual development. The scenarios assume GDP and population developments based on the respective SSP storyline, of which SSP2 (Fricko et al., 2017) serves as the central case, describing a middle of the road scenario and provides a mean challenge to climate mitigation and impact within the SSP framework (Riahi et al., 2017).

National policies are implemented in either 2020 or 2030, as the model has ten-year time resolution, at the model region resolution, meaning that national policies are recalculated to corresponding regional targets based on national historic data (Rogelj et al., 2017).

The main policy types implemented cover i.) emission reduction targets, ii.) share targets, iii.) capacity targets as well as iv.) efficiency increase targets. The first three policy types are implemented by directly adding constraints to the model per region. *Emission reduction targets* are derived by combining baseline regional emission levels, which are downscaled to national emission levels (van Vuuren et al., 2007) for countries within a region that do not have specific emission reduction targets, with national emission reduction targets. The derived national emission levels are aggregated back to the model region level, which are implemented as upper constraints on GHG emission levels in the respective time-periods. In order to avoid any rebound effects, in case regions contain countries without emission reduction targets, emission levels for that region are restricted to baseline levels. *Share targets* come in many different variations (e.g., renewable energy share of primary energy, biofuel share in transport). Baseline energy levels are proportionally downscaled to the country level using historical (2010) energy data. These are then used to recalculate the national share targets at the regional level. If within a region, countries have defined different types of share targets, then these are harmonized to the share constraint type used by the largest country, in terms of energy share, within that region, so that the aggregate effect of national targets is modelled within each region. *Capacity targets* defined by countries are recalculated into a constraint requiring relevant production technologies to provide a minimum energy output equivalent to the installed capacity, using regionally specific technology parameters (e.g., conversion efficiency, capacity factor). The fourth type of policy, *efficiency improvement targets*, are implemented via adjusting the autonomous energy efficiency improvement (AEEI) indicators of the MACRO model (linked to MESSAGE) based on the total final energy savings as estimated by the IMAGE model.

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POLES CDL (GLOBAL)

Model description

The POLES (Prospective Outlook on Long-term Energy Systems) model (Keramidas et al, 2017) is a global partial equilibrium simulation model of the energy sector with an annual step, covering 38 regions world-wide (G20, OECD, principal energy consumers) plus the EU. The model covers 15 fuel supply branches, 30 technologies in power production, 6 in transformation, 15 final demand sectors and corresponding greenhouse gas emissions. GDP and population are exogenous inputs of the model. The model can provide insights of the evolution of global and local technology developments. The model can assess the market uptake and development of various new and established energy technologies as a function of changing scenario conditions. The global coverage allows an adequate capture of the learning effects that usually occur in global markets (Criqui, 2015). The model represents the adjustments of energy supply and demand to prices, while accounting for delayed reaction. POLES can also assess the global primary energy markets and the related international and regional fuel prices under different scenario assumptions. To this end, it includes a detailed representation of the costs in primary energy supply (in particular oil, gas and coal supply), for both conventional and unconventional resources. Major countries for the oil, coal and gas markets are represented.

The model can therefore be used to analyse the impacts of energy and climate policies, through the comparison of scenarios concerning possible future developments of world energy consumption and corresponding GHG emissions under different assumed policy frameworks (T. Vandyck , 2016). Policies that can be assessed include: energy efficiency, support to renewables, energy taxation/subsidy, technology push or prohibition, access to energy resources, etc.

Mitigation policies are implemented by introducing carbon prices up to the level where emission reduction targets are met: carbon prices affect the average energy prices, inducing energy efficiency responses on the demand side, and the relative prices of different fuels and technologies, leading to adjustments on both the demand side (e.g. fuel switch) and the supply side (e.g. investments in renewables). Non-CO2 emissions in energy and industry are endogenously modelled with potentials derived from literature (marginal abatement cost curves). Air pollutants are also covered (SO2, NOx, VOCs, CO, BC, OC, PM2.5, PM10, NH3) thanks to a linkage with the specialist GAINS model. Projections for agriculture, LULUCF emissions and food indicators are derived from the GLOBIOM model (dynamic look-up of emissions depending on climate policy and biomass-energy use), calibrated on historical emissions and food demand (from UNFCCC, FAO and EDGAR). A full documentation of POLES is available at http://ec.europa.eu/jrc/poles.

Policy implementation

All POLES scenarios have a common socioeconomic context defined by the population (The Ageing Report, EC 2015; UN Population Division, UN 2015) and economic growth (The Ageing Report, EC 2015; World Economic Outlook, IMF April 2017; CIRCLES, OECD 2014). These inputs are broadly consistent with SSP2. All scenarios share assumptions on discount rates for annual energy investments and certain factors representing lifestyle (e.g. urbanization, dwellings size, mobility evolution); energy taxation and subsidies are constant at their observed historical levels.

All scenarios include adopted energy and climate policies worldwide for 2020. The INDC scenario includes all pledges, including conditional contributions up to 2025 or 2030 (depending on the country). For countries not individually represented, pledges of countries belonging to a region are summed into a pledge representative of that region. Only pledges that can be included in the modelling framework of POLES are considered (for instance, POLES does not explicitly represent an objective in reforestation areas).

Most regulatory measures are included in POLES through several instruments: imposed parameters like fuel standards for vehicles or capacity for nuclear; feed-in tariffs for renewable technologies in the power sector; subsidies in liquid biofuel production costs for renewables in transport; additional energy taxation for energy efficiency objectives; economy-wide carbon value for GHG emissions targets. The carbon value affects the whole economy including agriculture and land use, through average energy prices and the relative prices of different fuels and technologies, inducing fuel switch and energy efficiency responses on the demand side and new technology investments on the supply side (e.g. renewables). Emissions reductions in each sector were achieved depending on the economic attractiveness of mitigation options across sectors.

Non-CO2 emissions in energy and industry are endogenously modelled with marginal abatement cost curves derived from literature (GECS 2002, EPA 2012). Air pollutants are also covered (SO2, NOx, VOCs, CO, BC, OC, PM2.5, PM10, NH3) using emission factors derived from the GAINS model. Projections for land use, LULUCF emissions, agriculture and food indicators are derived from the GLOBIOM model (historical data from UNFCCC, FAO and EDGAR); these parameters are modelled via look-up tables for each country/region, depending on climate policy and biomass-energy use (thus replicating marginal abatement cost curves for LULUCF and agriculture).

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REMIND-MAGPIE 1.7-3.0 (GLOBAL)

Model description

REMIND models the global energy-economy-climate system for 11 world regions and for the time horizon until 2100. For the present study, REMIND in its version 1.7 was used. REMIND represents five individual countries (China, India, Japan, United States of America, and Russia) and six aggregated regions formed by the remaining countries (European Union, Latin America, sub-Saharan Africa without South Africa, Middle East / North Africa / Central Asia, other Asia, Rest of the World). For each region, intertemporal welfare is optimized based on a Ramsey-type macro-economic growth model. The model explicitly represents trade in final goods, primary energy carriers, and in the case of climate policy, emission allowances and computes simultaneous and intertemporal market equilibria based on an iterative procedure. Macro-economic production factors are capital, labour, and final energy. REMIND uses economic output for investments in the macro-economic capital stock as well as consumption, trade, and energy system expenditures.

By coupling a macroeconomic equilibrium model with a technology-detailed energy model, REMIND combines the major strengths of bottom-up and top-down models. The macro-economic core and the energy system module are hard-linked via the final energy demand and costs incurred by the energy system. A production function with constant elasticity of substitution (nested CES production function) determines the final energy demand. For the baseline scenario, final energy demands pathways are calibrated to regressions of historic demand patterns. More than 50 technologies are available for the conversion of primary energy into secondary energy carriers as well as for the distribution of secondary energy carriers into final energy.

Policy implementation

All scenarios are based on socio-economic assumptions from the SSP2 scenario (Fricko et al. 2017), including GDP, population, demand for energy and food, technology availability and costs, etc.. In all scenarios, fuel taxes and subsidies are represented (Jewell et al. 2018). Taxes are assumed to stay constant, while subsidies are assumed to be phased out until 2050 in all regions and all scenarios.

Implementation of climate policies differs depending on the time horizon and scenario. Until 2020, currently observed policies are implemented as lower bounds for absolute technology deployment for various low-carbon technologies (bio-energy, photovoltaic, wind, nuclear, electric vehicles), or share targets for renewables or low-carbon energy in different countries. Furthermore, to mimic the effect of fuel efficiency standards in transport, upper bounds on final energy usage informed by results from the IMAGE model are implemented.

In the NDC scenario, all the national policies were implemented as well, and extended to 2030 if applicable, but in addition regionally differentiated carbon taxes were implemented. These were iteratively adjusted to secure achieving the economy-wide emission targets from the NDCs for each region. Carbon taxes apply to all greenhouse gas emissions, using 100 year global warming potentials. The interplay between carbon prices and sectoral policies is bidirectional: In some cases, the carbon prices required for reaching the 2030 emission target lead to an overachievement of the policy indicators, and become non-binding. In other cases the technology policies are binding and lead to lower carbon prices than would be required without those additional policies. This is important to keep in mind for the interpretation of the resulting regionally differentiated carbon prices.

In scenarios with long-term global carbon budgets of 400, 1000 and 1600 Gt CO2 from 2011-2100, globally harmonized carbon taxes are iteratively adjusted, such that the budget target is met. The temporal profile of the carbon tax is exogenously set to an exponential increase with 5% per year until 2060, and linear increase thereafter. This profile is chosen so as to limit the temporal overshoot of the carbon budget, and thus reduce the need for removal of CO2 from the atmosphere.

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REMIND uses reduced-form emulators derived from the detailed land-use and agricultural model MAgPIE (Lotze-Campen, H. *et al*, 2008; Popp, A. *et al*, 2014) to represent land-use and agricultural emissions as well as bioenergy supply and other land-based mitigation options. Beyond CO_2, REMIND also represents emissions and mitigation options of major non-CO_2 greenhouse gases (Strefler et al., 2014; EPA, 2013).

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WITCH2016 (GLOBAL)

Model description

WITCH-GLOBIOM (World Induced Technical Change Hybrid) is an integrated assessment model designed to assess climate change mitigation and adaptation policies. It is developed and maintained at the Fondazione Eni Enrico Mattei and the Centro Euro-Mediterraneo sui Cambiamenti Climatici. It is a global integrated assessment model with two main distinguishing features: a regional game-theoretic setup, and an endogenous treatment of technological innovation for energy conservation and decarbonisation. A top-down inter-temporal Ramsey-type optimal growth model is hard linked with a representation of the energy sector described in a bottom-up fashion, hence the hybrid denomination. The regional and intertemporal dimensions of the model make it possible to differentiate and assess the optimal response to several climate and energy policies across regions and over time. The non-cooperative nature of international relationships is explicitly accounted for via an iterative algorithm which yields the open-loop Nash equilibrium between the simultaneous activity of a set of representative regions. Regional strategic actions interrelate through GHG emissions, dependence on exhaustible natural resources, trade of fossil fuels and carbon permits, and technological R&D spill overs. R&D investments are directed towards either energy efficiency improvements or development of carbon-free breakthrough technologies. Such innovation cumulates over time and spills across countries in the form of knowledge stocks and flows.

The competition for land use between agriculture, forestry, and bioenergy, which are the main land-based production sectors, is described through a soft link with a land use and forestry model (GLOBIOM, Global Biosphere Management Model, see above). A climate model (MAGICC) is used to compute climate variables from GHG emission levels and an air pollution model (FASST) is linked to compute air pollutant concentrations. While for this exercise WITCH is used for cost-effective mitigation analysis, the model supports climate feedback on the economy to determine the optimal adaptation strategy, accounting for both proactive and reactive adaptation expenditures.

WITCH-GLOBIOM represents the world in a set of a varying number of macro regions – for the present study, the eversion with 13 representative native regions has been used; for each, it generates the optimal mitigation strategy for the long-term (from 2005 to 2100) as a response to external constraints on emissions. A model description is available in Bossetti et al. (2006), and Emmerling et al (2016), and a full documentation can be found at http://doc.witchmodel.org.

Policy implementation

Population (KC and Lutz 2017) and GPD (Dellink et al. 2017) in WITCH model for the SSP2 scenario are exogenous inputs. The model includes a portfolio of policy instruments (Aldy et. Al, 2016) . In this paper we implement the NDCs and national policy emission targets, and also the NDCs and national policy explicit energy targets, such as energy intensity, efficiency, renewable and technology specific deployment targets. Concerning the sector specific policies, the WITCH model can only individualize the transport sector. Policies targeting the transport sector have been implemented at an aggregated sectoral level.

The regional shadow prices of the short term policies, imposed by the emission targets of the NDCs and national policies are used to price all emissions including the land use sector by region. This way the effort imposed on the land use is equal to the one imposed on the energy system.

The long term targets are implemented through a sector-wide carbon tax imposed on the energy and land use systems by region in such way that meets the scenario specifications (Emmerling et al, 2016).

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AIM V2.1 (NATIONAL (JAPAN)/GLOBAL)

<u>Model description</u>

AIM V2.1 is a one-year-step recursive-type dynamic general equilibrium model that covers all regions of the world. The AIM/CGE model includes 17 regions and 42 industrial classifications. For appropriate assessment of bioenergy and land use competition, agricultural sectors are also highly disaggregated. Details of the model structure and mathematical formulae are described by Fujimori et al.. The production sectors are assumed to maximize profits under multi-nested constant elasticity substitution (CES) functions and each input price. Energy transformation sectors input energy and value added are fixed coefficients of output. They are treated in this manner to deal with energy conversion efficiency appropriately in the energy transformation sectors. Power generation values from several energy sources are combined with a Logit function. This functional form was used to ensure energy balance because the CES function does not guarantee an energy balance. Household expenditures on each commodity are described by a linear expenditure system function. The parameters adopted in the linear expenditure system function are recursively updated in accordance with income elasticity assumptions. In addition to energy-related CO_2, CO_2 from other sources, CH_4, N_2O, and fluorinated gases (F-gases) are treated as GHGs in the model. Energy-related emissions are associated with fossil fuel feedstock use. The non-energy-related CO_2 emissions consist of land use change and industrial processes. Land use change emissions are derived from the forest area change relative to the previous year multiplied by the carbon stock density, which is differentiated by AEZs (Global Agro-Ecological Zones). Non-energy-related emissions other than land use change emissions are assumed to be in proportion to the level of each activity (such as output). CH_4 has a range of sources, mainly the rice production, livestock, fossil fuel mining, and waste management sectors. N_2O is emitted as a result of fertilizer application and livestock manure management, and by the chemical industry. F-gases are emitted mainly from refrigerants used in air conditioners and cooling devices in industry. Air pollutant gases (BC, CO, NH_3, NMVOC, NO_x, OC, SO_2) are also associated with fuel combustion and activity levels. Essentially, emissions factors change over time with the implementation of air pollutant removal technologies and relevant legislation.

Policy implementation

All parameter assumptions to quantify the SSP2 scenario is described in (Fuijimori et al, 2017). Population and GDP are exogenous sources.

The carbon tax is the main policy instrument in the AIM model, but also regulations or (implicit) policy indicators can be imposed by changing model input parameters. Some policy targets that either cover multiple sectors or that are not directly linked with the model input parameters (e.g. intensity targets, renewable capacity targets) cannot be directly implemented into the model, and are checked afterwards. If these targets are not met, parameters (e.g. representing energy efficiency) are imposed iteratively.

We basically change the logit function parameters for the share of fuel usages and power generation technological shares. For the energy consumption or energy intensity targets, we have controlled the autonomous energy efficiency improvement parameters iteratively because the energy consumption itself is affected by the price changes which only can be seen after the model simulation. We also implement the fuel taxes by changing the current tax level.

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AIM/ENDUSE [JAPAN]

Model description

AIM/Enduse is a partial equilibrium, dynamic recursive model developed by the National Institute for Environmental Studies (NIES), which is characterized by the detailed descriptions of energy technologies in the end-use sectors as well as the energy supply sectors in Japan. This model is characterized by detailed representation of technologies, in which technologies are selected by linear programming minimizing total energy system costs given exogenous parameters such as energy service demands, energy prices, technological parameters, and carbon prices or emissions constraints. It includes non-CO_2 greenhouse gases covered by the Kyoto protocol, and these emissions are converted into CO_2-equivalents using GWP100 factors taken from the IPCC AR4. This model covers not only energy sectors but also non-energy sectors such as industrial processes and waste management, but AFOLU sector is not taken into account. It covers 10 sub-regions in Japan which is broadly coinciding with the areas of 10 public power supply firms, so as to consider characteristics of energy supply and demand across the various-regions. The electricity dispatch module, that is hard-linked with the energy end-use and other energy supply sectors module, explicitly represents the load curve in each region, and capacity of electricity interconnection between sub-regions.

Policy implementation

In AIM/Enduse [Japan], energy technologies are selected based on linear programming and minimize total energy system costs given the exogenous parameters, such as energy service demands, energy prices, technological parameters, and emission prices. The socio-economic conditions, such as population and gross domestic products (GDP), are taken from Nationally Determined Contribution (NDC) scenario in Japan, see Oshiro et al. (2017) for more detail. Even in the no policy scenario, where no climate policy is implemented, some mitigation options are selected due mainly to increase of energy prices, while the technological change in this scenario is relatively moderate.

In the climate policy scenarios, the main driver is economy-wide carbon pricing, while other sectoral policies are also taken into consideration. For example, in the power sector, renewable target mentioned in the NDC is considered which is to increase its share by 22-24% in 2030. Also, the availability of nuclear power would be largely affected by the political condition rather than technological one, maximum capacity of nuclear power is imposed according to nuclear target mentioned in the NDC. In the energy demand sectors, some sector-specific policies associated with the NDC, such as the building energy standards and the fuel economy standards which have been already implemented or planned, are also taken into account.

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COPPE-COFFEE 1.0 (GLOBAL) AND BLUES (NATIONAL)

Model description

COPPE-COFFEE model is a global optimization model of the energy and land systems based on the MESSAGE platform. It is an intertemporal optimization model, in which the optimal solution provides the minimum cost of the global energy and land-use systems. The COFFEE (COmputable Framework For Energy and the Environment) model has been developed at COPPE, Brazil, for assessing climate, land, energy and environmental policies, providing relevant information to experts and decision-makers on the possible development strategies and repercussions of long term climate scenarios (Rochedo, 2016).

The model has 18 regions, for which all energy and land systems are modelled from 2010 to 2100, and has detailed estimations for the most relevant greenhouse gases (CO_2, CH_4 and N_2O), including a very detailed set of mitigation options for all sectors. The model is based on exogenous demands for energy services (from all economic sectors) and food products, for all regions.

The energy system model is based on a very detailed representation of energy resources and conversion technologies, including power plants, oil refineries, advanced biofuels, CCS infrastructure, transportation technologies, industrials processes and others (Rochedo, 2016). As for the land system representation, COFFEE presents a singular perspective: the model is completely integrated via hard-link with the energy system, which allows for assessing trade-offs and synergies for mitigation strategies in both the energy and land system. However, the COFFEE model is not spatially explicit, which results in a simplified structure for representation land-use dynamics. COFFEE methodological approach is based on different types of land covers that can be modified between one another. In addition, all land covers are desegregated in categories based in the relative cost of opportunity for agricultural production. Therefore, certain type of land covers can be used for agricultural production, to meet the demand for food (crops, livestock, processed food) and bioenergy (Rochedo, 2016).

The Brazilian Land Use and Energy System (BLUES) model, is a perfect foresight, partial equilibrium model covering the Brazilian energy, industry, buildings, transportation and AFOLU sectors. BLUES divides the country into 5 distinct geographic sub-regions plus a sixth national region for interconnection with the rest of the world through import/export. BLUES is the product of gradual implementation of several versions of a MESSAGE model for Brazil (Borba et al., 2012; Nogueira et al., 2014; Koberle et al., 2015; Rochedo, 2016). It chooses the energy system configuration with the least total system cost over the entire time horizon of the study, in this case 2010 to 2050. The model minimizes costs of the entire energy system, including electricity generation, agriculture, industry, transport and the buildings sectors. BLUES finds optimized mixes for the energy system as a whole, rather than evaluating sectorial optimal solutions. It includes CO2, CH4 and N2O emissions associated with land use, agriculture and livestock, fugitive emissions, fuel combustion, industrial processes and waste treatment.

BLUES has six native regions. One main overarching region into which five sub-regions are nested following the geopolitical division of the country. The energy system is represented in detail across sectors, with over 1500 technologies available in and customized for each of its six native regions. The representation of the land-use system includes forests, savannas, low- and high-capacity pastures, integrated systems, cropland, double cropping, planted forests, and protected areas. Cropland is made up of Land use is also regionalized and customized for each sub-region, with yields and costs varying from region to region. Demand is exogenous but endogenous energy efficiency measures permit demand responses through technological options.

http://themasites.pbl.nl/models/advance/index.php/Model_Documentation_-_BLUES.

Policy implementation

COFFEE model uses SSP2 projections for GDP and population (Dellink, 2017). The storyline of the SSP2 scenario affects the model assumptions, such as those used for determining the energy service and food-related demand for all sectors. More detailed analysis is available in (Rochedo, 2016).

Climate policy is implemented via an emissions budget for CO2. For non-CO2 GHGs, an emissions price is implemented, which is in line the globally determined carbon price (interactively), and then multiplied by the AR4 GWP values for each gas (at this time, only CH4 and N2O).

Generally, regulations and policies are implemented in the model via constraints as part of the linear programming algorithms. Specifically, we differ between absolute regulations (e.g. renewable capacity target) and relative regulations (e.g. share of renewables, share of electric vehicles). The former is modelled by minimum capacity/activity constraints, whilst the latter are modelled with user-defined constraint that represent the share equation. Other policies, such as efficiency standards, are modelled by limiting the available set of technologies in the model. For instance, efficiency standard of power plants is modelled by limiting the expansion of lower efficiency power plants, favouring new plants with higher efficiency and/or lower emission factor. The same approach is used for implementing efficiency standard in the transportation sector.

Policy targets that cover multiple sectors or are set as an intensity of GDP or population (e.g. intensity targets, renewable shares of final energy) are very difficult to be directly implemented into the model. The results are analysed and, if the targets are not met, modification to the constrains and carbon cost are adjusted iteratively.

The BLUES model uses SSP2 GDP projections (Dellink et al., 2017) as a starting point, and then adjust them to match historical rates and short-term growth projections by the Brazilian Central Bank (BCB, 2015). The middle SSP2 scenario has estimates for Brazilian GDP annual growth rates averaging 2.2% annual average GDP growth rate for the 2010-2050 period (SSP database, 2015; Riahi et al, 2017). Although such sustained growth rates might have been reasonable to expect a few years ago, recent developments caused a marked reduction in economic activity in Brazil that has made such estimates obsolete. The average growth rate for the period 2011-2014 was just 1.5% per year (ADVFN, 2015; IGBE, 2015). The most recent estimates published by the Brazilian Central Bank indicate Brazilian GDP shrinking by 3.81% in 2015, shrinking again by 3.54% in 2016, and returning to modest growth in subsequent years (BCB, 2018).

In order to create realistic GDP projections for Brazil, we adjust SSP2 growth rates by replacing average growth rates for the periods 2010-2015 and 2015-2020 by average historic and projected rates derived from BCB, 2018). The resulting projection is shown in the table below, which translates to an annual average of 1.9% for the whole period 2010-2050 (Koberle, 2018). This 1.9% annual growth rate compounds over 40 years, resulting in a Brazilian GDP in 2050 that more than doubles compared to 2010.

GDP projections for Brazil in the BLUES model framework Source: (Köberle, 2018)
2010-2015; 1.5%**;**
2015-2020; 0.3%;
2020-2025; 2.8%;
2025-2030; 2.4%;
2030-2035; 2.3%;
2035-2040; 2.1%;
2040-2045; 1.9%;
2045-2050: 1.8%

Regulation (e.g energy targets) are implemented in the model as follows via constraints on capacity and/or activity of specific technologies. For example, car efficiencies and corresponding costs are model input parameters that can be changed to enforce fuel efficiency standards, or minimal renewable electricity targets are input parameters to the model and result in higher proliferation of renewables compared to baseline. This is also used for those policy instruments that were translated into policy targets (see CD-LINKS protocol), such as feed-in-tariffs that were translated to renewable electricity targets. Net-zero deforestation is imposed after 2030 to reflect the required afforestation of more than 30 Mha, to compensate for private land currently with a deficit of the legal requirement for natural vegetation stipulated by the 2012 Forest Code (Soares-filho et al., 2014). NDC policies for land use are implemented via constraints imposing the target area for each land use measure via the areas established in the Brazilian NDC (GofB, 2015) and via the Low Carbon Agriculture Plan, or Plano ABC (MAPA, 2012)

Climate policy is implemented via an emissions budget for CO2 and, for non-CO2 GHGs, an emissions price is implemented in line with a globally determined carbon price from global model runs multiplied by the AR4 GWP values for each gas.

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DNE21+ V.14 (NATIONAL (JAPAN)/GLOBAL)

Model description

Dynamic New Earth 21 Plus (DNE21+) is an energy and global warming mitigation assessment model developed by the Research Institute of Innovative Technologies for the Earth (RITE) (Akimoto et al., 2010; Akimoto, 2014; RITE, 2015). The model is an intertemporal linear programming model for assessment of global energy systems and global warming mitigation in which the worldwide costs are to be minimized. The model represents regional differences, and assesses detailed energy-related CO2 emission reduction technologies up to 2050.When any emission restriction (for example, an upper limit of emissions, emission reduction targets, targets of energy or emission intensity improvements, or carbon taxes) is applied, the model specifies the energy systems whose costs are minimized, meeting all the assumed requirements, including assumed production for industries such as iron and steel, cement, and paper and pulp, transportation by automobile, bus, and truck, and other energy demands. The energy supply sectors are hard-linked with the energy end-use sectors, including energy exporting/importing, and the lifetimes of facilities are taken into account so that assessments are made with complete consistency kept over the energy systems. Salient features of the model include: analysis of regional differences between 54 world regions while maintaining common assumptions and interrelationships; a detailed evaluation of global warming response measures that involves modelling of about 300 specific technologies that help suppress global warming; and explicit facility replacement considerations over the entire time period. The model assumes energy efficiency improvements of several kinds of technologies and cost reductions of renewable energies, carbon dioxide capture and storage (CCS) and so on for the future within the plausible ranges based on the literature.

Policy implementation

The model is based on the baseline of the SSP2 scenario (Fricko et al, 2017). Near-term policies are implemented by translating CD-LINKS protocol (policy indicators) into additional constraints which are suitable for DNE21+. GHG emissions reduction target, CO2 intensity target, Energy intensity targets for total primary energy supply (TPES) and industry sector, energy consumption reduction in TPES and industry sector relative to baseline, cap on TPES and coal consumption, gas and oil import, share of gas and non-fossil energy in TPES, share of renewables in TPES and electricity, renewable electricity production, electricity capacity of biomass, hydro, solar and wind, share of renewables in transport, biofuel share in transport, number of electric and plug-in vehicles, energy savings and CO2 emissions reduction relative to baseline in building sector are explicitly represented by converting the figures of the targets into input parameters of the model. For power plant standards and transport fuel efficiency standards, specific technology options by region by time point, e.g., low-efficiency coal power plant or small low-efficiency internal combustion engine passenger vehicle, which does not meet the standards are excluded in the model.

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GEM-E3 (GLOBAL)

Model description

GEM-E3 model is a hybrid, recursive dynamic general equilibrium model that features a highly detailed regional and sectoral representation (Capros, 2014; E3MLab, 2017). The model provides insights on the macroeconomic and sectoral impacts of the interactions of the environment, the economy and the energy system. GEM-E3 allows for a consistent comparative analysis of policy scenarios, ensuring that in all scenarios, the economic system remains in general equilibrium. The model has been calibrated to the latest statistics (GTAP 9, IEA, UN, ILO) while Eurostat statistics have been included instead of the GTAP IO tables for the EU Member States. The GEM-E3 model simultaneously calculates the equilibrium in goods and service markets, as well as in the labour and capital markets based on an optimization of objective functions (welfare for households and cost for firms), and includes projections of: full Input-Output tables by country/region, national accounts, employment, balance of payments, public finance and revenues, household consumption, energy use and supply, GHG emissions and atmospheric pollutants. The model is modularly built allowing the user to select among a number of alternative closure options and market institutional regimes depending on the issue under study. Production functions feature a CES structure and include capital, labour, energy and intermediate goods, while the formulation of production technologies happens in an endogenous manner allowing for price-driven derivation of all intermediate consumption and the services from capital and labour. The model simulates consumer behaviour and explicitly differentiates durable and disposable goods and services. The simulation framework is dynamic, recursive over time, linked in time though the accumulation of capital and equipment. The GEM-E3 regions are linked via endogenous bilateral trade in line with the Armington assumption. This model version features 19 countries/regions, explicitly representing the G-20 members apart from those that are Members of the European Union, as EU28 is represented as one region. The sectoral detail of this model version is high, with 39 separate economic activities, including a distinct representation of the sectors that manufacture low-carbon power supply technologies, electric cars and advanced appliances. In addition, the model includes a detailed representation of the power generation system (10 power technologies) and a highly detailed transport supply module (private and public transport modes). Key novel features of the GEM-E3 model include the involuntary unemployment and an explicit representation of the financial sector. In addition, the GEM-E3 environmental module covers all GHG emissions and a wide range of abatement options, as well as a thoroughly designed carbon market structure (e.g. grandfathering, auctioning, alternative recycling mechanisms) providing flexibility instruments that allow for a variety of options of emission abatement policies.

Policy implementation

The National Policies scenario (Reference scenario) develops on exogenous assumptions on main socio-economic drivers. The GDP growth assumptions are in line with projections by DG ECFIN, OECD, IMF and World Bank for the short-term to 2020 and then develop in line with the SSP2 scenario projections. Population growth (UN), labor market projections (ILO) and emissions (SSP2) are also considered during the construction of the National Policies scenario, along with the development of technological growth and the respective productivities.

The GEM-E3 model features a detailed representation of the power generation system (10 power technologies) and the transport sector, along with the respective bottom-up power supply and transport modules (private and public transport modes, see Karkatsoulis et al. 2017). Nevertheless, for this application, the GEM-E3 methodological framework does not make use of the bottom-up endogenous, energy system modules for power supply and transport, but instead, features a one-way soft linkage with other energy system or Integrated Assessment models, and in particular with PRIMES EU28 energy system model and IMAGE IAM model for the non-EU regions (see Vrontisi et al, 2019) for more details on the methodological approach). Through this soft-link, an implicit implementation of certain policies is achieved, in accordance with the implementation incorporated by the energy system or IAM model that is used for the soft-link. This approach enables a consistent energy system projection, even in the lack of detailed power technology representation and other relevant limitations.

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*CHINA TIMES (NATIONAL, CHINA)

<u>Model description</u>

China TIMES, a dynamic linear programming energy system optimization model, was developed for 5-year intervals extending from 2010 to 2050 on the basis of China MARKAL model (Chen 2005; Chen 2007; Chen 2010). The model incorporates the full range of energy processes including exploitation, conversion, transmission, distribution and end-use (Chen 2014, Chen 2016a; Zhang, 2016; Shi, 2016; Ma 2016; Huang 2017;). Over 500 existing and advanced energy supply and demand technologies are introduced in the model. Five demand sectors, agriculture, industry, commercial, residential (divided into urban and rural) and transportation, are considered and further divided into around 50 sub-sectors (Zhang, 2016; Shi, 2016; Ma 2016). Stock based material flow analysis approach, discrete choices method, Gompertz model and etc. are used to project energy service demands for the 50 sub-sectors according to given social economic development scenarios (Chen 2016b, Yin 2013, Li 2017). Price elasticity for each sub-sector is introduced in the model to allow carbon mitigation to be achieved by change of production mode and consumption pattern and by the deployment of low- and non-carbon technologies. Local air pollutants such as SO2, NOx, PM10, PM2.5 and etc. as well as energy-related water consumption could also be simulated with the China TIMES model

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*IPAC-AIM/TECHNOLOGY V1.0 (NATIONAL, CHINA)

See http://ipac-model.org.cn/About%20IPAC%20Model.html

*GCAM-USA (NATIONAL, USA)

Model description

The Global Change Assessment Model (GCAM) is a partial equilibrium integrated assessment model that couples a suite of dynamic-recursive models of the global energy, economy, agriculture and land-use systems with a reduced-form atmosphere-carbon-cycle-climate model [3]. This study use GCAM-USA, a U.S. focused version of GCAM, that breaks the energy and economy components of the U.S. into 50 states and the District of Colombia in addition to modelling the simultaneous interactions of 31 geopolitical regions outside of the U.S (Iyer et al, 2017a, Iyer et al, 2017b). The principle drivers of GCAM-USA are population growth, labour participation rates and labour productivity, along with representations of resources, technologies and policy. The energy system formulation in GCAM-USA consists of detailed representations of extractions of depletable primary resources such as coal, natural gas, oil and uranium along with renewable sources such as bioenergy, solar, wind and geothermal. Wind, solar and geothermal resources are represented at the state-level for the U.S. and at the level of the 31 other GCAM regions. The supply of bioenergy is modelled in the agriculture and land-use component of the model, along with competition for land among alternative uses, at the national level for the U.S. and at the level of the 31 other GCAM regions. GCAM-USA also includes representations of the processes that transform these resources to final energy carriers which are ultimately used to deliver goods and services demanded by end users in buildings, transportation and industrial sectors. Key energy transformation sectors (refining and electric power), and end-use sectors (buildings, transportation and industry) are modelled at the state-level for the U.S. and at the level of 31 other regions. Each technology in the model has a lifetime, and once an investment is made, technologies operate till the end of their lifetime or are shut down if the variable cost exceeds the market price. The deployment of technologies in GCAM depends on relative costs and is achieved using a logit-choice formulation which is designed to represent decision making among competing options when only some characteristics of the options can be observed.

GCAM Documentation, 2016. http://jgcri.github.io/gcam-doc/toc.html.

Iyer, G., Ledna, C., Clarke, L., McJeon, H., Edmonds, J., Wise, M., 2017a. GCAM-USA Analysis of US Electric Power Sector Transitions. http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-26174.pdf. Pacific Northwest National Laboratory.

Iyer, G., Ledna, C., Clarke, L.E., Edmonds, J., McJeon, H., Kyle, G.P., Williams, J.A., 2017b. Measuring Progress from Nationally Determined Contributions to Mid-Century Strategies. Nature Climate Change (forthcoming).

*AIM-INDIA [IIMA] (NATIONAL, INDIA)

Model description

Indian AIM/Enduse is a bottom-up optimization model that provides a techno-economic perspective at national level with sectoral granularity. Built on a disaggregated, sectoral representation of the economy, it provides a detailed characterization of technologies and fuel based on their availability, efficiency levels and costs. It estimates the current and future energy consumption and GHG emissions of all sectors. It uses linear programming to provide a set of technologies that will meet the exogenous service demand at the least cost while satisfying techno-economic, emissions- and energy-related constraints.

The model has been set up for five major sectors and their respective services, technologies, reference years and discount rates. These sectors are agriculture, industry, power, residential (including commercial) and transportation. Multiple services in each sector have been examined to provide a better understanding of the sector. For example, fifteen industries have been selected to represent the industry sector, while passenger and freight characterize travel demand in the transport sector. The model comprises of over 450 existing, advanced, and futuristic energy supply and demand technologies.

Vishwanathan, S.S., Garg, A., Tiwari, V., Kankal, B., Kapshe, M., Nag, T. (2017) Enhancing Energy Efficiency in India: Assessment of Sectoral Potentials Copenhagen: Copenhagen Centre on Energy Efficiency, UNEP DTU Partnership. ISBN: 978-87-93458-13-0.

Garg, A., Vishwanathan, S.S. and Choksi, P. P. (2017). Informing the international negotiations on climate: Benchmarking of India's national contributions post COP-21. In Garg, H. P., Singh, S. K., and Kandpal, T. C. (Eds.), Advances in Solar Energy Science and Engineering (Volume-4) (pp 355-381) New Delhi: Today & Tomorrow's Printers and Publishers. ISBN: 81-7019-574-4.

Shukla, P. R., Rana, A., Garg, A., Kapshe, M., & Nair, R. (2004). Climate Policy Assessment for India - Applications of Asia-Pacific Integrated Model . Hyderabad: University Press.
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*INDIA MARKAL (NATIONAL, INDIA)

Model description

TERI's India MARKAL model has been continuously developed over the past two decades and exists as a rich and disaggregated database of energy demand and supply technologies representing India's energy system. The model has been used to develop and examine scenarios to identify and prioritise choices for mitigation and energy efficiency and explore the implications of different emissions constraints. The model has been used to inform policy making within the country (providing inputs for India's NDCs) as well as across a number of national and international studies related with energy security, mitigation and climate change. The model has been used across several studies in the past to analyse implications for India's energy sector. These include Energising India – Towards Resilient and Equitable Energy System (Bery, S., Mathur, R., Gosh, A., 2016), Air Pollutant Emissions Scenario for India, Energy Security Outlook, Pathways to deep decarbonisation and the Energy Report – India Renewable Energy by 2030.

The MARKAL (MARket ALlocation) model is a bottom up dynamic linear programming cost optimization model depicting energy supply, conversion and consumption across demand sectors of a complete generalised energy system. The MARKAL family of models is unique, with applications in a wide variety of settings and global technical support from the international research community. The optimization routine used in the model's solution selects from each of the sources, energy carriers, and transformation technologies to produce the least-cost solution, subject to a variety of constraints. The user defines technology costs, technical characteristics (e.g., conversion efficiencies), and energy service demands.

The current model database, developed by Ritu Mathur, Atul Kumar, Aayushi Awasthy, Sugandha Chauhan, Kabir Sharma, Swapnil Shekhar and Prakriti Prajapati is set up over a 50 year period extending from 2001-2051 at five-yearly intervals originally intended to coincide with the Government of India's Five-Year plans. In the model, the Indian energy sector is disaggregated into five major energy consuming sectors, namely, agriculture, commercial, industry, residential and transport sectors. End use demands for each of the sectors are derived exogenously using excel based/econometric models.

On the supply side, the model considers the various energy resources that are available both domestically and from abroad for meeting various end-use demands. These include both the conventional energy sources (coal, oil, natural gas, and nuclear) as well as the renewable energy sources (hydro, wind, solar, biomass etc.). The availability of each of these fuels is represented by constraints on the supply side.

The relative energy prices of various forms and source of fuels play an integral role in capturing inter-fuel substitutions within the model. Furthermore, various conversion and process technologies characterized by their respective investment costs, operating and maintenance costs, technical efficiency, life etc. that meet the sectoral end-use demands are also incorporated in the model. In case of technologies that are specific to India, country specific costs are included (capital costs and O&M costs), while globally existing technologies have made use of international sources of data as well. Cost reduction in future in the emerging technologies has also been assumed based on an understanding of the particular technology development.

The database in its current form incorporates 47 end-uses spanning more than 350 technologies. While the demands are set up in line with basic driving parameters such as projected population, urbanization and GDP, the various scenarios include emission constraints and/or reflections of policies and measures that provide varying priorities to alternative energy forms over the modelling timeframe. in order to meet the requirements of CD-LINKS scenarios.

Bery S., Ghosh A. Mathur, R. et al. (2016). Energising India: Towards a Resilient and Equitable Energy System- SAGE Publication, 2016.

*PRIMES_V1 (NATIONAL, EU)

Model description

The PRIMES model provides detailed projections of energy demand, supply, prices and investment to the future, covering the entire energy system including emissions for each individual European country and for Europe-wide trade of energy commodities. The distinctive feature of PRIMES is the combination of behavioural modelling following a micro-economic foundation with engineering and system aspects, covering all sectors and markets at a high level of detail. PRIMES focuses on prices as a means of balancing demand and supply simultaneously in several markets for energy and emissions. The model determines market equilibrium volumes by finding the prices of each energy form such that the quantity producers find best to supply matches the quantity consumers wish to use. Investment is generally endogenous in PRIMES and in all sectors, including for purchasing of equipment and vehicles in demand sectors and for building energy producing plants in supply sectors. The model handles dynamics under different anticipation assumptions and projects over a long-term horizon keeping track of technology vintages in all sectors. Technology learning and economies of scale are fully included and are generally endogenous depending on market development. The PRIMES model comprises several sub-models (modules), each one representing the behaviour of a specific (or representative) agent, a demander and/or a supplier of energy. The sub-models link with each other through a model integration algorithm, which determines equilibrium prices in multiple markets and equilibrium volumes meets balancing and overall (e.g. emission) constraints. The agents' behaviours are sector-specific. The modelling draws on structural microeconomics: each demand module formulates a representative agent who maximises benefits (profit, utility, etc.) from energy demand and non-energy inputs (commodities, production factors) subject to prices, budget and other constraints. The constraints relate to activity, comfort, equipment, technology, environment or fuel availability. The supply modules formulate stylised companies aiming at minimising costs (or maximising profits in model variants focusing on market competition) to meet demand subject to constraints related to capacities, fuel availability, environment, system reliability, etc.

PRIMES is a hybrid model in the sense that it captures technology and engineering detail together with micro and macro interactions and dynamics. Because PRIMES follows a structural modelling approach, in contrast with reduced-form modelling, it integrates technology/engineering details and constraints in economic modelling of behaviours. Microeconomic foundation is a distinguishing feature of the PRIMES model and applies to all sectors. The modelling of decisions draw on economics, but the constraints and possibilities reflect engineering feasibility and restrictions. The model thus combines economics with engineering, ensuring consistency in terms of engineering feasibility, being transparent in terms of system operation and being able to capture features of individual technologies and policies influencing their development. Nevertheless, PRIMES is more aggregated than engineering models, but far more disaggregated than econometric (or reduced form) models. The model performs analytical cost estimations and projections by sector both in demand and supply, as well as for infrastructure. Supply-side modules determine commodity and infrastructure prices by end-use sector (tariffs) by applying various methodologies by sector as appropriate for recovering costs depending on market conditions and regulation where applicable. Pricing and costing include taxes, subsidies, levies and charges, congestion fees, tariffs for use of infrastructure etc. Usually these instruments are exogenous to the model and reflect policy assumptions. The PRIMES model is fully dynamic and has options regarding future anticipation by agents in decision-making. Usually, PRIMES assumes perfect foresight over a short time horizon for demand sectors and perfect foresight over long time horizon for supply sectors. The sub-models solve over the entire projection period in each cycle of interaction between demand and supply and so market equilibrium is dynamic and not static. All formulations of agent behaviours consider technologies, which are either existing at present or expected to become available in the future.

E3MLab, PRIMES Model Version 6 2016-2017 - Detailed model description, (2016). http://www.e3mlab.ntua.gr/e3mlab/PRIMES%20Manual/The%20PRIMES%20MODEL%202016-7.pdf

P. Capros, N. Tasios, M. Kannavou, M. Aslanoglou, C. Delkis E. Kalaintzakis C. Nakos, M. Zampara, S. Evangelopoulou, (2017), "Modelling study contributing to the Impact Assessment of the European Commission of the Electricity Market Design Initiative". https://ec.europa.eu/energy/en/studies

P. Capros, N. Tasios, A. De Vita, L. Mantzos, L. Paroussos. 2012. Model-based analysis of decarbonising the EU economy in the time horizon to 2050, In Energy Strategy Reviews, Volume 1, Issue 2, Pages 76-84, ISSN 2211-467X, https://doi.org/10.1016/j.esr.2012.06.003.

Fragkos, P., Tasios, N., Paroussos, L., Capros, P. & Tsani, S. (2017) "Energy system impacts and policy implications of the European Intended Nationally Determined Contribution and low-carbon pathway to 2050", Energy Policy, Volume 100, January 2017, Pages 216-226

P. Capros, L. Mantzos, L. Parousos, N. Tasios, G. Klaassen, T. Van Ierland. 2011. Analysis of the EU policy package on climate change and renewables, In Energy Policy, Volume 39, Issue 3, 2011, Pages 1476-1485, ISSN 0301-4215, https://doi.org/10.1016/j.enpol.2010.12.020.

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*RU-TIMES 3.2

Model description

The RU-TIMES model is based on the Integrated MARKAL-EFOM System aimed at modelling and long-term planning of energy systems and technological processes. The model covers major sectors and industries of Russian economy, including energy industries (power and heat, oil, gas, coal, nuclear, renewables, etc.), ferrous and non-ferrous metallurgy, transport, chemical and petrochemical industry, residential and commercial buildings, foreign trade with energy resources. The current and prospective technology databases are developed for each sector/industry, based on the national statistics and data and international data sources (IEA, OECD, etc.). The technological characteristics, domestic and world primary energy prices, costs of production by different energy sources, GDP growth rate, economic structure, limits of the use of energy sources capacity, as well as some other indicators are used as the exogenous parameters in the model. The scenarios of economic development are developed with regard to the strategic planning documents, such as the Russian energy strategy, long term socio-economic development programs and others. RU-TIMES is a partial equilibrium model, focused on the energy supply and consumption, not covering forestry and land use sectors, agriculture, waste management, and most of non-CO2 gases (includes only CO2 and CH4).

Safonov G et al, Low carbon development strategy in Russia: transition from fossil fuels to green energy sources, Moscow State University - TEIS Publishing House, 2016 [in Russian].

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SDSN/IDDRI, Pathways to Deep Decarbonization- 2015 synthesis report, Paris, 2015.

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Potashnikov V., Lugovoy O., Projections of the energy balance and greenhouse gas emissions based on RU-TIMES model by 2050, Scientific Vestnik of Gaidar's Institute of Economic Policy, #5, Moscow, 2014 [in Russian]

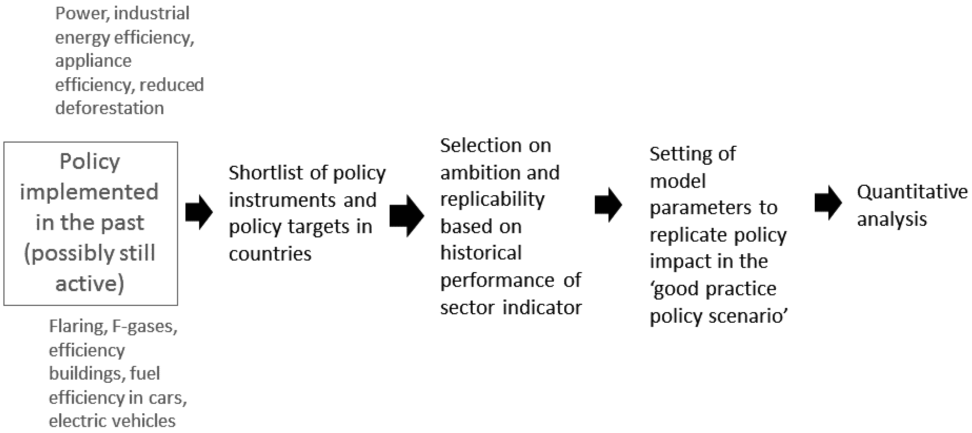
SUPPLEMENTARY 5 REDUCING GLOBAL GREENHOUSE GAS EMISSIONS BY REPLICATING SUCCESSFUL SECTOR EXAMPLES: THE "GOOD PRACTICE POLICIES" SCENARIO

S5.1 Introduction

The starting point of our study was a list of successful policies for nine policy areas (see Table 5-1 in article). In this document we describe the method for selecting these policies, and the choices made for each policy area.

S5.2 Selection of successful policies and translation to policy impact for implementation into the IMAGE model

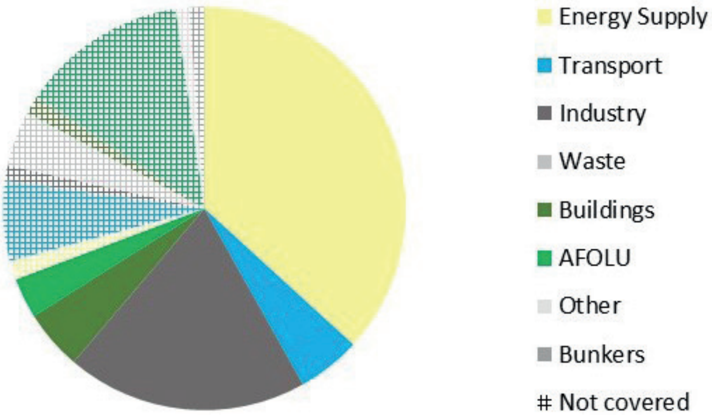
The selection of successful policies is for the most part based on Fekete et al. (2015), but some were added. These policies were identified from sources covering the global landscape: the Climate Policy Database (NewClimate Institute, 2015), den Elzen et al. (2014a); Healy et al.(2016); Höhne et al. (2015a), and technical papers from the UNFCCC on mitigation benefits of actions, and initiatives and options to enhance mitigation ambition (UNFCCC, 2013, 2014a). The selected sectors were these policies were implemented cover a large share of global GHGs and successful policies and were relatively easy to identify, subsequent research could focus on other sectors. Then, based on the resulting shortlist of successful examples for each policy area, we selected one policy based on 1) that it can be easily translated to other countries, 2) the likely impacts, 3) easy implementation in the existing model. Then, for each sector, one policy with the highest performance for a pre-defined sector indicator was selected (See Supplementary Figure 5-1), based on the criteria that it was suitable for scaling up to the global level and not unrealistic in other geographical contexts. The latter is important, as for example, countries with access to large hydro potential can introduce specific renewable policies that cannot be easily replicated by other countries.



Supplementary Figure 5-1 Schematic representation of methodology for selecting successful policies and translating them to model parameters based on performance of a sector indicator.

As the mitigation impact of the selected policies is evaluated in this study, it is assumed that countries could learn from the successful countries, but can adjust these policies or choose different instruments to reach the same goal. Not all policy instruments are well equipped to deliver on the impacts, or some are more effective than others, also depending on the settings of the policies. In our study, policy instruments were translated to policy targets based on historical performance of sector indicators. These sector indicators should, as much as possible, represent trends independent from national factors, especially via activity indicators. This included population and density trends, expected growth of the complete economy or specific sectors, current status of sector structure of the economy, current status of existing policies, and energy production and consumption.

The nine policy areas that are represented in our study cover 65% of 2010 GHG emissions (see Supplementary Figure 5-2). Although we cover many areas, especially those with successful policies, possibly other areas or more successful policies within one area could be identified. This would be input to further research.



Supplementary Figure 5-2 Coverage of greenhouse gas emissions in 2010 in sectors of selected successful policies

S5.2.1 Increase renewables in electricity production

Over 140 countries have renewable energy targets and many of those are supported by economic incentives or regulatory instruments (REN21, 2014). In several countries, these policies have contributed to a rapid growth of renewable energy capacity. In Supplementary Table 5-1 exemplary policy activities for renewables are shown from Uruguay, Costa Rica, the Pacific Islands and the Dominican Republic, developing countries with specifically ambitious target and comprehensive supportive policies. Also the UK and Germany were included and have implemented RE policies already since the beginning of this century. As an example from the African continent, the section describes ambitious renewable policies in Morocco. For countries, where renewable energy policies have existed for a certain period of time, we compare historic trends of the share of renewables, for countries which are just starting to develop such frameworks, we demonstrate the targets to compare their ambition.

Supplementary Table 5-1 Shortlist of renewable policies in electricity production sector

Main sector	Policy action and sector	Country	Indicator value (%p growth)	Good practice policy candidate
energy supply	Increase renewables in electricity production[1)]	United Kingdom	1.0[2)]	Renewable Obligation in 2002. Support scheme for renewable electricity projects
		Germany	1.6[2)]	Renewable Energy Act (Erneuerbaren Energi en Gesetz (EEG))
		Denmark	3.0[2)]	Renewable energy is promoted through a premium tariff, net-metering and tenders for offshore wind parks. Public Service Obligation (PSO) scheme to finance grid expansion
		Uruguay	4.5[3)]	- RE target 90% in 2015 and tax exemptions for RE investments - Increase renewable share in electricity through country dependent policy mix
		Costa Rica	0.9[4)]	- RE target 100% in 2021 and National Energy Plans - Diversification of the energy matrix - Increased of alternative and more stable renewable sources, through their V and VI National Energy Plans
		Tuvalu	NA[5)]	RE target 100% in 2020, Master Plan for Renewable Electricity and Energy Efficiency in Tuvalu, and Renewable Energy Project (PIGGAREP) for the Pacific Islands
		Dominican Republic	0.9[6)]	RE target 20% in 2020, Development of renewable sources of Energy and energy Incentives (e.g. tax exemptions) through law
		Morocco	3.5	- Capacity Target: 2 GW of wind, 2 GW of solar and a 2 GW increase in hydropower capacity by 2020, 42% in 2020 and support schemes for RES-E2009 - 2009 National Energy Strategy, which sets objectives in the areas of electricity fuel mix and its optimization, and the development of renewable energy source

Source: 1) (REN21, 2014) *2) Based on 2004 to 2012 electricity consumption from* (IEA, 2014a)*, 3) According to* (2014a)*, the RE share by 2011 was approximately 72%. If we account for the RE target by 2015, the increase per year is 4.5 percentage point, 4) Costa Rica´s RE share by 2011 was 91%. Therefore, the increase per year is 0.9 percentage point (IEA, 2014). 5) Specific data on RE share for this country is not available, 6) The RE share by 2011 for the Dominican Republic was 12%. Therefore, the increase per year is 0,9 percentage point* (IEA, 2014a)*. 7) While the share of RE electricity output in 2010 was approximately 17%* (IEA, 2014a)*, by 2011 it decreased to 10%, due to a strong decreased of hydropower generation*.

We selected the UK and Germany as examples of successful policies, as here the policy regime has proven to be effective. But, different policy instruments were used in these countries. The UK implemented the Renewable Obligation in 2002, a system requiring energy suppliers to fulfil a certain quota of RE, either through own installations or through the purchase of certificates. This is similar to a renewable portfolio standard. Germany accepted the Renewable Energy Act (Erneuerbaren Energi en Gesetz (EEG)), with a feed-in tariff as the main instrument, incentivising investments in renewable since 2000.

Translation of these policies into policy targets can be done by setting the renewable share of all countries worldwide to the current share of the UK and Germany, or by assuming the same increase in renewable electricity. We have chosen the latter, as the first is independent of the current share of renewable implementation in a specific country. After the calculations, renewable shares were checked to see if they are realistic. Implementation of UK and German policies resulted in average growth rates of the renewable electricity shares in these two countries were 1.35 percentage points annually since 2002, based on data from IEA Energy Balances (IEA, 2014a). We therefore assumed that this historical performance of 1.35%point growth represented the policy impact. As a high share of solar and wind could cause problems with grid integration, some countries might need to increase grid integration, install smart grids or storage, as is already done for example in Denmark (IRENA, 2017).

S5.2.2 Reduce flaring and venting in oil and gas production

The literature shows that large reductions in non-CO_2 emissions from oil and gas production can be achieved at relatively low costs (Lucas et al., 2007). Interestingly, still only few countries have policies in place to control this sector (Healy et al., 2016). Supplementary Table 5-2 below shows exemplary policies in the oil & gas sector in Russia, Norway and United States, all countries with an important share of extraction of oil and gas and policies in place to limit emissions from those activities. It further describes some activities in Trinidad and Tobago, with an economy in development an extremely high dependence on fossil fuel exports.

Supplementary Table 5-2 Shortlist of flaring and venting policies in oil and gas production sector

Main sector	Policy action and sector	Country	Indicator value	Good practice policy candidate
Energy supply	Reduce flaring and venting in oil and gas production	United States	4.7% annual reduction between 2012 and 2025	- US methane target: 40-45% reduction below 2012 by 2025 (executive rule)[6)] - Voluntary partnership policy to encourage methane emissions reductions in the oil and gas sector (Natural gas START Program)[5)]
		Russia[3)]	3.8% annual reduction between 2008 and 2012	- Target to reduce flaring to 5% = 95% utilization[2)] target linked with non-compliance penalties. Different payments apply for different types of pollutants relevant to APG - Incentives to reduce flaring: market liberalization and preferential market access - Regulatory reform for clustering projects with supplies of associated gas from multiple fields
		Norway[4)]	4.4% annual reduction between 1990 and 2000	Taxation of oil and gas activities (starting in 1991) Carbon Capture Storage Operation
		Trinidad and Tobago	n.a.	Petrotrin Oil Fields Associated Gas Recovery and Utilization PoA. Energy management program (for petrochemical plants and policy framework for energy efficiency in preparation[1)]

Source: 1) (UNEP Risoe, 2013) 2) (Roelfsema et al., 2014), 3)(Carbon Limits, 2013), 4) IEA (2011), 5) (EPA, 2016), 6) (IEA, 2015)

The USA policy on methane reductions is ambitious, but implementation is uncertain due to the roll back of many climate policies in this country. Based on the projections in the Annual Energy Outlook 2014 (EIA, 2014), the US would decrease to 77.4 ktCO_2e per Mtoe fuel produced by 2025, which is an annual reduction of 4.7% (EIA, 2014),. Russia introduced in 2009 a license requirement with at 95% utilisation target together with incentives to reduce flaring (e.g. use APG in power production) (Carbon Limits, 2013). Between 2009 and 2012 oil and gas intensity improved by 3.8% per year. Norway is an oil and gas exporting country, but at the same time has strict environmental policies. Volumes of gas flaring as a percentage of oil production has decreased substantially over the last two decades (Bank, 2004). It has in place an Gas flaring regulation, and a carbon tax, which was introduced in 1991. This tax proved to be a successful incentive in establishing zero routine gas flare environment in the oil and gas industry. It agrees to end routine flaring by 2030 as part the World Bank Gas Flaring Initiative. In addition, associated CO_2 is removed from the produced gas and reinjected into a storage reservoir (Eseduwo and Arugu-Iwori, 2010). As a result, most of Norway's recovered gas is exported, while the remnant of APG is, not surprisingly, re-injected. The GHG intensity of oil and gas production in Norway decreased by 4.4% between 1990 and 2000. As the carbon tax implementation in Norway resulted in the highest reduction from those on the short list, the annual policy impact of 4.4% $ktCO_2$/Mtoe was replicated in all regions for the period 2015 to 2030.

S5.2.3 Enhance energy efficiency of industrial production

Energy efficiency is an important option for GHG reductions in the industry sector. The shortlist of policies for industry efficiency contains ambitious policies that are being implemented in various countries, such as China, India, Ireland, South Korea, japan and Australia (see Supplementary Table 5-3) . Because industry sub-sectors are different in terms of energy use and efficiency, it is difficult to define an overall industry sector indicator. On this aggregated level, only final energy use per GDP is available, but this also includes the impact of structural changes in the economy.

As the industry policy in Ireland performs best on this indicator, we have chosen this policy to represent good practice. But this is not linked directly to the TIMER model implementation, and therefore we have chosen the 1% efficiency reduction (above autonomous efficiency improvements) as the underlying policy goal. This means, that we improve efficiency per physical unit by 1% relative to the current policies scenario. We realise that is a very aggregate target, and future work should disaggregate this target to different sub-sector, such as steel, cement and other industry. But no good candidates have been found thus far.

Supplementary Table 5-3 Shortlist of energy efficiency policies in industry sector

Main sector	Policy action and sector	Country	Indicator value[1)] (GJ/tonnes of product)	Indicator value[2)] GJ/US$(2005)) (in PPP) annual reduction over 2000-2011	Good practice policy candidate [1), 2), 3)]
Industry	Enhance energy efficiency of industrial production	China		-1.9	Top 1000/10000 Programme Energy Conservation Plan, with ambition to reduce energy consumption by 20% from 2006 to 2010
		India		-1.6	Energy Conservation Act 2001, PAT scheme - Mission for Enhanced Energy Efficiency 2008
		Ireland	- 1.0[1)]	-3.5	Energy Agreements Programme (launched in 2006), voluntary energy efficiency targets from participating firms, intending to support annual 1% cuts in national energy consumption above BAU
		South Korea		-2.9	National Energy Basic Plan (2008 – 2030)
		Japan		0.3	The Act on the Rational Use of Energy, Keidanren Voluntary Action Plan (targets set by industry), voluntary emissions trading scheme (cap and trade scheme), mandatory benchmarking policy (energy efficiency targets based on benchmarks)
		Australia		-2.4	Energy Efficiency Opportunities Act (2006) and Opportunities (EEO) program (2006 – 2014)

Source: 1)(Tanaka, 2011), 2) (ABB, 2013a, 2013b, 2013c, 2013d, 2013e, 2013f), 3) (Reinaud and Goldberg, 2012), 4) (EEX, 2015)

In Ireland, the Sustainable Energy Authority of Ireland (SEAI) established energy agreements with companies or institutions, aiming for a 1% annual decrease of energy consumption relative to current trends (Tanaka, 2011). The SEAI backs the agreements through financial support, creating opportunities for networking and provision of information.

S5.2.4 Reduce fluorinated gas emissions

Fluorinated gases have long-lived atmospheric lifetimes and are emitted through a variety of industrial processes and consumer products. But alternatives for HFC use are being developed and deployed for most applications (Velders et al., 2015). Fluorinated gases (F-gases) are used in the industry sector, but also in the buildings and transport sector.

These emissions have increased in the last decades specifically in the refrigerants industry and the car industry, where they are used to replace ozone depleting substances. In the absence of additional policies, they are expected to increase further in the future, however, environmentally friendly alternatives are already available for most sectors (UNEP, 2011, 2015e).

Supplementary Table 5-4 Shortlist of f-gas emissions reduction policies

Main sector	Policy action and sector	Country	Indicator value (f-gas reduction/ HFC reduction) 2005-2012	Good practice policy candidate
Industry	Reduce Fluorinated emissions	USA, Mexico, Canada		North American Proposal 2014 HFC submissions to the Montreal Protocol
		EU	+5.7%/+4.0%	- Reduction of F-gas emissions by two-thirds compared to 2014 levels[1)] - Proposed amendment to the Montreal Protocol
		China	+0.1%/+0.5%	HFC phase-down programs[2)]
		United States	+3.6%/+0.7%	Significant New Alternatives Policy (SNAP) Program
		All parties to the Montreal Protocol		Proposed amendment to the Montreal Protocol submitted by Canada, Mexico and the United States of America[3)]

Source: 1)(Schwarz et al., 2011), 2) (UNFCCC, 2014b), 3) (UNEP, 2015d)

The successful HFC and F-gas policies of the individual countries EU, China and the USA that we found, are not more ambitious then the Proposed Amendment to the Montreal Protocol (see Supplementary Table 5-4). For this reason, we have assumed this proposal to represent the most successful policy, but scale this up to include PFC emissions (see below). This proposal addressed phase down of HFCs and was adopted in 2016. Developed countries will start to phase down HFCs by 2019, resulting in 85% reductions relative to specified baseline after 2036. The baseline is calculated as the average HFC consumption and production for the period in 2011-2013 and 15% of HCFC emissions for developed countries. Historical HCFC emissions, necessary to calculate the HFC baseline were taken from the Ozone Secretariat (UNEP, 2015c), together with Global Warming Potentials (GWP) from Solomon et al., (2007). This is also extended to PFC and SF6, as strong reductions are being implemented and technically possible, for example the new EU F-gas regulation is aiming for 66% reduction of all fluorinated relative to 2010 (EEA, 2015). Most PFC emissions from aluminium can be eliminated, and 43% BAU emissions from semiconductor manufacturing could be abated at breakeven cost (GNCS, 2012a). SF6 from electrical equipment has practical recovery rates of 80%, and SF6 in magnesium production can be replaced by HFC-143 with a smaller atmospheric lifetime (GNCS, 2012b).

S5.2.5 Enhance efficiency of building envelope

The residential building envelope is critical in determining how much energy is required for heating and cooling that represents over one-third of building energy use (IEA, 2013). For buildings, it is important to start implementing sustainable standards very soon to avoid locking in inefficient building structures. Countries such as Mexico, Tunisia, Japan, and EU have in place ambitious energy efficiency policies in the buildings sector (see Supplementary Table 5-5).

Supplementary Table 5-5 Shortlist of envelope efficiency policies in residential buildings sector

Main sector	Policy action and sector	Country	Indicator value	Good practice policy candidate
Buildings	Enhance efficiency of building envelope (heating/ cooling)	Mexico		Housing NAMAs: Ecocasa 1 & Ecocasa 2 Programs[1)]
		Germany	40 kWh/m² primary energy 15 kWh/m² final energy	Financial support for new and refurbished buildings with a certain efficiency standard from KfW [2)]
		China	N.A.	Regulations for Energy efficiency of building design and operation in new and refurbished buildings in urban areas: Requirements for heat transfer coefficient of building envelope elements and design of building (e.g. orientation)[3)]
		Republic of Korea	Nearly zero kWh/m² in 2030[4)]	Korean energy roadmap: net zero energy consumption for new buildings by 2025 [4)]
		Japan	108 kWh/m² final energy*	Design and Construction Guidelines on the Rationalization of Energy Use for Houses: heat coefficient requirements for building envelope and other elements, differentiated by climate zone [5)]
		EU	Nearly zero kWh/m² in 2020	Directive on new buildings

*Source: 1) (Ecofys, 2015a), 2)(KfW, 2014), 3) (BigEE, 2011) 4) (Schuetze, 2015), 2015) 5)(Asian Business Council, 2015). *Using the median value of various climate zones based on own calculations*

The Republic of Korea aims to update building codes gradually, such that by 2025 all newly constructed buildings will be zero-energy buildings (Park et al., 2015) (see Supplementary Table 5-5). In the EU, the European law requires member states to assure that in 2020, all new buildings are nearly zero-energy buildings. Historical performance of energy use per m^2 were not available, but we choose the EU building codes to represent good practice and energy consumption per square meter was selected as performance indicator for buildings energy efficiency. In contrast to the EU policy, we have assumed 2030 as target year. Furthermore, the policy target was defined for heating for newly constructed buildings only, which was set to 0 kWh/m^2 by 2030.

S5.2.6 Set efficiency standards for appliances and lighting

There is substantial room for improving appliance efficiency given the high rates of renovation and rapidly increasing demand (Healy et al., 2016). Specifically, for appliances, there is substantial room for increasing ambition already before 2020 given the high rates of renovation and rapidly increasing demand (Braun et al., 2014).

Supplementary Table 5-6 Shortlist of efficiency policies for appliances in residential buildings sector

Main sector	Policy action and sector	Country	Indicator value	Good practice policy candidate
Buildings	Set efficiency standards for appliances and lighting	USA	n.a.	Energy Star Program
		Japan	n.a.	Top-runner program[1)]
		EU (UK, Sweden, Netherlands, France, Slovakia, Finland, Czech Republic)	1.8% improvement of efficiency based on ODEX indicators[2)]	Combined effects of EU legislation, national programs, awareness campaigns, supplier obligations, white certificate schemes and voluntary agreements

Source: 1) (Braun et al., 2014), 2) (ISIS, 2014)

We found successful policies on efficiency of appliances in the USA, Japan and the EU (see Supplementary Table 5-6). The most effective policies seem to be implemented in the EU member states UK, Sweden, Netherlands, France, Slovakia, Finland, Czech Republic. The historic energy efficiency progress of these measures is represented by the ODEX index (Enerdata, 2010), which is a weighted average of sub-sectoral indices. These sub-sectoral indices are calculated from different energy consumption indicators and measured in physical units (e.g. kWh/appliance). Between 2001 and 2012 these countries showed an annual improvement of appliance efficiency of 1.8%, based on the ODEX index (Enerdata, 2010), and retrieved from the MURE database (Odyssee-Mure). This improvement was used for the policy target in this area. In addition we assume that all incandescent light bulbs are phased out, as is already done in the EU (Perino and Pioch, 2017) and in Brazil (Soares, 2016)

S5.2.7 Improve fuel efficiency of cars

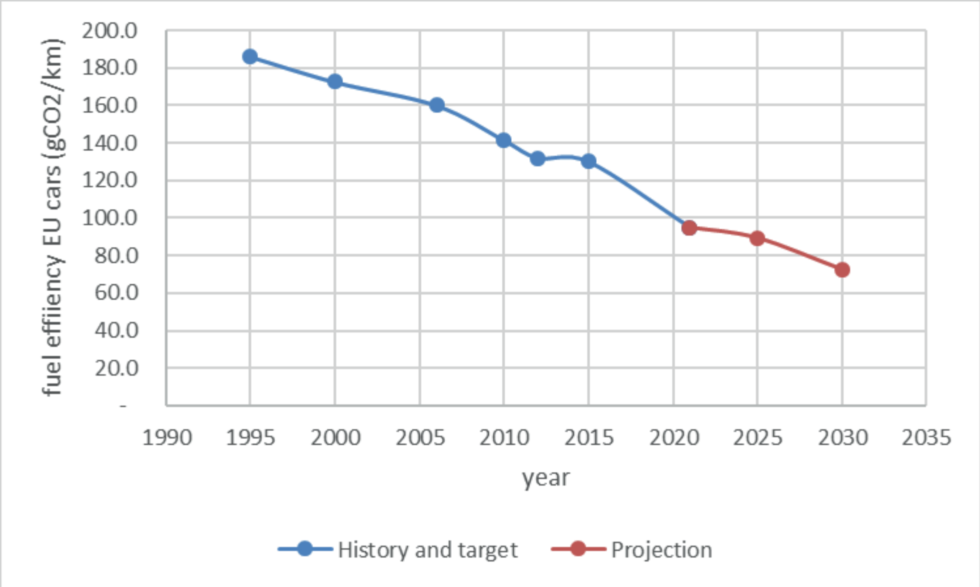
For the transport sector, we focus on the areas of efficiency of cars, and the support of electric cars. The first area is one where many countries are active already (GFEI, 2014; ICCT, 2014). A number of countries have implemented efficiency standards or emission intensity targets for new cars. The exact design of the policy and the ambition of the targets varies (see Supplementary Table 5-7). Many countries regularly revise the targets over time and increase their stringency (e.g. EU, Japan, China, and USA).

Supplementary Table 5-7 Shortlist of fuel efficiency policies in car transport sector

Main sector	Policy action and sector	Country	Indicator value	Good practice policy candidate
Transport	Improve fuel efficiency of cars [1]	China		Fuel efficiency standard for light duty vehicles
		South Korea		Fuel efficiency standard for light duty vehicles
		Japan		Fuel efficiency standard for light duty vehicles
		US & Canada		Fuel efficiency standard for light duty vehicles
		EU[2]		Fuel efficiency standard for light duty vehicles
		Brazil		Fuel efficiency standard for light duty vehicles
		Mexico		Fuel efficiency standard for light duty vehicles
		India		Fuel efficiency standard for light duty vehicles

Sources: 1) (ICCT, 2014); 2) (European Commission, 2015)

Figure 1 in the IEA (2012) report on fuel economy shows the EU and Japan have implemented the most ambitious fuel efficiency standards for cars. In addition, already in 2013 the EU Environment Committee of the European Parliament voted on a regulatory proposal to define CO_2 emission targets for new passenger cars and accepted an indicative range for 2025 of 68-78 gCO_2/km. This is an ambitious target, but has not been implemented yet. The EU policy was selected as most successful. The annual increase of efficiency between 1990 and 2015 was 1.8% per year (ICCT, 2018). If we extrapolate this to the year 2030, we arrive at 83gCO_2/km and 30 km/l (see Supplementary Figure 5-3). Translating gCO_2/km to km/l is done by using the CO_2-intensity of gasoline and diesel from the (EIA, 2017) and assuming that the ratio between gasoline and diesel (43% gasoline (Eurostat, 2015)) cars remains the same after 2013. We apply halve of the gap between official and real world fuel-economy figures, estimated at 30% (ICCT, 2016), as we assume that due to current attention, the gap will be smaller by 2030. The result is a 26.0 km/l policy target for fuel efficiency of cars by 2030.



Supplementary Figure 5-3 Shortlist of fuel efficiency policies in car transport sector

Note that we now use the absolute efficiency level and not the annual as policy target, as we assume that production and selling of cars is done in an international context, and efficiencies in different countries can more easily approach each other.

S5.2.8 Increase number of electric cars (charged with renewable electricity)

Electric mobility is only starting to develop, but at a sometimes surprisingly quick pace. As examples, both Colombia and India have NAMA's under development on introducing electric cars (see Supplementary Table 5-8)

The Supplementary Table 5-8 shortlists electric cars policies in transport sector. Colombia intends to reach a 20% penetration of electric cars, but they did not specify the period for attaining this target (Ecofys, 2015b). Chile intends to introduce 70,000 electric vehicles in 2020, including cars, taxis, mini buses and fleet vehicles which is 1% of the total fleet (Ecofys, 2015a).

Supplementary Table 5- 8 Shortlist of electric cars policies in transport sector

Main sector	Policy action and sector	Country	Indicator value	Good practice policy candidate
Transport	Increase number of electric cars (charged with renewable electricity)	Norway	6% of new vehicles in 2013[2)] 23.5% share of new cars by 2015[7)]	- Incentives for the purchase of electric vehicles include: Economic incentives through tax levies, preference parking and driving lanes, investments in charging infrastructure[3)], - All new cars sold by 2025 must be plug-in hybrid, electric or hydro
		Colombia	20%, no year specified	Electric Vehicles NAMA 20% penetration for passenger transport [4)],
		India	6% in 2020 for BEV 11% in 2020 for HEV 4% in 2020 for PHEV	National Electric Mobility Mission 20205[6)]
		Chile		E-mobility readiness plan[5)] 70,000 electric vehicles in 2020, (1% of total fleet on the road (cars, taxis, mini buses, fleet vehicles)

2) (Shahan, 2014); 3) (Guardian, 2014); 4) (Ecofys, 2015b); 5) (Ecofys, 2015a); 6) (Government of India, 2012); 7) (IEA, 2016)

Norway provides significant tax exemptions for electric vehicles, allows electric cars in bus lanes, waives road tolls and parking fees and has put in place a great number of free charging stations (IEA, 2016). In addition, they aim for zero (electric or hydrogen) or low (plug-in hybrids) emission new cars by 2025. In fact, Norway already achieved 23.3% market share in 2015 for newly sold cars (IEA, 2016). This policy was selected to represent good practice and the policy impact was replicated in all regions, but only by 2030, as other countries need to start building infrastructure first.

S5.2.9 Reduce deforestation in forests

For the LULUCF sector, the main focus is halting deforestation and thereby reducing emissions. For deforestation, a number of countries have already shown that they are able to reduce their national deforestation rates. A number of international initiatives such REDD+ have also mobilized the international community to address the issue of deforestation and support countries in their efforts to reduce emissions from deforestation and forest degradation.

Supplementary Table 5-9 Shortlist of deforestation policies in LULUCF sector

Main sector	Policy action and sector	Country	Indicator value	Good practice policy candidate
LULUCF	Reduce deforestation in forests	Brazil[2)]	Yearly deforested area[1] 1.95 Mha / 0.58 Mha (19952005/ 2010-2014)	Reduction of national deforestation rate according to fulfilment of the Action Plan for Deforestation Prevention and Control in the Legal Amazon (PPCDAm)
		Guyana[3)]		Partnership with Norway in a global REDD program to prevent leakage as deforestation rate is already zero
		Madagascar[3)]		Commitment to triple land area under protection, covering 10% of the country, more than 60,000 square kilometres (2003)
		Kenya[3)]		REDD+ program to protect the carbon stock of about 200,000 hectares of woodland and dry forest
		India[3)]		National Forest Policy act (1988)
				Decentralized Joint Forest Management (JMF) programs

1) (FAOSTAT, 2017) 2) (Nepstad et al., 2014) 3) (Union of Concerned Scientists, 2014)

The successful example that was chosen is the Action Plan for Deforestation Prevention and Control in the Legal Amazon (PPCDAm). The PPCDAm calls for an 80% reduction of the annually deforested area in the Amazon by 2020. Brazil is well on track for reaching this target as PRODES[34] has estimated that the deforestation in the Legal Amazon has decreased from the 1996 - 2005 average of 1.95 Mha/year to an average of 0.58 Mha/year for the period of 2010 - 2014. The policy impact was based on a recent (gross) deforestation rate, using official FAO estimates and national reporting to FAO FRA (FAOSTAT, 2017) of recent annual deforestation rates. It is assumed that the national deforestation rate could be decreased by 44% as of 2030 and no leakage occurs to other countries.

[34] The PRODES (Gross Deforestation Monitoring Program in Amazonia) is a national program that provides annual rated of gross deforestation in the Legal Amazonia, carried out by Instituto Nacional de Pesquisas Espaciais.

S5.3 Comparison with previous study from Fekete et al (2015)

To get an indication of the sensitivity of the impact on GHG emissions, we compare our results with the results from the bottom-up model as published in Fekete et al. (2015). Assumptions in the bottom-up model were updated to make them comparable with the current study. The emissions gap with the median estimate of the 2°C pathway from this analysis is somewhat smaller, and equal to 4.5 $GtCO_2eq$[35]. The difference is largely explained from the assumptions around the implementation of the renewable electricity target: in the bottom-up framework coal is first coal replaced by renewables, while the IMAGE-TIMER model coal and gas are replaced depending on their costs. In addition, it accounts for efficiency improvements and replacement of fossil fuels by renewables at the same time. A further difference of approximately 0.7 $GtCO_2e$ were found in both the F-gas emissions reductions due to different baseline assumptions and electricity use in demand sectors due to difference in emission factors.

[35] 2010 GHG emissions are 0.3 $GtCO_2$ higher than the results presented in this paper

SUPPLEMENTARY 6 INTEGRATED ASSESSMENT OF INTERNATIONAL CLIMATE MITIGATION COMMITMENTS OUTSIDE THE UNFCCC

S6.1 Supplementary data

Roelfsema, Mark (2022), "A decade of climate policy", Mendeley Data, V1, doi: 10.17632/krxvpxn8b9.1

6.s.1 – List of ICIs.xlsx

S6.2 Selection of climate initiatives

The climate initiatives, as described in the article, were selected to cover the largest economic sectors, and meet five other criteria.

I. It should include multiple parties and act in multiple countries/regions (i.e. no bilateral initiatives were included),
II. It should have a large expected global impact (roughly 0.1 $GtCO_2eq$ or more),
III. It should have clear commitments with quantified mitigation targets or concrete measures, or estimates are available based on GHG emissions from publications or literature
IV. for which it is specified how the overall target (if any) is applied to individual actors,
V. It should only include direct GHG emission target or specific measures, e.g. no finance, subsidies and carbon taxes

The result of the selection can be found in 'List of climate initiatives_selection.xlsx' on the worksheet 'list with climate initiatives'. The list was retrieved on the 1st of May 2015 from the climate initiatives platform and supplemented with initiatives found in (UNFCCC, 2013, 2015f; Wouters, 2013). If one criterion is not met, the climate initiative is not taken into account. This is described in the last column.

In the process of analysing the climate initiatives, several new ones were launched after the brake-off date of 1 May 2015. These new initiatives were not included in our study. It is difficult to indicate how large the impact is, as many initiatives are expected to take action in the same sectors as already included international initiatives, but currently there is no insight whether these include many more new participants. Furthermore, four international initiatives that were assessed, but based on the current status have a small impact, could increase in the near future:

- **RE100**. The aim is for at least 100 companies to make a global 100% renewable commitment with a clear timeframe for reaching their goal. Up till now 16 companies have joined. See the report by (NewClimate Institute, 2016) for post-COP21 estimates of reductions.
- **Aichi biodiversity targets**. A set of multilateral agreements aimed at preserving biodiversity, determined within the Convention on Biological Diversity in which 196 countries take part. These targets were assessed using the IMAGE model, and these targets are not expected to result in emission GHG reductions compared to baseline. A more ambitious preservation target would have a significant effect on a short timescale.
- **The Sustainable Development Goals** consist of 17 goals and each has several target for achieving this goal. Although governments have declared the SDGs to be consistent, the interaction between SDG targets is not completely known (McCollum et al., 2017). The climate goal is aligned with the Paris Agreement, but the impact of many other goals and targets that are expected to have impact on GHG emissions needs further investigation, such as the clean and affordable energy goal.
- **Climate and Clean Air Coalition (CCAC)** aims to reduce black carbon emissions from diesel vehicles, biomass stoves, brick kilns, coke ovens and waste burning. As there is a large uncertainty in the climate effects of BC, and BC is also not included in the basket of Kyoto-gas emissions, the results were not included in our assessment. In addition the methane targets have a large overlap with the Global Methane Initiative.

Some initiatives recently published information on targets and some new initiatives have also started. The following may be promising in the near future:

- **The Climate Group States & Regions Alliance/CDP States and Regions**. The alliance includes 27 local government bodies that share expertise, demonstrate impact and aim to influence international climate dialogue. The group provides an annual report on the climate targets set by local governments. In the case the US would fully withdraw from the Paris Agreement, climate policy by US States could result in additional GHG reductions. Also the recently launched **America's Pledge initiative** could contribute to this. This initiative compiles and quantifies GHG commitments made by US federal state, cities and businesses in the US to reduce their GHG emissions in line with the US NDC.
- **We Mean Business / Science Based Targets**. We Mean Business is a coalition of organisations working with thousands of the world's most influential businesses and investors. Science Based Targets is part of this and helps businesses to establish targets in line with climate science. See the report 'Business end of climate change' by (NewClimate Institute, 2016), which is based on CDP data, for post-COP21 estimates of reductions.

- **En.lighten, Tropical Forest Alliance, WWF Climate Savers and Refrigerants, Naturally!** The University of Cambridge (2015) assessed these four international collaborations and also the Cement Sustainability Initiative, all involving the private sector. Together they are estimated to achieve 0.2 $GtCO_2eq$ by 2020 with current commitments, and up to 0.5 GtCO2eq if they either adopt commitments of the leaders or expand membership. **En.Lighten** was set up by the United Nations Environment Programme and the Global Environment Facility and aims to accelerate a global market transformation towards more efficient lighting.
- **Bridging the gap/SloCat**. Both initiatives are multi-stakeholder initiatives that link transport and climate change. They promote action in both the public and private transport sectors.
- **Sustainable Energy for All** initiative is a multi-stakeholder partnership between governments, the private sector and civil society. Launched by the UN Secretary-General in 2011, it has three linked objectives to be achieved by 2030: 1) ensure universal access to modern energy services, 2) double the global rate of improvement in energy efficiency, 3) double the share of renewables in the global energy mix. This initiative also includes the Global Alliance for Clean Cooking Stoves, Zero Routine Flaring, and the Global Energy Efficiency Accelerator Platform. We included the flaring initiative in our assessment as this initiative has specific targets for individual countries.
- **European Wind Initiative** and the **Solar Europe Industry** Initiative are EU-only initiatives (so not international) that aim for a 20% share of wind energy in EU electricity consumption by 2020 and 12% share of solar energy.

S6.3 Documentation of data sources for baselines and targets

The impact assessment was based on the IMAGE/TIMER SSP2 baseline, but the assessment was done outside these models. The basis for each climate initiative baseline are 2010 GHG emissions taken from a literature source together with baseline emissions growth taken from a selection of representative economic sectors from the IMAGE/TIMER model. If the historic emissions were not available, these emissions were scaled using information from literature about participation of actors in specific sectors. The target or estimate of impact on GHG emissions was based on literature. The sources and assumptions are described in the two tables in this section

S6.3.1 Baselines

Supplementary Table 6-1 Shortlist of deforestation policies in LULUCF sector

Climate Initiative Type	Climate Initiative	Source of 2010 emissions	Sectors included in baseline trend						
			Energy Supply	**Transport**	**Industry**	**Buildings**	**AFOLU**	**Other**	**International Bunkers**
Individual	Carbon Disclosure Project	(CDP, 2015b)	Y (CO_2)	N	Y (CO_2)	N	N	N	N
ICI	C40 Cities and Covenant of Mayors[**)]	(C40 Cities, 2013; Kona et al., 2015)	Electric car/bus, urban residential, small industry (CO_2)	Car/bus (CO_2)	Small industry (other, not cement/ steel) (CO_2)	urban residential (CO_2)	N[*)]	N	N
ICI	Cement sustainability initiative	(WBCSD, 2012) / TIMER	N	N	Cement industry (CO_2)	N	N	N	N
ICI	Global Fuel Economy Initiative	2010 emissions based on ((JRC and PBL, 2012; IEA, 2014b; UNFCCC, 2014a))	N	Cars (CO_2)	N	N	N	N	N
UN	Kigali Amendment	TIMER [HFCs] (UNEP, 2015c, 2016b) [HCFCs]	N	HFC	HFC	HFC	N	N	N
ICI	Global Methane Initiative	IMAGE/TIMER	Y (CH_4)	N	N	N	Waste,	N	N
ICI	New York Declaration of Forests	IMAGE	N	N	N	N	CO_2	N	N

Climate Initiative Type	Climate Initiative	Source of 2010 emissions	Sectors included in baseline trend						
UN	International shipping sector (IMO)	TIMER	N	N	N	N	N	N	Shipping (CO_2)
UN	International aviation sector (ICAO)	TIMER	N	N	N	N	N	N	Aviation (CO_2)
ICI	Zero Routine Flaring by 2030	TIMER	Losses/leakages (CO_2)	N	N	N	N	N	N

**) Note that waste CH_4 emissions are also an important emission source in cities, but as not aggregated 2010 emission data was available for the two city initiatives, these were not taken into account.*

***) Overlap between the two initiatives is assumed to be 25% based on (Wouters, 2013)*

S6.3.2 Targets

Supplementary Table 6-2 Target sources and assumptions for the global assessment of climate initiatives

Climate Initiative Type	Initiative	Target	Source historical emissions	Source overall reduction target	Comment
Individual	Carbon Disclosure Project	1.4% annual reduction until 2030 (in line with 2° C goal), 0.7% annual reduction until 2030 (not in line with 2° C goal) or no reduction (no long-term target)	(CDP, 2015b)	Reduction estimate from (CDP, 2012; Moorhead Nixon, T., 2014)	35% of 2010 emissions represents companies with targets in line with 2° C, 15% represent companies with target, but not in line, remaining companies without long-term targets
ICI	C40 Cities and Covenant of Mayors	C40: 250 MtCO2e by 2020 for 59 cities, Same percentage reduction relative to BAU in 2030	(C40 Cities, 2013)	(C40 Cities, 2013)	Scaled with population based on (C40 Cities, 2015)
ICI		CoM: estimate 2020, Same reduction relative to BAU in 2030	(Kona et al., 2015)	(Kona et al., 2015) / TIMER	In the publication, the group of cities was divided into three groups (1990, 2000, 2005-2008), and both shares, and total absolute reduction were included. These were translated into reduction rates relative to baseline and were applied to TIMER baseline for cities (see Section 2.1 article)
ICI	Cement sustainability initiative	45% reduction of CO2-intensity by 2050 compared to 2005	((WBCSD, 2012)/ TIMER	(IEA and WBCSD, 2009; WBCSD, 2012)	CSI accounts for 30% of global 2010 cement emissions (WBCSD, 2012)
ICI	Global Fuel Economy Initiative	50% reduction in new car fuel consumption (L/100km) by 2030 compared to 2005 levels for participating countries	2010 emissions based on (UNFCCC, IEA, EDGAR)	(GFEI, 2014)	Country historical car transport emissions were first retrieved from UNFCCC database, if not available from World Energy Outlook 2011 (IEA, 2011b), and otherwise from EDGAR ((JRC/PBL et al., 2012))

Climate Initiative Type	Initiative	Target	Source historical emissions	Source overall reduction target	Comment
UN	Kigali Amendment to the Montreal Protocol	Reduction based on phase-down schedule from proposal (40%-70% reduction relative to proposal baseline by 2030)	TIMER [HFCs] (EPA, 2013b) [HCFCs]	(UNEP, 2016b)	
ICI	Global Methane Initiative	Implementation of cost-effective measures (0-10 $/tCO2e)	IMAGE/TIMER	(EPA, 2013a)	Combination of EPA cost curves and aim to reduce cost effectively
ICI	New York Declaration of Forests	Net zero deforestation by 2030	IMAGE	(New York Declaration of Forests, 2014)	Target is only applied to countries listed in reported. The emissions are determined by calculating the 2010 share of each country per IMAGE region based on (FAOSTAT)
UN	International shipping sector (IMO)	19-26% reduction relative to baseline	TIMER	(IMO, 2011)	
UN	International aviation sector (ICAO)	annual 1.5% fuel efficiency until 2020, annual 2% fuel efficiency until 2050	TIMER	(ICAO, 2010)	
ICI	Zero Routine Flaring by 2030	Mandatory measures to improve energy efficiency and to reduce greenhouse gas emissions	TIMER	(World Bank, 2015b)	Target is only applied to countries listed in reported. The emissions are determined by calculating the 2010 share of each country per TIMER region based on (UNFCCC, IEA, EDGAR)

S6.4 Sectoral coverage of selected initiatives

Part of the assessment of the impact of international initiatives on greenhouse gas emissions consisted of an analysis of the sector distribution of selected international initiatives. The sectors in which these international initiatives take action were compared with the sector definition from the IMAGE 3.0 modelling framework (See Supplementary Table 6-1). This analysis shows that except from the freight transport and rural buildings sector, actions from these initiatives cover almost all sectors.

Supplementary Table 6-3 Sector coverage of selected international initiatives based on IMAGE/TIMER sector definition

TIMER/IMAGE sector definition				**Cities**	**Companies**	**GFEI**	**HFC proposal**	**GMI**	**NYDF**	**IMO**	**ICAO**	**Zero Routine Flaring**
Energy supply	electricity production	buildings - residential	urban	x	x							
			rural		x							
		buildings - service		x	x							
		transport		x	x							
		industry			x							
		other			x							
	fossil fuel conversion				x			X				x
	hydrogen				x							
Transport	passenger	bus		x								
		train		x								
		car		x		x						
		high speed train										
		air									x	
	freight	inland shipping										
		freight train										
		medium truck										
		heavy truck										
		air cargo									x	
		international shipping								x		

TIMER/IMAGE sector definition			Cities	Companies	GFEI	HFC proposal	GMI	NYDF	IMO	ICAO	Zero Routine Flaring
Residential	Household appliances	urban	x								
	Lighting	urban	x								
	Cooking	urban	x								
	Water heating	urban	x								
	Space heating	urban	x								
	Space cooling	urban	x			x					
	Household appliances	rural									
	Lighting	rural									
	Cooking	rural									
	Water heating	rural									
	Space heating	rural									
	Space cooling	rural				x					
Service			x								
Industry	cement			x							
	steel			x							
	other		x	x		x					
Agriculture							x				
Forestry								x			

SUPPLEMENTARY 7 BEYOND NATIONAL CLIMATE ACTION: THE IMPACT OF REGION, CITY, AND BUSINESS COMMITMENTS ON GLOBAL GREENHOUSE GAS EMISSIONS

S7.1 Author contributions

Contributions MR: data collection/cleaning, developing conceptual framework (i.a. Roelfsema (2017)), building analysis framework, analysing results, writing paper

S7.2 Detailed methods on the subnational actors' commitments dataset preparation

Cities are local governments that are administrative units of a specific geographical territory. In our analysis, the term "cities" includes towns, urban communities, districts, and counties, as defined by the actors themselves and often also defined in the country's legal system. Regions are subnational administrative units that are generally broader in population and in scope than cities. They usually have separate governing bodies from national and city governments but encompass lower administrative levels of government; often, they are the first administrative level below the national government. "Regions" in this report includes US and Indian states, German Länder, and Chinese provinces. Regions can also include councils of subnational governments acting together.

The emissions inventory totals and data for quantifiable climate commitments used for the calculations were mostly self-reported by entities through one of the reporting platforms presented in Supplementary Table 7-1.

Supplementary Table 7-1 Sector coverage of selected international initiatives based on IMAGE/TIMER sector definition

Climate Action Platform	**Data source**
Alliance of Pioneer Peaking Cities	Alliance of Pioneer Peaking Cities (2016). Accessed from: http://www.huanjing100.com/p-1307.html. Peak emissions years were used in the calculation of the cities' projected carbon emissions.
C40 Cities for Climate Leadership Group	C40 Cities for Climate Leadership. Accessed June 2019 from: https://www.c40.org/cities.
ICLEI Local Governments for Sustainability carbon*n*® Climate Registry	ICLEI Local Governments for Sustainability carbon*n*® Climate Registry (www.carbonn.org). (Data provided directly by ICLEI in June 2019). Individual targets and action plans for carbon*n* participants based on 2018 GPC Inventory responses. In cases where baseline information for participating actors was absent, it was supplemented with baseline information from data collected from carbon*n*'s reporting members (individual targets, action plans, and progress data) in March 2018.
CDP Cities	CDP (2019b). 2018 Cities Emissions Reduction Targets; 2018_Cities Community-wide Emissions Map; 2018 Cities Renewable Energy Targets Map.csv; 2018 City-wide Electricity_Mix. Accessed May 2019 from: www.data.cdp.net.
CDP 2018 Disclosure Survey	CDP. (Provided directly from CDP in July 2019). *GHG emissions and action data for companies based on the 2018 responses*.
Compact of States and Regions	Compact of States and Regions. (Data provided directly by the Compact of States and Regions in February 2019). 2018 States and Regions Open Portal Dataset, collected via CDP States and Regions 2018 Information Request.
EU Covenant of Mayors for Climate & Energy	EU Covenant of Mayors for Climate & Energy. Individual targets and emissions data for reporting members. Accessed April 2019 from: www.globalcovenantofmayors.org.
Under2 Coalition	Under2 Coalition (Secretariat The Climate Group). Membership and action data collected from signatories' appendices. Accessed June 2019 from: https://www.under2coalition.org/members.
Global Covenant of Mayors for Climate & Energy	Global Covenant of Mayors for Climate & Energy. (Data provided directly by Global Covenant of Mayors in June 2019). Individual targets and emissions data for reporting members.
US Climate Alliance	U.S. Climate Alliance. Accessed July 2019 from: https://www.usclimatealliance.org/state-climate-energy-policies. Information from this source was supplemented through desk research of participants' climate action targets or plans.
US Climate Mayors	US Climate Mayors. Accessed July 2019 from: www.climatemayors.org and http://climatemayors.org/actions/climate-action-compendium/. Information from this source was supplemented through desk research of participants' climate action targets or plans.

Different platforms report participants' climate actions in different formats and to different levels of detail: CDP Cities report the breakdown of direct (scope 1) emissions and electricity use-related (scope 2) emissions of subnational actors, whereas others do not include information on emissions scopes if inventory information is reported by an actor. Climate action platforms also capture different types of targets, that span absolute GHG emissions reduction, energy efficiency, renewable energy, and intensity-based targets, among others.

To address the inconsistencies in each platform's method of categorising targets and to include as many subnational actors' targets as possible, we chose the most common targets across platforms. We included region- or city-wide absolute GHG emission reduction targets and quantified emission levels under each target using the following variables: actor's base year scope 1 and scope 2 emissions, the target percent reduction, the target base year, the target year, and the actor's most recent GHG inventory year and the 2015 inventory scope 1 and scope 2 emissions. Sector-level and government-operations targets for cities and regions were excluded if city- or region-wide emissions reduction targets existed. This study did not consider energy efficiency and renewable energy targets without GHG emission reduction targets.

In sum, the we have applied the following hierarchy of data selection:

1. Region- or city-wide absolute GHG emissions reduction targets, in terms of:
    - Absolute emissions reduction
    - Reduction relative to base year emissions
2. Government (e.g., direct and indirect GHG emissions from buildings and other government-owned sources) GHG emission reduction targets, in terms of:
    - Absolute emissions reduction
    - Reduction relative to base year emissions

We also supplemented data from other sources. Chinese subnational commitments were derived from the C40 Cities for Climate Leadership Group, the iGDP China Policy Mapping Tool (IGDP, 2019), and the Chinese cities and provinces participating in the Alliance of Pioneer Peaking Cities (2016). China's 2012 emissions inventory data (including both scopes 1 and 2) of these cities in 2012 were taken from Liu & Cai (Liu and Cai, 2018). GDP data were derived from the China Economic Database (CEIC, 2019). For US subnational actors, we filled some data gaps on baseline emissions and climate action commitments through internet desk research of city climate action plans and progress reports.

The emissions data for the subnational commitments was carefully examined for their correctness. We applied filters to exclude commitments with historical per capita GHG emissions lower than 0.2 tCO_2e/capita and higher than 40 tCO_2e/capita, with a few exceptions for which were able to verify the correctness of the data (e.g., many GHG commitments for local government operations, which often had very low per capita GHG emissions values, were still included in the analysis).

To calculate the emissions time series for individual subnational actors, we used three tiers of interpolation between the starting year of our projections (=2016) and the quantifiable emissions reduction targets, depending on data reported by individual actors.

- Tier 1: if inventory year and inventory emissions are both available, we interpolate between the latest inventory emissions reported and the target year emissions, assuming a constant rate of decrease.
- Tier 2: if inventory emissions are known but not inventory year, we assume that inventory year is 2010, and apply the same interpolation as Tier 1 (the average year of last inventories was 2013; we assumed an earlier year of 2010 in order to not overestimate the emissions reductions for 2016 and consequently the emissions reductions between 2016 and 2030).
- Tier 3: for cases with no inventory emissions or inventory year, we base our interpolations on base year emissions and base year.

For regions and cities that only report one target year, we assume a constant rate of reduction until the target year, after which we assume emissions have the same trend as the current national policies scenario. For regions and cities that have multiple targets, we interpolate from either the inventory or baseline emissions, whichever is available, up to the first target year (i.e., 2030). If a longer-term target (i.e., 2050) is available, we interpolate from the first target year (i.e., 2030) to the second target year (i.e., 2050) by assuming different rates of reduction between the target years. This approach indicates that there would be limited, if not zero, additional emissions reductions compared to the current policies scenario if actors do not have targets beyond 2020.

For Chinese cities, because of the nature of China's Alliance of Pioneer Peaking Cities' peak emissions year targets, we had to calculate the emissions reductions differently. We extrapolated emissions from 2012 until 2030, assuming the rate of change in emissions is identical to the rate of change in population. The population projection time series data is obtained from UN World Urbanization Prospects (UN DESA, 2014). For two Chinese cities (Nanping and Jinchang) and two provinces (Sichuan and Hainan) that did not have population projections available, we used national level emissions growth rates based on the TIMER BAU model to extrapolate future emissions pathway. After the last target year, we assumed that the emission levels follow current national policies scenario emission projections until 2030. For subnational actors that report inventory-year emissions that are lower than the estimated target-year emissions, we assumed that these actors have achieved their target emissions reductions in the inventory year and then assumed a constant emissions level after the inventory year (i.e., no additional reductions are assumed).

S7.3 Detailed methods on the companies' commitments dataset preparation

CDP used three separate datasets to develop the country-specific climate action dataset used in this analysis. First, there are the **raw response data** that companies provide annually through CDP's climate change questionnaire at the request of investors or purchasers. These data include targets, reporting year and base year GHG emissions global inventories, and scope 1 and 2 country-level emissions breakdowns for the reporting year.

Second, there are two separate datasets that result from CDP's annual data cleaning processes that follows the disclosure cycle:

- The **clean and complete dataset (CCDS)** is the full GHG dataset (Griffin and Taylor, 2016; Sawbridge and Griffin, 2016; Sawbridge et al., 2016a, 2016b, 2016c). The final output includes cleaned emissions data from responding companies, as well as estimated emissions values (see the statistical framework and bottom-up estimation methodology documents) for non-responding companies included in the corporate sample.
- The **cleaned corporate targets dataset (CCTD)** uses similar internal consistency checks to validate and clean the data describing emissions reduction and renewable energy targets. This dataset also employs relevant and available emissions data from current and previous years' responses and CCDS to better contextualize the target data.

The **country-specific climate action dataset** used for this analysis essentially combines the CCTD with the country-level scope 1 / scope 2 emissions breakdowns provided in the raw response data. Elements of the CCTD also incorporate global emissions data from raw responses or the CCDS, based on the approach described in CDP (CDP, 2018) .

While CDP is not necessarily comprehensive of all corporate global climate action, they report that over 6,900 companies responded to their climate change questionnaire (CDP, 2019b). Of these companies, about half reported that they had an absolute or intensity GHG emissions reduction target in place (CDP, 2019b).

The CDP questionnaire for companies encourages the use of GWPs from the IPCC's Fifth Assessment Report (AR5) (IPCC, 2014b) for reporting emissions. We consider these data to be comparable with that reported in terms of AR4 GWPs as most companies are categorised to be emitting predominantly CO_2, with only a minimal amount of tracked emissions ($<$1%) coming from non-CO_2 emissions from the waste sector.

The current reporting year (inventory) emission values were calculated as the sum of total scope 1 and 2 emissions in the country of operation, while target year emission values were calculated using the company's target percentage in emissions reduction for absolute targets, anticipated emissions reduction for emission intensity targets.

As some companies make multiple commitments, we selected one reduction target from the dataset, for each country branch, based on the following priority order:

- Target years after 2017 were preferred to those before 2017
- Absolute emission reduction targets were preferred to intensity targets
- scopes preferred in order of "scope 1+2", "scope1+2+3", "scope 1", "scope 1+3", "scope 2", "scope 2+3"
- Targets closest just before and closest to 2030 are preferred

Those records from the CDP dataset that were reported as "poor quality" or reported higher company GHG emissions from the operating branch than the total company were removed from the dataset.

Based on historical emissions and the selected commitments, an emission pathway was constructed of each company branch. This pathway consists of interpolated emissions between base year, start year and the selected target year. If the target year is before 2030, emission growth in line with the current policies scenario is assumed.

As with subnational actor commitments, we assumed a linear interpolation of emission levels between the starting year (2016) and the short- to mid-term target year (between 2016 and 2030), as well as between the short- to mid-term target year and the long-term target year. After the last target year, we assumed that the emission levels follow current national policies scenario emission projections until 2030.

We also collected company-level revenue data to estimate the aggregate scale of companies with commitments in economic terms. The revenue data were collected from the 2019 Fortune Global 500 (Fortune, 2019), Forbes Global 2000 (Murphy et al., 2019), and Hoovers datasets (D&B Hoovers, 2019), supplemented, when possible, with desk research. Companies' combined revenue estimated for each country reflects companies making quantifiable commitments to reduce GHG emissions, whose headquarters are in that country, and whose revenue data is publicly available.

S7.4 Additional information on the calculation of net aggregate GHG impact of commitments

S7.4.1 Quantification of total emissions from subnational actors and companies with commitments after accounting for overlaps

The total GHG emissions from individual actors' commitments (E_{NSA}(t)) are calculated as:

$$E_{NSA}(\mathrm{t}) = E_R(\mathrm{t}) + \left\{\left(E_C(t) - E_{C,R}(\mathrm{t})\right) - E^*_{C,R}(t)\right\} + \left\{\left(E_B(\mathrm{t}) - E_{B,RC}(\mathrm{t})\right) - E^*_{B,RC}(t)\right\} + \left\{\left(E_P(\mathrm{t}) - E_{P,RCB}(\mathrm{t})\right) - E^*_{P,RCB}(t)\right\} \quad (2)$$

where

E_{NSA}(t): total projected GHG emissions from non-state actors with commitments in year *t*.

E_R(t): aggregate of projected GHG emissions from regions with commitments in year *t*;

E_C(t): aggregate of projected GHG emissions from cities with commitments in year *t*;

$E_{C,R}$(t): aggregate of projected GHG emissions from cities with commitments geographically overlapping with E_R(t) in year *t*;

$E^*_{C,R}$(t): additional GHG emissions reductions from cities with commitments overlapping with E_R(t) in year *t*, after comparing the level of ambition;

E_B(t): aggregate of projected GHG emissions from energy end-use companies with commitments (excluding electricity-generating companies) in year *t*;

$E_{B,RC}$(t): aggregate of projected GHG emissions from energy end-use companies with commitments geographically overlapping with E_R(t) and E_C(t) in year *t*;

$E^*_{B,RC}$(t): additional GHG emissions reductions from energy end-use companies with commitments overlapping with E_R(t) and E_C(t) in year *t*, after comparing the level of ambition;

E_P(t): aggregate of projected GHG emissions from electricity-generating companies with commitments in year *t*;

$E_{P,RCB}$(t): aggregate of projected GHG emissions from electricity-generating companies with commitments geographically overlapping with E_R(t), E_C(t) and E_B(t) in year *t*; and

$E^*_{P,RCB}$(t): additional GHG emissions reductions from electricity-generating companies with commitments overlapping with E_R(t), E_C(t) and E_B(t) in year *t*, after comparing the level of ambition.

S7.4.2 Share of electricity-related GHG emissions in total direct and electricity-related GHG emissions from cities

Supplementary Table 7-2 Share of electricity-related GHG emissions in total direct and electricity-related GHG emissions from cities.

Country	Value	Source
Brazil	17%	average of 14 cities data from CDP (CDP, 2019b)
Canada	20%	average of 15 cities data from CDP (CDP, 2019b)
China	45%	Authors' estimate from Liu (2016) on four major cities (Beijing, Shanghai, Tiangjin, Chongqing) in 2009
EU28	34%	average of 53 cities data from CDP (CDP, 2019b)
India	20%	Authors' estimate from Ramachandra et al. (2015) on seven cities (Delhi, Mumbai, Hyderabad, Chennai, Kolkata, Bangalore, Ahmedabad) in 2009-2010
Indonesia	57%	average of 2 cities data from CDP (CDP, 2019b)
Japan	54%	average of 2 cities data from CDP (CDP, 2019b)
Mexico	25%	average of 5 cities data from CDP (CDP, 2019b)
South Africa	60%	average of 5 cities data from CDP (CDP, 2019b)
US	38%	average of 81 cities data from CDP (CDP, 2019b)

S7.4.3 Detailed description of the "partial effect" method

The partial effect method only counts the additional reductions of cities to regions if they are unambiguously more ambitious. Ideally, we would compare a city's commitment to the emissions reductions of that city expected under the region-level commitment, but such information does not exist. Therefore, we implement this approach by considering only reductions if a city's target is more ambitious than a long-term emission trajectory consistent with the 2 °C goal. Country-specific long-term trajectories are estimated from Höhne, den Elzen and Escalante (Höhne et al., 2014) by taking roughly the central estimates of all effort-sharing approaches; the values for 2030 used in the analysis are presented in Supplementary Table 7-3.

Supplementary Table 7-3 Indicative 2030 emission levels implied by 2 °C-consistent emission trajectories under a range of effort sharing approaches used as a threshold for quantifying net additional impact. Source: authors' estimate based on Höhne et al. (2014).

Country	**Emissions in 2030 relative to 2015 levels**
Brazil	-40%
Canada	-50%
China	-20%
EU28	-50%
India	+50%
Indonesia	-30%
Japan	-50%
Mexico	-40%
South Africa	0%
USA	-50%

S7.4.4 Detailed description of the "partial conservative effect" method

The partial conservative effect method assumes that there is always a group with "laggard" subnational actors and companies that do not implement any climate action. We assume that this group accounts for the same amount of 2016 GHG emissions as the actors with commitments ("frontrunners"). So, a group of frontrunners, a group of laggards, and a group of followers in between exist. Implicitly, the group of followers implement climate action in line with the national current policies scenario (or NDCs). The assumption on the size of these groups is not based on statistical data, as such data on progress is not available. These size assumptions can be improved when this data comes available. Therefore, we have assumed that the group of laggards have the same size, in terms of emissions, as the group of frontrunners.

This "laggard" group is assumed to follow a business-as-usual scenario, which is derived from the TIMER model, which forms part of the integrated assessment model IMAGE 3.0 (Stehfest et al., 2014). It describes future energy demand and supply for 26 global regions, of which some are large countries (e.g., US, China), and can assess the implications of energy system trends for all major greenhouse gases and air pollutants. The model is built up from different modules, including energy demand modules for transport, industry, buildings and modules for energy supply, industrial processes and emissions.

For this study, no policy, business-as-usual scenario projections for cities and companies were developed by calculating a weight average of a selection of subsectors. The weighting factors to develop the business-as-usual projections is provided Supplementary Table 7-4 and Supplementary Table 7-5.

Supplementary Table 7-4 Weight (as percentage of total emissions coming from urban areas) applied to total sub-sector CO2 emissions from TIMER Model to construct (per country) aggregated CO2 emission projections for cities (for scope 1 and scope 2 emissions)

Sector	**Sub-sector**	**Weight scope 1**	**Weight scope 2**
Industry	Cement	0%	0%
	Steel	0%	0%
	Other	75%	75%
Transport	Bus	75%	
	Train	50%	
	Car	Share of urban population	75%
	High speed train	50%	
	Air	0%	
	Trucks	50%	
	Other freight	0%	
Residential	Urban	100%	100%
Services		100%	100%
Other		75%	75%
Losses/leakages		0%	0%
Bunkers		0%	0%

Supplementary Table 7-5 Weight applied to total sub-sector CO2 emissions from TIMER Model to construct (per country) aggregated CO2 emission projections for companies (for scope 1 and scope 2)

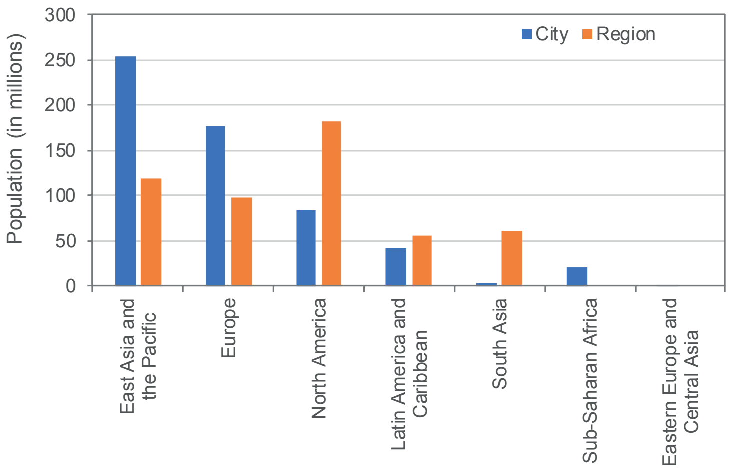
Sector	**Sub-sector**	**Weight scope 1**	**Weight scope 2**
Industry	Cement	100%	100%
	Steel	100%	100%
	Other	100%	100%
Transport	Bus	0%	
	Train	0%	
	Car	5%	25%
	High speed train	0%	
	Air	0%	
	Trucks	0%	
	Other freight	0%	
Residential	Urban	0%	0%
Services		100%	100%
Other		100%	100%
Losses/leakages		100%	100%
Bunkers		0%	0%

For illustration purposes, we show an example of calculating aggregated additional city impact relative to the region (see top panel in Figure 7-1 of the article). Suppose the “forerunner” cities in area (C-R) cover 120 $MtCO_2e$/year in 2015, and this group has committed to an annual 2.8% emission reduction rate below 2015 by 2030; the “laggard” cities group which by definition also covers 120 $MtCO_2e$/year in 2015, follows a lower 0.2% business-as-usual emission reduction rate below 2015 by 2030. Further suppose the group of regions (area (C-R)) have on average committed to a 1.4% emission reduction rate below 2015 by 2030. This method assumes that the “forerunner” cities in area (C-R) would deliver emissions reductions additional to those of the regions only when the average emissions reduction rate of “forerunner” cities in area (C-R) and the “laggard” cities, i.e. 1.5% (*2.8%+0.2%*)/2), is larger the regions’ 1.4%. In this case the additional mitigation impact is 0.12 $MtCO_2e$/year (0.1%*120).

S7.5 Supplementary data on the GHG emissions coverage per actor group

S7.5.1 Regions and cities

The regions and cities included in this study represent a population of 579 million, while participating regions hold nearly 514 million people. In other words, they represent populations that rival those of large countries; only China and India have larger populations. Cities taking climate action hold more people than the US and Brazil combined, while regions taking climate action represent a population about four times the size of Japan’s (World Bank, 2019).

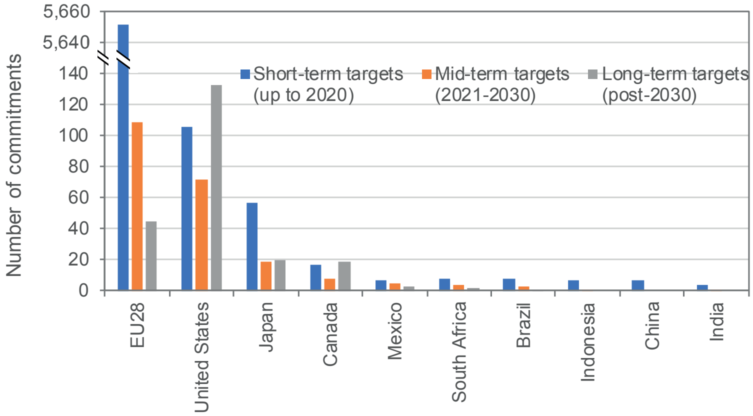


Supplementary Figure 7-1 Population of cities and regions making quantifiable commitments to reduce GHG emissions by geographic region. Data source: various

Europe and North America host the greatest number of cities and regions making quantifiable commitments to reduce GHG emissions. Subnational governments in East Asia and the Pacific, however, represent the largest collective population (Supplementary Figure 7-1). Many of the participating actors in this region are megacities – urban areas home to more than 10 million people – that exercise huge influence over their countries and region's emissions. While relatively few actors are making quantifiable commitments in South Asia and Latin America these cities and regions also represent large populations, giving their efforts substantial influence within their countries. Cities making quantifiable climate commitments in Latin America and the Caribbean collectively hold 41 million people, roughly 4 million more than Canada's 2018 population (World Bank, 2019b).

The vast majority (93% percent) of subnational governments' quantifiable emission reduction commitments focus on short-term targets, aiming to reduce emissions by or in 2020. The remaining 7% of targets are split relatively evenly between mid-term targets – which set target years between 2021 and 2030 – and long-term post-2030 targets (Supplementary Figure 7-2). In terms of the share of emissions, subnational actors with only short-term (by or in 2020) targets, and no mid- or long-term targets, represent 34 % of all subnational actors' base year emissions in 2015. Among subnational actors, the most common short-term emissions reduction target is 22%, while the most common midterm (2021-2030) emissions reduction target is 40%, and the most common target for longer-term targets (set after 2030) is 80%.

The heavy focus on short-term targets reflects, in large part, high levels of adoption of a 2020 goal by the European participants in the Global Covenant of Mayors for Climate and Energy, which are mostly small towns and communities with relatively low emissions. This trend also applies – less dramatically – across other geographic locations. One exception is the US, which leads in terms of the number of cities and states making long-term quantifiable commitments. More than half of the US cities and states with 2050 targets also had mid-term targets for years after 2025.



Supplementary Figure 7-2 Number and target years of cities and regions' quantifiable commitments to reduce GHG emissions in the ten major emitting economies.

S7.5.2 Companies

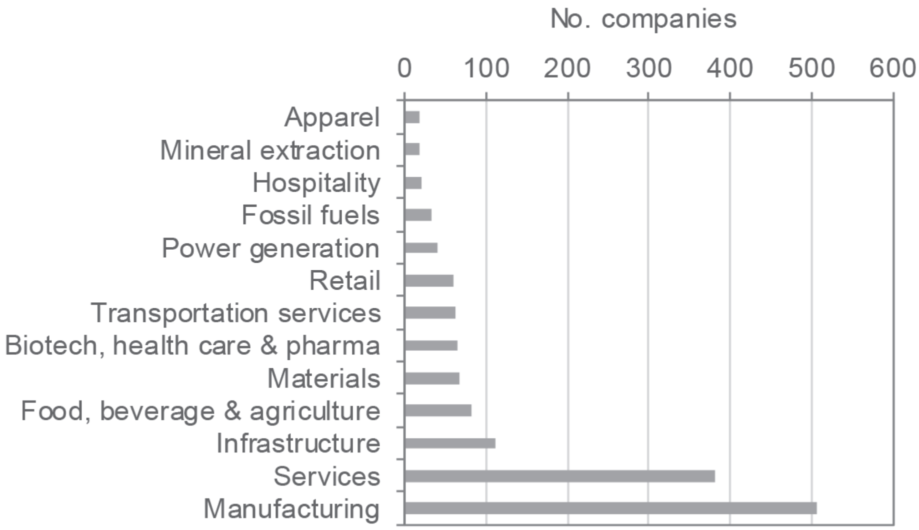
Nearly 1,500 companies, operating within 10 of the world's major emitting economies, have made quantifiable commitments to reduce GHG emissions through CDP. Their combined revenue totals over $21 trillion US Dollars (USD), roughly the size of the US GDP (World Bank, 2019a). More than 450, or just over 20%, of the world's largest companies – defined in terms of their membership in the 2019 Fortune Global 500 and Global Forbes 2000 lists – are included in this total.

Across the 10 major emitting economies this report considers, the EU28, the US, and China host the greatest number of companies making quantifiable GHG reduction commitments. Targets set by companies headquartered in the US and the EU28 cover markedly more (self-defined) baseline emissions than companies in other regions, likely reflecting the high level of participation in these locations. Similarly, the largest concentration of revenue is found among companies headquartered in the US, the EU28, and Japan.

As with commitments by regions and cities, most company commitments focus on short-term timelines, up to or in 2020. Across the GHG emissions reduction commitments made by companies reporting quantifiable emissions reductions to CDP in the 10 major emitting economies, 58% have targets up to or in 2020; 40% aim for target years between 2021 and 2030; and 2% set targets after 2030. The most common GHG emissions reduction target aims to cut GHG emissions by roughly 20%, with varying base years between 1990 and 2018 (the most common base year is 2014). Company branches with only short-term (by or in

2020) targets, and no mid- or long-term targets, represent 45.2 % of all companies' base year emissions.

Commitments span a wide range of sectors, with particularly high concentration in the manufacturing and services sectors (Supplementary Figure 7-3). More than 500 commitments each reference renewable energy and fuel efficiency, while over 350 commitments in energy efficiency, and nearly 200 mention transport.



Supplementary Figure 7-3 The distribution of companies making quantified GHG emissions reduction commitments by sector. Data source: CDP Corporate Climate Targets Dataset 2018

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ACKNOWLEDGEMENTS

It all started with reading the 'Turning point' written by Fritjof Capra who argued that mechanist thinking is now replaced by more holistic and ecological thinking. This was a new way of viewing the world for me and inspired me to think about societal problems. Although my colleagues at the insurance company where I was working at that moment were afraid that I would turn into an activist, I decided to learn more about the environment. For this purpose, I looked for a way to use my quantitative skills on a more societal topic and in a multi-disciplinary environment. I followed the master environment and resource management at the VU University and started working at PBL in 2009. This was sometimes difficult as I had to start again from scratch but was also very motivating as my work was immediately relevant for the climate negotiations.

My promotors Detlef van Vuuren, Heleen de Coninck, and Michel den Elzen inspired me through their amazing knowledge of climate policy and full dedication to the job. Detlef taught me how to structure papers, ask the right questions that go one step further, but also that once and a while a discussion on other topics than climate can be fun and stimulating. Heleen de Coninck showed me that also social skills, people management and networking are important skills for researchers, and that eagerness to understand complexities is key to becoming a good researcher. Michel transferred an enormous knowledge of international and domestic policies and taught me to look critically at both produced numbers and written text.

Since 2009 I have worked with many PBL colleagues who I can impossibly all sum up. However, the atmosphere at KLE and PBL have always been very pleasant. I remember the evenings that we discussed bottom-up policy for the first time with Angelica, Andries, Jasper, Maarten, and Sebastiaan (in my memory) at café Miltenburg. This was one of the sparks that started my PhD voyage. Rineke was always there to support me with tea, but with most of all asking about the fun things I did during the weekend and listening to my worries. Later came the great discussions and fun things with the UU gang Mariesse, Harmen-Sytze, David, and Mathijs. During this period new colleagues entered who increased the joy of working at PBL such as Annemieke, Anteneh, Heleen, Hsing-Husan, Isabela, Jonathan, Kendall, Klara, Martine, Nicole, Oreane, Stratos, and Vassilis. Of course, I want to thank Jeroen for his endless efforts to help, share data and publish our news items and articles on the PBL website. Other colleagues who have been around for most of my period at PBL and helped creating an inspirational KLE environment are Bart, Jelle, Jos, Kees, Jan M. Jan R., Paul, Pieter B., Pieter H., Suzanne, and Tom. In addition, Mark v O en Marcel outside KLE always kept me in the loop on other topics such as finance and biodiversity actions by non-state actors. At Nijmegen University, Jean Francois was an inspiration to work with as he always was

discussing on how to increase the realism of climate policy modelling. Since the start of my job at PBL I worked with NewClimate and its predecessors, and therefore Takeshi, Niklas, Nadine, Hanna, Sybrig felt and feel like close colleagues, with who it is always a pleasure to work with.

As the topics of my dissertation deal with international climate policy, I had the pleasure to work with many people all over the world. It started with DG CLIMA (Tom, Ariane, Miles and Oliva) already in 2009 who funded various PBL projects, but most of all helped improving our research by critically looking at our work. During the CD-LINKS and ENGAGE projects I had the great pleasure to work with many people from IIASA, PIK, CMCC, E3MLab, COPPE, TERI, IIMA, ERI, Tsinhua University, NIES, RITE, PNNL, Wageningen University, and Kaist. Since 2015, in the work on non-state actors Angel Hsu, Sander Chan, Thom Hale, Andrew Clapper and many people from NewClimate created a fascinating journey to put the global assessment of non-state and subnational actors on the international agenda by organising workshops and writing great reports and papers.

My parents always supported me in my sometimes-unexpected choices such as giving up my job at an insurance company and starting a PhD. My brother and his family were always interested in how I was progressing.

There is a long list of friends who made life enjoyable next to the PhD writing, but who also supported me in the process. These are Rob, Diederik, Dinette and Victor, who together with Femia, Harko, Maartje, Marije, Matthijs, Nanda, Patrick, Paul and Rachel form my 'AP and beyond' friends. Some I already know since we were twelve years old. Of course, also Da(Ma)JaFri (Daniel, Jamy, Friso) and Alfred helped me mentally to get through hard working periods by organising theatre visits, wine tastings, great diners and 230 km cycling tours. In addition, the whole wine tasting club Ganymedes has always been and still is a milestone of the month for enjoying good company. Also, Brahim, Rianne, Aart and Rivka helped me do fun things and listen to my PhD stories. During COVID times, but also thereafter, Gerty, Adinda, Olivier and Anoesjka helped me relax by having long lunches, dinners and even board games (?). These diners and nice get togethers were also done with Angeliek and Nienke.

Finally, although I switched from finance to climate, I still have good memories of working at Delta Lloyd, especially because of the colleagues Ji-Kwen, Peter, Marc, Edwin and of course Diederik who was already a friend before and still is.

CURRICULUM VITAE

Mark Roelof Roelfsema was born on 11 December 1973 in Amsterdam, the Netherlands. After having received the master title for business mathematics and informatics at VU university in 1997, he spent almost 10 years in the financial world as a quantitative analyst and financial risk manager. In 2007, he started a new master program on environment and resource management which he finished in 2008. For this purpose, he did research to the amenity value of coral reefs as part of house prices which supported the economic valuation of Bermuda's coral reef. In 2009 he started at PBL where since he worked on the assessment of domestic policies and climate actions from non-state and subnational actors in the context of the climate negotiations that resulted in the Copenhagen Accord, Cancun Agreements and Paris Agreement. This work was done for projects from the European Commission supporting DG CLIMA and the horizon 2020 projects CD-LINKS and ENGAGE. During this period, he also worked as a freelancer on sustainable finance, developed an energy modelling program for the Nijmegen University, and analysed non-state and subnational actors, but also EU climate- and energy policies, at Utrecht University.

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