Chapter 4: Mitigation and development pathways in the near- to mid-term

Coordinating Lead Authors: Franck Lecocq (France), Harald Winkler (South Africa)

Lead Authors: Julius Partson Daka (Zambia), Sha Fu (China), James Gerber (USA), Sivan Kartha (USA), Volker Krey (Austria), Hans Lofgren (Sweden), Toshihiko Masui (Japan), Ritu Mathur (India), Joana Portugal Pereira (Brazil), Benjamin Kenneth Sovacool (Denmark), Maria Virginia Vilariño (Argentina), Nan Zhou (USA)

Contributing Authors: Michel den Elzen (the Netherlands), Reuben Dlamini (eSwatini), Noel Healy (USA), Niklas Höhne (Germany), Angel Hsu (Singapore), Nina Khanna (USA), Claire Lepault (France), Ford Runge (USA)

Review Editors: Marzio Domenico Galeotti (Italy), Alberto Pedace (Argentina)

Chapter Scientist: Kaleem Anwar Mir (Pakistan)

Date of Draft: 09/01/2020

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Executive summary

[*To be completed in SOD*]

4.1 Introduction

Mitigation pathways have been central to each of the Working Group III contributions to the IPCC previous five assessment reports, whereas development pathways have received less attention.

In AR5, mitigation pathways were assessed in a single chapter (Clarke et al. 2014), whereas the present Assessment considers long-term mitigation pathways in chapter 3 and near- to medium-term pathways in this chapter 4. Both assessments include sub-system mitigation pathways across several sectoral chapters. The special report on global warming of 1.5°C (SR1.5) included a chapter on mitigation pathways compatible with pursuing that temperature goal in the Paris Agreement (Rogelj et al. 2018a).

Development pathways are key drivers of emissions outcomes and were explored in a Special Report on Emissions Scenarios (Nakicenovic et al. 2000). Some early framing of development pathways was included in the Third Assessment Report (William R. Moomaw et al. 2001) and further developed in the Fourth Assessment Report (Sathaye et al. 2007). A chapter of AR5 updated key findings on drivers such as consumption, finance, technology and more (Fleurbaey et al. 2014a). The special report on global warming of 1.5°C (SR1.5) considered strengthening mitigation (de Coninck et al. 2018a) in the context of poverty, inequality and sustainable development (Roy et al. 2018). Both mitigation and development pathways affect emission trajectories.

4.1.1 Framing: Accelerating mitigation and shifting development pathways

In 2015, the global community adopted the Sustainable Development Goals (SDGs) and the Paris Agreement. The Agreement and SDGs are to be implemented in a context of high uncertainty (fragmentation, populism, economic nationalism, inequality, poverty, migration, social cohesion, etc.). In this context, this chapter focuses on mitigation and development pathways in the near- and medium-term. It considers three questions: (1) What are we doing now? I.e., what is the current state of affairs, with respect to the identified policy problem (climate)?; (2) What do we ultimately need to do? I.e., what must the state of affairs shift to, in order to address the policy problem; and (3) How do we shift there? I.e., what interventions are at society's disposal to bring about the necessary shift?

What is the problem and what are we doing now? The emissions gap between projected emissions based on nationally determined contributions (NDCs) and temperature goals set in the Paris Agreement is widening (UNEP 2019a). The sum of NDCs is not sufficient to keep global warming well below 2 °C or to pursue 1.5 °C, with the gap between projected emissions of current policies and unconditional and conditional NDCs estimated to be around 4 to 7 Gt CO_2-eq in 2030 (see Table 4.2). Furthermore, there is an implementation gap, with uncertainty whether current policies are sufficient to achieve mitigation targets in NDCs, and whether sufficient support is available. **This provides compelling evidence that continuing along the same development pathways that led to high emissions will not address the problem (*robust evidence, high agreement*).**

What is a broad range of possible solutions? This chapter considers both accelerating mitigation and shifting development pathways. Some countries, regions, cities, communities and non-state actors are taking the leadership in transformational change. Many technologies exist to bridge the emissions gap, yet, despite these efforts, GHG emissions are projected to continue to rise (see Chapter 2). A lens of shifting development pathways opens up a wider range of mitigation actions, while achieving broader development goals. Development pathways that address multiple objectives are thus more effective than single-minded or carbon centric approaches.

What do we need to do now? Evidence from the global mitigation pathways and the sectoral chapters suggest that meeting climate objectives such as those embodied in the Paris Agreement would require rapid transformations across sectors and regions. Such transformation would require that key enabling conditions be put into place. The chapter considers six high-level enabling conditions—multi-level governance, institutional capacities, behavioural change, technological innovation, policy, and finance—that enable both accelerated mitigation and shifts in development pathways. In Chapter 4 and 13 and throughout the AR6, various policies, programs, approaches and processes are discussed that can align with putting these enabling conditions into place in a manner that can allow for transformative change.

4.1.2 Position of Chapter 4 in the overall WGIII flow of argument and scope of literature assessed

The framing of development pathways relates to Chapter 1 and, to the extent that development pathways are sustainable, to the systems chapters (6-11) and to the consolidation of sustainable development in Ch.17.

WGIII refers to the period from now up to 2030 as near-term; mid-term from 2030 up to 2050; and long-term from 2050 and beyond (the long-term is assessed in chapter 3). Chapter 3 is working backward from the long-term goals, including temperature, and assesses mitigation in the long-term (beyond 2050 up to 2100 or even 2300) to draw the near- and mid-term implications of long-term temperature and mitigations goals. Chapter 4 works forward from current and planned mitigation (including NDCs) and from current development paths to assess the implications for near- and mid-term Greenhouse Gases (GHG) emissions and development goals. It also examines the nature of the shifts in development pathways needed to meet ambitious climate objectives, and the enabling conditions that could make such a shift possible.

Chapter 13 assesses the literature on national policies and policy analysis, while Chapter 4 studies based on quantitative modelling of mitigation and development pathways, in particular at the national scale. Chapter 13 adds more texture on institutional and governance machinery; policy choice, design and implementation; as well as policy formulation processes, actors and structure across scales. Chapter 4 and 13 complement one another in consideration of sustaining action and accelerating mitigation, and shifting development pathways. Chapters 14, 15 and 16 deepen the analysis of the enabling conditions necessary to accelerate mitigation and shift development pathways, in terms of international cooperation, finance and investment and technology respectively. The present chapter analyses the question as to “how to shift development pathways and accelerate the scale and pace of mitigation” in terms of broad strategies, while Ch.13 and 14 detail the policy instruments that could help induce such paths.

Chapter 4 draws on four major strands of literature: (1) an emerging literature on development pathways – conceptual, empirical, and model-based, including at the national scale; (2) a rapidly expanding, model-based, literature on mitigation pathways in the near- and mid-term; (3) studies of NDCs (a term that was coined in 2013, so that literature is new since AR5); and (4) a broader literature on transformation and shifts in development pathways, including from non-climate literatures.

Since development pathways and mitigation options depend for a large part on national level objectives and circumstances, this chapter is primarily concerned with literature at country level (or in the case of the European Union, at regional level), while Chapter 3 is primarily concerned with literature at global scale, the latter being the only scale at which temperature increase can be assessed, in the long-term. This chapter is also concerned mostly with economy-wide development and mitigation pathways, as distinct from detailed sectoral work that is assessed in the systems chapters 5 to 11.

4.1.3 Roadmap for remainder of Chapter 4

Chapter 4 is organized so that both the accelerated mitigation perspectives and the innovative development pathways perspectives are assessed. The chapter recasts emissions within the broader context of development pathways, and examines how shifting development pathways can have a major impact on mitigative capacity, and thus enable less-carbon intensive paths.

Section 4.2 demonstrates that collective mitigation actions fall short of pathways consistent with the Paris temperature goals. Section 4.3 introduces development pathways (given its relative novelty in IPCC assessments), considers the implications of mitigation for development and *vice versa*, and articulates an approach on *both* accelerating mitigation *and* shifting development pathways.

Section 4.4 discusses what it means to shift development pathway, and accelerate the scale and pace of mitigation, and what levers are available to policy makers. It contextualizes this in terms of risk and uncertainty, and implications for development prospects. Urgent action is put in the context of equity and just transition for an effective societal climate response. Section 5 integrates adaptation into considerations of development pathways.

4.2 Mitigation actions across scales

4.2.1 Mitigation targets and measures in nationally determined contributions

A central instrument of the Paris Agreement is the Nationally Determined Contributions (NDCs), submitted by each country reflecting national efforts to reduce GHG emissions and build resilience to the impacts of climate change. Every five years, collective progress will be compared against long-term goals of the Paris Agreement. Considering the outcome of a global stocktake, countries will prepare subsequent NDCs, showing progression in their ambition and enhance international cooperation (UNFCCC 2015a).

Prior to COP21, in 2015, most countries submitted their INDCs (Intended Nationally Determined Contributions), which include mitigation targets for 2025 or 2030. INDCs become first NDCs on ratification, and by December 2019, the official NDC registry contained 184 first NDCs, equivalent to 99% of total anthropogenic GHG emissions, and one second NDC. Countries will take the first stock in 2023 based on their progression towards achieving the objectives of their second NDC, to be submitted by 2020 (UNFCCC 2015a). [*needs update in SOD*]

Submitted NDCs vary in content, scope and background assumptions. First NDCs contain mitigation targets, and in many cases also provisions about adaptation. Baseline years vary from 1990 to 2015. Nearly half of the mitigation targets in first NDCs are expressed in terms of deviation below business-as-usual, while others include fixed-level targets (either reductions or limitations compared to base years), intensity targets (in terms of GHG, CO_2 or energy) or policies and measures (UNFCCC 2016a). Some developing countries included unconditional targets, while others included conditional ones, the latter with higher ambition if finance, technology and capacity building support from other developed countries is provided (UNFCCC 2016a). In some NDCs, the additional mitigation is quantified, in others not. [*Need to assess further literature from systematic searches undertaken*]

Most first NDCs cover all specific sectors, including AFOLU and LULUCF, and communicate specific targets for individual sub-sectors to support their overall mitigation targets. Concrete actions and priority areas are more detailed in the energy sector, with increased share of renewable energies and energy efficiency plans being highlighted in the majority of NDCs. Given the uncertainty behind LULUCF emission and removal accounting (Grassi et al. 2017b; Jian et al. 2019), several countries stated that their framework for accounting is still to be defined and will be considered in later NDC submissions. There are also variabilities about the GHG included and the global warming potentials (GWPs) used to aggregate emissions. Most countries only refer to carbon dioxide, methane and nitrous oxide emissions aggregated based on IPCC AR2 or AR4 metrics, while few NDCs also included fluorinated gases and used IPCC AR5 GWPs.

There is considerable literature on country-level mitigation pathways, including but not limited to NDCs. Country distribution of this literature is very unequal (*robust evidence, high agreement*). In particular, there is a growing literature on (I)NDCs, with a wide scope which includes estimate of emissions levels of NDCs (see section 4.2.2.2); alignment with sustainable development goals (Antwi-

Agyei et al. 2018), ambition (Höhne et al. 2018a; Vogt-Schilb and Hallegatte 2017) energy development (Scott et al. 2018); and the legality of downgrading NDCs (Rajamani and Brunnée 2017). Other studies note that many NDCs contain single-year mitigation targets, and suggest that a multi-year period is important for more rigorous monitoring (Elliott et al. 2017; Dagnet et al. 2017).

The literature also points out that beyond the 'headline numbers', information in (I)NDCs is difficult to analyse (Pauw et al., 2018). Information for 'clarity, transparency and understanding' is to be communicated with NDCs, although initial guidance was not specific (UNFCCC 2014). While the adoption of the Paris rule-book provided some greater specificity (UNFCCC 2018a,b), the information included in the NDCs remains uneven. Many NDCs omit important mitigation sectors and do not adequately provide details on costs and financing of implementation (Pauw et al., 2018). Countries are also invited to explain how their NDCs are fair and ambitious, though the way this has been done so far has been criticized as insufficiently rigorous (Winkler et al., 2018).

As of December 2019, the peer-reviewed literature on NDCs extends to about 580 journal articles in total, covering many different aspects of NDCs. About 40% of this literature mentions pathways or scenarios, but only a subset of those articles include quantitative estimates that are relevant for the NDC assessment in Section 4.2.2. The regional distribution is not uniform but focuses mostly on large emitting countries. It reveals a large predominance of studies about China (though not necessarily from authors in China) with some 125 articles (20% of total). Other countries and regions with a large body of literature on NDCs include India (12%), Brazil (8%), the European Union (7.5%), Indonesia and Japan (5% each). This regional distribution is consistent with the wider literature on mitigation (see Box S1 in the Supplementary Material to this Chapter), possibly with the exception of the United States which is underrepresented in the literature on NDCs compared to the wider mitigation literature.

[*We intend to include text boxes on the NDCs of China, the US, EU and India in the SOD, based on the following literature respectively*]

[*China NDC*]

(Wu et al. 2017; Mu et al. 2017; Xing et al. 2017a, 2016; Fu et al. 2017; Mu et al. 2018b; He 2015; Zhu and Liu 2017; He 2016; Mu et al. 2018a; Xing et al. 2017b; Yang et al. 2017; Fang et al. 2019; Yang and Teng 2018; Yang et al. 2018; Fragkos and Kouvaritakis 2018; Wei et al. 2018; Dong et al. 2018a; Dai and Masui 2017)

[*USA NDC*]

(Chen and Hafstead 2019; Clarke et al. 2016; Bistline et al. 2018; Galik et al. 2017; Patrizio et al. 2018; Schweizer and Morgan 2016; Shahiduzzaman and Layton 2017)(Sands et al. 2014; Mai et al. 2014; Karali et al. 2014; Erickson and Lazarus 2018; Creason et al. 2018)

[*EU NDC*]

(Vandyck et al. 2016; Fragkos and Kouvaritakis 2018; Fragkos et al. 2018; Schiffer 2015; Fragkos et al. 2017; Spencer et al. 2017; Deetman et al. 2013; Jiang et al. 2017; Vrontisi et al. 2019; Solano Rodriguez et al. 2017; Pollitt et al. 2015; Kettner et al. 2019; Jägemann et al. 2013; European Commission 2019; EEA 2018; Hübler and Löschel 2013; Capros et al. 2019; Wachsmuth and Duscha 2019; 2019; Nabernegg et al. 2017; Vrontisi et al. 2019)

[*India NDC*]

(Kumar et al. 2017; Aggarwal 2017; Chakrabarty and Chakraborty 2017; Akash et al. 2017; Chaturvedi 2015; Mathur and Shrivastava 2017; Shukla et al. 2017; Dhar et al. 2017; Busby and Shidore 2017; Mittal et al. 2018; Fragkos and Kouvaritakis 2018)

4.2.2 Aggregate effects of NDCs and current policies

4.2.2.1 Introduction

Near-term mitigation targets submitted as part of NDCs to the UNFCCC, as well as currently implemented policies, provide a basis for assessing potential emissions levels up to 2030 at the national, regional and global level. The following sections present an evaluation of the methods used for assessing projected emissions under NDCs and current policies, so-called "current policies scenarios" (Section 4.2.2.2), and the results of these assessments at global, regional and national level, including the evidence base underpinning these assessments (Section 4.2.2.3). This is followed by an assessment of the implementation gap between what currently implemented policies are expected to deliver and what the ambitions laid out under the full implementation of the NDCs would achieve (Section 4.2.2.4), and by a comparison of ambitions across different countries or regions (Section 4.2.2.5). Finally, the uncertainties of projected emissions associated with NDCs and current policies are estimated and measures to reduce uncertainties in the specification of NDCs are discussed (Section 4.2.2.6).

The literature reviewed in this section includes globally comprehensive assessments of NDCs and current policies, both from the peer-reviewed and non-peer-reviewed literature (but not unpublished model results) as well as synthesis reports by the UNFCCC Secretariat, government reports other than NDCs, national and sectoral studies for individual countries/regions and sectors.

The aggregate effects of NDCs provide information on where emissions might be in 2025/2030, working forward from where we are. Chapter 3 of this report works backwards from temperature goals, defining a range of long-term global pathways consistent with 1.5, 2 and higher °C. By considering the two together, it is possible to assess whether NDCs are collectively consistent with 1.5, 2 and higher temperature pathways (see Cross-Chapter Box Comparison of NDCs and current policies with the 2030 GHG emissions from long-term temperature pathways, p.4-17).

4.2.2.2 Methods to project emissions under NDCs and current policies

A variety of different methods are used to assess emissions implications of NDCs and current policies over the time horizon to 2025 or 2030. A distinction needs to be made between projections explicitly submitted as part of an official communication to UNFCCC (e.g., Biennial Report, Biennial Update Reports or National Communications) and independent studies.

Methods that are used in independent studies (but that can also underlie the official communications) can broadly be separated into two groups,

(i) system modelling studies which analyse policies and targets in a comprehensive modelling framework such an integrated assessment, energy systems or integrated land-use model to project emissions (or other indicators) of mitigation targets in NDCs and current policies, either at the national or global scale (noting some differences in the systems), and

(ii) hybridized approaches that typically start out with emissions pathways as assessed by other published studies (e.g., the IEA World Energy Outlook, national assessments such as those specified in the NDCs) and use these directly or apply additional modifications to them.

System modeling studies are conducted at global, regional and national scales. Global models provide an overview, are necessary for assessment of global phenomena (e.g. temperature change), can integrate climate models and trade effects. National models are typically more granular, often representing technologies and linkages in an economy, relevant to national development pathways. Here a variety of modelling paradigms are found, including optimization and simulation models, myopic and with foresight, monolithic and modular (see Annex C: Scenarios and modelling methods).

Among the hybridized approaches which are mostly used to generate globally comprehensive projections, three broader categories can be distinguished, (i) studies that extrapolate from existing estimate (nationally from NDC scenarios) or globally from IEA WEO), (ii) combinations of model projections for some and researchers' estimates for other countries; and (iii) studies of the impacts of policies on baseline or business-as-usual pathways (which much debate in the literature on different baselines).

Beyond the method applied, studies also differ in a number of dimensions, including their spatial resolution and coverage, their sectoral resolution and coverage, the GHGs that are included in the assessment, the set of scenarios analysed (Reference/Business-as-Usual, Current Policies, NDCs, etc.), and finally the degree to which individual policies and their impact on emissions are explicitly represented (cf. Table 4.1).

First, the studies are relevant to different spatial levels, ranging from macro-scale regions with globally comprehensive coverage (Section 4.2.2.3.1) to national level (Section 4.2.2.3.2) and subnational and company level in a few cases (Section 4.2.3). It is important to recognize that globally comprehensive studies typically resolve a limited number of countries individually, in particular those that contribute a high share to global emissions, but have poor resolution of remaining countries or regions, which are assessed in aggregate terms. Conversely, studies with high resolution of a particular country tend to treat interactions with the global scale in a limited way. The recent literature includes attempts to provide a composite global picture from detailed national studies (Bataille et al. 2016a; DDPP 2015; Roelfsema et al.).

A second dimension in which the studies are different is their comprehensiveness of covering different emitting sectors. Some studies focus on the contribution of a single sector, for example the Agriculture, Forestry and Other Land Use (AFOLU) sector (Grassi et al. 2017a) or the energy system (incl. both energy supply and demand sectors), to emission reductions as specified in the NDC. Such studies give an indication of the importance of a given sector to achieving the NDC target of a country and can be used as a benchmark to compare to comprehensive studies, but adding sectoral contributions up represents a methodological challenge.

Third, GHG coverage is different across studies with some focusing on CO2 only, while others taking into account the full suite of GHGs as reported under the UNFCCC transparency framework[1] (UNFCCC 2019). For the latter, different metrics for aggregating GHGs to a CO2-equivalent metric are being used, typically GWP 100 from different IPCC assessments (see Table 4.1)

Fourth, typically studies cover a set of scenarios, though how these scenarios are defined varies widely. The literature reporting IAM results often includes *Nationally Determined Contribution* (NDC), which are officially communicated, and *Current Policies* (CP) as interpreted by modellers. Studies based on national modelling, by contrast, tend to define scenarios reflecting very different national contexts. In both cases, modellers typically include a so-called *No Policy Baseline* scenario (alternatively referred to as R*eference or Business-as-Usual scenario)* which does not necessarily reflect currently implemented policies and thus raises questions as a reference (see section 4.3.3.1). There are also various approaches to considering more ambitious action compared to the CP or NDC projections that are covered in addition.

Five, studies differ in the way they represent policies (current or envisioned in NDCs), depending on their internal structure. For example, a subsidy to energy efficiency in buildings may be explicitly modelled (e.g., in a sectoral model that represents household decisions relative to building insulation), represented by a proxy (e.g., by an exogenous decrease in the discount rate households use to make choices), or captured by its estimated outcome (e.g., by an exogenous decrease in the household demand for energy, say in an energy system model or in a compact CGE). Detailed representations (such as the former example) do not necessarily yield more accurate results than compact ones (the latter example), but the set of assumptions that are necessary to represent the same policy will be very different.

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[1] CO2, CH4, N2O, HFCs, PFCs, SF6 and NF3.

Finally, policy coverage strongly varies across studies with some just implementing high level targets specified in policy documents and NDCs while others represent the policies with the largest impact on emissions and some looking at very detailed measures and policies at subnational level. In addition, in countries with rapidly evolving policy environments, slightly different cut-off dates for the policies considered in an emission projection can make a significant difference for the results (Dubash et al. 2018).

Table 4.1 Overview of methods used for projected emissions of NDCs and/or current policies (adapted from (Luderer et al. 2018c)**). A more extensive version of this table can be found in the Supplementary Material to Chapter 4, Table S4.1.**

Study/ Reference	Policy cut-off[a]	Regions	Sectors	Emissions[b]	Scenarios[c]	Methods[d]
(Climate Action Tracker 2018)	11/2018	Global	Energy, AFOLU	Kyoto	CP, NDC	literature review, additional analysis
PBL (Kuramochi et al. 2018)	11/2018	Global	Energy, AFOLU	Kyoto	CP, NDC	literature review, global IAM, ILM
ADVANCE (Vrontisi et al. 2018; Luderer et al. 2018a)	4/2017*	Global	Energy, AFOLU	Kyoto	NDC	10 global IAMs
CD-LINKS (McCollum et al. 2018; Roelfsema et al.)	12/2016	Global	Energy, AFOLU	Kyoto	CP, NDC	7 global IAMs
GECO (Keramidas et al. 2018)	11/2018	Global	Energy, AFOLU	Kyoto	CP, NDC	literature review, global IAM, ILM
U. Melbourne (Meinshausen and Alexander 2017)	11/2016	Global	Energy, AFOLU	Kyoto	NDC	literature review, IPCC scenario database
(Climate Interactive 2017)	4/2017*	Global	Energy, AFOLU	Kyoto	NDC	Simulation model
(Holz et al. 2018)	12/2016*	Global	Energy, AFOLU	Kyoto	NDC	literature review, additional analysis
(Keesler et al. 2019)	11/2019	Argentina	Energy, AFOLU	Kyoto	CP, NDC	National ESM
(ClimateWorks Australia 2018)	2018	Australia	Energy, AFOLU	Kyoto	CP, NDC	National ESM
(Koberle et al.; Rochedo et al. 2018)	12/2016	Brazil	Energy, AFOLU	Kyoto	CP, NDC	National ESM
(Fu et al. 2017; Fu 2018)	11/2017	China	Energy	CO2	CP, NDC	National ESM
(Li et al. 2019)	12/2018	China	Energy	CO2	CP, NDC	National ESM
(Yang et al. 2018)	1/2017	China	Energy	CO2	NDC	National ESM
(European Commission 2018)	11/2018	EU	Energy, AFOLU	Kyoto	CP, NDC	Regional ESM, ILM, CGE
(Vrontisi et al. 2019)	12/2016	EU	Energy	Kyoto	CP, NDC	Regional ESM and CGE
(Dubash et al. 2018)	2011-2015	India	Energy	CO2	CP, NDC	15 national ESMs
(Vishwanathan et al. 2018a; Vishwanathan and Garg)	12/2016	India	Energy	CO2	CP, NDC	National ESM
(Mathur and Shekhar)	12/2016	India	Energy	CO2	CP, NDC	National ESM
(Oshiro et al. 2019)	12/2016	Japan	Energy, AFOLU	Kyoto	CP, NDC	2 National ESMs

Study/ Reference	Policy cut-off[a]	Regions	Sectors	Emissions[b]	Scenarios[c]	Methods[d]
JMIP (Sugiyama et al. 2019a)	3/2018	Japan	Energy, AFOLU	CO2/Kyoto	NDC	4 National ESMs
(Safonov et al.)	12/2016	Russia	Energy	CO2	CP, NDC	National ESM
Rhodium (Pitt et al. 2019)	11/2019	USA	Energy	Kyoto	CP, NDC	National ESM

Notes: [a] in case policy cut-off date is not explicitly specified in the publication or accompanying information, the study submission date minus six months is used as proxy; [b] CO2 = CO2 only, Kyoto = Kyoto GHGs; [c] CP = Current Policies, NDC = Nationally Determined Contribution; d IAM = Integrated Assessment Model, ESM = Energy Systems Model, ILM = Integrated Land Model, CGE = Computable General Equilibrium Model

In addition to assessing the emissions outcomes of NDCs, some studies report development indicators, meaning a wide diversity of socio-economic indicators (Altieri et al. 2016; Bataille et al. 2016a; Jiang et al. 2013) (Benavides et al. 2015; Chai and Xu 2014; Delgado et al. 2014; La Rovere et al. 2014a; Paladugula et al. 2018; Parikh et al. 2018; Zevallos et al. 2014; Zou et al. 2016), the share of low carbon energy (Bertram et al. 2015; Riahi et al. 2015), renewable energy deployment (Roelfsema et al. 2018c) or investments into low-carbon mitigation measures (McCollum et al. 2018) to track progress towards long-term temperature goals.

4.2.2.3 Projected emissions under NDCs and current policies by 2025/2030

Table 4.2 presents the evidence base for the assessment of projected emissions of NDCs and current policies until 2030. It covers 16 countries and regions responsible for about 76% of global GHG emission and draws quantitative estimates from 30 studies (see Table S4.2 in the Supplementary Material to Chapter 4). The table allows comparing emission projections from national and globally comprehensive studies as well as official communications by countries to the UNFCCC at the national/regional level. The global aggregates presented in Table 4.2 derive from globally comprehensive studies only and are not the result of aggregating country projections up to the global level. As different studies report different emission indicators, the table includes four different indicators: CO2 and GHG emissions, in- or excluding AFOLU emissions. Where possible, multiple indicators are included per study.

[*Note that the data collection effort to underpin the quantitative assessment is still ongoing*[2] *and will lead to increased coverage of countries and studies over the course of the AR6 drafting process.*]

4.2.2.3.1 Globally comprehensive studies

The UNFCCC Secretariat has assessed the aggregate effect of NDCs twice. The first report considered the intended NDCs in relation to 2°C (UNFCCC 2015b), whereas the second considered NDCs also in relation to 1.5 °C (UNFCCC 2016b).

A range of globally comprehensive studies (den Elzen et al. 2016a; Luderer et al. 2016; Rogelj et al. 2016, 2017a; Vandyck et al. 2016; Rose et al. 2017; Vrontisi et al. 2018) which estimate aggregate emissions outcomes NDCs and current policies have previously been assessed in IPCC SR1.5, Cross-Chapter-Box 11.

Current policies lead to median global GHG emissions of 60 GtCO2-eq with a full range of 57-65 by 2030 and unconditional and conditional NDCs to 56 (54-62) and 52 (49-56) GtCO2-eq, respectively (*medium evidence, high agreement*) (Table 4.2). Globally comprehensive and national-level studies project emissions of current policies and NDCs to 2025 and 2030 and, in general, are in good agreement about country-level emission projections based on current policies and NDCs.

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[2] See https://data.ene.iiasa.ac.at/ar6-scenario-submission/#/about

These estimates are close to the ones provided by the IPCC SR1.5 (Cross-Chapter-Box 11) and the UNEP emissions gap report (UNEP 2019a)[3].

Globally, the gap between projected emissions of current policies and the unconditional and conditional NDCs is estimated to be around 4 and 7 GtCO$_2$eq in 2030, respectively (Table 4.2) (medium evidence, medium agreement) , with many countries requiring additional policies to meet their self-determined mitigation targets as specified under the NDCs (*limited evidence*).

[*With the NDCs expected to be updated by the end of 2020, the chapter team plans to update the estimates between the SOD and FGD for studies that have been covered in the methods section by the time of the SOD so that AR6 can provided added value compared to SR1.5.*]

4.2.2.3.2 National studies

A large body of literature on national and regional emissions projections, including official communications of as part of the NDC submissions and independent studies exist. A subset of this literature provides quantitative estimates for the 2030 timeframe. As highlighted in Section 4.2.1, the number of independent studies varies considerably across countries with an emphasis on the largest emitting countries which is reflected in Table 4.2 (see Table S4.2 in the Supplementary Material to Chapter 4). A few deviations between these groups of studies require further attention. For China, global studies tend to show higher projections of current policies and NDCs in 2030 by several hundred MtCO2eq per year, but the ranges across the two groups of studies still overlap to a good degree. The opposite situation is found for Australia where global studies project lower emission growth in both current policy and NDC scenarios than national studies. Despite these differences for a few countries the comparison shows that there is generally good agreement between the different types of studies, so therefore providing evidence that these quantitative estimates are fairly robust.

4.2.2.3.3 Sectoral studies

Sectoral studies are essential in understanding the contributions of concrete measures of NDCs and current policies. For example, approximately 98% of NDCs include the energy sector in their mitigation contributions and around 50% of which include a specific target for renewables share (Stephan et al. 2016). Transport is covered explicitly in 75% of NDCs, although specific targets for the sector exist in only 21% of NDCs (PPMC and SLoCaT 2016). Measures or targets for buildings are referred to explicitly in 27% of NDCs (GIZ 2017). 36% of NDCs include targets or actions that are specific to the agriculture sector (FAO 2016). LULUCF (mitigation) is included in 80 % of all submitted NDCs, and 59 % included adaptation, and 29 % referred to REDD+ in their NDCs.

Greater sectoral expertise and involvement will be critical to accomplishing development and climate goals due to enhanced availability of information and expertise on specific sectoral options, greater ease of aligning the NDC with sectoral strategies, and greater awareness among sector-level decision-makers and stakeholders (NDC Partnership 2017) (Fekete et al. 2015). Sector-specific studies are assessed in the sectoral chapters (6-11) of this report.

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[3] Note that the statistical metrics reported are slightly different across the reports. For example, IPCC SR1.5 reported the 25th to 75th range while the UNEP emissions gap report uses median and 10th to 90th percentile ranges.

Table 4.2 Assessment of projected emissions of current policies and NDCs by 2030 for 16 individual countries/regions and the world.

Region	GHG share [%][a]	Type[b]	# studies	Current Policies 2030 emissions				NDC 2030 emissions (unconditional/conditional)[c]			
				CO_2 only [$GtCO_2$] median (min - max)[d]		Kyoto GHGs [$GtCO_2$-eq] median (min - max) [d]		CO_2 only [$GtCO_2$] median (min - max) [d]		Kyoto GHGs [GtCO2-eq] median (min - max) [d]	
				incl. AFOLU	excl. AFOLU	incl. AFOLU	excl. AFOLU	incl. AFOLU	excl. AFOLU	incl. AFOLU	excl. AFOLU
CHN	26	global				14.5 (14.4 - 14.6)	15.6 (14.4 - 18.1)			15.3 (14 - 17.5)	15.2 (14.4 - 17.9)
		national			12.1 (11.3 - 12.8)	13.2			10.6 (10.1 - 11)	14.7 (14.1 - 15.3)	
USA	13	global				5.05	5.81 (5.48 - 6.33)			4.89 (4.64 - 5.2)	5.36 (4.64 - 6.08)
		national		4.99	5.36	6.46 (5.11 - 6.66)		3.13	3.62	4.2	
		official				5.27	6.36			4.7 (4.64 - 4.76)	
EU	8.6	global				2.92	3.37 (2.94 - 3.92)			2.93	3.39 (3.17 - 3.42)
		national		3.07	2.84	2.81 (2.81 - 3.73)	3.99	2.8	2.58	3.41	
		official					3.99				
IND	7.2	global				4.48 (3.97 - 4.98)	4.56 (4.24 - 5.32)			5.2 (4.29 - 6.01)	5.34 (4.56 - 6.19)
		national		3.99	5.21 (3.93 - 6.5)	4.89 (4.81 - 4.96)	5.16	3.59	4.69 (3.53 - 5.85)	5.35	5.29
RUS	4.7	global				2.28	2.85 (2.71 - 3)			2.65 (2.47 - 2.9)	2.68 (2.61 - 3.36)
		national			1.54				1.54	2.49	
		official					2.79			2.65	
JPN	2.7	global				1.15	1.11 (1.02 - 1.21)			1 (0.984 - 1.02)	1.05 (0.99 - 1.08)
		national		1.17 (1.14 - 1.2)	1.11 (1.1 - 1.13)	1.29 (1.28 - 1.29)		0.95 (0.92 - 0.99)	0.93 (0.87 - 0.94)	1.04 (1.01 - 1.07)	
		official					1.08			1.04	1.08
BRA	2.5	global				1.79	1.32 (1.12 - 1.43)			1.24 (1.18 - 1.31)	1.18 (0.88 - 1.3)
		national		0.638	0.501	1.57 (1.33 - 1.81)		0.552	0.498	1.25 (1.2 - 1.3)	
		official								1.25 (1.2 - 1.3)	
IDN	1.9	global				2.83	1.5 (1.01 - 1.52)			2.05 (1.7 - 2.28)	1.24 (0.88 - 1.82)
		official								1.91 (1.69 - 2.03)	1.77 (1.63 - 1.82)
CAN	1.6	global				0.61	0.66 (0.63 - 0.76)			0.548 (0.482 - 0.571)	0.55 (0.52 - 0.67)

		official					0.721				0.517
MEX	1.5	global				0.686	0.74 (0.69 - 0.84)			0.73 (0.62 - 0.76)	0.67 (0.54 - 0.76)
		national									
		official								0.69 (0.62 - 0.76)	
KOR	1.4	global				0.508	0.53 (0.46 - 0.57)			0.46 (0.44 - 0.47)	0.46 (0.44 - 0.47)
		official				0.55 (0.54 - 0.56)					
AUS		global					0.566			0.441 (0.43 - 0.45)	
	1.4	national				0.686	0.73 (0.66 - 0.76)			0.55 (0.54 - 0.57)	0.54 (0.53 - 0.59)
		official									0.536
TUR	1.3	global				0.526	0.64 (0.58 - 0.91)			0.93 (0.93 - 0.93)	0.95 (0.64 - 1)
		official					0.999			0.928	
ZAF	1.1	global				0.747	0.65 (0.64 - 0.77)			0.51 (0.4 - 0.66)	0.63 (0.4 - 0.67)
		official				1				0.51 (0.4 - 0.61)	
ARG	0.77	global					0.47 (0.44 - 0.49)			0.4 (0.32 - 0.5)	0.39 (0.32 - 0.48)
		national				0.4 (0.39 - 0.41)					
		official								0.43 (0.37 - 0.48)	
Sum	75.7										
World	100	global		44.5 (42.8 - 50.9)	38.6 (35.6 - 40.2)	59.7 (57.1 - 65)				55.8 (53.6 - 61.7)	52.4 (48.8 - 56.1)

Notes: [a] 2018 Share of global Kyoto GHG emissions based on EDGAR inventory [data provided by chapter 2]. [b] Type distinguishes between independent globally comprehensive studies (that provide information at the country/region level), independent national studies and official communications via Biennial Reports, Biennial Update Reports or National Communications. [c] To date only at the global level values for conditional NDCs are provided. [d] If more than one value is available, a median is provided and the full range of estimates (in parenthesis).

4.2.2.4 Tracking progress in implementing and achieving NDCs

Legally, the NDCs are not yet implemented before 2020 and countries are required to submit their first biennial transparency report on progress made in implementing and achieving NDCs under Article 4 of the Paris Agreement before 31 December 2024 only (UNFCCC 2018a). Thus, no official data exists yet on tracking progress of individual NDCs. However, the rules for tracking progress were agreed at COP24 (UNFCCC 2018a).

Meanwhile, there is some literature at global and national level that aims at assessing whether countries are on track or progressing towards implementing their NDCs and to which degree the NDCs collectively are sufficient to reach the temperature targets of the Paris agreement (den Elzen et al. 2019a) (Höhne et al. 2018a) (Peters et al. 2017). Most of these studies focus on major emitters such as G20 counties and with the aim to inform countries to strengthen their ambition regularly, e.g. through progress of NDCs and as part of the global stocktake (Höhne et al. 2018a; Peters et al. 2017). However, a limited number of studies assess the implementation gaps of conditional NDCs in terms of finance, technology and capacity building support Some authors conclude that finance needed to for fulfil conditional NDCs exceeds available resources or the current long-term goal for finance (USD100 billionyr^{-1}) (Pauw et al. 2019); others suggest that assessment of financial resources for forest-related activities as an approach to triggering conditional NDCs (Kissinger et al. 2019). The literature suggests that consistent and harmonised approach to track progress of countries towards their NDCs would be helpful (den Elzen et al. 2019b; Peters et al. 2017; Höhne et al. 2018b), and negotiations on common tabular format are due to conclude in 2020.

Globally, the implementation gap between current policy scenarios and the unconditional and conditional NDCs is estimated to be around 4 and 7 GtCO$_2$eq, respectively (Table 4.2). In other words, many countries will need to implement additional policies to meet their self-determined mitigation targets as specified under the NDCs. For example, within the G20, Argentina, Australia, Canada, the European Union, Republic of Korea, South Africa and the United States have been identified to require further action to meet their own NDCs (den Elzen et al. 2019b). Studies that assess the level of projected emissions under current policies indicate that new policies (that are covered in more recent projections) have reduced projections, by about 2 GtCO$_2$eq since the adoption of the Paris Agreement in 2015 to 2019 (UNEP 2019b) (den Elzen et al. 2019a; Climate Action Tracker 2019).

4.2.2.5 Assessments of fairness and ambition of NDCs

Most countries provided information on how they consider their NDCs to be fair and ambitious in the NDCs submitted to UNFCCC and many of these NDCs refer to specific national circumstances such as social, economic and geographical factors when outlining why they are fair and ambitious. Further, several Parties provided information on specific criteria for evaluating fairness and ambition, including criteria relating to: responsibility and capability; share of emissions; development and/or technological capacity; mitigation potential; cost of mitigation actions; the degree of progression or stretching beyond the current level of effort; and the link to objectives and global goals (UNFCCC 2016a).

Recent literature has assessed equity, analysing how fairness is expressed in NDCs in a bottom-up manner (Cunliffe et al. 2019; Mbeva and Pauw 2016; Winkler et al. 2018b). Meanwhile, various assessment frameworks have been proposed to analyse, benchmark and compare NDCs at national, regional or at sectoral level (Jiang et al. 2017; Wakiyama and Kuramochi 2017; Fridahl and Johansson 2017; den Elzen et al. 2016a; Aldy et al. 2017; Holz et al. 2018; Höhne et al. 2018a). For more on equity, see section 4.4.4.

According to its Article 2.2, the Paris Agreement will be implemented to reflect equity and the principle of common but differentiated responsibilities and respective capabilities, in the light of different national circumstances, the latter clause being new, added to the UNFCCC principle (Rajamani 2017;

Voigt and Ferreira 2016). Possible different interpretations of equity principles lead to different assessment frameworks (Lahn 2017; Lahn and Sundqvist 2017).

4.2.2.6 Uncertainty in estimates

Some studies assume full successful implementation of all of the NDCs' proposed measures, sometimes with variations to account for some of the NDC features which are subject to assumed conditions related to finance and technology transfer. Countries have an obligation to "pursue domestic mitigation measures" under Article 4.2 of the Paris Agreement (UNFCCC 2015c), but they are not legally bound to the result of reducing emissions (Winkler 2017a). Some authors consider this to be a lack of a strong guarantee that mitigation targets in NDCs will be implemented (Nemet et al. 2017). Others point to growing extent of national legislation to provide a legal basis for action (Iacobuta et al. 2018) (see Chapter 13). Whether the legal basis is national or international, there may be an implementation gap between targets and measures implemented (Brauch 2012). These factors together with incomplete information in NDCs mean there is uncertainty about the estimates of anticipated 2030 emission levels. The aggregation of targets results in large uncertainty (Rogelj et al. 2017a). This uncertainty could be reduced with clearer guidelines for compiling future NDCs and explicit specification of technical details, including energy accounting methods, harmonized emission inventories (Rogelj et al. 2017a) and finally, increased transparency and comparability (Pauw et al. 2018).

There are many factors that influence the global aggregated effects of NDCs. There is limited literature on systematically analysing the impact of uncertainties on the NDC projections with some exception (Benveniste et al. 2018; Rogelj et al. 2017a). The UNEP Gap Report contains a box on uncertainties and NDCs. The main factors include variations in overall socio-economic conditions; uncertainties in inventories; conditionality; targets with ranges or for single years; accounting of biomass; and GWP values from different assessment reports (UNEP 2017a).

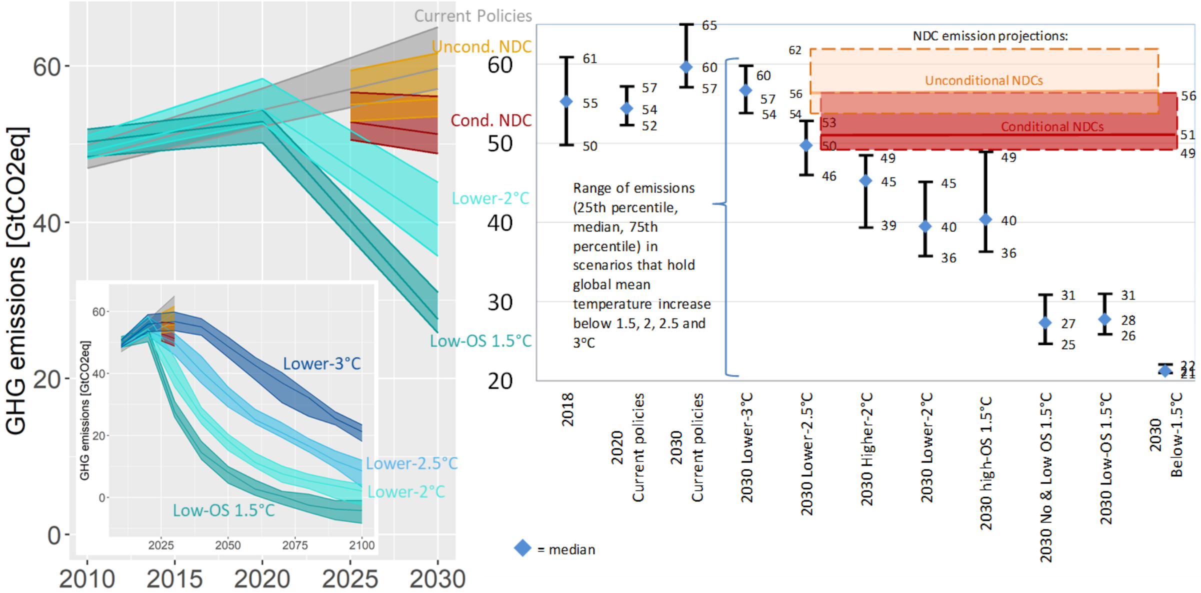
Cross-Chapter Box 1: Comparison of NDCs and current policies with the 2030 GHG emissions from long-term temperature pathways

Authors: Michel den Elzen, Céline Guivarch, Volker Krey, Elmar Kriegler, Franck Lecocq, Keywan Riahi, Harald Winkler

Introduction

The Paris Agreement (PA) sets a long-term goal of holding the increase of global average temperature to ‘well below 2°C above pre-industrial levels’ and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels. This is underpinned by the ‘aim to reach global peaking of greenhouse gas emissions as soon as possible’ and ‘achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century’ (UNFCCC 2015d). The PA adopts a bottom-up approach in which countries determine their contribution to reach the PA’s long-term goal. These national targets, plans and measures are called ‘nationally determined contributions’ or NDCs.

The NDCs are the central instrument of the PA to achieve its long-term goal. It thus combines a global goal with a country-driven (bottom-up) instrument to a hybrid climate policy architecture to strengthen the global response to climate change. All signatory countries committed to communicating nationally determined contributions including mitigation targets, every five years (Rogelj et al. 2016; Vandyck et al. 2016; den Elzen et al. 2016b; UNEP 2019a; Vrontisi et al. 2018). While the NDCs mostly state targets, countries are also obliged to pursue domestic mitigation measures to achieve the objectives. The literature examines the emissions outcome of the range of policies implemented to reach these targets.



Cross-Chapter Box 1, Figure 1: Comparison of projections of global GHG emissions that would emerge from the implementation of current policies and NDCs (colored boxes in upper right corner) with near-term GHG emissions from cost-effective transformation pathways consistent various long-term temperature goals. Left panel shows evolution over time while right panel shows historical emissions (2018) and projected emissions for 2020 and 2030. The inlay in the left panel displays the development of GHG emissions of long-term temperature pathways until 2100.

Notes: GHG emissions are expressed in CO_2-equivalent based on GWP100 from AR4. Projected emissions of current policies and NDCs from Section 4.2.2 (Table 4.2) show median and full range. The figure shows the near-term development of the emissions from long-term temperature pathways from Section 3.3.3, showing the median and interquartile range (25th to 75th percentile). Historical emissions from 2018 are based on EDGAR inventory.

Emissions gap

A comparison between the projected emission outcomes of current policies, the NDCs (unconditional and conditional, see Section 4.2.2) and cost-effective mitigation pathways reaching different temperature goals in the long-term (see Section 3.3.3) allows identifying different ‘emission gaps’ in 2030 (Figure 1). First, the implementation gap between ‘current policies’ and unconditional and conditional NDCs is estimated to be around 4 and 7 GtCO2eq in 2030, respectively (Section 4.2.2 and Table 4.2). Second, the comparison of unconditional (conditional) NDCs and cost-effective long-term mitigation pathways gives rise to a 2030 median emissions gap of 28-34 $GtCO_2eq$ (23-29 $GtCO_2eq$) for limiting warming to 1.5°C and 11-16 $GtCO_2eq$ (6-10 $GtCO_2eq$) for limiting warming to 2°C[4]. GHG emissions of unconditional (conditional) NDCs are broadly consistent with 2030 emission levels of cost-effective long-term pathways staying below 3°C (2.5°C).

[*Quantitative emission gap estimates are preliminary and included here for illustrative purposes. They will be updated for the SOD.*]

Other ‘gap indicators’

Beyond the quantification of different GHG emissions gaps, there is an emerging literature that identifies gaps between current policies, NDCs and long-term temperature in terms of other indicators, including for example the deployment of renewable energy sources, energy efficiency improvements or investments into mitigation measures (McCollum et al. 2018; Roelfsema et al.). It should be noted that such comparisons are less straight forward as the link between long-term temperature goals and such indicators is less pronounced. [*With additional quantitative scenario information becoming available towards the SOD, an attempt will be made to assess and present such alternative ‘gap indicators’ in the SOD.*]

Adaptation

[*The Paris Agreement and the NDCs in addition to mitigation also cover adaptation. The plan is for the SOD is therefore in collaboration with WGII to address the link with adaptation, e.g. drawing on literature on the water-energy-land nexus. This information will either be integrated here or in a separate box.*]

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[4] The emission gap ranges provided here correspond to the difference between median values of NDCs and the different subcategories of 1.5 and 2°C pathways.

4.2.3 Mitigation efforts in subnational and non-state action plans and policies

In the decision adopting the Paris Agreement, the importance of the role of non-government and subnational stakeholders is stressed. Non-state actors, e.g. companies, civil society, cities and regions, have emerged to undertake a range of carbon mitigation actions (Hsu et al. 2019; Hsu et al. 2018b) both at the individual level and in partnership through national and international cooperative initiatives (Hsu et al. 2018a). National action was assessed in 4.2.2. International cooperative initiatives take a variety of forms, ranging from those that focus solely on non-state actors to those that engage national and even local governments. They can also range in commitment level, from primarily membership-based that do not require specific actions to those that require members to tackle emissions reductions in specific sectors or aim for transformational change.

Quantification of the (potential) impact of these actions is still limited. Almost all studies estimate the potential impact of the implementation of the individual actions and initiatives, but do not factor in that they may not reach their targets. The main reason for this that there is very limited data currently available from individual actors (e.g., annual GHG inventory reports) and initiatives to assess their progress towards their targets; there are a few studies that attempted to assess progress of initiatives by looking into the initiatives' production of relevant outputs (Chan et al. 2018). Quantification does not yet cover all commitments and only a selected number of initiatives is analysed. Most of these studies exclude commitments that are not (self-)identified as climate change mitigation-related, those that are not connected to international networks, or those that are communicating in languages other than English.

Hsu et al. (2019) calculate that within the umbrella of such overarching initiatives, more than 6,000 cities and regions have made quantifiable commitments to reduce GHG emissions; participating cities represent a collective population of 579 million (more than Brazil and the United States combined), whereas participating regions are home to approximately 514 million people (four times the total population of Japan). They find that particularly in the USA the potential impact of actors other than the national government is most significant, with studies including scenarios with and without federal action (WRI 2019). (Roelfsema et al. 2018a) project that transnational emissions reduction initiatives, a subset of non-state and subnational actors outside of the scope of national commitments under the Paris Agreement, could deliver 5 Gt CO_2e emissions reductions by 2030 below a no action scenario. Roelfsema et al. (2018b) suggest that potential reductions from non-state actions are projected to be of similar magnitude as those under the NDCs. This study models the overlap of reductions in NDCs and transnational emission reduction initiatives outside of the UNFCCC, finding a maximum estimate of overlap of around 70% by 2020 and 80% by 2030 (Roelfsema et al. 2018a). We do not fully understand the extent to which ambitious action by non-state actors is additional to what national governments intend to do.

In Table 4.3 and Figure 4.1, we report estimates of the emissions reductions from 27 distinct sub-national efforts at mitigating climate change. When adding up the efforts, such efforts could reduce as much as 39 Gt of CO2e in 2030. **If the commitments and goals of the multiple initiatives are fully implemented and do not replace efforts elsewhere, global emissions are reduced in 2030 to a level that is consistent with pathways towards 2°C, possibly even to 1.8°C, though this is assessed with low confidence (*limited evidence, medium agreement*)**.

Table 4.3: Emissions reduction potential for sub-national actors by 2030 and 2050

Sector	**Leading Actor**	**Name**	**Scale**	**Target(s)**	**Emissions reduction potential (GtCO2e/year)**				**Source**
					Min (2030)	***Max (2030)***	***Min (2050)***	***Max (2050)***	
Energy efficiency	Intergovernmental (UNEP)	United for Efficiency (U4E)	Global (focus on developing countries)	Members to adopt policies for energy-efficient appliances and equipment	0.6	1.2			(NewClimate Institute et al. 2019)
Buildings	Business (AIA)	Architecture 2030	Global (focus on North America)	New buildings and major renovations shall be designed to meet an energy consumption performance standard of 70% below the regional (or country) average/median for that building type and to go carbon- neutral in 2030	0.2	0.2			(NewClimate Institute et al. 2019)
Transport	Business (aviation sector)	Collaborative Climate Action Across the Air Transport World (CAATW)	Global	Two key objectives: 1) 2% annual fuel efficiency improvement through 2050, 2) Stabilise net carbon emissions from 2020	0.6	0.6			(NewClimate Institute et al. 2019)
Transport	Business	Lean and Green	Europe	Member companies to reduce CO2 emissions from logistics and freight activity by at least 25% over a five-year period	0.02	0.02			(NewClimate Institute et al. 2019)
Transport	Hybrid	Global Fuel Economy Initiative (GFEI)	Global	Halve the fuel consumption of the LDV fleet in 2050 compared to 2005	0.5	0.5			(NewClimate Institute et al. 2019)
Transport	Business	Below50 LCTPi	Global	Replace 10% of global transportation fossil fuel use with low-carbon transport fuels by 2030	0.5	0.5	2.1	2.1	(World Business Council for Sustainable Development 2016, 2017)

Renewable energy	Business	European Technology & Innovation Platform Photovoltaic (ETIP PV)	Europe	Supply 20% of electricity from solar PV technologies by 2030	0.2	0.5			(NewClimate Institute et al. 2019)
Renewable energy	Intergovernmental (African Union)	Africa Renewable Energy Initiative (AREI)	Africa	Produce 300 GW of electricity for Africa by 2030 from clean, affordable and appropriate forms of energy	0.3	0.8			(NewClimate Institute et al. 2019)
Renewable energy	Hybrid	Global Geothermal Alliance (GGA)	Global	Achieve a five-fold growth in the installed capacity for geothermal power generation and a more than two-fold growth in geothermal heating by 2030	0.2	0.5			(NewClimate Institute et al. 2019)
Renewable energy	Business	REscale LCTPi	Global	Support deployment of 1.5 TW of additional renewable energy capacity by 2025 in line with the IEA's two degrees scenario	5	5			(PwC 2015; World Business Council for Sustainable Development 2018)
Renewable energy	Business	RE100 initiative	Global	2,000 companies commit to source 100% of their electricity from renewable sources by 2030	1.9	4			(NewClimate Institute et al. 2019)
Renewable energy	Intergovernmental (EU)	European Wind Initiative (EWI)	Europe	Wind energy to account for a 20% share of total EU electricity consumption by 2020 (33% by 2030)	0.2	0.6			(Data Driven Yale et al. 2018)
Renewable energy	Government (US DOE)	SunShot Initiative (SSI)	North America	Drive down the cost of solar electricity to USD 0.06 per kilowatt-hour or USD 1 per watt (not including incentives)	0.2	0.6			(Data Driven Yale et al. 2018)

Renewable energy	Government (US NREL)	Wind Program North America	North America	Generate 20% of the US electricity demand via wind energy by 2030	0.2	0.5			(Data Driven Yale et al. 2018)
Forestry	Hybrid	Bonn Challenge / Governors' Climate and Forests Task Force (GCFTF) / New York Declaration on Forests (NYDF)	Global	End forest loss by 2030 in member countries and restore 150 million hectares of deforested and degraded lands by 2020 and an additional 200 million hectares by 2030	5.4	5.6			(NewClimate Institute et al. 2019)
Non-CO2 emissions	Government	Climate & Clean Air Coalition (CCAC)	Global	Members to implement policies that will deliver substantial short-lived climate pollutant (SLCP) reductions in the near- to medium-term (i.e. by 2030) for HFCs and methane	1.4	1.4			(NewClimate Institute et al. 2019)
Non-CO2 emissions	Intergovernmental (World Bank)	Zero Routine Flaring	Global	Eliminate routine flaring no later than 2030	0.4	0.4			(Data Driven Yale et al. 2018)
Cities and regions	Cities and regions	Under2 Coalition	Global	Local governments (220 members) aim to limit their GHG emissions by 80 to 95% below 1990 levels by 2050	4.6	5			(NewClimate Institute et al. 2019)
Cities and regions	Cities and regions	Global Covenant of Mayors for Climate & Energy (GCoM)	Global	Member cities have a variety of targets (+9,000 members)	1.4	1.4			(NewClimate Institute et al. 2019)
Cities and regions	Cities and regions	Global Covenant of Mayors for Climate & Energy (GCoM)	Global	Member cities have a variety of targets (+9,000 members)	1.4	1.4			(Global Covenant of Mayors for Climate and Energy 2018)

Cities and regions	Cities and regions	Global Covenant of Mayors for Climate & Energy (GCoM)	Global	Member cities have a variety of targets (+9,000 members)			2.6	5.4	(Global Covenant of Mayors for Climate and Energy 2018)
Cities and regions	Cities and regions	C40 Cities Climate Leadership Group (C40)	Global	94 member cities have a variety of targets, aiming for 1.5°C compatibility by 2050. The network carries two explicit goals: 1) to have every C40 city develop a climate action plan before the end of 2020 (Deadline 2020), which is "deliver action consistent with the objectives of the Paris Agreement" and 2) to have cities achieve emissions neutrality by 2050	1.5	1.5			(NewClimate Institute et al. 2019)
Cities and regions	Cities and regions	Compact of States and Regions	Global	Compares the ambition of disclosed targets from 49 states and regions to the ambition of the Nationally Determined Contributions (NDCs) and long-term targets of their national government counterparts. Additionally, the analysis compares the states and regions and national government trajectories to a 1.5°C trajectory to assess whether the targets are aligned with the 1.5°C goal.	0.41	0.41			(The Climate Group and CDP 2019)

Cities and regions	Cities and regions	Compact of States and Regions	Global	Compares the ambition of disclosed targets from 49 states and regions to the ambition of the Nationally Determined Contributions (NDCs) and long-term targets of their national government counterparts. Additionally, the analysis compares the states and regions and national government trajectories to a 1.5°C trajectory to assess whether the targets are aligned with the 1.5°C goal.	0.37	0.37	0.2	0.2	(The Climate Group and CDP 2019)
Cities and regions	Cities and regions	Compact of States and Regions	Global	Compares the ambition of disclosed targets from 49 states and regions to the ambition of the Nationally Determined Contributions (NDCs) and long-term targets of their national government counterparts. Additionally, the analysis compares the states and regions and national government trajectories to a 1.5°C trajectory to assess whether the targets are aligned with the 1.5°C goal.	-0.69	-0.69	-0.55	-0.55	(The Climate Group and CDP 2019)
Agriculture	Business	Climate Smart Agriculture (CSA) LCTPi	Global	Reducing agricultural and land-use change emissions from agriculture by at least	3.7	3.7			(World Business Council for Sustainable Development 2018)(PwC 2015)

				50% by 2030 and 65% by 2050. 24 companies and 15 partners					
Multisectoral	Business	Science Based Targets initiative (SBTi)	Global	By 2030, 2,000 companies have adopted a science- based target in line with a 2°C temperature goal	2.7	2.7			(NewClimate Institute et al. 2019)

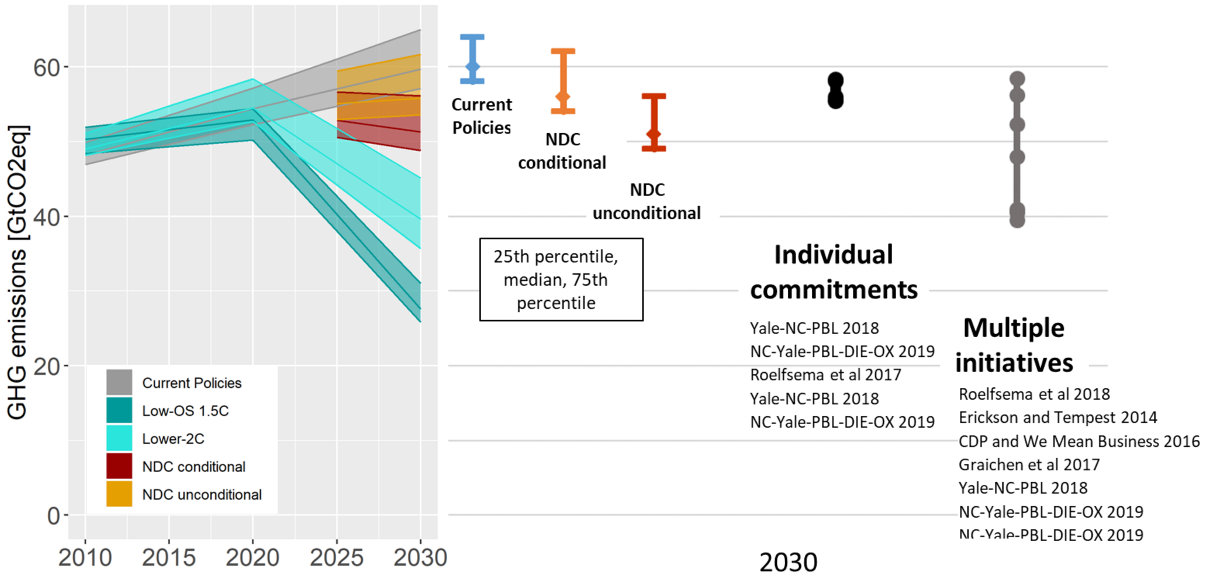

Figure 4.1: Emissions reduction potential for sub-national actors by 2030. Data on LHS and 2030 range of emissions for current policies, conditional NDC and unconditional NDC from Cross-Chapter Box Comparison of NDCs and current policies with the 2030 GHG emissions from long-term temperature pathways on emissions. Each dot on the RHS represents a study.

Equally important to note here is that none of the studies reviewed in Figure 4.1 quantified the potential impact of financial sector actions, e.g. divestment from emission intensive activities. Several action that could contribute to further reductions are not covered by most of the analyses, in particular when aggregating individual actions: Commitments to reduce emissions in the supply chain, commitments by financial institutions to redirect their investments away from fossil fuels and social movements. Moreover, only a limited number of studies on the impact of actions by diverse actors go beyond 2050 (see Table 4.3). A reason may be that analysts recognise the increasing uncertainties with longer time horizons.

As Figure 4.1 and Table 4.3 indicate, activities by businesses do have the potential to significantly contribute to global mitigation efforts. For example, the SBT (Science-Based Targets Initiative) encourages companies to pledge reducing their emissions at rates which, if they were applied globally and fully implemented, would place the world on a 2°C or 1.5°C pathway by specifying how much and how quickly they need to reduce their greenhouse gas emissions. As of November 2019, 689 companies have pledged science-based climate action and 285 companies have approved SBT. Another example is the Low Carbon Technology Partnerships initiative (LCTPi), which is comprised of over 160 companies and 70 partners that are committed to accelerating the transition to a low-carbon economy through innovation and collaboration, annually monitoring progress against each action plan.

Actions by cities and subnational regions are spread widely and initiatives of these actors have huge potential to add additional reductions, due to their large geographical scope. (Hsu et al. 2019) find largest potential in that area. Several regions like California and Scotland have set themselves zero emission targets (Höhne et al. 2019).

Initiatives focused on forestry have very high emissions reduction potential due to the current high deforestation rates, and due to the ambitious targets of many of these forestry initiatives, such as the New York Declaration on Forest’s goal to end deforestation by 2030 (Hsu et al. 2019; Höhne et al. 2019). On the other hand, uncertainties in global forest carbon emissions (and therefore potential reductions) are high and despite a multitude of initiatives in the sector, actually measured deforestation rates have not declined since the initiative was announced in 2014 (see Chapter 7).

Initiatives focused on non-CO2 emissions, and particularly on methane, can achieve sizable reductions, in the order of multiple GtCO2e/year. Initiatives on renewable energy are not only initiated by groups of countries, but also business entities and private sector consortiums. The Global Cement and Concrete Association (formerly the Cement Sustainability Initiative), which includes 30% of the world's cement production, has contributed to the development of consistent energy and emissions reporting from member companies in its nearly 20-year history. The CSI also suggested possible approaches to balance GHG mitigation and the issues of competitiveness and leakage (Cook and Ponssard 2011). The member companies of the GCCA (CSI) have become better prepared for future legislation on managing GHG emissions and developed management competence to respond to climate change compared to non-member companies in the cement sector (Busch et al. 2008).

It is also important to note that individual actors' commitments and international initiatives that commit to GHG mitigation activities are absent in many of the 'hard-to-abate' sectors, e.g. iron and steel, cement and freight transport (see Chapters 9 and 10). Discourse analysis finds five storylines in urban governance texts that support transformation of cities to carbon neutrality – diverse meanings, new economy, city as laboratory, technological fixes and reframing 'good' urban citizenship (Tozer and Klenk 2018).

4.2.4 Mid-century low-emission development strategies at national level

Beyond the 2025-2030 horizon, an increasing amount of literature describes mitigation pathways for the mid-term (up to 2050). We assess literature reflecting on the UNFCCC process (Section 4.2.4.1), other national plans and strategies (Section 4.2.4.3) and academic work (Section 4.2.4.4 and 4.2.4.4).

4.2.4.1 Country level mitigation pathways in the short- and medium-term: Overview

Regarding assessment of the future climate mitigation targets, the long-term global-scale scenarios have been assessed in Chapter 3 and the aggregate effects of NDCs in the short term in section 4.2.2. On the other hand, the Paris Agreement requests the medium-term national low GHG emission development strategy (long-term strategy) of each country. This means that the near-term and middle-term GHG mitigation actions at country level become important in order to achieve the 2°C or 1.5°C target collectively. In this section, the existing national level emission scenarios and the long-term strategies in 2050 are discussed. [*Note the intention to add further figures and analysis, once information in a national scenario database becomes available in a response to a call to modeling teams*]

4.2.4.2 GHG Mitigation target under UNFCCC and Paris Agreement

The Paris Agreement requests that Parties should strive to formulate and communicate long-term low GHG development strategies by 2020. As of November 2019, 13 countries had submitted their own long-term strategies, as shown in Table 4.4.

Many of the countries that have already submitted the long-term strategy target 80% emissions reduction in 2050 relative to a reference (1990, 2000 or 2005 levels). Marshall Islands, Fiji and Portugal target zero emission by 2050. In the case of Germany, the long-term target was updated from 80-95% reduction of GHG in 2050 to GHG neutrality by 2050.

Table 4.4 Long-term low GHG emission development strategy (as of November 24, 2019) [*NOTE: In final version of Chapter 4, this Table might be replaced by reference to relevant summary table of long-term strategies on the UNFCCC website*]

Country	Date submitted	GHG reduction target
USA	Nov. 16, 2016	80% reduction of GHG in 2050 compared to 2005 level
Mexico	Nov. 16, 2016	50% reduction of GHG in 2050 compared to 2000 level
Canada	Nov. 17, 2016	80% reduction of GHG in 2050 compared to 2005 level

Germany	Nov. 17, 2016 Rev: Apr. 26, 2017 Rev. May 4, 2017	Greenhouse gas neutrality by 2050 (Old target: 80-95% reduction of GHG in 2050 compared to 1990 level)
France	Dec. 28, 2016 Rev: Apr. 18, 2017	75% reduction of GHG in 2050 compared to 1990 level
Benin	Dec. 12, 2016	
Czech Republic	Jan. 15, 2018	80% reduction of GHG in 2050 compared to 1990 level
UK	April 17, 2018	80% reduction of GHG in 2050 compared to 1990 level
Ukraine	July 30, 2018	66-69% reduction of GHG in 2050 compared to 1990 level
Republic of the Marshall Islands	Sept. 25, 2018	Net zero greenhouse gas emissions by 2050
Fiji	Feb. 25, 2019	Negative emissions in 2050 (Very High Ambition scenario)
Japan	June 26, 2019	80% reduction of GHG in 2050, and decarbonized society as early as possible in the 2nd half of 21st century
Portugal	Sept. 20, 2019	GHG neutrality by 2050

4.2.4.3 National emission pathways to mid-century

Since the 2000s, an increasing number of studies have quantified the emission pathways to mid-century by using national scale models. In the early stages, the national emission pathways were mainly assessed in the developed countries such as Germany, UK, France, the Netherlands, Japan, Canada, and USA. For example, Deutscher Bundestag in Germany (2002) showed the robust and sustainable 80% emission reduction pathways in Germany. In Japan, 2050 Japan Low-Carbon Society scenario team (2008) assessed the 70% reduction scenarios in Japan, and summarized the necessary measures to “Dozen Actions towards Low-Carbon Societies.”

In the developing countries, China, India, South Africa assessed their national emission pathways. For example, a Scenario Building Team (2007) quantified the Long Term Mitigation Scenarios for South Africa. It shows the emission scenarios with strategic options “Start now,” “Scale up,” “Use the market” and “Reaching for the Goal” in South Africa.

Prior to COP21, many national emission pathways contributing to remaining within a 2°C limit were assessed, and for an IPCC special report some studies tried to assess the emission pathways to help pursue a 1.5°C limit. A recent IPCC special report found that global pathways with no or limited overshoot of 1.5 °C need to reach net zero around 2050 (IPCC 2018a). Models approximate a contribution to a global limit of 1.5°C in national scenarios in two main ways: by reflecting a carbon price or carbon budget corresponding to 1.5°C scenario estimated from the global analysis, or by reducing national net CO2 emissions to zero by 2050. The former assumes a uniform global allocation or price, while the latter assumes that countries individually reach net zero at the same time; neither assumption is likely to hold in reality but is useful for modeling. Figure 4.2 shows the national scale emission pathways from the IIASA database and the targets of NDC and long-term strategy of that country.

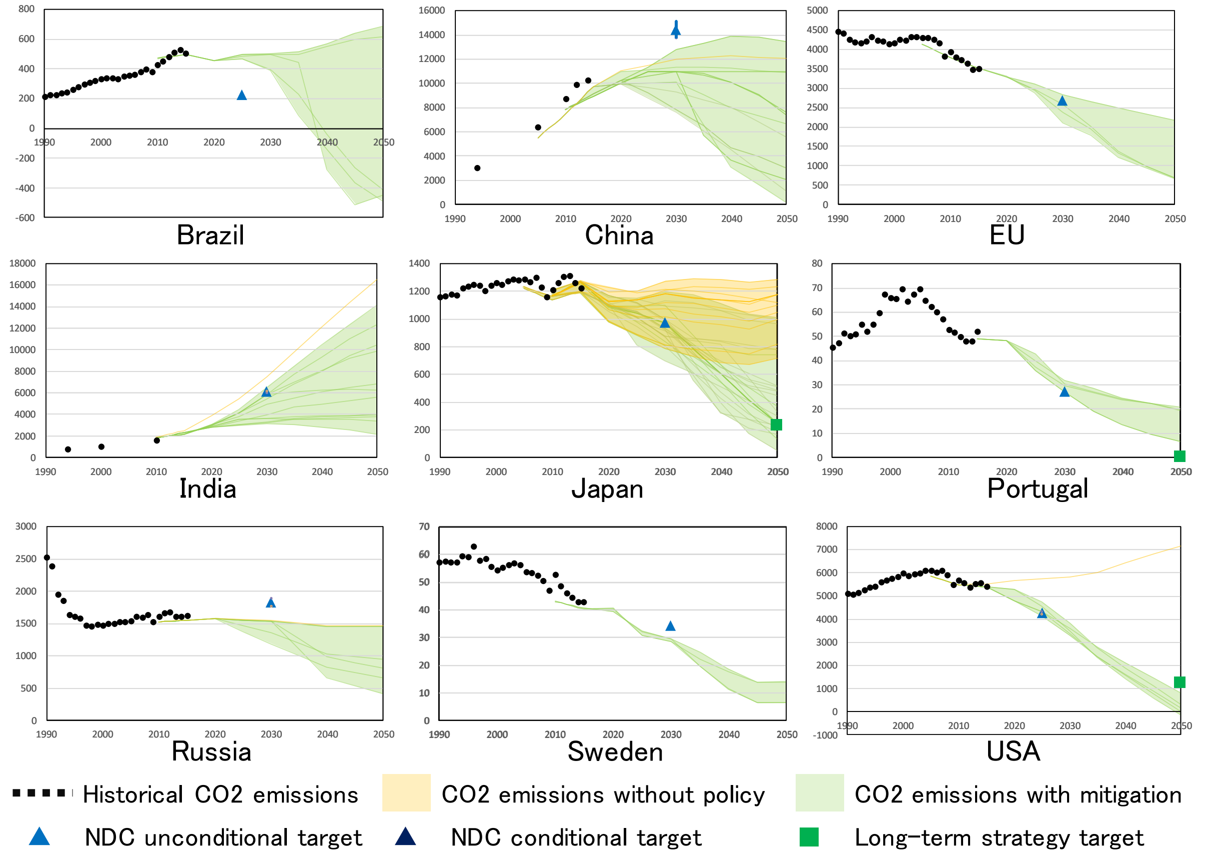

Figure 4.2 CO_2 emission pathways to mid-century from existing studies and targets of NDC and long-term strategy at national scale (Unit: MtCO2) *[Note: This figure shows only the countries which are included in the AR6 national database and CD-LINKS. When the AR6 national database will be updated, these figures will be updated.]*

Oshiro et al. (2018) shows the difference between the implications of a 2°C scenario (80% reduction of CO2 in 2050) and a 1.5 °C scenario (net zero CO_2 emission in 2050) for Japan. For a net zero emission scenario, BECCS is a key technology, and the emissions from energy sector have to be negative in 2050. The building and transport sectors will have to be almost zero, requiring energy efficiency improvement and electrification. Drastic reduction activities will have to be introduced immediately, and, as a result, the mitigation target in the present NDC is considered not sufficient to achieve a 1.5°C scenario. (Jiang et al. 2018) show the possibility of negative emissions in the power sector in China by 2050. (Samadi et al. 2018) indicate the widespread use of electricity-derived synthetic fuels in end-use sectors as well as behavioral change for the 1.5 degree scenario in Germany.

In addition to those analyses, Vishwanathan et al. (2018), Chunark and Limmeechokchai (2018) and Pradhan et al. (2018b) shows the possibility of national scenarios in India, Thailand and Nepal, respectively, that help to achieve a 1.5 degree scenario. In these studies, because of the high economic growth and increase of GHG emissions in BAU case, CO_2 emissions in 2050 do not reach to be zero. In accordance with the development stage, the appropriate emission pathways can be drawn. In order to achieve a 1.5°C target, mitigation measures for not only energy related CO_2 emissions but also non-CO_2 emissions become important. Especially, in developing countries, the share of non-CO_2 emissions is relatively high. (La Rovere et al. 2018) treat mitigation actions in AFOLU sector.

At the 2019 Climate Action Summit, a total of 77 countries indicated their aim to reach net zero CO2 emissions by 2050. Various countries have adopted official mitigation strategies all the way up to 2050, that are not yet reflected in the communications to the UNFCCC. National targets for net zero are contained in laws, strategies or other communications, including the following examples:

- Sweden adopted a Climate Act and Climate Policy Framework that include a long-term target to have zero net greenhouse gas emissions by 2045 at the latest (Swedish Environmental Protection Agency 2017)
- France second "low-carbon national strategy" (published 2018) has an objective of carbon neutrality by 2050 (about 55 MtCO2 gross emissions, offset by domestic carbon sinks in agriculture and forestry). The strategy is under review at the moment. Net zero is also the basis of the recent revision of the official notional price of carbon for public investment in France (Quinet et al. 2019).
- The UK has adopted by law a zero net emissions target by 2050 (Committee on Climate Change 2019).
- EU reported the net zero GHG emission pathways by 2050 (European Commission 2018).
- New Zealand has adopted by law a goal to reduce its greenhouse gas emissions to a near-neutral level by 2050 (New Zealand 2019).

[*Add other examples as they become available*]

Scenarios are stories told in words and numbers (Raskin et al. 2002). Much of the literature cited above on accelerating mitigation is based on quantitative modeling, drawing on socio-economic futures at global scale in SSPs (Schweizer and Kriegler 2012). Literary representations of future worlds have emerged in literature. Literary fiction can inform 'world-making' and make links between larger societal transformation and personal accounts of climate change (Nikoleris et al. 2017). Focus groups of Australian citizens create consistent futures, focused not on economic and material growth, but on inclusive, peaceful and equitable futures, sometimes frugal; the study is careful to indicate the views are not representative of the Australian population (Boschetti et al. 2014). Another study suggests that hope is an important practice in a volatile and potentially catastrophic age, and suggests that relations between humans and nature must both recognize human power and its embeddedness in material relations (Head 2016).

4.2.4.4 Assessment of multi-national and multi-model analysis

Chapter 3 reported on multi-model analyses of global emissions in the long term. At the national scale, multi-model analyses are still limited, though the multi-national analyses are growing. The following are examples of literature proposing country-level mitigation pathways in the near- to medium-term:

- DDPP (Deep Decarbonization Pathways Project) consists of 16 countries, and participated institutes in each country used their own models to estimate the deep decarbonisation pathways from the viewpoint of each country's perspective (Waisman et al. 2019).
- COMMIT (Climate pOlicy assessment and Mitigation Modelling to Integrate national and global Transition pathways) is also the research project in which many countries in the world attend to assess the country contributions to the target of the Paris Agreement (COMMIT 2019).
- Mitigation Action Plans and Scenarios (MAPS) with detailed studies of mitigation potential and socio-economic implications in Brazil, Chile, Colombia and Peru (La Rovere et al. 2018; Benavides et al. 2015; Zevallos et al. 2014; Delgado et al. 2014). The experiences of the MAPS programme suggests that co-production of knowledge by researchers and stakeholders strengthens the impact of research findings, and in depth studies of stakeholder engagement provide lessons (Boulle et al. 2015; Raubenheimer et al. 2015; Kane and Boulle 2018), which can assist building capacity for long-term planning in other contexts (Calfucoy et al. 2019).

- CD-LINKS (Linking Climate and Development Policies – Leveraging International Networks and Knowledge Sharing) explore the complex interplay between climate action and development at both the global scale and some national perspectives. The climate policies for G20 countries up to 2015 and some levels of the carbon budget are assessed for short-term and long-term, respectively (Rogelj et al. 2017b).

- National model comparisons were implemented such as for USA (Bistline et al. 2018) and Japan (Sugiyama et al. 2019b). From the model comparison, the range of future projections among the different models can be indicated.

- APERC (Asia Pacific Energy Research Centre) publishes the APEC Energy Demand and Supply Outlook regularly, and in the 7 edition, it covers 21 APEC countries, and by using the common framework, 2 degree scenario which follows the carbon emissions reduction pathway included in the International Energy Agency's Energy Technology Perspectives (IEA 2017) is assessed country by country (APERC 2019).

- Low-Carbon Asia Research Project covered the low carbon emission scenarios for several countries and cities in Asia (Matsuoka et al. 2013). The mitigation activities were summarized into 10 actions toward Low Carbon Asia to show a guideline to plan and implement the strategies for an LCS in Asia (Low-Carbon Asia Research Project 2012).

- CLIMACAP–LAMP is an inter-model comparison exercise that focused on energy and climate change mitigation in Latin America (Clarke et al. 2016). Results from both national models and global models are assessed in this project.

4.2.5 What is to be done to accelerate mitigation

Section 4.2.5 summarizes the lessons learned, notably in terms of technical content, from the mitigation pathways that go beyond the NDC in 2030 and further reduce emissions down in the medium-term.

4.2.5.1 Lessons from global mitigation pathways

As discussed in Chapter 3, global models reveal that deep, rapid greenhouse gas emissions reductions are needed to limit global temperature increase. A reasonable (66%) chance of limiting global temperature increases to well below 2°C depends on global energy-related carbon emissions peaking by 2020 and falling by more than 70% during the next 35 years (see chapter 3 and Cross-Chapter Box Comparison of NDCs and current policies with the 2030 GHG emissions from long-term temperature pathways, p.4-17). This implies, globally, a tripling of the annual rate of energy-efficiency improvement, retrofitting the entire building stock, cutting industry CO_2 emissions by 65-90% from 2020 level, generating 70 - 95% of electricity from low-carbon sources by 2050, and shifting almost entirely to electric cars (IRENA 2019; IPCC 2018b; Geels et al. 2018).

Transformative technological and institutional changes for the near-term include demand reductions through efficiency and reduced activity, rapid decarbonisation of the electricity sector and fuel switching in other sectors (*robust evidence, medium agreement*) (Van Vuuren et al. 2016; Bataille et al. 2018) (see Chapter 6). Figure 4.3 shows increasing share of renewable energy in several countries, contributing to decarbonization pathways, and shown in relation to various ranges. Yet very high shares of renewable electricity generation are projected for many countries with low renewable penetration today.

Countries/states that have made rapid progress include Scotland (target of 100% by 2020), Austria (2030) and Denmark (2035), see section 4.2.3, and some larger countries like Germany and states such as California have made significant progress. Other have ambitious long-term targets. Thus, an important component of rapid decarbonisation of the power sectors is illustrated in Figure 4.3.

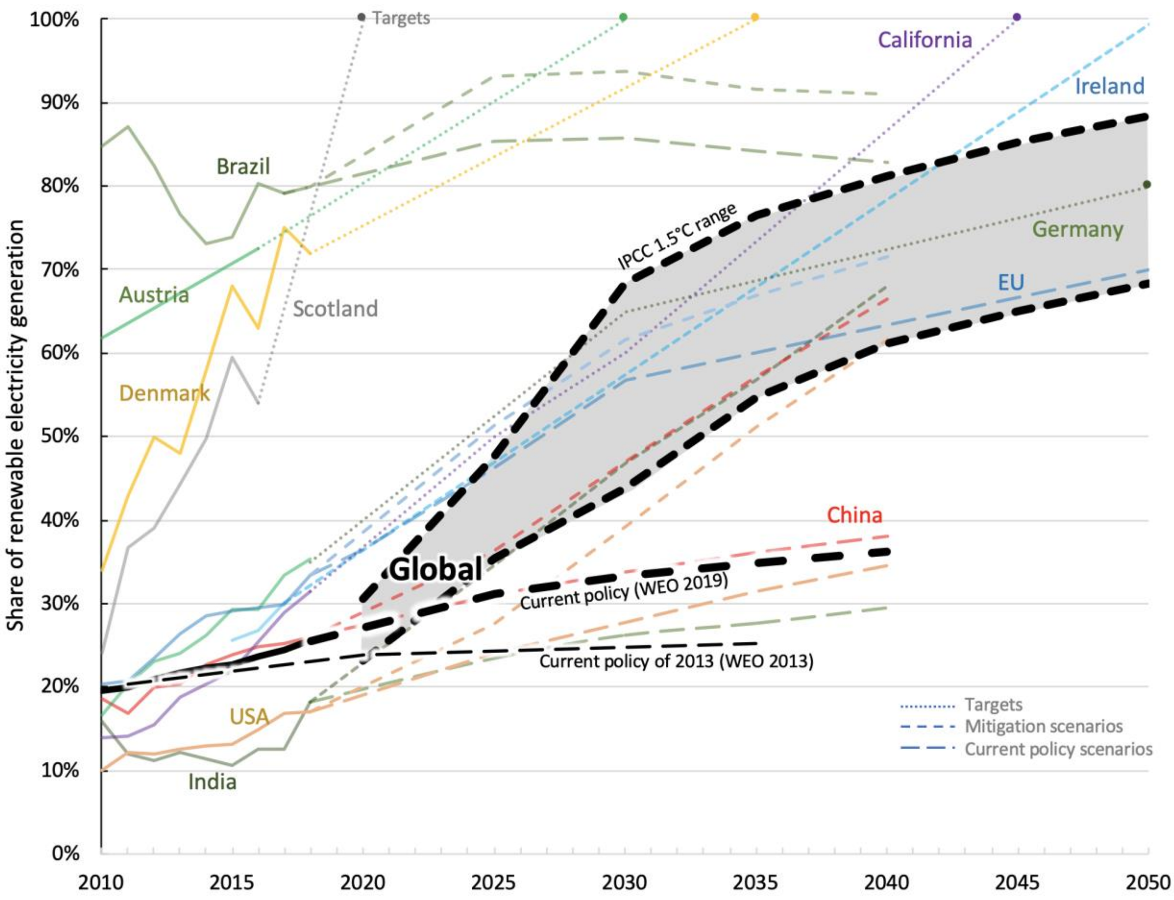

Figure 4.3. Historical and projected levels and targets for the share renewables in electricity generation. Sources: IEA energy balances for past trends, (Altieri et al. 2016; Chiodi et al. 2013; Elizondo et al. 2017; Jiang et al. 2016; Kuramochi et al. 2017; Oshiro et al. 2018; Vaillancourt et al. 2017; Vishwanathan et al. 2018). Global pathways are taken from IEA World Energy Outlook 2013 and 2019, IPCC 1.5°C Special Report (20th to 80th percentile of 1.5°C low and no overshoot scenarios) [*intend to add from IPCC AR6 scenario database for SOD*]

At national scale, a majority of the studies evaluate contributions towards 2˚C pathways, with most literature from countries in Asia (China, India, Japan); the European Union; North America; and South Africa and Brazil. Major characteristics of mitigation pathways are:

- Almost all papers address demand-side energy efficiency, conservation, and energy use; several studies emphasize industry and transport actions.
- Cleaner fuels, particularly renewable, non-fossil, and some biofuels, are seen as necessary in all research.
- Carbon capture and storage (CCS) is considered necessary in half of the papers reviewed (Ashina et al. 2012; Chilvers et al. 2017; Jiang et al. 2013; Kuramochi et al. 2017; Herreras Martínez et al. 2015; Massetti 2012; Mittal et al. 2018; Oshiro et al. 2018; Xunzhang et al. 2017; Roberts et al. 2018; Solano Rodriguez et al. 2017; Thepkhun et al. 2013; Vishwanathan et al. 2018).
- A few studies recognize the need for behaviour / lifestyle changes, particularly in transport through mode-shifting and reduced mobility demand (Aggarwal 2017; Ashina et al. 2012; Canzler and Wittowsky 2016; Dhar et al. 2018; Vishwanathan et al. 2018).

At global scale, 1.5˚C scenarios have focused on Asia (India, Japan, China, and Beijing City in China), see Table 4.5. In addition to the changes outlined above, scenarios typically include:

- Carbon dioxide (CO_2) removal (including CCS) to reduce emissions from sources with no identified mitigation measures and achieve necessary net negative emissions (Deetman et al. 2013; Massetti 2012; Solano Rodriguez et al. 2017).
- Bioenergy adoption (including hydrogen) alongside increased electrification and power-sector decarbonization (Ashina et al. 2012; Chilvers et al. 2017; Herreras Martínez et al. 2015; Massetti 2012; Oshiro et al. 2018; Vaillancourt et al. 2017).
- Electrification of industrial processes and adoption of fuel-cell vehicles and district heating and cooling in industry, transport, and building sectors (Ashina et al. 2012; Chiodi et al. 2013; Deetman et al. 2013; Fragkos et al. 2017; Massetti 2012; Mittal et al. 2018; Oshiro et al. 2017b; Oshiro et al. 2018; Saveyn et al. 2012; Vaillancourt et al. 2017; Zhou et al. 2019; Xunzhang et al. 2017).
- National and sectoral policies and explicit carbon prices to enable innovation (Dhar et al. 2018; Jiang et al. 2013; Oshiro et al. 2017a).
- Transforming human behaviour through information technology, the internet of things (IOT), and sharing-based economies (Aggarwal 2017; Ashina et al. 2012; Canzler and Wittowsky 2016; Dhar et al. 2018; Vishwanathan et al. 2018).

4.2.5.2 Country and Regional Pathways

This section describes insights on accelerating mitigation that can be drawn from literature on mitigation pathways in different regions and countries. **There is an increasing amount of accelerated mitigation pathways in the literature, and of mitigation plans that look to acceleration. There is increasing understanding of the technical content of accelerated mitigation pathways, differentiated by national circumstances. The literature, however, does not adequately include demand-side options, systems analysis, nor does it correctly reflect on non-CO2 GHGs (*robust evidence, medium agreement*).** Many papers are on European or Asian countries. Little research exists for Latin America, Africa, and Southeast Asia. Options vary by country and by goals (see Table 4.5).

Table 4.5. Summary of Mitigation Strategies by Region/Country

		Asia			Latin America	Africa	North America		EU			
		JPN	**CN**	**IND**	**Brazil**		**Canada**	**USA**	**EU**	**Ireland**	**Italy**	**UK**
Overarching	Reducing short-lived climate pollutants	Asia study										
	Information technology and IOT	X		X								
	Demand reduction (e.g., behaviour change)			X			X					80% reduction[iv]
	Shared economy	X		X								
Power sector	CCS	X	X	X	X		X			80-95% reduction[iii]	80-95% reduction[iii]	80% reduction[iv]
	Renewable targets	X	42% reduction[i]	X	X	X	X	X	95% reduction[ii]	80-95% reduction[iii]	80-95% reduction[iii]	80% reduction[iv]
	Waste to energy	X										

	Hydrogen	X		X								80% reduction[iv]
	Bioenergy	X			X		X				80-95% reduction[iii]	
Industry	CCS	X		X	X							
	Electrification		42% reduction[i]			X	X	X	95% reduction[ii]	80-95% reduction[iii]	80-95% reduction[iii]	
	Renewables		42% reduction[i]	X	X	X				80-95% reduction[iii]		
	Efficiency improvements	X	42% reduction[i]	X	X	X	X	X	95% reduction[ii]	80-95% reduction[iii]	80-95% reduction[iii]	80% reduction[iv]
Transport	Efficiency improvements	X	42% reduction[i]	X	X	X	X	X	95% reduction[ii]	80-95% reduction[iii]	80-95% reduction[iii]	80% reduction[iv]
	Fuel-cell vehicles	X		X								
	Mode shift	X	42% reduction[i]	X	X		X		95% reduction[ii]		80-95% reduction[iii]	
	Electrification	X	42% reduction[i]	X	X	X	X		95% reduction[ii]	80-95% reduction[iii]	80-95% reduction[iii]	80% reduction[iv]

	Biofuels	X	X	X	X		X		95% reduction[ii]	80-95% reduction[iii]		80% reduction[iv]
Buildings	Efficient appliances	X	42% reduction[i]	X		X	X	X	95% reduction[ii]	80-95% reduction[iii]	80-95% reduction[iii]	80% reduction[iv]
	Fuel switching and electrification	X	42% reduction[i]	X		X	X		95% reduction[ii]	80-95% reduction[iii]	80-95% reduction[iii]	80% reduction[iv]
	Better thermal insulation	X	42% reduction[i]	X			X			80-95% reduction[iii]		80% reduction[iv]
	District heating and cooling	X	42% reduction[i]									80% reduction[iv]
Agriculture and Forestry	Electrification						X					
	Land use				X							
References		(Oshiro et al. 2018; Kuramochi et al. 2017; Saveyn et al. 2012; Ashina et al. 2012;	(Jiang et al. 2013, 2016; Zhou et al. 2019; Xunzhang et al. 2017; Aggarwal 2017; Khanna et al. 2019; Zhou et al. 2018; Dong et al. 2018b)	(Vishwanathan et al. 2018b; Dhar et al. 2018; Mittal et al. 2018; Aggarwal 2017)	(Herreras Martínez et al. 2015a; Borba et al. 2012)	(Altieri et al. 2016; Ouedraogo 2017)	(Vaillancourt et al. 2017)	(Shahiduzzaman and Layton 2017)	(Hübler and Löschel 2013; Solano Rodriguez et al. 2017; Schiffer 2015;	(Chiodi et al. 2013)	(Massetti 2012)	(Chilvers et al. 2017; Roberts et al. 2018b)

		Oshiro et al. 2017a)							Deetman et al. 2013)			

Note: [i] 42% reduction in 2050 from 2010 levels [ii] 95% reduction in 2050 from 1990 levels [iii] 80-95% reduction in 2050 from 1990 levels; [iv] 80% reduction in 2050 from 1990 levels.

4.2.5.2.1 Asia

In Asia, regional concerns about health and air quality (air pollutants and short-lived climate pollutants [SLCPs] are drivers for aggressive climate-change mitigation. Demand-sector energy-efficiency improvements and supply-sector shifts to less-carbon-intensive or non-fossil fuels can address these concerns by meeting multiple objectives.

Limiting temperature rise to 1.5°C or 2°C requires efficiency improvements and fuel-switching (including electrification) but also demand reduction through behaviour changes and mode shifting that is less commonly included; and energy conservation through thermal insulation of buildings, CCS, and information technology and the IOT.

For example, in Japan, 1.5˚C or 80% emissions reduction by 2050 requires the newest technologies and transformative strategies. This means CCS and increased bioenergy adoption plus waste-to-energy and hydrogen-reforming from fossil fuel in the power sector (Ashina et al. 2012; Oshiro et al. 2017, 2018), fuel-cell technologies for buildings and transport, and use of information technology and IOT to transform human behavior and transition to a sharing economy.

In China, new technologies, policies, and strategies extend beyond the nuclear, renewable-energy, CCS, and energy-efficiency measures in most outlook studies. Seven to 10 CSS projects by 2020 and accelerated nuclear and renewable development are projected to be needed (Jiang et al. 2016;Jiang et al. 2013; Lee et al. 2018). Estimated investment of RMB 2.8 trillion is needed by 2020 / 2030, and RMB 2.9 trillion by 2050, equal to 5% of China's total GDP in 2020, 1.3% in 2030, and 0.6% in 2050 (Jiang et al. 2016). On the demand side, non-conventional electrical and renewable technologies, particularly in the industrial sector, are needed to reduce CO_2 (Khanna et al. 2019; Zhou et al. 2019).

In India, electrification, hydrogen, and biofuels are key to decarbonizing the transport sector Dhar et al. 2018; Mittal et al. 2018; Vishwanathan et al. 2018), and renewable energy and CCS are needed in the power and industrial sectors. Demand-sector strategies include use of information technology and the internet, a transition to a sharing economy, and increasing infrastructure investment (Dhar et al. 2018; Vishwanathan et al. 2018). Behavior and lifestyle change along with stakeholder integration in decision-making are considered key to implementing new transport policies (Aggarwal 2017; Dhar et al. 2018).

Research on Southeast Asia has focused on supply-side strategies including CCS, but reducing CO_2 emissions will also enhance energy security, reduce import dependence, and improve air quality (Thepkhun et al. 2013).

4.2.5.2.2 Latin America

In Brazil, most of the energy is used in transport and industry sector, as well as future growth thus the mitigation strategies has also focused on the two combined with electricity generation sector (Guerra et al. 2015). Without accelerated policy effort the emissions can increase 2-3.5 fold, but technologically models show that the emission levels below that of 2010 is feasible (Lucena et al. 2016). In addition to demand reduction, the power sector offers the greatest supply-side mitigation opportunities. CCS, BioCCS including in the industrial sector, is a promising low-carbon option along with replacing fossil fuels with bioenergy, hydroelectric, biomass, solar and wind (Herreras Martínez et al. 2015; Lucena et al. 2016; Borba et al. 2012). Demand-side changes focus on biofuels and mode shifting in transport (Borba et al. 2012). Although not having a significant role, nuclear energy is part of the solution (Lucena et al. 2016). Under cost optimization scenarios, renewable energy including biomass could account for more than 30% of total electricity generation and in a high tax scenario, the CO2 emission reductions could exceed 50% (Nogueira de Oliveira et al. 2016) , indicating policy intervention needs to happen to achieve accelerated transitions. It is worth noting that separate from the technological solutions, recent government reversals of deforestation governance could impose new risks to meeting the 2°C targets (Rochedo et al. 2018).

As in other parts of the region, the costs of electricity generation are an important factor in Chile. One study found an increase of 8.3 and 9.6 USD/MWh in the electricity price when modeling a USD 20/tCO_2-eq carbon tax, with mitigation between 1.1 and 9.1 million tCO_2-eq per year on average (Benavides et al. 2015). A study of nationally appropriate mitigation actions (NAMAs) in Peru found efficient lighting the most advanced NAMA, yet still in the 'readiness' phase in 2014 (Zevallos et al. 2014). Comparative analysis of NAMAs in Brazil, Colombia, Chile, Peru and South Africa suggests that the character, scope, policy horizon and potential success of an action are closely linked to the developmental path of countries and consequently that mitigation actions directly address development objectives would have a better chance of being implemented (Garibaldi et al. 2014).

4.2.5.2.3 Africa

Unlike other regions, Africa has a key development goal to expand energy access. This implies substantial future CO2 emissions growth (~10% annually) from increased electrification. The region currently uses few renewable and non-fossil fuels (Ouedraogo 2017). Key strategies for combating CO2 emissions growth include improving industry and building energy efficiency and more use renewables including biomass (Altieri et al. 2016; Ouedraogo 2017). For South Africa to achieve development and mitigation objectives through a rapid decarbonisation strategy, the electricity sector needs to decarbonize by retiring coal-fired power plants or replacing them with solar PV, and wind generation; CCS is not considered feasible (Altieri et al. 2016).

4.2.5.2.4 North America

For Canada to achieve the 2°C goal, space and water heating, road transport, and industrial and agricultural processes must be electrified (Vaillancourt et al. 2017).

For the USA to meet its Paris Agreement target requires significant fuel switching away from coal, e.g., to gas for industrial use and nuclear and renewables for electricity generation (Shahiduzzaman and Layton 2017).

4.2.5.2.5 Europe

France's mitigations focus on biofuel and possible increases in fossil energy taxes (Doumax-Tagliavini and Sarasa 2018).

In Germany, one study points to the transportation sector, including electromobility information and communication technologies, as key (Canzler and Wittowsky 2016). Other research (Schmid and Knopf 2012) suggests that reducing CO_2 emission by 95% in 2050 compared to 1990 levels requires: widespread electrification of private vehicles by 2030, phase-out of coal by 2020, shift from road to rail transport, reduced distances travelled, large-scale renewable generation, and a fourfold increase in the energy-efficiency growth rate.

For Ireland, achieving 80%-95% emissions reduction below 1990 levels by 2050 requires changes in energy technology, efficiency, and renewables use. This includes shifting to biofuels and electric vehicles, improving building envelopes, fuel switching for residential buildings, and replacing service-sector coal use with gas and renewables. Mitigation costs are estimated to be less than 2% of GDP in 2050 (Chiodi et al. 2013).

For Italy, zero-emission electricity is achievable with a combination of renewable and nuclear energy; and coal, natural gas, and biomass equipped with CCS (Massetti 2012).

For the UK, power sector decarbonization and low-carbon electricity for heating and transport are insufficient to reduce emissions to zero by 2050. Additional strategies are improved insulation to reduce energy demand; efficient building appliances and heating systems; and supply-sector transformation with CCS, hydrogen, and community-scale solutions (Chilvers et al. 2017; Roberts et al. 2018).

For the EU, 80% emissions reduction requires shifting to renewable energy – including biomass, wind, and solar – and buildings- and transport-sector strategies that are less costly than using CCS in electricity generation and industry (Hübler and Löschel 2013; Solano Rodriguez et al. 2017). Reducing emissions by 80% by 2050 will require EU-wide, rather than individual-country, solutions. Member countries need to agree on minimum-cost targets. The expected 1,000-TWh growth in EU electricity consumption by 2050 can be met by renewable energy sources if trade in emissions is employed. This could double the share of renewables to about 50% by 2050. After 2030, with rising CO_2 prices, CCS also becomes profitable (Schiffer 2015).

4.2.5.3 Near- and medium-term opportunities to accelerate the scale and pace of mitigation

Despite the insights it provides, the deep mitigation pathway literature assessed above still does not fully capture important opportunities to accelerate mitigation. This section explores literature on the demand side (4.2.5.3.1), systems thinking (4.2.5.3.2), and cost assessment (4.2.5.3). Links to other development goals, such as local pollution, which can be significant (see 4.3.3.4) are also rarely included. These issues are addressed in other strands of the literature, but there is no or limited connection to the pathway literature.

4.2.5.3.1 Lowering Demand, Downscaling Economies

Studies have identified technological and policy pathways to 2˚C and 1.5˚C targets, but most focus on supply-side options, including negative emissions technologies (CCS and others) that are not fully commercialized. Costs to research, deploy, and scale up these technologies are often high; higher carbon prices are a key policy to meet these costs. Recent studies have addressed lowering demand through energy conversion efficiency improvements, but few studies have considered demand reduction through efficiency (Grubler et al. 2018) and the related supply implications and mitigation measures.

Five main drivers of long-term energy demand reduction that can meet the 1.5˚C target include quality of life, urbanization, novel energy services, diversification of end-user roles, and information innovation (Grubler et al. 2018). A low-energy-demand scenario requires fundamental societal and institutional transformation from current patterns of consumption, including: decentralized services and increased granularity (small-scale, low-cost technologies to provide decentralized services), use value from services (multi-use vs. single use), sharing economies, digitalization, and rapid transformation driven by end-user demand. This approach to transformation differs from the status quo and current climate change policies in emphasizing energy end-use and services first, with downstream effects driving intermediate and upstream structural change.

Radical low carbon innovation involves systemic, cultural, and policy changes and acceptance of uncertainty in the beginning stages. However, the current dominant analytical perspectives are grounded in neoclassical economics and social psychology, and focus primarily on marginal changes rather than radical transformations (Geels et al. 2018). Some literature is beginning to focus on mitigation through behavior and lifestyle changes, but specific policy measures for supporting such changes and their contribution to emission reductions remain unclear (see also Section 4.4.2 and Chapter 5).

4.2.5.3.2 System Analysis

Most models and studies fail to address system impacts of widespread new technology deployment, for example: 1) material and resources needed for hydrogen production or additional emissions and energy required to transport hydrogen (Japan's policy); or 2) materials, resources, grid integration, and generation capacity expansion limits of a largely decarbonized power sector and electrified transport sector. These impacts could limit regional and national scale-ups.

Systemic solutions are also not being sufficiently discussed, such as low-carbon materials; light-weighting of buildings, transport, and industrial equipment; and addressing the food-energy-water nexus. These solutions reduce demand in multiple sectors, improve overall supply chain efficiency, and require cross-sector policies. Using fewer building materials could reduce need for cement, steel, and other materials and thus need for production and freight transport.

Increased bioenergy consumption is considered in many 1.5˚C and 2˚C scenarios. System thinking is needed to evaluate bioenergy's viability because increased demand could affect land and water availability, food prices, and trade (Sharmina et al. 2016). To adequately address the energy-water-food nexus, policies and models must consider interconnections, synergies, and trade-offs among and within sectors, which is currently not the norm.

A systems approach is also needed to support technological innovation. This includes recognizing unintended consequences of political support mechanisms for technology adoption and restructuring current incentives to realize multi-sector benefits. It also entails assimilating knowledge from multiple sources as a basis for policy and decision-making (Hoolohan et al. 2018).

Current literature does not explicitly consider systematic, physical drivers of inertia, such as capital and infrastructure needed to support accelerated mitigation (Pfeiffer et al. 2018). This makes it difficult to understand what is needed to successfully shift from current limited mitigation actions to significant transformations needed to rapidly achieve deep mitigation.

4.2.5.3.3 Short-lived pollutants

Climate change mitigation and reduction of SLCPs are mutually compatible objectives. Recent research shows that temperature increases are likely to exceed 1.5°C during the 2030s and 2°C by mid-century unless both CO_2 and SLCPs are reduced (Shindell et al. 2017; Rogelj et al. 2018a). In Asia especially, co-benefits of drastic CO_2 mitigation measures are reduced emissions of methane, black carbon, sulphur dioxide, nitrogen oxide, and fine particulate matter by approximately 23%, 63%, 73%, 27%, and 65% respectively in 2050 as compared to 2010. levels These co-benefits are much larger than effects of measures that only reduce air pollutants (Hanaoka and Masui 2018).

Rapid SLCP reductions, specifically of methane, black carbon, and tropospheric ozone, have immediate co-benefits including meeting sustainable development goals for reducing health burdens of household air pollution and reversing health- and crop-damaging tropospheric ozone. SLCP mitigation measures can have regional impacts, including avoiding premature deaths in Asia and Africa and warming in central and Northern Asia, southern Africa, and the Mediterranean (Shindell et al. 2012). Reducing outdoor air pollution could avoid 2.4 million premature deaths and 52 million tonnes of crop losses for four major staples (Haines et al. 2017). Existing research emphasizes climate and agriculture benefits of methane mitigation measures with relatively small human health benefits. Research also predicts that black carbon mitigation could substantially benefit global climate and human health, but there is more uncertainty about these outcomes than about some other predictions. Other longer-term co-benefits of SLCP reduction include slowing the amplifying feedback in climate change, reducing risk of non-linear changes, and reducing long-term cumulative climate impacts and mitigation costs (Rogelj et al. 2018a).

4.2.5.3.4 Kigali impact

An example of co-benefits and close linkage between SLCP and climate change mitigation is the simultaneous improvement in energy efficiency in refrigeration and air-conditioning equipment during the hydrofluorocarbon (HFC) phase-down, as recognized in the Kigali Amendment to the Montreal Protocol. The Kigali Amendment and related national and regional regulations are projected to reduce future radiative forcing from HFCs by about half in 2050 compared to a scenario without any HFC controls, and to reduce future global average warming in 2100 from a baseline of 0.3-0.5°C to less than 0.1°C, according to a recent scientific assessment of a wide literature (World Meteorological Organization (WMO) 2018). The rapid phase-down of HFCs under the Kigali Amendment is possible because of extensive replacement of high-global-warming-potential (GWP) HFCs with commercially available low-GWP alternatives in refrigeration and air-conditioning equipment. Each country's choices of alternative refrigerants will likely be determined by energy efficiency, costs, and refrigerant toxicity and flammability. National and regional regulations will be needed to drive technological innovation and development (Polonara et al. 2017).

4.2.5.3.5 Lack of cost and co-benefit estimates

Despite potentially significant implications of mitigations for development objectives (see Section 4.3.3), only a few studies have evaluated total costs and co-benefits (Chiodi et al. 2013; Jiang et al. 2016). The cost of not employing mitigations has not been assessed at all, and information is lacking on societal and environmental costs of insufficient mitigation.

Finally, a large share of accelerated mitigation pathways is analysed using techno-economic or partial equilibrium models (see Annex C) that do not capture the economy-wide consequences of mitigation. Those can be significant (Pollitt et al. 2015), as discussed in section 4.3.3.

4.3 Development pathways and mitigation options

4.3.1 Framing of development pathways

4.3.1.1 What are development pathways?

The term *development pathway* is defined in various ways in the literature (see Table 4.6 below), but generally these definitions refer to the evolution over time of a society's defining features.
A society's development pathway can be described, analysed, and explained from a variety of perspectives, capturing a range of possible features, trends, processes, and mechanisms. It can be examined in terms of specific quantitative indicators, such as population, urbanization level, life expectancy, literacy rate, GDP, carbon dioxide emission rate, average surface temperature, etc. Alternately, it can be described with reference to trends and shifts in broad socio-political or cultural features, such as democratization, liberalization, colonization, globalization, consumerism, etc. Or, it can be described in a way that highlights and details a particular domain of interest; for example, as an "economic pathway" , "technological pathway", "demographic pathway", or others. Any such focused pathway is more limited, by definition, than the more general and encompassing notion of a development pathway.

Being representations of the evolution over time, development pathways can be discussed retrospectively, viewing trends in a historical light, or prospectively, anticipating possible future pathways. Development pathways, and specifically prospective development pathways, can reflect societal objectives, as in "low-emission development pathways", "climate-resilient development pathways", "sustainable development pathways", and as such can explicitly embed normative assumptions or preferences. A national development plan (see Section 4.3.2) is a representation of a possible development pathway for a given society.

While a particular choice of how to characterize a development pathway is made in light of the specific features one is interested in examining, it is also influenced by our explicit and implicit priorities, values, disciplinary backgrounds, and political world views. The process of defining and describing a society's development pathway in fact contributes to the ongoing process of understanding, explaining and defining the historical and contemporary meaning and significance of a society. Narratives of development are thus important in shaping a society's development pathways. Different framings of development pathways influence society's understanding of the conceivable spectrum of its future options and prospects, and include framings such as economic growth, shifts in industrial structure, technological innovations, reframing stories of development (from growth to well-being, see Chapter 5) and making development more sustainable (see Chapters 1 and 17).

Scenario exercises are structured undertakings to improve understanding of alternative future development pathways, often drawing on stakeholder input and accepting the deep and irreducible uncertainty inherent in societal development into the future. It helps improve understanding of constraints, trade-offs, and choices. “Scenario analysis offers a structured approach for illuminating the vast range of possibilities. A scenario is a story, told in words and numbers, describing the way events might unfold. If constructed with rigor and imagination, scenarios help us to explore where we might be headed, but more, offering guidance on how to act now to direct the flow of events toward a desirable future” (Raskin et al. 2002). Scenario exercises are effective when they enable multi-dimensional assessment, and accommodate divergent normative viewpoints (Kowarsch et al. 2017). They are valuable for the quantitative and qualitative insights they can provide, and also for the role they can play in providing a forum and process by which diverse and even mutual antagonistic stakeholders can come together, build trust, improve understanding, and ultimately converge in their objectives.

There are many studies aimed at describing development pathways through scenario exercises, some examples of which are given in Table 4.6.

Table 4.6 Development pathways at global, national and local scale

Scale	**Process and publication**	**Description of development pathways**
Global	IPCC Special Report on Emission Scenarios (Nakicenovic et al. 2000)	Four different narrative storylines describing relationships between emission driving forces and their evolution over the 21st century.
Global	Shared Socioeconomic Pathways (Riahi et al. 2017)	Five narratives describing alternative socio-economic developments, including sustainable development, regional rivalry, inequality, fossil-fueled development, and middle-of-the-road development, using long-term demographic and economic projections reflecting the wide uncertainty range found in the scenario literature.
Global	Futures of Work (World Economic Forum 2018)	Eight possible visions of the future of work in the year 2030, based on different combinations of three core variables: the rate of technological change and its impact on business models, the evolution of learning among the current and future workforce, and the magnitude of talent mobility across geographies—are likely to influence the nature of work in the future,
National	Mt Fleur Scenarios (Galer 2004)	Four socio-political scenarios intended to explore possible futures of a newly post-apartheid South Africa, which included three dark prophecies and one bright vision which reportedly influenced the new leadership.
National	Mitigation Action Plans and Scenarios (MAPS) (Winkler et al. 2017; Raubenheimer et al. 2015)	Mitigation and development-focused scenarios modeling including socio-economic implications for Brazil, Chile, Peru, and Colombia, linked sectoral and economy modeling combined with intensive stakeholder engagement.
National	Deep Decarbonization Pathways (Waisman et al. 2019)	Mitigation-focused scenarios for sixteen countries from each country’s perspective, carried out by local institutes using domestic models.
Local	New Lenses on Future Cities (Shell Global 2014)	Six city archetypes used to create scenarios to help understand how cities could evolve through more sustainable urbanisation processes and become more efficient, and have coped with major development challenges in the past.

4.3.1.2 Shifting development pathways

Development pathways evolve as the result of the countless decisions being made and actions being taken at all levels of societal structure, as well due to the emergent dynamics within and between institutions, cultural norms, technological systems, and the biogeophysical environment. Society seeks to make decisions and take actions that influence the future development pathway when it endeavours to achieve certain outcomes. At the global scale, examples include the goals of the Paris Agreements, the SDGs, or increased equality, complemented by seeking to avoid other outcomes, such as catastrophic climate change, recalcitrant poverty, or socioeconomically harmful biodiversity loss (Steffen et al. 2015). At the national and local scales, similar objectives may apply, such as a country's Nationally Determined Contribution (see section 4.2), or efforts that are consistent with it at the sub-national scale (Hsu et al. 2017).

In the case where **transformative changes are made that substantively disrupt existing developmental trends (such as stubbornly rising GHG emissions, structural inequality, or long-standing behavioural preferences) can be referred to as *shifting development pathway***s. Section 4.4 examines the process by which societies may aim to shift development pathways.

The multiple sustainability challenges (Steffen et al. 2015) facing humankind are of diverse forms. Ecological sustainability challenges include reducing GHG emissions, protecting the ozone, controlling pollutants such as aerosols and persistent organics, managing nitrogen and phosphorous cycles, etc. The response of the global community is reflected in the SDGs, and the interactions for 17 goals have been systematically studied (Pradhan et al. 2017) and a set of indicators have been developed (United Nations 2018). Socioeconomic sustainability challenges include conflict, persistent poverty, and socially corrosive inequality, elaborated more fully in the SDGs. Evidence suggests that effectively treating them in isolation as independent technical challenges is unlikely. This suggests identifying *ultimate drivers* that are impelling society along a development pathway that is vulnerable to multiple stainability challenges.

The drivers can be understood under the categories of enabling conditions, as elaborated in section 4.4.2 and Figure 4.5: governance, institutions, behaviour, innovation, policy and finance. The first three categories tend to refer to *ultimate drivers*, the latter three to more *proximate drivers* (Raskin 2000). These, in turn, are fluid and evolve over time, and are amenable to intentional change, to greater or lesser degrees and over longer or shorter time scales, based on a range of different measures and processes. Bringing about intentional changes in these ultimate drivers requires taking action to put in in place the *enabling conditions* that can facilitate change in a positive direction (see section 4.4). **In sum, though development pathways result from the actions of a wide range of actors, it is possible to shift development pathways through policies and enhancing enabling conditions (*limited evidence, medium agreement*).**

4.3.2 Implications of development pathways for mitigation and adaptation

4.3.2.1 Key development priorities for countries

At the global level, the Sustainable Development Goals (SDGs) adopted by all the United Nations Member States in 2015 are delineated with a view to end poverty, protect the planet and ensure that all people enjoy peace and prosperity by 2030. The 17 SDGs are integrated and imply that development must balance social, economic and environmental sustainability. However, national development priorities differ across regions/countries and also over time being strongly linked to the local contexts within which improvement in well-being of people needs to be understood as the central objective. While economic growth is generally seen as a key development driver, national priorities arise in response to multiple objectives ranging from poverty eradication to providing energy access, addressing concerns of inequality, education, health, clean air, water and jobs among others.

Income inequality persists globally and exists both across and within countries. For example, data indicates that the poorest 5% of Americans have the same income as the richest 5% of Indians (about USD 3000-4000 per month) (Milanovic 2012). As a result, eradicating poverty and reducing inequality is a development priority in many countries, such as Brazil (Grottera et al. 2017a), Indonesia (Irfany and Klasen 2017) or South Africa (Winkler 2018). Also, inequality relates not only to income, but also to other dimensions such as in access to energy services (Tait 2017). High and inclusive growth, energy access and employment feature as key development priority elements within India's Nationally Determined Contributions (GoI 2015). Further, the priority of poor countries and communities with low capacities to adapt, is to focus on zero poverty and zero impacts rather than zero carbon.

Accordingly, influencing a societies' development pathways draws upon a broader range of policies and other efforts than narrowly influencing mitigation pathways, to be able to achieve the multiple objectives of reducing poverty, inequality and GHG emissions. For instance, job creation and education are important elements that could play a key role in reducing inequality and poverty in developing countries like South Africa and India (Winkler et al. 2015a) (Rao and Min 2018), these also open up broader opportunities for mitigation.

4.3.2.2 Review of national development plans and assessment of literature about national development goals

There is evidence that Governments are increasingly resorting to development of national plans to build institutions, resources, risk/shock management capabilities to achieve national development. The number of countries with a national development plan has more than doubled, from about 62 in 2006 (Bank 2007) to 134 national development plans published between 2012-2018, indicating an enhanced comeback of the relevance of the practice possibly due to the need to plan for Sustainable Development Goals and therefore involve state and civil society in preparing and implementing plans at all levels of governance. Boxes 4.1, 4.2 and 4.3 provide brief descriptions of the latest national plans of China, India and South Africa respectively, that all intend to tie in multiple development priorities.

A systematic assessment of 107 national development plans and 10 country case studies provides useful insights regarding the type and content of the plans (Chimhowu et al. 2019). Some regions such as the Soviet Union moved away from national development plans while other countries like India, China, Malaysia continued this practice even in the wake of liberalisation. Various initiatives such as the World Summit for Children in 1990; the Heavily Indebted Poor Country initiative that started offering debt relief in exchange for commitments by beneficiary states to invest in health, education, nutrition and poverty reduction in 1996; and push towards Comprehensive Development Frameworks seem to have catalyzed the development of national actions plans across countries to estimate, measure and track investments and progress. Complexity science has over the years argued for new forms of planning based on contingency, behavior change, adaptation and constant learning (Colander and Kupers 2016); (Ramalingam 2013) and is increasingly focused on increasing resilience of individuals, organizations and systems (Hummelbrunner and Jones). Additionally there is rising interest in government failure, rent seeking and other aspects of the liberal critique of state driven development (Chimhowu et al. 2019).

Box 4.1 India's national development plan and mitigation

India's initial national development plans focused on improving the living standards of its people, increasing national income and food self-sufficiency. Accordingly, there was a thrust towards enhancing productivity of the agricultural and industrial sectors. While the main focus was towards maintaining high economic growth and industrial productivity in the successive plans, the elements of poverty eradication, employment generation and inclusive growth remained important priorities. The

12th Five Year Plan for the first time brought in a focus on sustainability and mentioned the need for faster, sustainable and inclusive growth. In recent times the focus of development has become even more broad based and India seeks to create a New India by 2022 in which the vision is the creation of an ecosystem which enables every Indian to reach his or her full potential. Accordingly the Strategy for New India @ 75 focuses on bringing innovation, technology, enterprise and efficient management together at the core of policy formulation and implementation (Government of India 2018). Development is envisaged as a mass movement wherein every individual experiences benefits in terms of better ease of living. Rapid growth with inclusion is envisaged such that policy making is rooted in Indian ground realities and emphasizes the welfare of all in both design and implementation.

However, inequality as measured by the Gini coefficient has increased in India in the last few years. Also, with a large and growing population, generating adequate employment is a key development priority. At the same time, the cities are increasingly facing critical levels of local air pollution, traffic congestion and issues of waste disposal. There is evidence that socio-economic development objectives can go hand in hand with meeting Paris agreement goals. Development strategies/pathways can be carefully designed so as to align towards multiple priorities and achieve greater synergistic benefits. For example, India’s solar programme is a key element in its NDC that could not only provide energy security and contribute to mitigation, but could simultaneously contribute to economic growth, improved energy access and additional employment opportunities, if policies and measures are carefully planned and implemented.

India’s recent development strategy has a strong focus on achieving broad-based economic growth to ensure balanced development across all regions and states and across sectors. There is a thrust on embracing new technologies while fostering innovation and upskilling, modernization of agriculture, improving regional and inter-personal equity, and bridging the gap between public and private sector performance, by focusing on efficient delivery of public services, rooting out corruption and black economy, formalizing the economy and expanding the tax base, improving the ease of doing business, nursing the stressed commercial banking sector back to a healthy state, and stopping leakages through direct benefit transfers, among other measures (Govt. of India 2018); (Government of India 2018).

Box 4.2 China’s five-year plans plan and mitigation

Similarly in China, apart from focusing on objectives of addressing poverty, health, education and public well-being of its people, China’s 13th 5 Year Plan puts down a thrust on modernization of agriculture, industry and infrastructure, new forms of urbanization and a clear intent of focusing on innovation and new drivers of development to proactively adapt to, understand and guide the new normal in economic development and comprehensively advance innovative, coordinated, green, open, and shared development so as to ensure that a moderately prosperous society is established in all respects (Central Compilation & Translation Press 2016).

The development and formulation of national plans can be viewed as an organised, conscious and continual attempt to select the best available alternatives to achieve specific goals or as a process of ongoing social deliberation with constant (re)negotiation of goals, policies and actions across communities and citizenries so that choices made are technically desirable and politically feasible.

Box 4.3 South Africa’s National Development Plan

South Africa adopted its first National Development Plan (NDP) in 2011 (NPC 2011), the same year in which the country adopted climate policy (RSA 2011) and hosted COP17 in Durban. Chapter 5 of the

NDP address environmental sustainability in the context of development planning, and specifically "an equitable transition to a low-carbon economy" (NPC 2011). The chapter refers explicitly to the need for a just transition, protecting the poor from impacts and any transitional costs from emissions-intensive to low-carbon. The plan proposes several mitigation measures, including a carbon budgeting approach, reference to Treasury's carbon tax, and the integrated resource plan for electricity. The NDP refers to coal in several chapters, in some places suggesting additional investment (including new rail lines to transport coal and coal to liquids), in others decommissioning coal-fired power "Procuring at least 20 000MW of renewable electricity by 2030, importing electricity from the region, decommissioning 11 000MW of ageing coal-fired power stations and stepping up investments in energy-efficiency" (NPC 2011: p.46). Reference to environmental sustainability is not limited to chapter 5 – the introductory vision statement includes acknowledgement "that each and every one of us is intimately and inextricably of this earth with its beauty and life-giving sources; that our lives on earth are both enriched and complicated by what we have contributed to its condition" (NPC 2011: p. 21); and the overview of the plan includes a section on climate change, addressing both mitigation and adaptation.

4.3.2.3 The link between development pathways and emissions

When it comes to climate mitigation, much of the attention seems to be focused on stabilization of GHG concentrations rather than the objective of making development more sustainable (Munasinghe 2007). Considerable literature has focused on the debate of how emission reduction must be approached and whether a "climate first" or a "development first" approach is ideal for moving forward to solve the problem (Davidson et al. 2003).

Analysis in the mitigation literature often frames mitigation policy as having development co-benefits, with the main objective being climate stabilization. This misses the point that development drives emissions, and not vice versa, and it is the overall development approach and policies that determine mitigation pathways. Moreover, interaction between, mitigation, adaptation and climate impacts are also often ignored (Valadkhani et al. 2016). Also, while mitigation pathways could have development co-benefits/synergies, they can also have tradeoffs.

However, it is increasingly clear that politically, climate change must be understood as a development problem (Winkler et al. 2015a). There is a vast body of literature supporting the fact that development pathways and policies have direct and – just as importantly – indirect implications for GHGs and the ability to adapt to climate change impacts (IPCC 2000), (Winkler 2017b). For example, development pathway that focuses on enhancing economic growth based on accelerated growth in manufacturing is likely to have a very different mitigation challenge as compared to one which focuses on services led growth. Similarly, development that encourages concentrated influx of people to large urban centres can have very different energy and infrastructure consumption patterns as opposed to development of smaller self-contained towns and cities.

Given that different development pathways can lead to different levels of GHG emissions, development can be made more sustainable by adapting technological innovation systems to focus more on socio-economic goals, adopting models of economic growth that enable equitable distribution, and using appropriate incentives/disincentives to enable behavior change towards environmental stewardship among other measures that can contribute to mitigation while ensuring a just transition. The implications for employment, education, mobility, housing and many other development aspects must be integrated and new ways of looking at development pathways which are low carbon must be considered. (Winkler 2017b).

Different development pathways can simultaneously alter the level of mitigation and adaptation challenges for a society. Literature suggests that if development pathways are to be changed to address the climate change problem, choices that would need to be made about development pathways would not be marginal (Stern and Professor 2009), and would require a new social contract to address a complex set of inter-linkages across sectors, classes and the whole economy (Winkler 2017b). The necessary transformational changes can be positive if it is rooted in the development aspirations of the economy and society in which it takes place (Dubash 2012) (Jones et al. 2013), though it can also lead to carbon colonialism if the transformation is imposed by Northern donors.

In sum, **development pathways can lead to different emission levels and mitigation challenges (*medium evidence, high agreement*)**. Thus, focusing on shifting development pathways can lead to larger systemic sustainability benefits.

4.3.2.4 Drivers of CO_2 emissions

There are several studies that have attempted to analyse the relationships between CO_2 emissions and development indicators with varying results.

Some studies examining the main factors driving CO_2 emissions strongly point to economic output being the most important and dominant positive driving factor, while energy intensity is the most dominant negative driving factor (Wang and Feng 2017) (Lin and Liu 2015). However, there are also several studies that indicate divergences (Chen et al. 2018a). (Sumabat et al. 2016) indicate that economic growth had a negative impact on CO_2 emissions in Philippines. (Baek and Gweisah 2013) found that CO_2 emissions tended to drop monotonously as incomes increased. (Lantz and Feng 2006) also indicate that per capita GDP is not related to CO_2 emissions. (Chen et al. 2018a) indicated that CO_2 emissions in China industry significantly reduced due to improvement in energy intensity. (Valadkhani et al. 2016) indicate that there is a large body of literature suggesting that the most significant driver of CO_2 emissions is GDP growth followed by population. Other studies indicate an emerging consensus that the relationship between CO_2 emissions and economic indicators depends on the level of development of countries (Nguyen and Kakinaka 2019) (Sharma 2011).

Some studies found that GDP per capita and urbanization are two main determinants of CO_2 emissions in the global panel, while other variables like trade openness, per capita total primary energy consumption, per capita electricity consumption etc. have statistically insignificant effects on CO_2 emissions (Sharma 2011). The policy implication of this study seemed to indicate that GDP per capita of only the high income countries led to more carbon dioxide emissions, and that these countries should pursue energy conservation policies in order to reduce emissions.

Several studies have examined the relationships between CO_2 emissions with income, renewable energy consumption, other primary energy consumption and population growth across countries in a particular region (25 African countries – (Zoundi 2017)).

There is also a large body of literature focusing on the compatibility of climate change mitigation! and economic inequality (Baek and Gweisah 2013)(Berthe and Elie 2015)(Grunewald et al. 2017a)(Hao et al. 2016)(Wiedenhofer et al. 2017)(Auffhammer and Wolfram 2014). However, the use of narrow approaches or simple methods of studying the relationships of income inequality and emissions by looking at correlations, may miss important linkages. The influence of inequality on social values such as status and civic mindedness and nonpolitical interests that shape environmental policy can influence overall consumption and its environmental impacts (Berthe and Elie 2015).

4.3.2.5 Making development more sustainable

A strong body of literature focusing on the "new normal" as a system with higher quality growth and focusing on "innovative development pathways" is emerging in recent times. These studies are increasingly seeking answers to questions like what innovation is needed to follow development

pathways that reduce inequality and GHG emissions (Zou et al. 2016). There is much discussion on the need for a new approach and frameworks that move towards systems thinking and provide a perspective on global innovation of development pathways (Zou et al. 2016).
Changing development pathways requires new ways of thinking with interdisciplinary research and use of alternative frameworks and methods suited for understanding of change agents, determinants of change and adaptive management among other issues (Winkler 2018). For instance, thinking about development pathways in a holistic and integrated manner with conscious efforts to promote health, nutrition and education can enhance the resilience of societies to the impacts of climate change.

Also, climate policy is not a self-control mechanism in the development system, and methods that back cast from development goals need to be improved.

In terms of the approaches/frameworks, tools that are used to examine different emission pathways are often unable to adequately represent many key development goals, and accept GDP growth as a wholly encompassing proxy for broader development and societal well-being. Accordingly, such models may capture only some dimensions of development that are relevant for mitigation options – ignoring distributional aspects and consistency with broader developmental goals (Valadkhani et al. 2016). Quantitative tools for assessing mitigation pathways could be more helpful if they could provide information on a broader range of development indicators, and moreover could model substantively different alternative development paths, and thereby provide information on which levers might shift development in a more sustainable direction.

Increasingly, alternative tools have been developed in the Mitigation Action Plans and Scenarios (MAPS) community (La Rovere et al. 2014b), but need to be further mainstreamed in the analysis (Shukla). The climate research community has developed Shared Socio-economic pathways (SSPs) that link several socio-economic drivers including equity in relation to welfare, resources, institutions, governance and climate mitigation policies in order to reflect many of the key development directions. However, literature suggests that development still largely remains a reference path and is generally treated as an exogenous input to most of the models.

4.3.3 Implications of mitigation for national development objectives

4.3.3.1 Introduction

Section 4.3.2 has outlined the diversity of development objectives that individual countries are pursuing, given national circumstances. This section examines how mitigation may impact the realization of these objectives in the short- and medium-term. It focuses on sustaining economic growth (4.3.3.2), providing employment (4.3.3.3), alleviating poverty and ensuring equity (4.3.3.4), and providing good air quality (4.3.3.5) – four objectives largely described in the literature.

In the pathway literature assessed here (see Supplementary Material Box S4.1), impacts of mitigation are discussed relative to a reference scenario, typically a “business as usual” scenario with no mitigation, though recent studies thus tend to use a “with current policies” scenario as baseline since in most countries some mitigation is undertaken. “With current policies”, however, is not easy to define, can differ depending on assumptions by officials and modelers, and by definition evolves over time. In addition, mitigation pathways often differ markedly from the reference (e.g., because of different directions of structural change, etc.), making the comparison of individual indicators less relevant. Given these conceptual difficulties, we report in this section both deviations from reference scenario and absolute numbers.

4.3.3.2 Mitigation and economic growth in the short- and medium-term

Most country-level mitigation modelling studies in which GDP is an endogenous variable report negative impacts of mitigation on GDP in 2030 and 2050, relative to the reference ((Nong et al. 2017) for Australia, (Chen et al. 2013) for Brazil, (Mu et al. 2018a), (Cui et al. 2019), (Mu et al. 2018b), (Li et al. 2017), (Zhao et al. 2018) for China, (Álvarez-Espinosa et al. 2018) for Colombia, (Fragkos et al. 2017) for the EU, (Mittal et al. 2018) for India, (Fujimori et al. 2019) for Japan, (Veysey et al. 2014) for Mexico, (Alton et al. 2014a) for South Africa, (Chunark et al. 2017) for Thailand, (Roberts et al. 2018b) for the UK, (Chen and Hafstead 2019) for the USA, (Nong 2018) for Vietnam) (*robust evidence, high agreement*) (Figure 4.4a). In all reviewed studies, however, GDP continues to grow even with mitigation (Figure 4.4b).

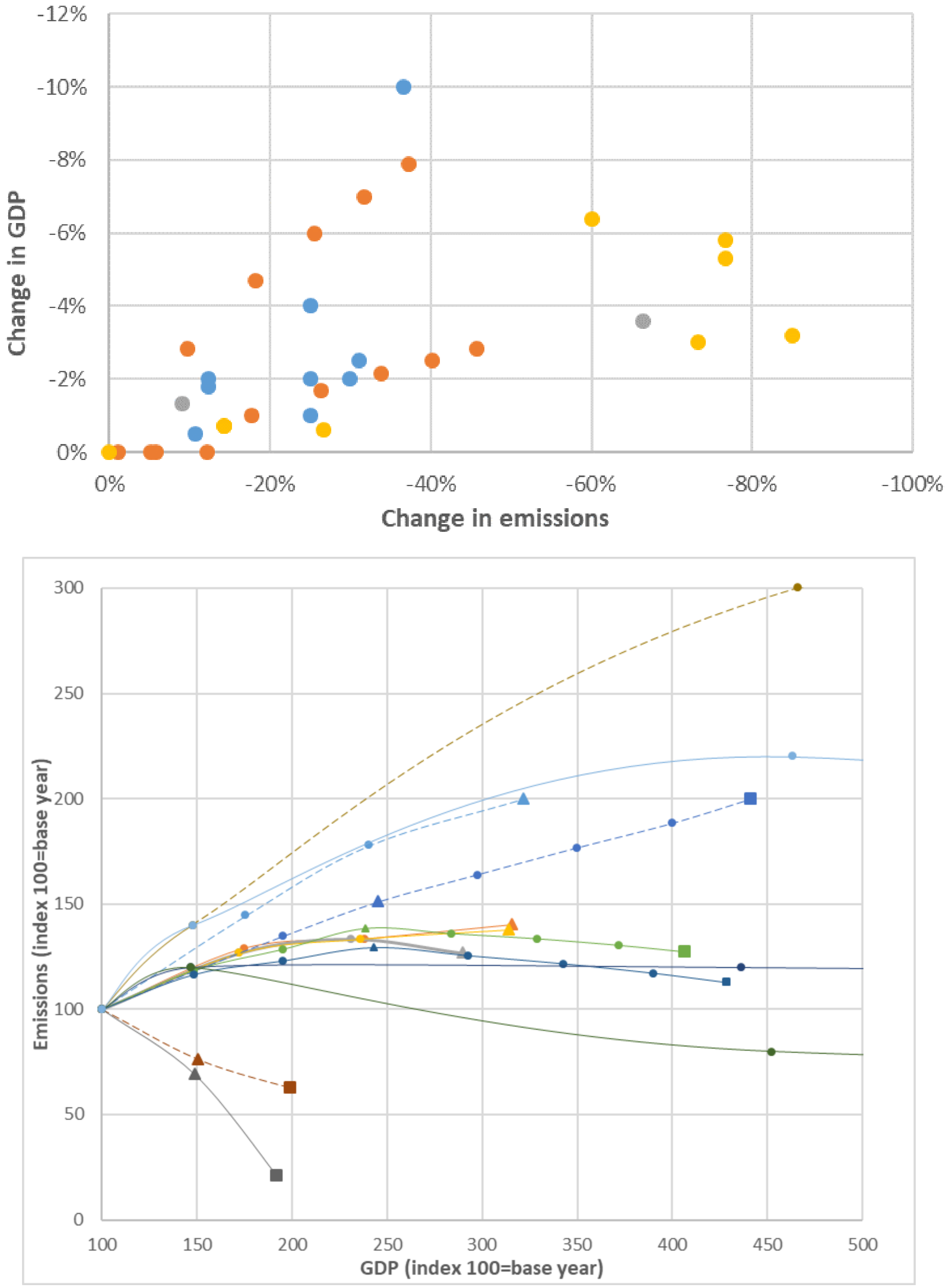

Figure 4.4. GDP against emissions in country-level modelling studies, in variations relative to reference (panel a) and in absolute terms (panel b, index 100 = model base year). Each point represents one simulation by one model for one country. In panel a, points with same colour refer to same model and same country. In panel b, each line refers to a different scenario, points with triangle marker refer to year 2030 simulations, points with square marker refer to year 2050. [*To be elaborated with data extracted from AR6 database of national scenarios.*]

Two major mechanisms interplay to explain the impact of mitigation on GDP. First, the constraint on carbon emissions leads to an increase in the price of GHG-intensive goods and services for firms and households, translating into higher factor costs (for firms) and higher costs of final goods and services (for households). Second, additional investment required for mitigation partially crowds out productive investment elsewhere (Fujimori et al. 2019), except in Keynesian models where increased public investment actually boosts GDP (Pollitt et al. 2015). Magnitude and duration of GDP loss depends on stringency of carbon constraint, degree of substitutability with less-GHG-intensive goods and services, assumptions about costs of low-carbon technologies and their evolution over time (e.g., (Cui et al. 2019), (Duan et al. 2018), (van Meijl et al. 2018)) and mitigation decisions by trading partners, which influences competitiveness impacts for firms ((Alton et al. 2014a), (Fragkos et al. 2017)) (high confidence).

In the short term, higher rigidities, such as limits to households and firms ability to change location in the short-run, presence of non-fully depreciated capital stock, labour market rigidities (Devarajan et al. 2011) may increase impacts on GDP. (These mechanisms may also, however, reduce growth in the reference scenario as well—thus reducing GDP growth in both.) In the medium term, on the other hand, physical and human capital, technology, institutions, skills or location of households and activities are more flexible. In addition, cumulative mechanisms such as induced technical change or learning by doing on low-emissions technologies and process may reduce the impacts of mitigation on GDP.

Assumptions about whether the reference scenario is, or not, on the efficiency frontier of the economy is critical for the assessment of whether mitigation costs can be reduced or even made negative (macroeconomic costs measured in terms of GDP, as well as marginal abatement costs or welfare costs) (Grubb 2014). Conceptually, if the economy is not on the production frontier in the reference scenario (say in point O, Figure 4.5), then there exists opportunities to simultaneously improve environmental quality and improve economic efficiency (e.g. moving from O to A or B, Figure 4.5). If the economy is already on the production frontier (e.g., point F on Figure 4.5), then there is a trade off in the short-run, until the production frontier can be changed (e.g., with structural change in the economy or technical change).

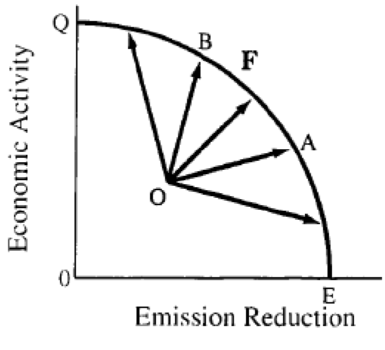

Figure 4.5. Relationship between economic activity and emission reduction (source: (Hourcade et al. 1996), p.271)

Most of the studies which find that GDP increases with mitigation in the short-run assume that the reference against which they are comparing the mitigation scenario is not optimal from an economic standpoint, and also assume that mitigation is undertaken in such a way that the source of non-optimality in the reference is lifted (Table 4.7). This is not the case, however, in Keynesian model, in which additional investment in climate mitigation does not crowd out investment elsewhere (Pollitt et al. 2015).

Table 4.7. Country-level modelling studies finding positive short-term outcome of mitigation on GDP relative to baseline [*More studies to be added; full table possibly moved to supplementary material if it becomes too large*]

(Antimiani et al. 2016)	European Union	GDP increases relative to reference only in the scenario with global cooperation on mitigation
(Willenbockel et al. 2017)	Kenya	The mitigation scenario introduces cheaper (geothermal) power generation units than in BAU (in which thermal increases). Electricity prices actually decrease.
(Siagian et al. 2017)	Indonesia	Coal sector with low-productivity is forced into BAU. Mitigation redirects investment towards sectors with higher productivity.
(Blazquez et al. 2017)	Saudi Arabia	Renewable energy penetration assumed to free oil that would have been sold at publicly subsidized price on the domestic market to be sold internationally at market price
(Wei et al. 2019)	China	Analyse impacts of feed-in tariffs to renewables, find positive short-run impacts on GDP; public spending boost activity in the RE sector. New capital being built at faster rate than in reference increases activity more than activity decreases due to lower public spending elsewhere.
(Gupta et al. 2019)	India	Investment is fixed share of GDP, so additional investment in low-carbon technology has an economic stimulus effect
(Huang et al. 2019)	China	Power generation plan in the baseline is assumed not cost-minimizing

As a corollary, country-level studies find that the negative impacts of mitigation on GDP can be reduced if pre-existing economic or institutional barriers are targeted in complement to the imposition of the carbon constraint. For example, if the carbon constraint takes the form of a carbon tax or of permits that are auctioned, the way the proceeds from the tax (or the revenues from the sales of permits) are used is critical for the overall macroeconomic impacts (Chen et al. 2013). Figure 4.6 shows that depending on the choice of accompanying policies, the same level of carbon constraint can yield very different outcomes for GDP. The potential for mitigating GDP implications of mitigation through fiscal reform is discussed in 4.4.1.2 below.

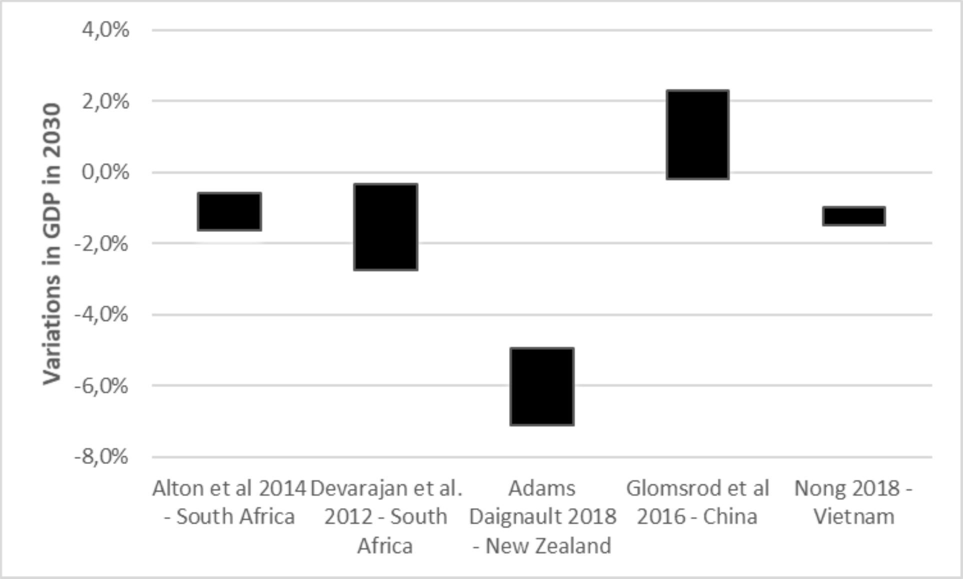

Figure 4.6. Range of variations in GDP relative to reference in 2030 associated with introduction of carbon constraint, depending on modality of policy implementation. Note: stringency of carbon constraint is not comparable across the five studies shown in the Figure [*More studies to be added*]

4.3.3.3 Mitigation and employment in the short- and medium-term

Numerous studies have analysed the potential impact of carbon pricing on labour markets. (OECD 2017) and (Chateau et al. 2018) find that the implementation of green policies globally (defined broadly as policies that internalize environmental externalities through taxes and other tools, shifting profitability from polluting to green sectors) need not harm total employment and that the broad skill composition (low-, high- and medium-skilled jobs) of emerging and contracting sectors is very similar, with the largest shares of job creation and destruction at the lowest skill level. To smoothen the labour market transition, they conclude that it may be important to reduce labour taxes, to provide education and training programs, and to compensate vulnerable households.

At the sectoral level, however, the changes are more substantial – sectors that are carbon-dependent (producing carbon or intensive users of carbon) (Huang et al. 2019) do less well and this is also true for countries that are dominated by such sectors (Arndt et al. 2013). Among the worker categories, low-skilled workers tend to suffer wage losses as they are more likely to have to reallocate, something that can come at a cost in the form of a wage cut (assuming that workers who relocate are initially less productive than those who already work in the sector). The results for alternative carbon revenue recycling schemes point to trade-offs: a reduction in labour taxes leads to the most positive employment outcomes while lump-sum (uniform per-capita) transfers to households irrespective of income yield a more egalitarian outcome.

The results from country-level studies using CGE models tend be similar to those at global level. Aggregate employment impacts are small and may be positive especially if labour taxes are cut (for Ethiopia and Turkey; see (Telaye et al. 2019), and (Kolsuz and Yeldan 2017), (Fragkos et al. 2017) for the EU, (Mu et al. 2018b) for China respectively). On the other hand, sectoral reallocations away from fossil-dependent sectors may be substantial (for South Africa; see (Alton et al. 2014a), for China see (Huang et al. 2019)). Targeting of investment to labor-intensive green sectors may generate the strongest employment gains (for France; see (Perrier and Quirion 2018), (van Meijl et al. 2018) for the Netherlands, (Patrizio et al. 2018) for the USA); and the changes in skill requirements between emerging and declining sectors are quite similar, involving smaller transitions than during the IT revolution (for the US, see (Bowen et al. 2018)).

In sum, the literature suggests that, when climate policies are put in place, it is important for policymaking to anticipate likely labour market impacts, including job losses in certain sectors, to prepare workers for job changes via education and training, and to consider reducing labour taxes to boost overall labour demands. The case for cutting labour taxes may be part of a case for using the fiscal surplus to cut distortionary taxes (Stiglitz et al. 2017a), as will be discussed in 4.4.1.

Like most of the literature on climate change, the above studies do not address gender aspects. These may be significant since the employment shares for men and women vary across sectors and countries. For example, in many developing countries, sectors in which women play a relatively important role – the collection of water and fuel wood (which, like other services produced by households for own consumption are not part of GDP) and agricultural production – may be negatively affected by climate change (Sen Roy 2018).

4.3.3.4 Mitigation and equity in the short- and medium-term

Climate mitigation may exacerbate socio-economic pressures on poorer households (Jakob et al. 2014). First, the price increase in energy-intensive goods and services—including food (Hasegawa et al. 2018)—associated with mitigation may affect poorer households disproportionally (Bento 2013), and increase the number of energy-poor (Berry 2019). Second, the mitigation may disproportionally affect low-skilled workers (see previous section). Distributional issues have been identified not only with explicit price measures (carbon tax, emission permits system, subsidy removal), but also with emissions standards (Davis and Knittel 2019), efficiency standards (Bruegge et al. 2019), or subsidies for renewables (Borenstein and Davis 2016).

Distributional implications, however, are context specific. In an analysis of the distributional impact of carbon pricing based on household expenditure data for 87 low- and middle-income countries, (Dorband et al. 2019) find that, in countries with a per-capita income of up to USD15,000 per capita (PPP adjusted), carbon pricing has a progressive impact on income distribution and that there may be an inversely U-shaped relationship between energy expenditure shares and per-capita income, rendering carbon pricing regressive in high-income countries, i.e. in countries where the capacity to pursue compensatory policies tends to be relatively strong.

The literature finds with high confidence that the detailed design of mitigation policies is critical for distributional impacts (*robust evidence, high agreement*). For example, (Vogt-Schilb et al. 2019) suggest to turn to cash transfer programs, established as some of the most efficient tools for poverty reduction in developing countries. In an analysis of Latin America and the Caribbean, they find that allocation of 30 percent of carbon revenues would suffice to compensate poor and vulnerable households on average, leaving the rest for other uses. This policy tool is not only available in countries with relatively high per-capita incomes: in Sub-Saharan Africa, where per-capita incomes are relatively low, cash transfers programs have been implemented in almost all countries ((Beegle et al. 2018), p. 57), and are found central to the success of energy subsidy reforms (Rentschler and Bazilian 2017).

Distributional concerns related to climate mitigation are also prevalent in developed countries, as demonstrated, for instance, by France's recent yellow-vest movement, which was ignited by an increase in carbon taxes. In that particular case, no compensation mechanism had been put in place when the tax was set up in 2014. It has been shown ex post that transfer schemes considering income levels and location could have protected or even improved the purchasing power of the bottom half of the population (Bureau et al. 2019). CGE analysis of the previous attempt at introducing a carbon tax in France suggests that reducing labor taxes coupled with targeted transfers could have been superior by limiting the macroeconomic burden associated with the tax (Combet et al. 2010)(Combet and Hourcade 2017). Policymakers may also consider protecting vulnerable households via direct tax reductions or reduced consumption taxes on goods serving basic needs (Baranzini et al. 2017).

4.3.3.5 Mitigation and local air pollution in the short- and medium-term

AR5 has outlined that mitigation policies have overall positive implications for local air quality, since local air pollution has typically the same sources as greenhouse gases. AR5 has also outlined that policies to mitigate GHG emissions and to mitigate local air pollution are better pursued jointly (IPCC 2014a) so that synergies can be exploited. SR1.5 has added to this assessment that mitigation pathways compatible with 1.5°C would lead to lower local air pollution, thus reducing the associated health risks and costs (Roy et al. 2018).

4.3.4 Articulation between accelerating mitigation and shifting development pathways

4.3.4.1 Introduction

The previous two sections have considered the implications of development pathways for mitigation, and vice versa. This section considers the articulation of accelerating mitigation and shifting development pathways, i.e., how mitigation objectives – such as those included in the Paris Agreement – can be considered within the context of shift development pathways. To address the challenge of widespread and rapid transformations implied by goals such as these, it is useful to consider potential societal responses as falling along a continuum. At one end are measures focused directly and specifically on reducing GHG emissions *per se*, and on the other are measures, policies, processes, and dynamics that more broadly influence the overall development pathway. The former are often referred to as mitigation measures, and are aimed at affecting the mitigation pathway by determining proximate drivers of emissions. The latter may be referred to as development measures and are aimed at affecting the development pathways so as to achieve societal objectives, and thus also can affect both proximate and ultimate drivers of emissions.

This section will review the ways in which actors can – and indeed continually are – making decisions and taking actions that affect the evolving societal development pathway, and the ways in which those decisions and actions can influence – positively or negatively – the pace and scale of mitigation as well as prospects of meeting other societal objectives. This section moreover finds that approaches based on a more comprehensive consideration of development measures, as opposed to mitigation measures alone, opens up wider and more effective options for meeting mitigation and other development objectives (see Chapter 13 on policies, institutions and related measures).

Given the observation (see section 4.2) that current and pledged mitigation efforts are insufficient relative to mitigation goals of the Paris Agreement, policymakers might usefully consider a broader palette of development measures as part of an overall strategy to meet those goals and achieve other development objectives. This is supported by other observations that mitigation measures alone will not achieve the long-term goals of the Paris Agreement (IPCC 2018a; Rogelj et al. 2016; UNEP 2018; Méjean et al. 2015; Munasinghe 2001; Winkler and Marquard 2009). The latter is also central to achieving national development goals.

4.3.4.2 Modifying development pathways, mitigative capacity, and emissions

Figure 4.7 below illustrates schematically the relationship between mitigation measures and development measures. Although the diagram has two distinct blocks and appears binary, the boundary between them is more appropriately seen as broad. Increasingly, mitigation measures are being discussed in the context of broader developmental shifts, for example in the context of a "Green New Deal" (Steiner 2009; Guertler 2012; Li 2014). The articulation between the two thus about the relationship among elements along a continuum.

Mitigation measures (narrowly defined) are shown on the left side. They are aimed at influencing the proximate drivers of emissions, such as the fuels used, the technologies with which those fuels are used, and, to some degree, the substitution of more carbon-intensive with less carbon-intensive products and services. Conventional mitigation measures include, for example, emissions taxes or permits, price incentives such as feed-in tariffs for low-carbon electricity generation, and fuel economy standards, and building codes (see Chapters 6-13).

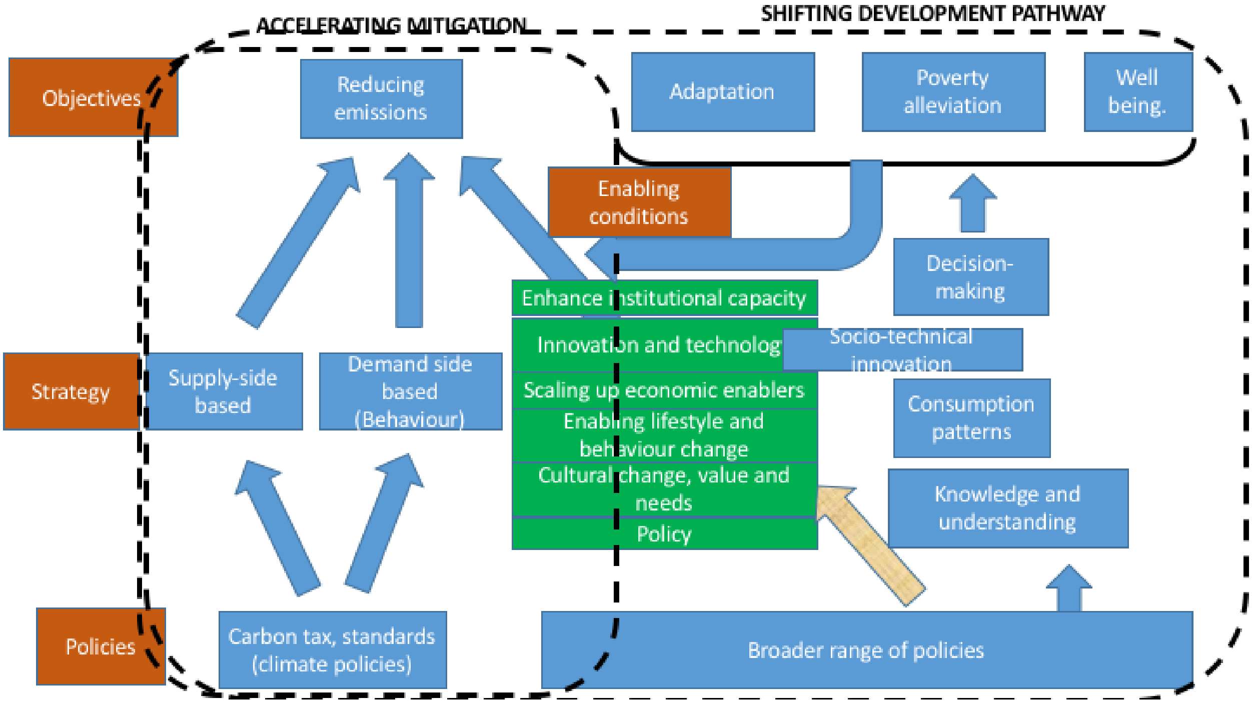

Figure 4.7. mitigation measures and broader development measures

4.3.4.3 Expanding the range of policies and other mitigative options

'Traditional' policy instruments to induce climate mitigation have been focused on demand side or supply side, and include five basic categories: direct regulation; market-based (or economic) instruments; information policies; and other approaches including information provision and transparency, government provision of public goods or services; and facilitation of voluntary actions. Policies may be formulated into packages, seeking to achieve multiple objectives (see Chapter 13).

Shifting development pathways, on the other hand, entails policy approaches that include a broader range of instruments and initiatives, and impact more fundamentally on the dynamics of systems. Simultaneously, focusing on shifting development pathways opens up a wider range of mitigation actions and achieves development goals.

As shown on the right hand side of Figure 4.7, the focus on development pathways affects mitigative capacity, by way of more broadly influencing development pathways. These approaches can affect the ultimate drivers of emissions (and development generally), such as: the systemic and cultural determinants of consumption patterns, the political systems and power structures that govern decision making, the institutions and incentives that guide and constrain socio-technical innovation, and the norms and information platforms that shape knowledge and discourse, and culture, values and needs (Raskin et al. 2002). These ultimate drivers determine the mitigative capacity of a society (Burch and Robinson 2005, 2007; Olowa et al. 2011; Winkler et al. 2007; Yohe 2001).

While the evolution of these drivers is subject to varied influences and complex interactions, there are also some levers by which policy makers might influence them. Figure 4.8 provides some examples of development measures that can affect these drivers.

Figure 4.8. Examples of development pathway measures, and the ultimate drivers they influence

Policies such as those listed in Figure 4.8 are typically associated with broader objectives than greenhouse gas mitigation. They are generally conceived and implemented in the pursuit of overall societal social objectives, such as job creation, macro-economic stability, economic growth, and public health and welfare. However, they can have major impacts on mitigative capacity, and hence can be seen as tools for greatly broadening mitigation options (*medium evidence, medium agreement*).

Consumption Patterns and Norms: Chapter 5 provides further detail on the impacts of large-scale, society-wide consumption patterns on mitigative capacity, and also the means by which past societal norms and preferences in consumption patterns can be influenced and evolve over time. Such changes result from policies aimed at meeting broader social objectives (e.g., that externalize social and environmental externalities), social movements that have catalytic or “tipping point” effects (e.g., student movements), and changes in institutions (e.g., educational curricula) (See Chapter 5).

Processes and institutions of decision-making can also strongly affect a society’s mitigative capacity. Policy measures can be taken to enhance institutional capacity, functional competence and technical expertise. Steps can also be taken to ensure democratic accountability and transparency. A major socio-economic transformation, such as the shift away from fossil fuel-based energy economy, can be expected to significantly disrupt the status quo, leading to a stranding of financial and capital assets and shifting of political-economic power. Ensuring the decision-making process is not unduly influenced by actors with much to lose is key to managing a transformation.

Socio-technical innovation: socio-technical innovation applies to many domains, even when applied to a specific well-defined technology. For example, expanding the deployment of photovoltaics can draw upon policies that support specific technical innovations (e.g., to improve photo-voltaics efficiency), or innovations in regulatory and market regimes (e.g., net-metering), to innovations in social organization (e.g., community-ownership). More fundamentally, innovation regimes can be led and guided by markets driven by monetizable profits (as much of private sector led technological innovation), or that prioritize social returns (e.g., innovation structures such as innovation prizes, public sector innovation, and socially-beneficial intellectual property regimes)

Knowledge and Discourse: Knowledge and discourse can be buttressed with more factual rigor with respect to the underlying challenges of climate change, both among the general public as well as among decision-makers.

Finance and investment: Chapter 15 includes a wide range of policy options for the finance sector aimed at redirecting investments from unsustainable to more sustainable options.

4.3.4.4 Addressing multiple objectives, both climate and development goals

Shifting development pathway opens up opportunities to address multiple objectives beyond mitigation, such as poverty alleviation, reducing unemployment, providing energy access, providing formal housing, providing mobility, etc. Case studies of India, Chile, Peru and Colombia suggest that multi-criteria decision analysis (MCDA) can support climate and development policy, by structuring the analyses, systematically include stakeholder deliberations, and provide tools to rigorously incorporate quantitative and qualitative co-impacts in multiple objective-based decisions (Cohen et al. 2019). Another example applies MCDA to energy development pathways in India, with illustrative examples from the cooking and buildings sectors (Khosla et al. 2015). Future skills and job creation goals can be achieved through development of renewable energy, particularly in the high-skill labour market (Hartley et al. 2019). As outlined in section 4.3.3, mitigation can have negative impacts on achieving other key development goals if not undertaken in ways that engage stakeholders, anticipate potential adverse impacts, and take steps to eliminate, compensate or alleviate such impacts. Compensations to affected groups can help, but feasibility in practice can be limited: sufficient compensation may not ultimately be provided, non-monetizable impacts may not be recognized, political interference and corruption may divert resources.

4.4 How to shift development pathways and accelerate the pace and scale of mitigation

4.4.1 How to shift development pathways

There are past examples of development pathways that address mitigation and (at least some) other development priorities—Brazil over the past decades being an example (see Box 4.5). It is also possible to construct plausible development pathways in the future that address mitigation and (at least some) other development priorities. For example, (Altieri et al. 2016) construct a pathway for South Africa in which energy-related CO2 emissions by 2030, unemployment peaks in 2030 (at about 30%) and decline to 12% by 2050 (relative to 25% in 2010), while GDP doubles by 2050. Similarly, national development plans already combine the pursuit of key development objectives and mitigation in countries such as India, China (as discussed in section 4.3.2) or South Africa (see Box 4.4).

This section aims at exploring how development pathways could be shifted in the short- and medium-term with view to both addressing some of the development priorities outlined in 4.3.2, and at reducing emissions and enhancing mitigative capacity. It explores several forms of shifting pathways, including via structural change (4.4.1.1) 4.4.1.4), fiscal reforms (4.4.1.2), changing location of activities and people and the provision of infrastructure (4.4.1.3), or poverty alleviation and providing energy access (4.4.1.4). Section 4.4.2 will then address common enabling conditions for such change.

There are practical options to shift development pathways in ways that both advance development objectives, increase resources to meet these goals and reduce emissions (*limited evidence, high agreement*). Such practical options might focus on a range of development goals (such as alleviating poverty and limiting inequalities, limiting spatial inequalities, providing universal energy access, provide infrastructure for social services); increase the resources available to meet these goals, for example, through fiscal reforms or structural change of the economy; and in achieve a mitigative capacity. Box 4.5 provides an example from Brazil as assessed in the literature.

Box 4.4 Development paths in Brazil and implications for GHG emissions

There is a growing literature on the complex interactions between development paths, climate mitigation and enabling conditions to promote mitigation capacity without undermining development opportunities. As the energy sector and deforestation are largest sources of GHG emissions, emphasis is given to these two sectors, especially in developing countries. Literature assesses ancillary benefits of sectoral policies that lead to decarbonisation pathways and simultaneously promote economic development, guarantee living standards to population, reduce inequality and create job opportunities (Bataille et al. 2016b, 2018; Pye et al. 2016; La Rovere et al. 2018; Waisman et al. 2019)(Maroun and Schaeffer 2012; Richter et al. 2018). While this is particularly challenging in developing countries, previous development paths shown this is possible. For instance, in the past two decades, Brazil did remarkable developments on multi-sectorial policies that simultaneously increased minimal wages of low income families, achieved universal energy access and raised quality of life and well-being to the large majority of the population (Bezerra et al. 2017; Grottera et al. 2018, 2017b; La Rovere et al. 2018), while reducing GHG emissions, mainly by controlling deforestation and expansion of cropland farming (Soterroni et al. 2019, 2018; Bustamante et al. 2018; Nunes et al. 2017). This led to significant social benefits, reduction of income inequality and poverty eradication (Bezerra et al. 2017; Grottera et al. 2017b), reflected in a decrease of the Gini coefficient and rise of the human development index (La Rovere 2017). In parallel, public policies reinforce environmental regulation and command-and-control instruments to limited deforestation rates and implemented market-based mechanisms to provide benefits to those protecting local ecosystems and enhancing land-based carbon sinks (Sunderlin et al. 2014; Hein et al. 2018; Simonet et al. 2019; Nunes et al. 2017). The private sector, aligned with public policies and the civil society, implemented the Amazon Soy Moratorium, a voluntary agreement that bans trading of soybeans from cropland associated with cleared Amazon rainforest and blacklists farmers using slave labour. This was achieved without undermining production of soybean commodities (Soterroni et al. 2019). As a result, the country halved its GHG emissions and reduced deforestation by 78 per cent, between 2005 and 2012 (INPE 2019a,b). This clearly shows that climate mitigation pathways are compatible with socioeconomic development, if a long-term and strategic vision creates enabling policies and mechanisms. Recently development pathways in the country faced a radical shift. Political changes redefined development priorities, lining up short-term vest interests, to the detriment of successful climate mitigation and social development policies. The current administration has lessened environmental agencies and forestry protection laws (e.g.: the forest code), while approving the expansion of cropland to protected Amazon rainforest areas and being permissive to illegal land grabbers (Ferrante and Fearnside 2019; Rochedo et al. 2018). As a result, in 2019, deforestation rate was the largest of this decade and rose by 30% compared to previous year [*update consolidated numbers from 2019 in SOD*] (INPE 2019b). Current policy on the Amazon may reach a tipping point, which could be irreversible, making it impossible to remediate loss ecosystems, and restore carbon sinks and indigenous people knowledge (Nobre 2019; Lovejoy and Nobre 2018; INPE 2019a). Further, recent announced fossil fuel subsidies and other fiscal benefits to increase exploitation of domestic oil resources may create carbon lock-ins that inhibits further low-carbon investments (Lefèvre et al. 2018). Brazil's may struggle to realize its contributions to the Paris Agreement. If deforestation rates keep rising, mitigation efforts will need to shift to the energy sector. However, according to Rochedo et al. (2018), mitigation costs in the energy sector in Brazil are three times higher than reducing deforestation and increasing land-based carbon sinks. Further mitigation strategies may involve not commercially available carbon capture and storage technologies, which may be inaccessible at the required scale (Nogueira de Oliveira et al. 2016; Herreras Martínez et al. 2015b).

4.4.1.1 Structural change

Developing countries have experienced a period of rapid economic growth in the past two decades. Patterns of growth have differed markedly across regions, with newly emerging East Asian economies building on transition to manufacturing—as China has done in the past—while Latin American countries tend to transition directly from primary sector to services (Rodrik 2016), and African countries tend to from productivity improvements in the primary sectors (Diao et al. 2019). Yet many countries still face the challenge of getting out the "middle-income trap" (Agénor and Canuto 2015), as labour-saving technological change and globalization have limited options to develop via the manufacturing sector (Altenburg and Rodrik 2017).

Looking ahead, several studies have illustrated how structural change could lead to reduced emissions intensity and higher mitigative capacity. In China, for example, the shift away from heavy industry (to light industry and services) has already been identified as the most important force limiting emissions growth (Guan et al. 2018), and as a major factor for future emissions (Kwok et al. 2018). However, exploring different patterns of sectoral composition of exports (Wu et al. 2019) find increased GDP, decreased employment but limited impacts on emissions.

Overall, (Altenburg and Rodrik 2017) argue that reallocation of capital and labour from low- to high-productivity sectors—i.e., structural change—remains a necessity, and that it is possible to combine it with reduced environmental footprint (including, but not limited to, mitigation). They argue that this dual challenge calls for **structural transformation policies different from those implemented in the past, notably because of the "systematic steering of investment behavior in a socially agreed direction", of the urgency and the need for encompassing policy coordination (*limited evidence, medium agreement*).**

4.4.1.2 Fiscal reforms

In many countries, fiscal systems are currently under stress to provide resources necessary to implement development priorities, such as, for example, providing universal health coverage and other social services (Meheus and McIntyre 2017) or sustainably funding pension systems in the context of aging populations (Asher and Bali 2017; Cruz-Martinez 2018). Overall, (Baum et al. 2017) argue that low-income countries are likely not to have the fiscal space to undertake the investment considered necessary to reach the SDGs. To create additional fiscal space, major options include improving tax recovery, reducing subsidies and levying additional taxes.

Mitigation offers an opportunity to create additional fiscal space, and thus to serve the objectives outlined above, by creating a new source of revenue for the government via carbon taxation or emissions permit auctioning and by reducing existing expenditures via reduction in subsidies to fossil-fuel. The 1991 tax reform in Sweden is an early example in which environmental taxation (including, but not limited to, fossil fuel taxation) was introduced as part of a package primarily aimed at lowering the marginal tax rates (more than 80% at the time), at reducing other taxes, while keeping most of the welfare state. To do so, the tax base was broadened, including through environmental and carbon taxation (Sterner 2007). Once in place, the carbon tax rate was substantially ramped up over time, and its base broadened (Criqui et al. 2019).

Looking ahead, the potential for using carbon taxation as a way to provide space for fiscal reform has been highlighted in the so-called "green fiscal reform" literature (Vogt-Schilb et al. 2019). The global potential is large, given the gap between the price of carbon observed under current carbon pricing schemes and the range of prices that have been found consistent with the objectives outlined in the Paris Agreement.[5] Similarly, the fiscal cost (not including the environmental cost) of global fossil fuel subsidies amounted to USD427 billion (Watts et al. 2019).[6] However, the size of the potential for creating fiscal space varies strongly across countries given differences in terms of current carbon prices and fuel subsidies.

As noted in 4.3.3., significant attention must be paid to implications on GDP, employment, and equity when implementing mitigation policies. There is also considerable literature providing insights on the political and social acceptability of carbon taxes, suggesting for example that political support may be boosted if the revenue is recycled to the tax payers or earmarked for areas with positive environmental effects (e.g., (Bachus et al. 2019) for Belgium, and (Beiser-McGrath and Bernauer 2019) for Germany and the USA), as well as on the difficulties associated with political vagaries (and economic consequences thereof) associated with the introduction of such instruments (Pereira et al. 2016). Similarly, "best practice" have been drawn from past experience on fossil-fuel subsidy reforms (Sovacool 2017; Rentschler and Bazilian 2017). Specific policies, however, depend on societal objectives, endowments, structure of production, employment, and trade, and institutional structure (including the functioning of markets and government capacity) (Kettner et al. 2019).

In the context of this section on development pathways, it is worth emphasizing that the fiscal reforms tied with climate mitigation are easier to pass in periods of low energy prices than in period of high energy prices—a link that does not exist with other forms of fiscal reforms. Second, potential revenues drawn from the climate mitigation component of the fiscal reform varies strongly with the context, and may not be sufficient to address the other objectives pursued. For example, (Jakob et al. 2016) find that the carbon pricing revenues that most countries in Sub-Saharan Africa could expect to generate only would meet a small part of their infrastructure spending needs. All the more so since, by construction, the fiscal base of environmental taxes is built to shrink. Additional sources of fiscal space must thus often be pursued, noting that higher domestic taxes are likely to involve trade-offs since they reduce the capacity of households and the private sector to consume and invest, something that may reduce growth over time and cut spending that meets basic needs and contributes to human development (Lofgren et al. 2013). It is also worth emphasizing that restructuring of the fiscal system amount to changes in the social contract of the society (Combet and Hourcade 2017, 2014), and thus represents a major economic and social decision.

4.4.1.3 Spatial distribution of households and firms and provision of transport infrastructure

The spatial distribution of households and firms—across both urban and rural areas—is a central characteristic of development pathways. Patterns of urbanization, territorial development, and regional

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[5] In 2019, a small share, of global GHG emissions, 13.1 percent, was covered by carbon pricing schemes with prices ranging from less than USD1 to USD 127 per tCO_2, yielding a weighted average price of USD 13.1 and US$43 billion in fiscal revenues. If emissions not covered by carbon prices are included, the global weighted average carbon price declines to USD 1.76 ((Watts et al. 2019), pp. 1866-1868). This price level may be compared to the conclusion of the High Level Commission on Carbon Prices that "the explicit carbon-price level consistent with achieving the Paris temperature target is at least USD40–80/tCO2 by 2020 and USD50–100/tCO_2 by 2030, provided a supportive policy environment is in place" (Stiglitz et al. 2017b).

[6] USD427 billion is around 0.5 percent of global GDP in 2018, USD84,930 billion (IMF 2019). If the global weighted average carbon price were to increase from USD 1.76 to USD40 per tCO_2 (the minimum according to (Stiglitz et al. 2017b)), the carbon revenue would amount to 1.15 percent of global GDP, assuming no change in global carbon quantities or global GDP). I.e., compared to other shocks to which the world economy has been exposed in recent decades (including shocks in oil prices), this shock is not exceptional.

integration have wide-ranging implications for economic, social and environmental objectives. (World Bank 2008). Notably, choices regarding spatial forms of development have large-scale implications for demand for transportation, and associated GHG emissions. For example, when housing prices increase in cities, the economic and social implications, notably in terms of spatial equity, trigger debates about policy intervention. Sustained increases in housing prices in agglomerations also have a significant positive impact on the energy demand associated with transport in the long-term, as households tend to relocate towards the periphery. If housing prices keep increasing in the future, very high carbon prices would be needed to significantly limit CO2 emissions associated with transport. If, on the other hand, house prices are curved down—through appropriate policies (rent control, zoning, etc.)—then the price of carbon needed to achieve the same emission reduction would fall sharply ((Lampin et al. 2013) for Paris).

Adequate provision of transport infrastructure is recognized as a necessary—though not necessarily sufficient—condition for economic growth, the provision of key social services and welfare. (Rozenberg and Fay 2019a) identify policy mixes for infrastructure—including transport, but also energy, sanitation, flood protection and irrigation—that could achieve universal access to water, sanitation, and electricity; greater mobility; improved food security; better protection from floods; and eventual full decarbonization—at an annual cost of between 2 and 8 percent of GDP. Crucially, they find that “infrastructure investment paths compatible with full decarbonization by the end of the century need not cost more than more-polluting alternatives […] Spending efficiency is key and depends on the quality of the policies.” In the transport case, specifically, avoiding city sprawl, accompanying policies to intensity usage of rail and promotion of electric vehicle are identified as ways in which the goal of providing adequate transport infrastructure to meet demand can be made compatible with low-emissions pathway at no additional cost (Rozenberg and Fay 2019b).

4.4.1.4 Poverty alleviation and energy access

The relationship between income inequality and GHG emissions has been found to be U-shaped. Decreasing inequality among the poor initially leads to higher emissions, but at some point the relationship shifts direction, and decreased inequality (amongst richer people) leads to decreasing emissions (Grunewald et al. 2017b). Globally, there is a debate as to whether reducing global inequality would result in lower (Rao and Min 2018) or higher emissions (Hubacek et al. 2017), but there is a consensus that the implications might be modest, and that the emissions associated with the lifestyle of the most affluent should also be addressed (Hubacek et al. 2017) (Otto et al. 2019).

Universal access to energy is a closely related goal, since the people deprived of access to reliable electricity are often also the poorest (Pachauri 2007). Though the goal of universal energy access still remains largely elusive (Rao and Pachauri 2017), large-scale decrease in photovoltaic electricity generation and widespread diffusion of information technologies (through cellphones) offer very promising perspectives in the short-run (Alstone et al. 2015). The implications for emissions of universal electricity access depend on electricity generation technology, but also on the structure of the demand. In a study on India, Brazil and South Africa, (Rao et al. 2019) estimate the emissions implications “within these countries’ energy demand projections in global scenarios of climate stabilization at 2 °C, but to different extents.” They also note that policies that encourage public transportation and sustainable housing construction are essential to limit these energy needs.

4.4.2 Enabling conditions that lead to transformational change

Section 4.2 showed that the pace and scale of change is too slow to keep temperature goals within reach. The mitigation targets in NDCs focus primarily on incremental and gradual changes rather than radical transformations. But deep transformations are now needed if emissions are to decline towards net zero by mid-century. Such transformational change can enhance broader sustainable development goals, if it is rooted in the development aspirations of the society in which it takes place (see 4.3.2).

Human history has seen multiple transformation of economies due to path-breaking innovations (Michaelowa et al. 2018), like the transformation of the energy system from traditional biomass to fossil fuels or from steam to electricity (Fouquet 2010, 2016a) (Sovacool 2016). However, (Fouquet 2016b) and (Smil 2016)CeC stress that even the most rapid global transformations have taken several decades.

Enabling transformational change implies creating the conditions that lead to that transformation already in the short term (Díaz et al. 2019), through higher levels of innovation, multilevel governance, transformative policy regimes and profound behavioural transformation (IPCC, 2018; Geels et al., 2018; Kriegler et al., 2017d; Rockström et al., 2017).

There is no single factor fostering such a transformation. Rather a range of enabling conditions—including governance, institutional capacities, behaviour and lifestyles, innovation, policy and finance—need to come together in a co-evolutionary process to shift development pathways that could scale the rapid, disruptive and transformative mitigation consistent with 2°C-1.5°C pathways (IPCC 2018)[7], (Hansen and Nygaard 2014; Rogge et al. 2017) (Geels et al. 2017; Rockström et al. 2017).

Enabling conditions in this chapter draw on enabling conditions identified in the special report on 1.5°C – governance, institutions, behaviour, innovation, policy and finance (de Coninck et al. 2018b). The six enabling conditions shown in Figure 4.9 are high-level conditions that enable both accelerated mitigation and shifts in development pathways. When applied to specific context, the enabling conditions may become more granular and specific.

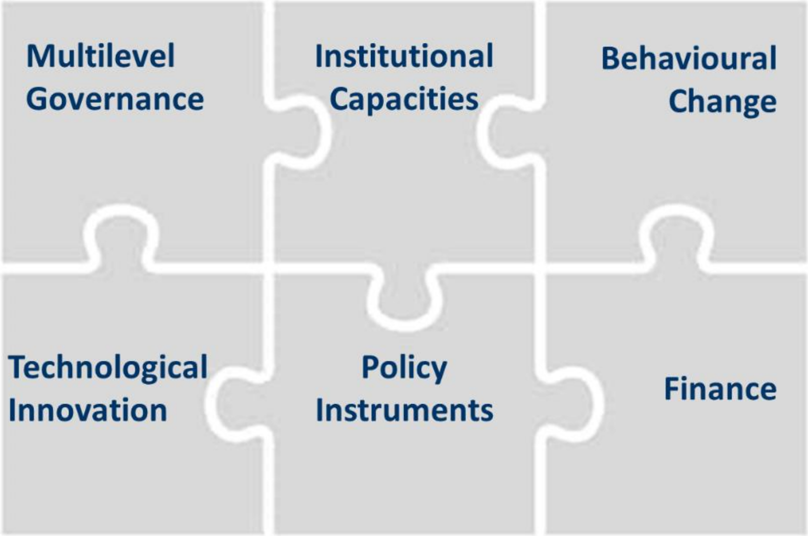

Figure 4.9: Enabling conditions – high-level overview

4.4.2.1 Governance and Institutional Capacity

Transformational change can be facilitated by innovative governance approaches (Clark et al. 2018)(Díaz et al. 2019). Enabling multilevel governance - better alignment across governance scales - and coordination of international organizations and national governments can help accelerate a transition to sustainable development and deep decarbonisation (Tait and Euston-Brown 2017) (Ringel, 2017) (Cheshmehzangi, 2016; Revi, 2017) (Michaelowa and Michaelowa 2017).

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[7] See in particular see section 5.6 "Conditions for Achieving Sustainable Development, Eradicating Poverty and Reducing Inequalities in 1.5°C Warmer Worlds", with sub-headings on 5.6.1 Finance and Technology Aligned with Local Needs; 5.6.2 Integration of Institutions; 5.6.3 Inclusive Processes; 5.6.4 Attention to Issues of Power and Inequality; 5.6.5 Reconsidering Values

Participatory and inclusive governance -partnerships between state and non-state actors-, and concerted effort across different stakeholders are crucial in supporting and hindering acceleration (Hering et al., 2014; Roberts, 2016; (Figueres et al. 2017); Leal Filho et al., 2018)(Lee et al. 2018; Clark et al. 2018); (Burch et al. 2014). So does partnerships through transnational climate governance initiatives, which coordinate nation-states and non-state actors on an international scale (Hsu et al. 2018). Although they are unlikely to close the gap of the insufficient mitigation effort of national governments (Michaelowa and Michaelowa 2017) (see section 4.2.3), they help building confidence in governments concerning climate policy and push for more ambitious national goals (UNEP 2018).

Enhanced institutional capacity and mechanisms are needed to strengthen coordination of multiple actors, complementarities and synergies between multiple objectives (Rasul, 2016) (Liu et al.,2018) so as to pursue climate action and sustainable development in an integrated and coherent way (Rogelj et al. 2018b; Von Stechow et al. 2016; McCollum et al. 2018; Fuso Nerini et al. 2019), (Roy et al. 2018) particularly in developing countries (Adenle et al., 2017; Rosenbloom, 2017).

Institutions that enable and improve human capacities and capabilities are a major driver of transformation. Promoting education, health care and social safety, also are instrumental to undertake climate change mitigation and cope with environmental problems (Sachs et al. 2019; Winkler et al. 2007).

4.4.2.2 Behaviour and lifestyles

Mitigation pathways in line with a 1.5°C or 2°C temperature goal assume substantial behavioural and societal change and low-carbon lifestyles as critical enabling factors (Masson-Delmotte et al. 2018; Rogelj et al. 2018a). Reaching the Paris Agreement goals will likely rely in part on reduced consumption of high-emissions goods and services. However, behavioural change is largely neglected in analyses of climate change mitigation for meeting international targets (Creutzig et al. 2016), and it is unclear to what extent behavioural factors (i.e., cognitive, motivational and contextual aspects) are taken into account in policy design.(Luis Mundaca, Sonnenschein, Steg, Höhne, & Ürge-Vorsatz, 2019; Dubois et al. 2019).

Transformative policies are much more likely to be successfully adopted and lead to long-term behavioural change if they are designed in accordance with principles of cognitive psychology (van der Linden et al. 2015). Actors in society, particularly individuals, do not respond in an economically "rational" manner based on perfect-information cost-benefit analyses, and compelling narratives can drive individuals to adopt new norms and policies (Shiller 2019)(Runge 1984). Rather, norms can be more quickly and more robustly shifted by proposing and framing policies designed with awareness of how framings interact with individual cognitive tendencies (van der Linden et al. 2015).

Economic policies can play a significant role in influencing people's decisions and behaviour. However, many drivers of human behaviour and values, work largely outside the market system. (Díaz et al. 2019; Winkler et al. 2015b) Policymakers can design more effective policies to shift consumption patterns by using the deep understanding of decision-making offered by behavioural science (UNEP 2017b).

Climate actions are related to knowledge but even strongly to motivational factors (Hornsey et al. 2016) (Bolderdijk et al. 2013); Boomsma et al., 2014), which explains the gap between awareness and action (Ünal et al., 2017). Social influences, particularly from peers, affect people engagement in climate action (Schelly 2014). Role models appear to have a solid basis in people's everyday preferences (WBGU 2011). Social norms can reinforce individuals' underlying motivations and be effective in encouraging sustainable consumption patterns, as many examples offered by behavioural science. Social networks also influence and spread behaviours. (Service et al. 2014) (Clayton et al. 2015)(Farrow et al. 2017)(Shah et al. 2019) These social influences can be addressed in climate policy.

Transformational strategies that align mitigation with subjective life satisfaction, and build societal support by positive discourses about economic, social, and cultural benefits of low-carbon innovations, promises far more success than targeting mitigation alone (WBGU 2011; Asensio and Delmas 2016; Geels et al. 2017). Given that present bias - being motivated by costs and benefits that take effect immediately than those delivered later- significantly shapes behavior, schemes that bring forward distant costs into the present or that upfront incentives, have proved to be more effective (Benartzi, 2012) (Zauberman et al. 2009)(van den Broek et al. 2017)(Safarzyńska 2018).

Finally, it may be easier altering behaviour through simple steps, identifying how a complex goal, like transformation into a low-carbon society, can be broken down into simpler, specific actions and interim targets. (Zauberman et al. 2009) (WBGU 2011).

4.4.2.3 Financial Systems

Financial systems are an indispensable element of a systemic transition (Fankhauser, Sahni, Savvas, & Ward, 2016; Naidoo 2020) But the financial system will need to evolve to play its role in financing sustainable development, by aligning incentives and investments with achieving climate and broader sustainability goal (UNEP Inquiry 2016). (Steckel et al. 2017) concludes that climate finance could become a central pillar of sustainable development by reconciling the global goal of cost-efficient mitigation with national policy priorities. International climate finance could support countries to introduce carbon pricing or remove fossil fuel subsidies, creating a fiscal space that may be used in support of the countries' sustainable development objectives. It also encourages less carbon-intensive production and consumption (Wall Street Journal 2019; Farid et al. 2016; World Bank 2014; CPLC 2017).

Policy efforts need to be effective in re-directing financial resources towards low-emission assets and services (UNEP 2015), mainstreaming climate finance within financial and banking system regulation, and reducing transaction costs for bankable mitigation technology projects (Mundaca et al. 2013; Brunner and Enting 2014). For example, although developed countries pledged USD100 billion per year to developing nations by 2020 to combat climate change, and global public and private investment in climate mitigation and adaptation is approximately USD455 billion per year, this is inadequate to the estimated USD2.4 trillion per year that is needed to transform systems to address climate change (Yeo 2019). Enabling conditions for scaling up public and private investment include acknowledging and disclosure of climate-related risk and the risk of transitions in financial portfolios (Clark et al. 2018; Masson-Delmotte et al. 2018).

The transition from traditional public climate finance interventions to the market-based support of climate mitigation (Bodnar et al. 2018) demands innovative forms of financial cooperation and innovative financing mechanisms to help de-risk low-emission investments and support new business models. These financial innovations may involve sub-national actors like cities and regional governments in raising finance to achieve their commitments (Cartwright 2015) (CCFLA, 2016) Moreover, public-private partnerships have proved to be an important vehicle for financing investments to meet the Sustainable Development Goals, including economic instruments for financing conservation (Díaz et al., 2019; Sovacool 2013).

Early action must enhance upscaling finance to achieve climate mitigation and sustainable development goals in the medium-term. Without a more rapid, scaled redeployment of financing, we will lock in development trajectories that hinder the realization of the global goals (Robins and Zadek, 2016) Investment are also needed that avoid trading off with the Paris Goals and other SDGs, as well as those that simultaneously reduce poverty, inequality, and emissions (Fuso Nerini et al. 2019).

4.4.2.4 Innovation and technologies

It is increasingly clear that digital changes are becoming a key driving force in societal transformation (Tegmark 2017)(Domingos, 2015; Schwab, 2016; Craglia et al, 2018). Digitalization is not only an "instrument" for resolving sustainability challenges, it is also a fundamental driver of disruptive, multiscalar change (Sachs et al. 2019) Information and communication technologies (ICT), artificial intelligence (AI), the internet of things (IOT), nanotechnologies, biotechnologies, robotics, are not usually categorized as climate technologies, but have a potential impact on GHG emissions (WEF, 2015; OECD, 2017c).

The research community has called for more "responsible innovation," (Pandza and Ellwood 2013) "open innovation," (Rauter et al. 2019) "mission-oriented" (Mazzucato and Semieniuk 2017) innovation, "holistic innovation," (Chen et al. 2018b) "next-generation innovation policy," (Kuhlmann and Rip 2018) or "transformative innovation" (Schot and Steinmueller 2018) so that innovation patterns and processes are commensurate to our growing sustainability challenges . There is a growing recognition that new forms of innovation must be harnessed and coupled to climate objectives (Fagerberg et al. 2016; Wang et al. 2018). As such, innovation and sociotechnical change can be channelled to intensify mitigation via "deliberate acceleration" (Roberts et al. 2018a) and "coalition building." (Hess 2018)

System innovation is a core focus of the transitions literature (Grin et al. 2010; Markard et al. 2012; Geels et al. 2017). Accelerating low carbon transitions thus not only requires a shift of system elements but also underlying routines and rules, and hence transitions shift the directionality of innovation. They hence concern the development of a new paradigm or regime that is more focused on solving sustainability challenges that cannot be solved within the dominant regime they substitute. Several studies have pointed at the important possible contributions of grassroots innovators for the start-up of sustainability transitions (Seyfang and Smith 2007; Smith et al. 2016; Seyfang et al. 2014). In particular, a range of studies have shown that users can play a variety of roles in promoting system innovation: shielding, nurturing (including learning, networking and visioning) and empowering the niches in relation to the dominant system and regime (Schot et al. 2016; Randelli and Rocchi 2017; Meelen et al. 2019).

Transformations con not be imposed from the top down, instead need stakeholder engagement and co-design to gain broad public support and buy-in.(Sachs et al. 2019)

4.4.2.5 Policy

Although many transformation has been driven by an innovative technology, government policy intervention was frequently a crucial component in the more rapid transformations (Michaelowa et al. 2018).

A shift in development pathways that includes accelerated mitigation, may best be achieved through integrated actions that comprise policies, both fiscal and other, in support of the broader SDG agenda. For effectiveness, these should be based on country-specific priorities, including the impact of mitigation on employment and income distribution, and the need to ensure political support for mitigation.

Stringent temperature targets imply bold policies in the short term (Rockström et al. 2017; Kriegler et al. 2018) that would also lead to reducing implementation challenges post-2030 (Kriegler et al. 2018; Roelfsema et al. 2018c). Early action is needed to enforce effective existing policy instruments and regulations, and to reform or remove harmful existing policies and subsidies (Díaz et al. 2019) A global roll-out of regionally-specific policies and ambitious sector-specific policies based on good practice could ease the implementation challenge.

Because low-carbon transitions are inevitably political, analyses need done *of* policy as well as *for* policy. Political scientists have developed a number of theoretical models that both *explain* policy-making processes and provide useful insights for *influencing* those processes (Geels et al. 2017). For example, theories of *policy networks* see policymaking as a deeply political process involving negotiations, compromises and the building of coalitions with stakeholders (Meckling et al. 2015). Similarly, policy implementation can be seen as a process also of improvisation, experimentation, and learning-by-doing, which can all further accelerate transitions (Geels et al. 2017)

These considerations reinforce the argument that policymakers should not rely exclusively upon single policy instruments. Policymakers should mobilise a range of policies, such as financial instruments (taxes, subsidies, grants, loans), regulatory instruments (standards, laws, performance targets) and processual instruments (demonstration projects, network management, public debates, consultations, foresight exercises, roadmaps) (Voß et al. 2007). The appropriate mix is likely to vary between countries and domains, depending on political cultures and stakeholder configurations (Rogge and Reichardt 2016), but is likely to include a combination of: a) standards, nudges and information to encourage low-carbon technology adoption and behavioural change; b) economic incentives to reward low carbon investments; and c) (most importantly) innovation support and strategic investment to encourage systemic change (Grubb 2014). These approaches can be mutually reinforcing: for example, carbon pricing can incentivise low carbon innovation, while targeted support for emerging niche technologies can make them more competitive encourage their diffusion and ultimately facilitate a higher level of carbon pricing. Even in Germany, the success of a “demand-pull” instrument such as the feed-in tariffs only worked as well as it did because it formed part of a broader policy mix including “supply-push” mechanisms such as subsidies for research and “systemic measures” such as collaborative research projects and systems of knowledge exchange (Rogge et al. 2015).

4.4.3 Taking uncertainties and risks into account

4.4.3.1 Major sources of uncertainties that accelerating mitigation / shifting development pathways face

As noted in 4.2.2.6 and 4.2.3, the global level of emissions in 2030—even with full achievement of the objectives spelled out in the NDCs—is uncertain (Benveniste et al. 2018; Rogelj et al. 2017a)(UNEP 2019a). Similarly, the emissions outcome of accelerated mitigation and of shifting development strategies also face multiple sources of uncertainty. Some key categories of uncertainty (with examples in brackets) include climate science (e.g. GWP values, emission factors, LULUCF emissions), socio-economic trends (productivity, demography, inequality), (technology; availability/costs of RE, CCS, technological breakthroughs, see chapter 16), behaviours and institutional norms (individual preferences and their evolution, behaviour of institutions; see chapter 5); and international context (stringency of mitigation policies in trading partners, international price of energy and other commodities, strength of global cooperation, geopolitics).

Some of these uncertainties can be easily captured by models. Others are better understood with qualitative ways of assessing risks. In this regard, qualitative narrative storylines (told in words) are complementary tools to quantitative scenarios, together helping to cope with high uncertainty (Kemp-Benedict 2012). (Hanger-Kopp et al. 2019) provide narratives of development pathways for 11 countries with view to, among others, better capturing the risks associated with these scenarios.

The role of the international context is a major source of uncertainty for national-level planning, especially for small- or medium-sized open economies that are very dependent on what happens abroad, notably in major trading partners (Alton et al. 2014b) (Dai et al. 2017), or in terms of financing/technology transfer that may be available from abroad (Baum et al. 2017). A second point worth emphasizing is that the combination of the uncertainties creates a gap between policies and measures—that is what national governments actually decide on—and the associated emissions outcome.

Risks can arise when seeking to shift development pathways, since such a complex processes involve a broad range of stakeholders, decision-making processes and multiple scales. Where shifts are intentional, they require a credible and trusted process for reconciling perspectives and balancing trade-offs, managing winners and losers and implementing compensatory measures when needed. Such processes need to manage the risk of inequitable or non-representative power dynamics (Helsinki Design Lab 2014; Kahane 2019; Boulle et al. 2015). More generally, stakeholder processes can be subject to regulatory capture by special interests, or outright opposition from a variety of stakeholders. Information asymmetry between government and business may shape the results of consultative processes. Managing such risks requires sufficiently strong and competent institutions.

4.4.3.2 Hedging strategies

In the presence of uncertainty and inertia/irreversibility, it is well known that hedging strategies should be considered.

The climate change problem is characterized by high degree of irreversibility and inertia. The first category of inertia is climatic: The total amount of GHG emissions to stay under 1.5 or 2°C limited. Overall emissions in 2030 at the level or above the amount expected from current NDCs "would not limit global warming to 1.5°C, even if supplemented by very challenging increases in the scale and ambition of emissions reductions after 2030" (IPCC 2018b). In fact, rates of emission reductions after 2030 would need to be substantially increased and carbon dioxide removal would need to be deployed to keep end-of-century targets (see also Chapter 3, section 3.5).

But the drivers of emissions are also characterized by high level of inertia, via long-lived capital stock or urban forms (Lecocq and Shalizi 2014), or more broadly mutually reinforcing physical, economic, and social constraints (Seto et al. 2016) that may lead to carbon lock-in (Erickson et al. 2015). Risks associated with long-lasting fossil-fuel power plants have been the object of particular attention. For example, (Pfeiffer et al. 2018) estimate that even if the current pipeline of power plants was cancelled, about 20% of the existing capacity would need to be stranded to remain compatible with 1.5°C or 2°C pathways—implying that additional capital accumulation would lead to higher sunk costs associated with stranded assets (Luderer et al. 2018b; Johnson et al. 2015; Kriegler et al. 2018).

In the adaptation literature, the notion of hedging against risks associated with (uncertain) climate change is now common place, as exemplified by the terminology of "climate resilient development" (Fankhauser and McDermott 2016). There is also a growing literature on hedging strategies for individual actors (e.g., firms or investors) in the face of the uncertainties associated with mitigation (e.g. policy uncertainty or the associated carbon price uncertainty) (e.g., (Morris et al. 2018) or (Andersson et al. 2016)). On the other hand, there is often limited discussion of uncertainty and of its implication for hedging strategies in the accelerated mitigation pathway literature. Exceptions include (Capros et al. 2019), who elicit "no-regret" and "disruptive" mitigation options for the EU through a detailed sensitivity analysis, and (Watson et al. 2015) who discuss flexible strategies for the U.K. energy sector transition in the face of multiple uncertainties.

4.4.4 Equity, including just transition

Equity is an ethical imperative, but it is also instrumentally an enabler of deeper ambition for accelerated mitigation (Hoegh-Guldberg et al. 2019). The literature supports a range of estimates of the net benefits – globally or nationally – of low-carbon transformation [*Reference Ch.3*], and it identifies a number of difficulties in drawing definitive quantitative conclusions (e.g., comparisons of costs & benefits among different actors, the existence of non-economic impacts, comparison across time, uncertainty in magnitude). One of the most important of these dimensions is the distributional consequences of mitigation, as well as a range of equity considerations arising from the uncertainty in net benefits, as well as from the distribution of costs and benefits among winners and losers (Rendall 2019; Caney 2016; Lahn and Bradley 2016; Lenferna 2018; Kartha et al. 2018b; Robiou Du Pont et al. 2017). For more on assessments of fairness in NDCs, see section 4.2.2.5).

While there is extensive literature on equity frameworks for national emissions allocations (Robiou du Pont and Meinshausen 2018) (Climate Action Tracker, 2017, 2018) (CSO Equity Review 2018, 2015, 2017) (Holz et al. 2018) (Kemp-Benedict et al. 2018), they have tended to focus on allocation of a global carbon budget among countries based on quantified equity frameworks. The implicit normative choices made in these analysis have limitations (Kartha et al. 2018a).

Ultimately, equity consequences depend on how costs and benefits are initially incurred and how they are shared as per social contracts (Combet and Hourcade 2017), national policy, and international agreements. The literature suggests a relation between the effectiveness of cooperative action and the perception of fairness of such arrangements. (Winkler et al. 2018a) demonstrate that countries have put forward a wide variety of indicators and approaches for explaining the fairness and ambition of their NDCs, reflecting the broader range of perspectives found in the moral philosophical literature cited above. (Mbeva and Pauw 2016) further find that adaptation and financing issues take on greater salience in the national perspectives reflected in the NDCs.

Thus, topics of equity and fairness have begun to receive a greater amount of attention within the energy and climate literature, namely through the approaches of gender and race (Pearson et al. 2017; Lennon 2017; Allen et al. 2019), environmental justice (Mohai et al. 2009), climate justice (Jenkins 2018; Routledge et al. 2018), and energy justice (Sovacool and Dworkin 2014). While such approaches frequently envision justice and equity as an ethical imperative, justice also possesses an instrumental value of enabling deeper and more socially acceptable mitigation efforts (Klinsky and Winkler 2018).

A more concrete focal point on these issues has been that of "just transition." Getting broad consensus for the transformational change implied by climate crisis requires 'leaving no one behind', i.e., ensuring (sufficiently) equitable transition for the relevant affected individuals, communities, and societies (Jasanoff 2018). The notion of a "just transition" was developed during the 1990s by North American trade unionists in response to new regulations to prevent water and air pollution. It was further taken up, for example, in the collaboration of the International Trade Union Confederation (ITUC), the International Labour Organization (ILO) and the UN Environmental Programme (UNEP) in promoting "green jobs" as necessary elements of a just transition (ILO 2015; Rosemberg 2015). In recent years the concept of a "just transition" has gained increased traction, for example incorporated in the outcome of the Rio+20 Earth Summit and more recently recognized in the preamble of the Paris Agreement, which states "the imperative of a just transition of the workforce and the creation of decent work and quality jobs in accordance with nationally defined development priorities" (UNFCCC 2015c). Some heads of state and government signed a '*Solidarity and Just Transition Silesia Declaration* first introduced at COP24 in Poland (HoSG 2018).

While the precise definition various by source, core elements tend to consistently appear: (1) investments in establishing low-emission and labour-intensive technologies and sectors; (2) research and early assessment of the social and employment impacts of climate policies; (3) social dialogue and democratic consultation of social partners and stakeholders (Smith 2017; Swilling and Annecke 2012); (4) training and skills development for exposed workers; (5) social protection alongside active labour markets policies; and (6) local economic diversification plans (Healy & Barry, 2017; Heffron & McCauley, 2018; Newell & Mulvaney, 2013).

A just transition could therefore require that the state intervene more actively in regulating prosperity and creating jobs in "green" sectors, in part to compensate for soon-to-be abandoned fossil-fuel-based sectors, and that governments, polluting industries, corporations and those more able to pay higher associated taxes pay for transition costs, provide a welfare safety net and adequate compensation for people and communities that have been impacted by pollution, marginalized or negatively impacted by a transition from a high to low carbon economy and society.

The just transition concept has thus become an international focal point tying together social movements, trade unions, and other key stakeholders to ensure equity is better accounted for in low-carbon transitions and to seek to protect workers and communities (Pollin and Callaci 2019). It also forms a central component of the burgeoning movement for a 'Green New Deal' — a package of policy options that aims to rapidly decarbonizes the economy while significantly reducing economic inequality(Hockett and Gunn-Wright 2019) A European Green Deal was adopted in December 2019 (European Commission 2019). Alliances around a just transition at the international scale include (see box 4.5).

Box 4.5: Selected organisations and movements supporting a just transition

BlueGreen Alliance (US)
Beyond Coal campaign (US)
Climate Justice Alliance (US)
Deutscher Gewerkschaftsbund (German Trade Union Confederation) (Germany)
European Trade Union Confederation (EU)
IndustriALL Global Union (global)
Indigenous Environmental Network (US)
International Labour Organization (global)
International Trade Union Confederation (Just Transitions Center) (global)
ITUC-affiliated Just Transition Centre (Global)
Just Transition Alliance (US)
Just Transition Fund (US)
Kentuckians for the Commonwealth (US)
Labor Network for Sustainability (US)
NAACP (US)
National Union of Mineworkers of South Africa (South Africa)
Sierra Club (US)
Sunrise Movement (US)
The Trade Unions for Energy Democracy initiative (Global)
Trade Union Confederation of the Americas (TUCA) ITUC's regional branch (Americas)
Transitions Town Movement (UK)
Women's Environment and Development Organization (Global)
350.org (Global)

A just transition at national, regional and local scales, can help to ensure that workers, communities, fence line communities, energy-poor, poor countries etc. are not left behind in the transition.

As Table 4.8 and Figure 4.10 reveal, no fewer than 7 national commissions or task forces on a just transition existed as of 2019 as well as 7 other sets of national policies and a multitude of other actors, networks, and movements. For instance, the German phase out of coal subsidies involved a savings package for unemployed miners and subsidy reform packages introduced by Iran, Namibia, the Philippines, Turkey, and the United Kingdom provide similar compensating measures to affected groups (Sovacool 2017). Spain's just transition plan for coal miners includes early retirement, redundancy packages, retraining for green jobs, and priority job placement for former miners.

Table 4.8: Commissions, policies, and movements behind a "Just Transition"

Country	National Commissions | Task forces | Dialogues	Ref:
Canada	Task Force on Just Transition for Canadian Coal Power Workers and Communities	(Government of Canada 2019)

Czech Republic	Czech Coal Commission	(Ministry of Industry and Trade Czech Republic 2019)
Germany	German Commission on Growth, Structural Change and Employment (German Coal Commission)	(Commission on Growth Structural Change and Employment 2019)
Ghana	The National Dialogue on Decent Work and 'Just Transition" to a Sustainable Economy and Society	(Ministry of Employment and Labour Relations of Ghana 2018)
New Zealand	Establishment of "Just Transitions Unit" within the ministry of Business, Innovation & Employment (MBIE)	(Ministry of Business Innovation & Employment New Zealand 2019)
Scotland	Just Transition Commission	(Scottish Government)
South Africa	National Planning Commission Just Transition Dialogue	(NPC (National Planning Commission) 2019)
Indonesia	Fossil fuel subsidy reform -President Joko Widodo removed subsidies for gasoline (2015) and diesel (2016) replacing them in part with investments in infrastructure, and poverty reduction programs.	(Chelminski 2018)
People's Republic of China	Mine closure provisions in the 13th Five Year Plan for Coal Industry Development, 2016-2020	(Piggot et al. 2019)
Scotland	Oil Worker Transition Fund	(Piggot et al. 2019)
Spain	Framework Agreement for a Just Transition of Coal Mining and Sustainable Development of the Mining Regions for the Period 2019-2027	(Ministerio Para la Transicion Ecologica Gobierno de España 2018)
South Africa	The One Million Climate Jobs Campaign National Employment Vulnerability Assessment (NEVA) Sector Job Resilience Plans (SJRPs)	(Strambo and Atteridge 2019)
The United States	Partnerships for Opportunity and Workforce and Economic Revitalization Plan (POWER+)	(White House 2016)
Vietnam	The Biogas program of the Vietnamese Ministry of Agriculture and Rural Development and the Netherlands Development Organization (SNV)	(International Labor Organization 2018)

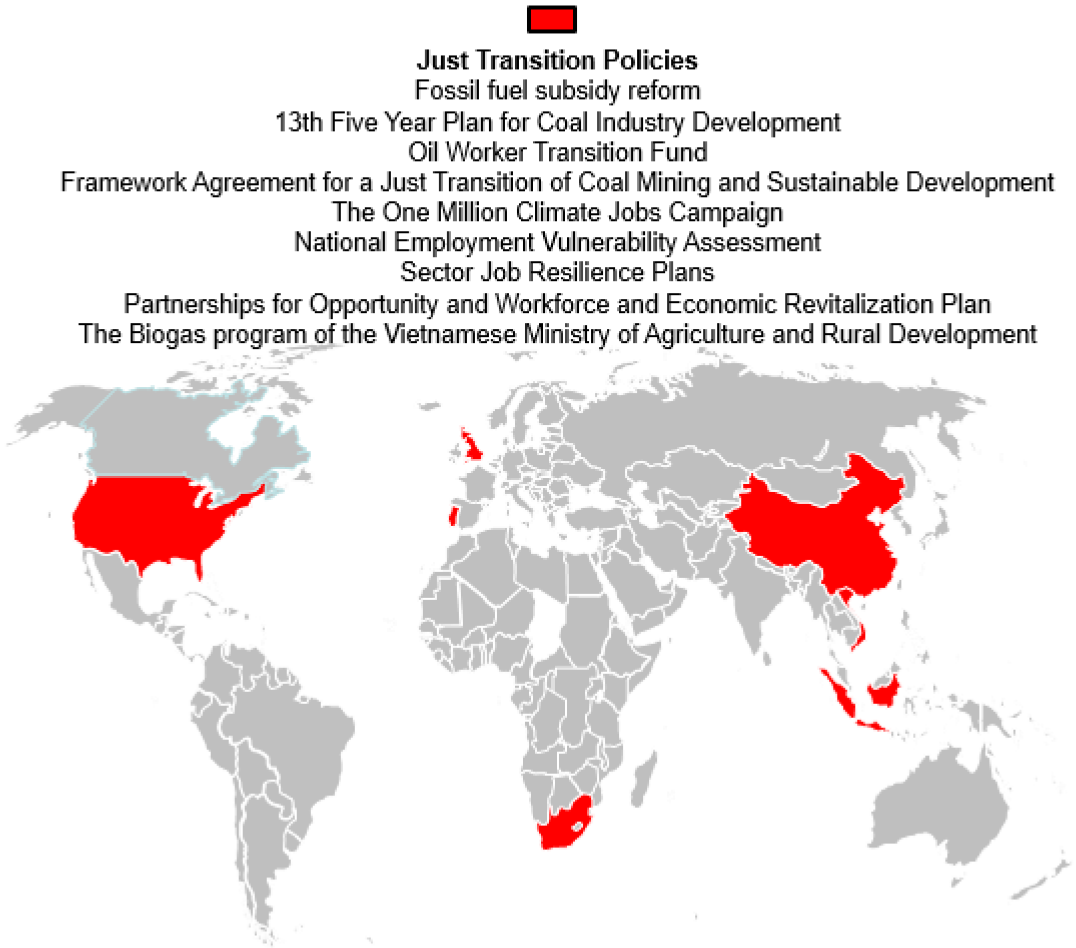

Figure 4.10: Just Transition Commissions and Policies Around the World, 2019

Nonetheless, ensuring equity in turn entails a fundamental shifting of development pathways. Such shifts will require a broad alliance of social actors supporting a just transition. Key enabling conditions include governance, behaviour and lifestyles, innovation, enhancing institutional capacities, policy and finance (see section 4.4.3 and (de Coninck et al. 2018b)).

Shifting development pathways will open broader options, thereby accelerating mitigation and reducing climate impacts – another important dimension of equity, in that the poor who are least responsible for climate change are most vulnerable to its impacts (See WGII, chapter 8).

4.5 Links to adaptation

The Paris Agreement includes mitigation and adaptation as key areas of action, and recognizes that adaptation is a global challenge faced by all with local, subnational, national, regional and international dimensions. The IPCC previous assessment (IPCC 2014b) emphasized that sustainable development is helpful in going beyond a narrow focus on separate mitigation and adaptation options and their specific co-benefits.

The IPCC special report on 1.5°C assessed mitigation options with adaptation co-benefits and trade-offs; including energy system transitions; land and ecosystem transitions (including addressing food system efficiency, sustainable agricultural intensification, ecosystem restoration); urban and infrastructure system transitions (including land use planning, transport systems, and improved infrastructure for delivering and using power); industrial system transitions (including energy efficiency, bio-based and circularity, electrification and hydrogen, and industrial Carbon Capture, Utilisation and Storage (CCUS); and carbon dioxide removal (including bioenergy with CCS, afforestation and reforestation, soil carbon sequestration, and enhanced weathering.) (IPCC 2018: supplementary information Table 4.SM.5.1).

The IPCC special report on climate change and land addresses greenhouse gas emissions from land-based ecosystems with a focus on the vulnerability of land-based systems to climate change, and also the potential of changes to land use and land management practices to mitigate and adapt to climate change. Many land use interventions can provide both mitigation and adaptation, and also provide a range of other benefits, including support of several sustainable development goals.

This section examines how development pathways can build greater adaptive and mitigative capacity, and then turns to specific links between mitigation and adaptation – in relation to agriculture, blue carbon and ecosystem services.

4.5.1 Development pathways can build greater capacity for both adaptation and mitigation

Shifting development pathways is critical to achieving mitigation goals. Previous assessments have reflected on making development more sustainable (Sathaye et al. 2007; Fleurbaey et al. 2014b; IPCC 2001). The special report found that sustainable development pathways to 1.5 °C broadly support and often enable the transformations required; that the implementation of mitigation options often leads to synergies but at the pace; and that “sustainable development has the potential to significantly reduce systemic vulnerability, enhance adaptive capacity, and promote livelihood security for poor and disadvantaged populations (high confidence)” (IPCC 2018b: direct quote 5.3.1). With careful management, shifting development pathways can build greater adaptive and mitigative capacity, as further confirmed in recent literature (Schramski et al. 2018; Harvey et al. 2014; Ebi et al. 2014; Rosenbloom et al. 2018; Antwi-Agyei et al. 2015; Singh 2018) The literature points to the challenge of careful design of specific measures, and overall shifting development pathways to achieve both mitigation and adaptation goals.

The enabling conditions outlined in section 4.4.2 will support such shifts in general. In the following we assess where there are synergies and trade-offs when linking adaptation and mitigation.

4.5.1.1 Governance and Institutional capacity

Governance and institutional capacity enable adaptation in a similar manner to mitigation. Within this general synergy, one difference in relation to adaptation relates to scale. Cities and sub-national governments tend to focus on adaptation, whereas institutions for managing mitigation are typically established by national governments (references needed; see ch 13). The private sector has direct involvement in mitigation, being required for reduce as part of national efforts, participating in carbon markets and voluntary initiatives, whereas adaptation tends to fall under corporate social responsibility. Mitigation-focused initiatives from non-state actors tend to attain greater completion than adaptation-focused initiatives (NewClimate Institute et al. 2019).

4.5.1.2 Behaviour and lifestyles

Actors who doubt that climate change is anthropogenic but believe that climate is changing will change lifestyles to adapt, but not to mitigate [lots of literature on farmers, voters who are in this category; add references]. On the individual level, adaptation is automatic but mitigation is undertaken deliberately. Chapter 5 considers behavioural change, including the reconsideration of values and what is meant by well-being, and reflecting on a range of actors addressing both adaptation and mitigation (see ch 5). Concrete initiatives to change behaviour and lifestyles includes the Transition Town movement, in which seek to implement a just transition – both in relation to adaptation and mitigation – in specific localities – assessed in special report (Roy et al. 2018).

4.5.1.3 Finance

Most climate funding supports mitigation efforts, not adaptation efforts (Buchner et al. 2019) (Halimanjaya and Papyrakis 2012). Mitigation projects are often more attractive to private capital (Abadie et al. 2013) (Buchner et al. 2019). Efforts to integrate adaptation and mitigation in climate change finance are limited (Locatelli et al. 2016) There is a perception that integration of mitigation and adaptation projects would lead to competition for limited finance dollars available for adaptation (Locatelli et al. 2016). On-going debates (Ayers and Huq 2009)(Smith et al. 2011) whether development finance counts as adaptation funding remain unresolved.

4.5.1.4 Innovation and technologies

Systems transitions that address both adaptation and accelerating mitigation include the widespread adoption of new and possibly disruptive technologies and practices and enhanced climate-driven innovation (IPCC 2018a). The literature points to trade-offs that developing countries face in investing limited resources in research and development, though finding synergies in relation to agriculture (Adenle et al. 2015). Other studies point to difference in technology transfers for adaptation and mitigation (Biagini et al. 2014) Adaptation projects tend to use existing technologies whereas mitigation climate actions are more likely to rely on novel technologies. Innovations for mitigation are typically (but not exclusively) north to south technology transfers (Biagini et al. 2014) Indigenous knowledge can be a unique source for techniques for adaptation (Nyong et al. 2007).

4.5.1.5 Policy

Chapter 13 considers the implications of specific policy instruments and integrated policy packages. Adaptation-focused pathways might reduce inequality, if adequate support is available and well distributed; however, there are risks that actors may wish to focus on adaptation for themselves (references?). Some studies suggest that cities might plan for possible synergies in adaptation and mitigation strategies, currently done independently (Grafakos et al. 2019). The literature suggests that cities might identify both mitigation and adaptation as co-benefits of interventions targeted at developmental goals (Dulal 2017).

4.5.2 Specific links between mitigation and adaptation

There is a strong link between mitigation and adaptation; here we assess commonly considered mitigation-focused climate actions in terms of adaptation implications. Adaptation can be a co-benefit of mitigation, but can also be a prerequisite for success of a mitigation climate action. Mitigation climate actions can be maladaptive as well. **Making development pathways more sustainable can build greater adaptive and mitigative capacity. Adaptation can be a co-benefit of mitigation, with specific examples of synergies (while not ignoring trade-offs) in relation to agriculture, blue carbon and ecosystem services (*medium evidence, medium agreement*).**

Here we focus on climate mitigation actions and links to adaptation in the areas of use and management of land and coastal systems. While specific mitigation actions are considered in sectoral chapters 6 (Energy Systems), 7 (Agriculture, Forestry, and other Land Uses) 8 (Urban systems) 9 (Buildings), 10 (Transport) 11 (Industry) we focus on sustainable agriculture, coastal ecosystems (“blue carbon”) ecosystem restoration, and prevention of ecosystem degradation because these areas are exemplary of the tradeoffs and synergies resulting from different mitigation pathways.

4.5.2.1 Sustainable Agriculture can have mitigation co-benefits and reduce trade-offs

Conservation agriculture can yield mitigation co-benefits through improved fertiliser use or efficient use of machinery and fossil fuels (Cui et al. 2018; Harvey et al. 2014; Pradhan et al. 2018a) and can help build adaptive capacity (Pradhan et al. 2018a; Smith et al. 2017). Climate smart agriculture (CSA) ties mitigation to adaptation through its three pillars of increased productivity, mitigation, and adaptation (Lipper et al. 2014) although managing trade-offs among the three pillars requires care

(Thornton et al. 2018a). The ‘4 per 1000’ goal to increase soil carbon by 0.4% per year (Soussana et al. 2019) is compatible with the three pillars of CSA. Sustainable intensification also complements CSA(Campbell et al. 2014)

Weindl et al estimate that mixed crop-livestock systems can avoid deforestation on 76 million ha globally, while reducing the costs of adaptation in agriculture by 0.3% of total production costs (Weindl et al. 2015). This example of providing a cost-effective mitigation co-benefits of adaptation action is supported by evidence from various regions (Thornton and Herrero 2015; Thornton et al. 2018b).

Agroforestry can sustain or increase food production in some systems, increasing farmers’ resilience to climate change (Jones et al. 2012). A meta-analysis of European agroforestry systems suggests that agroforestry in the European context provides ecosystem services, some of which are adaptative and mitigative (erosion control, enhanced soil fertility), but does not enhance provisioning (Torralba et al. 2016)

Some sustainable agricultural practices have tradeoffs, and their implementation can have negative effects on adaptation or other ecosystem services. Fast-growing tree monocultures or biofuel crops may enhance carbon stocks but reduce downstream water availability and decrease availability of agricultural land (Harvey et al. 2014). Similarly, Agroforestry can, in some dry environments, increase competition with crops and pastures, decreasing productivity, and reduce catchment water yield (Schrobback et al. 2011).

Agricultural practices can supply both mitigation and adaptation at the field scale, but if yields are lower interconnections of the global agricultural system can lead to deforestation elsewhere (Erb et al. 2016).

Implementation of sustainable agriculture can increase/decrease yields depending on context. (Pretty et al. 2006)

There are multiple agricultural mitigation options that southeast Asian countries could use to meet NDCs that would have an important adaptive impact (Amjath-Babu et al. 2019).

4.5.2.2 Blue carbon and mitigation co-benefits of adaptation actions

The Paris Agreement recognised that mitigation co-benefits resulting from Parties’ adaptation actions and/or economic diversification plans can contribute to mitigation outcomes (UNFCCC 2015: Article 4.7). In addition to the co-benefits identified in agriculture, recent literature has explored the potential of blue carbon.

Blue carbon refers to carbon stored in coastal ecosystems such as seagrasses, salt marshes, and mangroves (Wylie et al. 2016) and deltas (Fennessy et al. 2019) (Fourqurean et al. 2012) (Tokoro et al. 2014) thereby building adaptive capacity and contributing to mitigation by sequestering carbon while also providing habitat, referred to as a ‘triple-win’ (Sutton-Grier and Moore 2016).

The literature contains case studies of blue carbon in Kenya, India, Vietnam, and Madagascar (Wylie et al. 2016), the USA (Sutton-Grier and Moore 2016).; salt marshes in China (Gu et al. 2018) and tidal marshes in Australia (Macreadie et al. 2017); mangrove forests in Indonesia (Murdiyarso et al. 2015), with estimates for carbon stocks for mangroves in Africa, Asia and Latin America (Boone and Bhomia 2017), and globally 4.19 PgC in 2012 (Hamilton and Friess 2018) [*Check unit consistency, does the WGIII report use Mt , Pg, C or CO_2*]. Methane emissions partially offset the sequestration (Rosentreter et al. 2018).

Restoration of mangroves and coastal wetlands to sequester (blue) carbon increases carbon sinks, reduces coastal erosion and protects from storm surges, and otherwise mitigates impacts of sea level rise and extreme weather along the coast line (Alongi 2008; Siikamäki et al. 2012; Romañach et al. 2018). Coastal habitat restoration projects can also provide significant social benefits in the form of job creation.(Edwards et al. 2013)

4.5.2.3 Ecosystem restoration and preventing ecosystem degradation

The literature reports a varied range of examples of ecosystem restoration providing services and preventing degradation. Reforestation and coastal restoration are associated with improved water filtration, ground water recharge and flood control (Ellison et al. 2017)(Griscom et al. 2017). Afforestation reduce flooding through decreased peak river flow, also improved water quality and groundwater recharge (Berry et al. 2014). Tree planting led to more resilient livestock by providing shade and shelter (Hayman et al. 2012). Soil organic carbon may foster crop resilience to climate change (Aguilera et al. 2013).

The aforegoing examples are relevant to adaptation, while other studies make clear the synergies across adaptation and mitigation. Preventing degradation of landscapes can be both mitigation and adaptation (Arneth et al. 2019). Afforestation of degraded areas can produce large synergies between mitigation and adaptation through their impact on farmer livelihoods (Rahn et al. 2014). Reforestation for mitigation purposes can be more effective if done with adaptation in mind (Gray et al. 2011). While policy in Brazil has tended to focus on the Amazon as a carbon sink, the mitigation co-benefits of ecosystem-based adaptation actions have been highlighted in the literature (Gregorio et al. 2015) (Locatelli et al. 2011).

The literature reports synergies, as above, as well as trade-offs. Some reforestation programs are of limited success, and may have adverse environmental consequences, including desertification and increased erosion which are mal-mitigative (Cao et al. 2010).

4.6 Research gaps

[*To be completed in FOD*]

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Study	Policy cut-off[a]	Regions	Sectors	Emissions[b]/ GWP (if applicable)	Scenarios[c]	Policies	Methods[d]	References
Climate Action Tracker	11/2018	Global (33 countries in detail, covering x% of GHG emissions)	Energy, AFOLU	Kyoto gases/IPCC AR4	REF, CP, NDC	All policies (somewhat unclear)	Literature review (official, national, international sources), supplemented by additional bottom-up analysis (spreadsheet?)	(Climate Action Tracker 2018) method: https://climateactiontracker.org/methodology/
PBL Netherlands Environmental Assessment Agency	11/2018	Global (G20 countries with policy detail, NDCs for 78 countries, covering 91% of 2012 GHG emissions)	Energy, AFOLU	Kyoto gases/IPCC AR4	REF, CP, NDC	Expert-selected policies based on comprehensive policy inventory	CP: literature review (official, national, international sources), global IAM (IMAGE), ILM (GLOBIOM/G4M), NDC: FAIR model	(Kuramochi et al. 2018) online tool: https://themasites.pbl.nl/climate-ndc-policies-tool/
ADVANCE	4/2017 *	Global	Energy, AFOLU	Kyoto gases/IPCC AR4	REF, NDC	NDC: GHG targets	Set of global IAMs (AIM/CGE, IMAGE, IMACLIM, GCAM, GEM-E3, MESSAGE-GLOBIOM, POLES, REMIND, WITCH-GLOBIOM)	(Vrontisi et al. 2018; Luderer et al. 2018a) online database : https://db1.ene.iiasa.ac.at/ADVANCEDB/

Study	Policy cut-off[a]	Regions	Sectors	Emissions[b]/ GWP (if applicable)	Scenarios[c]	Policies	Methods[d]	References
CD-LINKS global	12/2016	Global,	Energy, AFOLU	Kyoto gases/IPCC AR4	REF, CP, NDC	CP: comprehensive policies; NDC: GHG targets, additional policies	Set of global IAMs (AIM/CGE, IMAGE, GEM-E3, MESSAGEix-GLOBIOM, POLES, REMIND-MAgPIE, WITCH-GLOBIOM)	(McCollum et al. 2018; Roelfsema et al.) online database: https://db1.ene.iiasa.ac.at/CDLINKSDB/
GECO 2018 study (JRC)	11/2018	Global G20 countries with policy detail)	Energy, AFOLU	Kyoto gases/IPCC SAR	REF, CP, NDC	Expert-selected policies based on comprehensive policy inventory	CP: literature review (official, national, international sources), global IAM (POLES), ILM (GLOBIOM/G4M)	(Keramidas et al. 2018)
NDC & INDC Factsheets (University of Melbourne)	11/2016	Global (195 countries)	Energy, AFOLU	Kyoto gases / IPCC AR4	NDC	NDC: Emissions pathways	literature review, IPCC scenario database	(Meinshausen and Alexander 2017) http://climatecollege.unimelb.edu.au/ndc-indc-factsheets

Study	Policy cut-off[a]	Regions	Sectors	Emissions[b]/ GWP (if applicable)	Scenarios[c]	Policies	Methods[d]	References
Climate Interactive	4/2017 *	Global (6 region)	Energy, AFOLU	Kyoto gases / IPCC AR4	NDC	NDC: Emissions pathways	Global simulator	(Climate Interactive 2017a) online tool: https://www.climateinteractive.org/tools/c-roads/ method: (Sterman et al. 2013)
Keesler, Orifici and Blanco	11/2019	National (Argentina)	Energy, AFOLU	Kyoto gases/IPCC AR4	CP, NDC	CP: comprehensive policies; NDC: GHG target	National ESM	(Keesler et al. 2019)
Climateworks Australia	2018	National (Australia)	Energy, AFOLU	Kyoto gases/IPCC AR4	CP, NDC	CP: comprehensive policies; NDC: GHG target	National ESM	(ClimateWorks Australia 2018)
Koberle et al. 2019; Rochedo et al. 2018	12/2016	National (Brazil)	Energy, AFOLU	Kyoto gases/IPCC ?	CP, NDC	CP: comprehensive policies, NDC: GHG target	National ESM (BLUES)	(Koberle et al.; Rochedo et al. 2018)

Study	Policy cut-off[a]	Regions	Sectors	Emissions[b]/ GWP (if applicable)	Scenarios[c]	Policies	Methods[d]	References
(Fu et al. 2017; Fu 2018)	11/2017	National (China)	Energy	CO_2/NA	CP, NDC	NDC	National ESM (China)	(Fu et al. 2017; Fu 2018)
(Li et al. 2019a)	12/2018	National (China)	Energy	CO_2/NA	CP, NDC	NDC: Emission peak by 2030, others?	National ESM (China TIMES)	(Li et al. 2019a) Method: (Shi et al. 2016)
(Yang et al. 2018)	1/2017	National (China)	Energy	CO_2/NA	REF, NDC	NDC: Emission peak, emission intensity	National ESM (China MAPLE), MACCs	(Yang et al. 2018)
China Renewable Energy Outlook	4/2017 *	National (China)	Energy	CO_2/NA	CP	CP: stated policies and extrapolation of current policies	National ESM (CNREC scenario modeling tools)	(ERI/CNREC 2017)
European Commission (2018)	11/2018	Regional (EU)	Energy, AFOLU	Kyoto gases/IPCC AR4	CP, NDC	CP: comprehensive policies; NDC: GHG target	Modeling tools for EU analysis (PRIMES, GAINS, GLOBIOM/G4M, CAPRI, GEM-E3, E3ME)	(European Commission 2018) method: https://ec.europa.eu/clima/policies/

Study	Policy cut-off[a]	Regions	Sectors	Emissions[b]/ GWP (if applicable)	Scenarios[c]	Policies	Methods[d]	References
								strategies/analysis/models_en
Vrontisi et al. 2019	12/2016	Regional (EU)	Energy	Kyoto gases/IPCC ?	CP, NDC	CP: comprehensive policies; NDC: GHG target	Regional ESM and CGE model (PRIMES, GEM-E3)	(Vrontisi et al. 2019a)
Dusbash et al. 2018	2011-2015	National (India)	Energy	CO_2/NA	CP, NDC	CP: comprehensive policies; NDC: GHG target	Set of 15 national ESM studies with a base-year of current policies pre-2015 and 2015	(Dubash et al. 2018)
Vishwanathan et al. 2019	12/2016	National (India)	Energy	CO_2/NA	CP, NDC	CP: comprehensive policies, NDC	National ESM (AIM/Enduse 3.0)	(Vishwanathan et al. 2018; Vishwanathan and Garg)
Mathur et al. 2019	12/2016	National (India)	Energy	CO_2/NA	CP, NDC	CP: comprehensive policies, NDC	National ESM (India MARKAL)	(Mathur and Shekhar)
Oshiro et al. 2019	12/2016	National (Japan)	Energy, AFOLU	Kyoto gases/IPCC ?	CP, NDC	CP, NDC	National ESM (AIM/Enduse, DNE21+)	(Oshiro et al. 2019)

Study	Policy cut-off[a]	Regions	Sectors	Emissions[b]/ GWP (if applicable)	Scenarios[c]	Policies	Methods[d]	References
JMIP/EMF35	3/2018	National (Japan)	Energy, AFOLU	CO_2/NA, Kyoto gases/AR4?	NDC	NDC: GHG target	National ESMs (AIM/Enduse[Japan], DNE21-Japan, IEEJ-Japan, TIMES-Japan)	(Sugiyama et al. 2019)
Safonov et al. (in review)	12/2016	National (Russia)	Energy	CO_2/NA	CP, NDC	CP: comprehensive policies, NDC	National energy systems models (Russia-TIMES)	(Safonov et al.)
Rhodium Group (Pitt et al. 2019)	11/2019	National (USA)	Energy	Kyoto gases/IPCC AR4	CP, NDC	CP: comprehensive policies; NDC: GHG target	National ESM (USA)	(Pitt et al. 2019)
EIA Annual Energy Outlook 2019	6/2018*	USA	Energy	CO_2	CP	CP: current laws and regulations	National ESM (NEMS)	(EIA 2019)

Notes: [a] in case policy cut-off date is not explicitly specified in the publication or accompanying information, the study submission date minus six months is used as proxy; [b] CO_2 = CO_2 only, Kyoto = Kyoto GHGs; [c] REF = Reference or business-as-usual, CP = Current Policies, NDC = Nationally Determined Contribution; [d] IAM = Integrated Assessment Model, ESM = Energy Systems Model, ILM = Integrated Land Model, CGE = Computable General Equilibrium Model

Table S4.2: Studies used from official data and independent sources to estimate the emissions in the target year under the NDC and under current policies for G20 members. Source: updated from (den Elzen et al. 2019)**.**

Country	**NDC scenario**	**Current policies scenario**	**Current policies & NDC scenarios (when official data not available)**
	Official data sources 1)	**Official data sources**	**Independent sources (1. global models and 2. national models)**
Argentina	Revised NDC (Government of Argentina 2016)	N/A	1. CAT (Climate Action Tracker 2019), JRC (Keramidas et al. 2018), Uni. Melbourne (Meinshausen and Alexander 2017) (NDC only) 2. Keesler, Orifici and Blanco (Keesler et al. 2019)
Australia	N/A	Commonwealth of Australia (Commonwealth of Australia 2018)	1. CAT, JRC, PBL (Kuramochi et al. 2018), Uni. Melbourne (NDC only), Climate Interactive (Climate Interactive 2017b) (NDC only) 2. Climate Works Australia (ClimateWorks Australia 2018)
Brazil	NDC (UNFCCC 2018)	N/A	1. CAT, JRC, PBL, Uni. Melbourne (NDC only), Climate Interactive 2. COPPE (Rochedo et al. 2018; Koberle et al.)
Canada	NDC; Environment and Climate Change Canada (Government of Canada 2019)	UNFCCC BR data portal (UNFCCC 2019)	1. CAT, JRC, PBL, Uni. Melbourne (NDC only), Climate Interactive
China	N/A	N/A	1. CAT, IEA (IEA 2018) 2), JRC, PBL, Uni. Melbourne (NDC only), Climate Interactive (NDC only), PNNL (NDC only) (Fawcett et al. 2015) 2. NCSC (Fu et al. 2017; Fu 2018) 3), Tsinghua University (Wang et al.; Li et al. 2019b); ERI/CNREC (ERI/CNREC 2017) (CP only)
EU28	European Environment Agency (EEA 2018)	European Environment Agency European Commission (European Commission 2018) UNFCCC BR data portal	1. CAT, JRC, PBL, Uni. Melbourne (NDC only) 2. E3M (Vrontisi et al. 2019b)

Country	NDC scenario	Current policies scenario	Current policies & NDC scenarios (when official data not available)
	Official data sources 1)	**Official data sources**	**Independent sources (1. global models and 2. national models)**
India	N/A	N/A	1. CAT, IEA[2)], JRC, PBL, Uni. Melbourne (NDC only), PNNL (NDC only), Climate Interactive (NDC only) 2. Mitra et al. (Mitra et al. 2017); Dubash et al. (Dubash et al. 2018); IIMA (Vishwanathan and Garg); TERI (Mathur and Shekhar)
Indonesia	NDC	N/A	1. CAT, JRC, PBL, Uni. Melbourne (NDC only), Climate Interactive (NDC only)
Japan	NDC	N/A [4)]	1. CAT, JRC, PBL, Uni. Melbourne (NDC only), Climate Interactive (NDC only); 2. NIES/RITE (Oshiro et al. 2019); JMIP (Sugiyama et al. 2019) (NDC only)
Mexico	NDC; Government of Mexico (Government of Mexico 2015)	N/A	1. CAT, JRC, PBL
Russia	INDC (UNFCCC 2017)	UNFCCC BR data portal	1. CAT, JRC, PBL, PNNL (NDC only), Climate Interactive (NDC only) 2. HSE (Safonov et al.)
Saudi Arabia	N/A: Saudi Arabia did not formulate a post-2020 GHG target (UNFCCC 2018)	N/A	1. CAT (based on KAUST (KAUST 2014)), JRC
South Africa	NDC	N/A	1. CAT, JRC, PBL, Climate Interactive (NDC only)
Republic of Korea	NDC	N/A	1. CAT, JRC, PBL, Climate Interactive (NDC only)
Turkey	INDC (UNFCCC 2017)	UNFCCC BR data portal	1. CAT, JRC, PBL
United States	NDC – US Department of State (U.S. Department of State 2016)	UNFCCC BR data portal	1. CAT, JRC, PBL, Iyer et al. (Iyer et al. 2015), Climate Interactive (NDC only) 2. Chai et al. (Chai et al. 2017); Rhodium Group (Pitt et al. 2019); PNNL (Iyer et al.); EIA (EIA 2019) (CP only)

N/A: Not available.

1) References provided only when the NDC emission levels are available in absolute terms.

2) Only CO_2 emissions from energy, therefore augmented with CAT, JRC and PBL estimates to produce economy-wide projections.

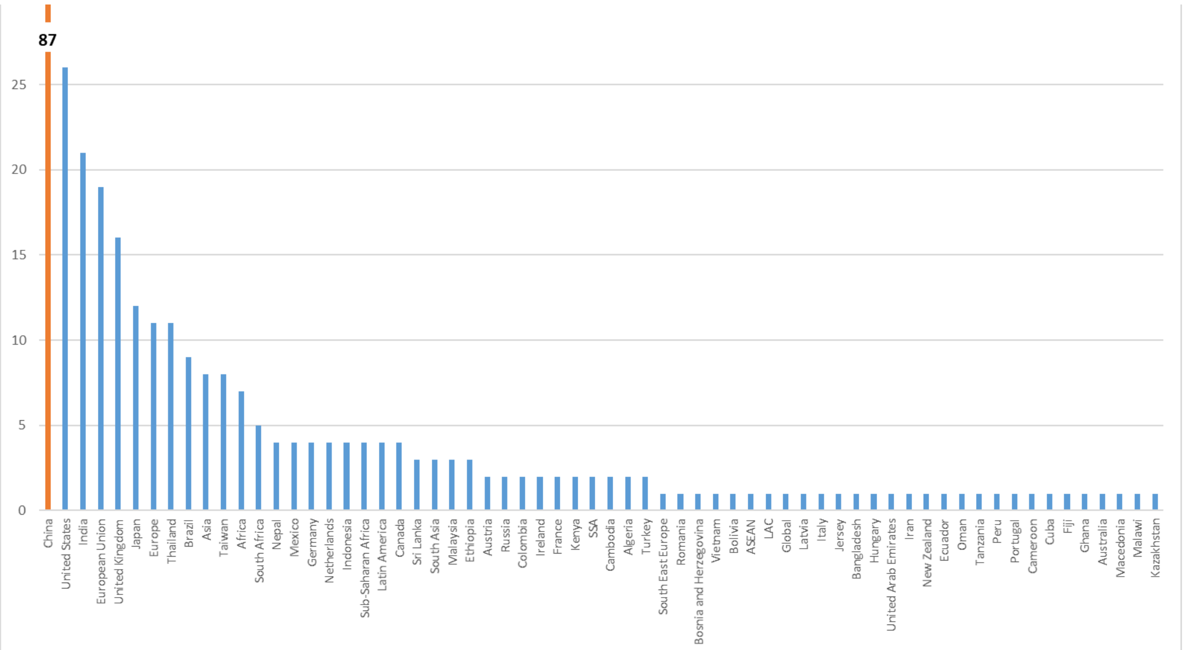
3) Augmented with the historical non-CO_2 GHG emissions data from China's First Biennial Update Report on Climate Change (People's Republic of China 2016), combined with the median estimate of

the 2010-2030 non-CO_2 emissions growth rates for China from five integrated assessment models (Tavoni et al. 2014), to produce economy-wide figures.

4) “With measures” scenario from the latest Biennial Report is not included because it is an NDC achievement scenario, which includes planned policies.

Supplementary Material Box S4.1

A fast-growing literature explores the implications of mitigation in the short- (up to 2030) and medium-run (up to 2050) by developing economy-wide scenarios. This literature is recent (75% published in 2015 or beyond) and very unevenly distributed geographically, with strong emphasis on China, and to a lesser degree India, the European Union and the U.S., while we could not find reference for more than half of the countries in the World (Box S4.1 Figure 1) (*high confidence*).



Box S4.1, Figure 1 Regional distribution of peer-reviewed references on national-level mitigation pathways identified during chapter preparation. Source: Authors. Method: Systematic search in the Web of Science and Scopus databases looking for combinations of terms “mitigation” and [name of country or other Party to the UNFCCC] and [any year between 2020 and 2050] anywhere in title, keywords and abstracts. The search yielded [1205] references, which the authors narrowed down to [333] relevant papers through abstract and core text reading. Additional [xxx] relevant references identified from other sources.

Implications of mitigation on national development objectives are also analysed in a large body of grey literature, e.g., reports commissioned by governments in the context of the preparation and/or the evaluation of national mitigation plans. Some of this literature is dedicated to exploring NDCs (see 4.2.1 and 4.2.2) or to exploring mid-century pathways (4.2.4), with a large variety of climate objectives.

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