

Chapter 4: Strengthening and implementing the global response

Coordinating Lead Authors: Heleen de Coninck (Netherlands) and Aromar Revi (India)

Lead Authors: Mustafa Babiker (Sudan), Paolo Bertoldi (Italy), Marcos Buckeridge (Brazil), Anton Cartwright (South Africa), Wenjie Dong (China), James Ford (Canada), Sabine Fuss (Germany), Jean-Charles Hourcade (France), Debora Ley (Guatemala/Mexico), Peter Newman (Australia), Seth Schultz (USA), Linda Steg (Netherlands), Taishi Sugiyama (Japan), Anastasia Revokatova (Russian Federation)

Contributing Authors: Stefan Bakker (Netherlands), Bronwyn Hayward (New Zealand), Amir Bazaz (India), Luis Mundaca (Sweden/Chile), Arjan van Rooij (Netherlands), Drew Shindell (USA), Joeri Rogelj (Austria/Belgium)

Review Editors: Rizaldi Boer (Indonesia), Diana Urge Vorsatz (Hungary)

Chapter Scientists: Chandni Singh (India) and Kiane de Kleijne (Netherlands)

Date of Draft: 30 July 2017

1 **Table of Contents**
 2
 3

4 **Executive Summary**..... 6
 5
 6 **4.1 Accelerating the global response to climate change**..... 9
 7
 8 **4.2 Pathways compatible with 1.5 °C** 10
 9 4.2.1 Pace of the development and deployment of adaptation and mitigation options 10
 10 4.2.2 Implications of climate-resilient pathways consistent with 1.5°C 11
 11 4.2.2.1 Climate-resilient pathways that reach or are consistent with 1.5°C. 12
 12 4.2.2.2 What are the implications of these pathways?..... 12
 13 4.2.2.2.1 Scale of transformations required 12
 14 4.2.2.2.2 Implications for adaptation 13
 15 4.2.2.2.3 Policy and decision-making implications 13
 16 4.2.3 Framing systemic issues: resilient economic systems, social systems, innovation systems,
 17 leadership and lifestyles **14**
 18 4.2.3.1 Disruptive Innovation..... 14
 19 4.2.3.2 Socio-Technical Innovation..... 14
 20 4.2.3.3 Decoupling 14
 21 4.2.3.4 Financial Systems..... 15
 22 4.2.3.5 Institutional Change and Political Leadership..... 15
 23 4.2.3.6 Behavioural Change 16
 24
 25
 26 **4.3 Assessment of current and emerging (adaptation and mitigation) options**..... 16
 27 4.3.1 Assessing accelerated transitions (environmental & geophysical, technological, economic, socio-
 28 cultural, institutional) **16**
 29 4.3.2 Energy system transitions **19**
 30 4.3.2.1 Renewable energy 19
 31 4.3.2.2 Electricity storage..... 19
 32 4.3.2.3 Carbon dioxide capture and storage in the power sector..... 20
 33 4.3.2.4 International transport options..... 20
 34 4.3.2.5 Options for adapting electricity systems to 1.5°C 20
 35 4.3.3 Land and ecosystem transitions **21**
 36 4.3.3.1 Agriculture and food 21
 37 4.3.3.2 Ecosystems and forests..... 23
 38 4.3.3.3 Urban green cover 25
 39 4.3.3.4 Synergisms and the systemic approach 25

1	4.3.4	Urban, infrastructure and industrial transitions.....	25
2	4.3.4.1	Options for 1.5°C transitions in urban areas	26
3	4.3.4.1.1	Sustainable Land Use, Urban Planning & Design	26
4	4.3.4.1.2	Green infrastructure & Ecosystem services	26
5	4.3.4.1.3	Sustainable Water and Environmental services	27
6	4.3.4.1.4	Sustainable Urban Agriculture & Forestry	27
7	4.3.4.1.5	The urban built environment.....	27
8	4.3.4.1.6	Resilient Urban energy systems	27
9	4.3.4.2	Sustainable and Resilient Transport systems	28
10	4.3.4.3	Industrial transitions - energy-intensive industry	29
11	4.3.4.4	Adaptation options in urban areas	30
12	4.3.4.4.1	Disaster risk reduction and resilience building	30
13	4.3.4.4.2	Migration.....	30
14	4.3.5	Short lived climate pollutants.....	30
15	4.3.6	Carbon dioxide from the atmosphere and CO ₂ capture, utilisation and storage	32
16	4.3.6.1	Bioenergy with carbon capture and storage	32
17	4.3.6.2	Direct air capture and storage.....	34
18	4.3.6.3	Afforestation and reforestation.....	35
19	4.3.6.4	Soil carbon sequestration and biochar	36
20	4.3.6.5	Ocean Alkalinisation (OA), marine and terrestrial Enhanced Weathering (EW).....	36
21	4.3.6.6	Ocean Fertilization	37
22	4.3.6.7	Carbon capture utilization & storage.....	38
23	4.3.6.8	Removal of non-CO ₂ greenhouse gases	38
24	4.3.6.9	Blue Carbon.....	38
25	4.3.7	Solar Radiation Management.....	39
26	4.3.7.1	Governance and institutional feasibility.....	39
27	4.3.7.2	Economics and cost	40
28	4.3.7.2.1	Social acceptability and ethics	41
29			
30			
31	4.4	Implementing far-reaching and rapid change	41
32	4.4.1	Enabling environments.....	41
33	4.4.1.1	Dynamic features of enabling environments	42
34	4.4.1.2	Systemic elements of enabling environments	43
35	Box 4.1:Case Study: Bhutan - mutually enforcing economic growth, carbon neutrality and happiness	44
36	Box 4.2:	Case study: Manizales, Colombia - Supportive national government and localised planning and	
37		integration as an enabling condition for managing climate and development risks	44

1	4.4.2	Implementing SD and the SDGs	45
2	Box 4.3:	Case Study: Bio ethanol in Brazil.....	46
3	Box 4.4:	Case Study: Slum Regeneration in Addis Ababa: Can Carbon Reduction Work with SDGs?	46
4	4.4.3	Enhancing multi-level governance.....	47
5	4.4.3.1	Institutions and their capacity to invoke far-reaching and rapid change	48
6	4.4.3.2	Multiple levels of governance: from global to local.....	48
7	4.4.3.2.1	Global governance	49
8	4.4.3.2.2	Community and local governance.....	50
9	Box 4.5:	Multi-level governance in the EU Covenant of Mayors: the example of the Provincia di Foggia	50
10	4.4.3.3	Interactions and processes for multi-level governance.....	51
11	Box 4.6: Watershed management in response to drought and El Niño Southern Oscillation (ENSO) in	
12		Southern Guatemala.	53
13	4.4.4	Enhancing institutional capacities.....	53
14	4.4.4.1	Capacity for policy design and implementation	54
15	4.4.4.2	Monitoring, reporting, and review institutions.....	54
16	4.4.4.3	Financial institutions	54
17	4.4.4.4	Co-operative institutions and social safety nets	55
18	Box 4.7:	Institutions for integrated policy design and implementation	56
19	Box 4.8:	Case: Indigenous Knowledge	56
20	4.4.5	Enabling lifestyle & behavioural change	57
21	4.4.5.1	Factors related to climate change actions	57
22	4.4.5.2	Behavioural anomalies	59
23	4.4.5.3	Strategies to promote actions on climate change.....	60
24	4.4.5.4	Acceptability of policy and system changes.....	63
25	Box 4.9: How transport behaviour in Singapore, Stockholm and London has changed	63
26	4.4.6	Enabling technological change and enhancing innovation	64
27	4.4.6.1	Recent innovations and their impact on 1.5°C	64
28	4.4.6.2	Emerging trends and 1.5°C-compatible technologies and innovation policy.....	65
29	4.4.6.3	1.5°C-relevant insights from innovation policy	65
30	4.4.6.4	Technology and the implementation of the Paris Agreement	66
31	4.4.7	Strengthening policy instruments.....	66
32	4.4.7.1	Mastering the cost-efficiency-equity challenge.....	68
33	4.4.7.2	Coordinating long run expectations: a matter of credibility and consistency of incentives ..	69
34	Box 4.10:	Emerging Cities and Peak Car Use: Evidence from Shanghai and Beijing.....	72
35	Box 4.11:	Climate Policy to enhance Deep Decarbonisation.....	73
36	4.4.8	Enabling climate finance.....	75
37	4.4.8.1	The quantitative challenge.....	75

1 4.4.8.2 Redirecting savings and de-risking low-carbon investment..... 76

2 4.4.8.3 Public commitments and evolution of the financial systems 77

3

4

5 **4.5 Integration and enabling transformation 78**

6 4.5.1 Knowledge gaps and key uncertainties **78**

7 4.5.2 Implementing mitigation..... **81**

8 4.5.3 Implementing adaptation..... **81**

9 4.5.4 Convergence with sustainable development **81**

10 **Box 4.12:** Consistency between NDCs and 1.5°C scenarios..... 81

11 **Box 4.13:** Solar Radiation Management: Methods, effectiveness and technical feasibility 85

12 **Box 4.14:** Cities..... 93

13 **Box 4.15:** Adaptation 93

14

15

16 **References** 101

17

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55

Executive Summary

Accelerating and upscaling the implementation of far-reaching, multi-level, cross-sectoral climate mitigation and adaptation actions, integrated with sustainable development initiatives, can facilitate the transition to a 1.5°C world. Current national pledges on mitigation and adaptation are inadequate to achieve the temperature targets of the Paris Agreement {4.4.3, Box 4.12}. To strengthen the global response, national governments would need to significantly raise their level of ambition and strengthen capacities to implement their commitments. For many developing countries, achieving this will require ‘financial, technological, and other forms of support’ to build capacity for effective climate governance and implementation, for which currently both local and international resources are insufficient. {4.4.4; 4.4.6}

Adaptation imperatives will be lower in a 1.5°C as compared to a 2°C world, yet transformative adaptation is necessary to address impacts on vulnerable systems and regions across the world.

Adaptation is necessary under current (1°C) warming conditions {Chapters 1, 3}. Learning from current adaptation and strengthening by mainstreaming within sustainable development, adaptive governance {4.4} and behavioural shifts {4.4.5}, as well as drawing on community participation and indigenous knowledge {Box 4.15} are important. While adaptation finance volumes have increased, gaps in current adaptation finance and ineffective monitoring mechanisms undermine action. {4.5.1}

The rates of change in energy technology deployment found in the modelling of emission pathways for 1.5°C are consistent with those observed historically. But the scale of the required energy, land and urban transitions, is larger. Such transitions require more planning and coordination across actors than the spontaneous or coincidental changes we have observed in the past. Mitigation actions with the potential for staying below 1.5°C and adaptation options that allow for coping with a 1.5°C world are related. Whether the simultaneous energy, land and urban transitions jointly succeed depends on behaviour and lifestyle changes, faster innovation and effective policies and governance. {4.2; 4.3.1; 4.4.3; 4.4.7}

The energy transition is taking place in many sectors and jurisdictions around the world, but follows a slower pace in energy-intensive industry, waste management and international transport. In solar energy, wind energy and energy storage systems, a transformation seems to be underway. The political, economic, social and technical feasibility of solar and wind energy has improved dramatically over the past few years. In industry, the options that lead to deep emissions reductions consistent with 1.5°C are limited by political, economic and technical constraints. Buildings offer an enormous potential for emission reduction, but barriers prevent this transformation. Transport and waste management improvements in many jurisdictions face economic and institutional barriers. {4.3.2; 4.3.4}

Global land use transitions, in combination with changes in behaviour, could enhance future mitigation. But, if not managed carefully, such transitions could be associated with significant changes in agriculture and forest systems that risk weakening ecosystem health, potentially leading to critical food, water and livelihood security challenges. Adaptation options such as ecosystem-based adaptation and community-based adaptation, and mitigation options such as emissions reductions from agriculture and livestock, afforestation and reforestation programmes, need continued governance, financial and policy support to be effective, and to be socially acceptable {4.3.3}. Behavioural change around meat consumption would reduce the pressure on land and emissions {4.4.5}.

Rapid, systemic transitions in urban areas will be a defining element in an accelerated transition to a 1.5°C world. These will be enabled by an integrated mix of feasible mitigation and adaptation measures, led by local and regional governments that are aligned with sustainable development and support economic development. They include sustainable land use, planning and urban design to alter urban form, demotorization and decarbonisation of transportation systems, and lowering and decarbonizing energy use in the built environment, especially buildings. In addition, strengthening ecosystem services and building green infrastructure to deliver sustainable water and environmental services and support urban agriculture and forestry are an economically feasible and a socially acceptable option, although institutional barriers need to be overcome. {4.3.4}

1 **Options that lead to a net removal of CO₂ from the atmosphere are affected by multiple feasibility**
2 **constraints. Therefore, the scale of deployment required in the 1.5°C pathways in Chapter 2 may be**
3 **challenging to implement. Measures to reduce short-lived climate pollutants (SLCPs) will be**
4 **implemented if the land, energy and urban transitions succeed.** Options to reduce SLCPs, methane, black
5 carbon and short-lived HFCs, can provide fast emissions reductions and unrivalled co-benefits in terms of
6 health due to prevention of air pollution, which enhances political feasibility. However, economic and social
7 feasibility are more complex. If the energy, land and urban transitions mentioned above succeed, the
8 emission of SLCPs will be greatly reduced {4.3.5}. Among the carbon dioxide removal (CDR) options,
9 bioenergy with carbon capture and storage (BECCS) and afforestation and reforestation (AR) are technically
10 feasible but face environmental, economic and social feasibility constraints. The energy requirements and
11 costs of direct air capture and storage (DACs) seem high, so far. Other options, including soil carbon
12 sequestration (SCS) and biochar, enhanced (ocean and terrestrial) weathering, blue carbon enhancement,
13 ocean iron fertilization, and other greenhouse gas removal (GGR) techniques need to be considered. {4.3.6}

14
15 **Uncertainty and concern surrounds any level of deployment of solar radiation management.** It is
16 uncertain whether global solar radiation management (SRM) technologies, in particular stratospheric
17 aerosols injection (SAI) and marine cloud brightening (MCB), could compensate for even part of the
18 temperature rise, and certainly not for all of it. Planned research on SRM is raising concerns about diverting
19 political attention away from conventional mitigation, and the consequent moral hazard around accelerating
20 implementation of mitigation options. Wide implementation of SRM would be controversial for reasons of
21 justice, equity and ethics. A single country or other stakeholder could act out of self-interest and potentially
22 inflict harmful impacts on other geographies, making it socially infeasible.

23
24 **Governance in a 1.5°C consistent world must be able to create an enabling environment for policy and**
25 **technology options, behavioural changes and innovation.** To forge 1.5°C action, a range of innovations
26 should be enabled including: accountable multi-level governance, coordinated sectoral policies to create
27 collaborative multi-stakeholder partnerships, greater public awareness and improved education and
28 facilitating conditions. Other synergistic approaches that leverage mitigation and adaptation potential should
29 also be realised, including mechanisms that forge international agreements and targets {4.4.1; 4.4.3}. Non-
30 state actors play a key role in the governance mechanisms.

31
32 **Numerous examples from around the world illustrate that 1.5°C -compatible, inclusive, prosperous**
33 **and healthy societies are possible. At the same time, very few cities, countries, businesses or**
34 **communities are truly in line with 1.5°C. Increased ambition, connecting emission reduction options**
35 **via interconnected value chains and governance, and enhanced capabilities are necessary.** Key 1.5°C
36 transition-enhancing institutional arrangements include: robust legal and regulatory frameworks, trustworthy
37 and equity-enhancing financial institutions, transparent and accountable monitoring processes, and
38 collaborative networks across scale and region. Practically everywhere around the world, but particularly in
39 developing countries, institutional and innovation capabilities are currently falling short in implementing far-
40 reaching measures at scale, and by a multitude of actors. Multinational networks supporting multi-level
41 climate action are growing, but challenges in scaling-up remain. {4.4.3; 4.4.4; case studies in 4.4}

42
43 **Changing behaviour and lifestyles is a necessary part of a strategy to enable a transition to 1.5°C.**
44 Measures include: enhancing public responsiveness to climate policy and systemic change, reducing
45 wasteful consumption, enabling end-use efficiency, decarbonising production and consumption, and dealing
46 with psycho-social barriers to effective and timely adaptation and mitigation options. Changing lifestyles and
47 behaviour can result in greater participation in governance for the 1.5°C transition through bottom-up
48 initiatives that, in turn, help gather political and public support for mitigation and adaptation, promoting
49 further action on climate change, creating a virtuous circle. {4.4.3; 4.4.5}

50
51 **Packages of policy instruments, working across governance levels and promoting innovation, are**
52 **needed to implement a rapid and far-reaching response.** Policy instruments, both price and non-price, are
53 needed to accelerate the deployment of carbon-neutral technologies before they can be more cost-effective
54 than fossil fuels, using a mix of regulation, grants, standards, subsidies, loans and feed-in tariffs, information
55 and social influence strategies to trigger innovation and align a low-carbon transition with equitable access to

1 sustainable development opportunities to address on-going challenges, like poverty, unemployment and debt.
2 {4.4.6; 4.4.7}.

3
4 **1.5°C -compatible worlds will require active intervention to reduce investment risks in low carbon**
5 **technologies and to redirect world savings. This implies the involvement of the financial sector including**
6 **central and multilateral banks.** Public guarantees and appropriate financial intermediation to improve the
7 quantity of bankable projects at a given carbon price and reduce risk-weighted capital costs could make low-
8 carbon assets attractive for investors. Public guarantees, development assistance and support of non-state
9 actors could facilitate enhanced adaptation investment. {4.4.8}

10
11 **Gaps in knowledge for implementing and strengthening the global response need to be resolved to**
12 **facilitate the transition to a 1.5°C world.** They include the questions of how much can be realistically
13 expected from innovation, behaviour and systemic political and economic changes in improving resilience
14 and reducing emissions; whether generalisable and practical principles of climate resilient governance can be
15 identified; and how the political incentives for climate action and the associated financial and socio-cultural
16 systems can be changed to make climate action happen. {4.5.1}

4.1 Accelerating the global response to climate change

This chapter discusses the implementation opportunities and challenges associated with a 1.5°C warmer world, from both mitigation and adaptation perspectives. From an adaptation perspective, impacts in a 1.5°C warmer world are still significant, but can be alleviated by adaptation and development responses. Expected impacts at 1.5°C pose lesser challenges for sustainable development than those at higher levels of warming (see Chapters 3 and 5). From a mitigation perspective, staying below 1.5°C means the global response needs to be more far-reaching and more rapid. This chapter is about how to implement and strengthen adaptation and mitigation responses in a 1.5°C context, where possible in a synergetic manner with the goals of sustainable development, equity and justice.

Previous IPCC reports examined ways of maximizing economic efficiency in staying below temperature limits by varying temporal and spatial distribution of various adaptation and mitigation actions. AR5 has shown that the social costs of meeting temperature limits depend critically on: (1) the mobilization of existing and future low-carbon and adaptation technologies; (2) creating the appropriate governance, finance and institutional enabling conditions; (3) reducing differential vulnerability and enabling the building of adaptive capacity, before adaptation limits are crossed; (4) mediating the economic impact (e.g., employment, consumptions, savings and investment) of diverting resources towards the decarbonisation of production and consumption. AR5 has also shown the importance of addressing the ‘equity dilemma’: the quantity of avoided emissions reductions required from the developing countries will need to be larger than that from developed countries over the rest of the century, while the cumulated per capita emissions remain far higher in developed countries.

The AR5 has not assessed temperature limits lower than 2°C, but most of its messages remain valid for 1.5°C. One main change, from a mitigation perspective, is that the transition to a 1.5°C world by 2050 leaves almost no temporal flexibility for lags in implementation, unless massive penetration of cheap carbon dioxide removal technologies becomes possible. The second significant difference is that a 1.5°C transition requires structural changes from the global- to the local-level in development pathways and governance, and in economic, financial, institutional, social and technical systems.

In the context of the Paris Agreement, the global response therefore implies the need to focus on: (1) accelerating the realization of ‘no-regret’ and ‘negative costs’ options to deliver short-term development, mitigation and adaptation co-benefits; (2) enabling environments that help address institutional, market and behavioural barriers to this; (3) accelerating the implementation of policy packages apt to deliver long-term development benefits and universal improvements in quality of life; (4) diverting investments from current trends, that can lead to a lock-in into climate-vulnerable and carbon-intensive development pathways; (5) reinforcing innovation processes, changes in lifestyles and spatial dynamics that will allow for further deep reductions in GHG emissions, and (6) enhancing the adaptive capacity of key systems at risk (e.g., water, energy, food, cities and coastal resources) to climate change impacts.

A challenge posed by the absence of temporal flexibility is the rapid reduction of the ‘implementation gap’ between the aspirational climate policies that have been assessed and tested over the past decades (e.g., carbon pricing, regulatory measures, financial instruments, research and development, capacity building) and their implementation. This includes those announced in the Nationally Determined Contributions (NDCs) at the heart of the Paris Agreement. Reducing this implementation gap cannot be done without considering the current conditions of the world economy, polity and society. A transition to a 1.5°C world may suffer from a lack of broad political and public support, if it exacerbates existing short-term economic and social tensions, including unemployment, poverty, inequality, financial tensions, competitiveness issues and trade. It may be hard to accelerate climate action if the loss of economic value of carbon-intensive assets, which appears unavoidable, cannot be minimized.

Therefore, this report examines how a 1.5°C -consistent transition can fulfil the universal implementation of the Sustainable Development Goals by 2030. This implies expanding the space for simultaneous development, adaptation, mitigation and risk reduction measures, as well as a shift in the production possibility frontier of the world economy.

1 The global context since the turn of the century is an increasingly interconnected world, with the human
2 population growing from the current 7.5 billion to over 9 billion by mid-century (United Nations 2015);
3 consistent growth of global economic output, wealth and trade; a significant reduction in extreme poverty, in
4 spite of local and regional economic crises; and rising inequality, exclusion and social stratification in many
5 regions. These are trends that could continue for the next few decades (Burt et al. 2014), as well as
6 potentially fast developing new, disruptive information, nano- and bio-technologies.
7

8 Nevertheless, a 1.5°C -consistent transition will take place in a challenging environment on which leading
9 economists and institutions have issued repeated alerts: from the ‘discontents of globalization’ (Stiglitz
10 2002), ‘depression economics’ (Krugman 2008), the structural ‘fault lines’ of the world economy and
11 excessive reliance of export-led development strategies (Rajan 2010), rising income inequality (Piketty
12 2014), risks of ‘secular stagnation’ (Summers 2016), to the ‘saving glut’ due to the failure of the financial
13 intermediation to bridge the gap between cash balances and long-term assets (Arezki et al. 2016).
14

15 Strengthening climate policies cannot alone resolve, and may even exacerbate, these fault lines.
16 Policymakers could address this by helping reduce the current regional and sectoral gap between the
17 ‘propensity to save and the propensity to invest’ (Summers 2016). The 1.5°C challenge indicates where
18 future savings could go to: stimulate growth and employment over the short-term; and over the medium-term
19 enhance productive, climate-resilient investments in sustainable infrastructures (Arezki et al. 2016); improve
20 resources management, and overcome structural barriers to mitigation and adaptation. Another area of
21 potential, is aligning climate policy with other public policies (fiscal, industrial, urban planning,
22 infrastructure, innovation) and thereby enabling greater access to basic needs and services, defined by the
23 SDGs, which could act as hedges against unstable and dualistic growth, and a further unsustainable
24 consumption and concentration of wealth (Piketty 2014).
25

26 Finally, reducing the development and climate policy implementation gap depends on an enabling
27 international governance and financial architecture that enables access to finance and technology and helps
28 address trade barriers. As the 1.5°C transition requires accelerated action, in multiple forms, across all world
29 regions almost simultaneously, it does not allow for free-riding. Hence, a key governance challenge is how
30 the gain from converging climate and sustainable development policies can contribute to the emergence of a
31 world governance based on reciprocity (Ostrom and Walker 2005) and partnership (United Nations 2016a)
32 and how different actors and processes in climate governance can reinforce each other to enable this (Gupta
33 2014; Andonova et al. 2017).
34
35

36 **4.2 Pathways compatible with 1.5°C**

37 **4.2.1 *Pace of the development and deployment of adaptation and mitigation options***

38 This section will assess rates of technological and societal change consistent with pathways to remain below
39 1.5°C, building on Chapter 2. Literature reveals two basic approaches to the question whether rates of
40 technological and societal change are realistic: expanding historical trends into the future (in both adaptation
41 and mitigation), and matching of historical trends with modelled outcomes (mitigation only). These, and
42 their outcomes, are discussed here.
43
44

45 The first approach is the analysis, evaluation and extrapolation of historical trends into the future. Such
46 studies in the mitigation field sometimes take a narrative approach, collecting, for instance, long-term data
47 on energy use and sources, analysing the drivers of the patterns observed, and applying the results towards
48 understanding the transition to a low-carbon world (Fouquet 2016). In addition, such extrapolation is done
49 using scenarios and models over relatively long time periods (typically several decades) assuming different
50 growth rates and patterns (Lamb and Rao 2015; Clarke et al. 2014).
51
52

53 In the field of adaptation, in order to understand how to adapt to a 1.5°C warmer world, past changes and
54 adaptations that have led to transformations can be studied (Fazey et al. 2016; Pelling et al. 2015; Gajjar et
55 al.). Adaptation pathways in the context of sustainable development are more extensively discussed in

Chapter 5 (Section 5.3). For implementation questions, it is important to note that adaptation pathways can help identify maladaptive actions (Juhola et al. 2016; Magnan et al. 2016; Gajjar et al.) and encourage social learning approaches across multiple levels of stakeholders in sectors such as marine biodiversity and fresh water supply (Butler et al. 2015; Bosomworth et al. 2015; van der Brugge and Roosjen 2015).

A second approach analyses how technologies have developed over time and contrasts those patterns against quantitative models to understand how contemporary technologies may develop in the future, and whether models are making sound assumptions (Höök et al. 2011). Van Sluisveld et al. (2015), based on five IAMs, tentatively conclude that, depending on how metrics are normalized, modelled rates of change of emissions are broadly consistent with past trends while for individual technologies this may not be the case, especially on the mid-term. However, Wilson et al. (2013) conclude that for technologies, models are generally more conservative than historic data suggest. A qualitative strand of this is pioneered by Geels and Schot (2007), who have developed a typology of trajectories of technological change, abstracting from the specific speed of change, and emphasizing the possibility and effects of shocks and other types of discontinuous change. Recently, Geels et al. (2016) also illustrate that energy transitions are associated with wider socio-economic transformations, and that models generally don't represent such processes, and Sovacool (2016) indicates that this gives reason to believe that energy transitions could go much faster. Kern and Rogge (2016) contend that indeed there is reason for optimism but that rather based on some 'autonomous' rate of change, the rate is determined by political will and the willingness to see energy transitions as a 'political, social and cultural project' rather than just a techno-economic one.

The two approaches reflect different but complementary views on how the past affects the present and the future, and what is to be learned from history. When extrapolating trends, we assume that time progresses forward and that we can learn from the past to understand the direction of technological change in the future. When fitting historical growth patterns into models, the second approach, we assume that time has a cyclic character, that history can repeat itself, and that patterns of change in the past can predict, to some extent, patterns of change in the future. Assessments of the rate of change will vary accordingly, with extrapolating studies emphasizing the slow, difficult process of change (Fouquet 2016) and fitting studies pointing towards the possible fast speed of (Wilson et al. 2013). Both approaches indicate that the rapidity of changes in the past have not necessarily been slower than the ones that pathways, including those assessed in Chapter 2, indicate.

4.2.2 Implications of climate-resilient pathways consistent with 1.5°C

[The assessment of the pathways towards 1.5°C worlds currently relies on the 1.5°C scenarios published in Rogelj et al. (2015) and the comparison of 1.5°C vis-à-vis 2°C pathways. The quantitative assessment will be adapted as the new ensemble of scenarios becomes available. Additionally, the delay scenarios for 2°C (Luderer et al. 2016) will be considered for orientation]

The main characteristics of 1.5°C pathways can be summarized as follows: they are below the emissions pathways of RCP2.6 in AR5, and all feature temperature overshoot. Global GHG emissions will need to change from the current ca. 50 GtCO₂eq yr⁻¹ to become net zero by mid-century and net negative thereafter. Under some burden sharing assumptions, this implies that large emitters, and regions and cities with high emissions, will need to achieve net-zero emissions by the 2030s. These additional emissions reductions required to move from a 2°C pathway to a 1.5°C world, according to IAMs, would largely be achieved by (a) accelerated reduction of fossil CO₂ emissions by demand reductions and electrification of end-use sectors in combination with decreases of carbon intensity of electricity, and (b) BECCS and management of land-use sinks and the use of emergent technologies in new currently undefined scenarios.

Almost the entire assumed abatement potential for non-CO₂ GHGs is already exhausted in 2°C scenarios, so few additional reductions are possible in the 1.5°C pathways. There is almost no room for growth in energy demand: from 350 EJ yr⁻¹ today to an upper bound of 450 EJ yr⁻¹ by 2100 (compared to on average 600 EJ yr⁻¹ for 2°C). If left unmanaged, this could have significant implications for the achievement of SDG7 on universal affordable access to clean energy by 2030, with potential limits to the reduction in poverty in fossil

1 fuel intense economies and regions.

2
3 Fossil-based electricity generation needs to be phased out earlier than for 2°C, carbon-free technologies must
4 be ramped up faster, and the share of electricity in final energy will need to rise more rapidly in 1.5°C -
5 consistent scenarios. This paragraph will thus first discuss the incremental changes for fossil phase out,
6 renewables, nuclear, carbon capture and storage for electricity, and the electricity share in final energy.
7 Furthermore, there will be a massive increase in electricity for transport, though this does not necessarily
8 exceed 2°C by much. Incremental mitigation in transport compared to 2°C mainly comes from demand
9 reductions (e.g. modal shift) and an increased use of biofuels in liquid energy carriers (cf. discussion on
10 potential for land use competition in the context of bioenergy in general below). Concerning industrial and
11 buildings emissions, 1.5°C scenarios feature reduction rates of 25% and 50% lower than for 2°C,
12 respectively.

13
14 *[A figure will be added depicting a set of global graphs showing emissions reduction by GHG/end-use as*
15 *stacked area graphs along with scales measuring the difference between 1.5°C and 2°C]*
16

17 18 4.2.2.1 *Climate-resilient pathways that reach or are consistent with 1.5°C.*

19 *[This section will provide a stocktake based on the pathways discussed in Chapter 2 plus any specific*
20 *adaptation or/and non-IAM pathways from Chapter 3 and any specific pathways provided by Chapter 5.]*
21 Climate-resilient pathways are pathways that combine mitigation and adaptation measures to achieve climate
22 objectives with the lowest possible trade-offs and the least negative side-effects. Note the difference with
23 ‘climate-resilient development pathways’, which are explained in Section 5.7. Denton et al. (2014) identifies
24 three key aspects of climate-resilient pathways within the context of global and regional environmental
25 limits: enhanced adaptation, reduced vulnerabilities and stringent emissions reductions. In the context of
26 sustainable development these pathways should not only be economically, technically and institutionally
27 feasible but also socio-culturally acceptable by addressing sustainable development concerns of addressing
28 poverty, employment, equity, fairness, and justice, in their regional contexts.

29
30 The emissions pathways from the IAM literature discussed above are mostly based on the Shared Socio-
31 economic Pathways (SSPs). Among the five SSPs (O’Neill et al. 2015) only SSP1 and SSP2 are consistent
32 with meeting a stronger mitigation target such as 1.5°C. SSP1 emphasises sustainable development and
33 hence is closest to the broader climate-resilient characterisation. The SSP2 includes a number of the same
34 social considerations in SSP1 but the literature suggests that mitigation requirements and costs along the
35 SSP2 pathway are significantly higher than along the SSP1 pathway (Riahi et al. 2015a).

36
37 *[Emissions pathways at global, regional, and national levels based on the non-IAM literature will be*
38 *assessed based on the relevant literature from Chapters 2 and 3 and the outcomes will be summarized and*
39 *contrasted to those from the IAM literature.]*
40

41 42 4.2.2.2 *What are the implications of these pathways?*

43 Some of the dimensions of interest to assess, based on the availability of the literature, include the scale of
44 the transformation needed, implications for adaptation and implications for policy and policy decision-
45 making.

46 47 48 4.2.2.2.1 *Scale of transformations required*

49 *[Discussion of the scale of social and technical innovation required based on details provided by Chapter*
50 *2.]*

51 The literature agrees that staying below 1.5°C would entail significantly greater transformation in terms of
52 energy systems and lifestyles compared to the 2°C temperature target. Chapter 2 indicates that this would
53 entail 40% more investments on the shorter term compared to a situation without a temperature target,
54 requiring larger deployment of resources and investments.

4.2.2.2.2 *Implications for adaptation*

Warming of 0.5°C (from 1.5°C to 2°C) leads to significant increases in temperature and precipitation extremes in most regions. However, the projected changes in climate extremes under both warming levels depend on the emission pathways, with different greenhouse gas (GHG)/aerosol forcing ratio and GHG levels (Wang et al. 2017b).

The avoided climate impacts of moving from 2°C to 1.5°C warming are difficult to define from existing IAM literature (which are typically based on model inter-comparison projects) and are complicated by the uncertainties in climate model responses and internal climate variability (Mitchell et al. 2017; James et al. 2017). Hence, limited available evidence tends to be case and model-specific and mostly from non-IAM literature.

[This will be linked to the Chapter 3 on specific impacts, such as sea level, temperature and precipitation extremes, etc.]

One such study reported that a lower global mean temperature is likely to be decisive for the future of tropical coral reefs, a key system at risk defined by AR5 (Schleussner et al. 2016; IPCC 2014a). A 1.5°C scenario reduces the risk of severe degradation due to temperature-induced bleaching from virtually all coral reefs with an end-of-century 2°C warming, to 90 % in 2050 and projected to decline to 70% by 2100.

In contrast, the analysis of precipitation-related impacts in Schleussner et al. (2016) reveals distinct regional differences and hot-spots of change. Regional reduction in median water availability for the Mediterranean is found to nearly double from 9% to 17% between 1.5°C and 2°C, and the projected lengthening of regional dry spells increases from 7% to 11%, which would have negative implications for agricultural yields depending on crop types as well as world regions. Schleussner et al. (2016) have also reported about 10 cm lower levels for a 1.5°C scenario sea level rise projections, compared to an estimated 50 cm rise by 2100 for a 2°C scenario.

4.2.2.2.3 *Policy and decision-making implications*

1.5°C pathways raise the bar on the design and coordination of the policy responses and sustainable development actions needed to effectively deal with the scale and pace of mitigation and finance, and which address distributional implications as well as adaptation to climate impacts. Some literature seems to suggest that the level of resources, cost and efforts needed to get to 1.5°C is high. For example, Su et al. (2017) showed that achieving 1.5°C will require tripling the carbon price and doubling the mitigation cost compared to with the 2°C case, though this does not account for the cost of avoided impacts with lower warming.

This report considers policy instruments and targets, alongside mitigation and adaptation options. Policy instruments, such as a carbon tax or regulation for ecosystem resilience, are discussed in Section 4.4.7. Mitigation options, such as solar energy, or adaptation options, such as water management, are assessed for feasibility in Section 4.3. Policy targets can be used by policymakers for orientation purposes. Examples consistent with 1.5°C include a fully renewable electricity system by 2035 (a policy target by Denmark) or a low-carbon steel industry by 2050. The assessment presented in Chapter 2 implies regional policy targets in different sectors. In this section, these will be assessed as to what this means for generic policy instrumentation and other approaches (Section 4.4) such as innovation, behaviour and lifestyle, and finance.

Managing costs and distributional implications require a policy mix approach that takes account of unintended cross-sector, cross-nation, and cross-policy trade-offs essential to manage the transition to low GHGs economies (Droste et al. 2016).

4.2.3 *Framing systemic issues: resilient economic systems, social systems, innovation systems, leadership and lifestyles*

Chapter 2 has indicated that limiting global warming to well below 2°C or 1.5°C requires a radical transition through deep decarbonisation starting immediately, not merely a fine tuning of current trends. The goal of the Paris Agreement (UNFCCC 2015) of staying well below a 2°C temperature rise, or below 1.5°C, cannot be achieved using climate mitigation policy alone, and expands the scope of this assessment to disruptive technological and social innovation along with economic, institutional, governance, social and behavioural change that will enable ‘global peaking of greenhouse gases as soon as possible’ (UNFCCC 2015 Article 4.1) and fast emission declines after that (Rogelj et al. 2015).

4.2.3.1 *Disruptive Innovation*

Disruptive innovation is a form of technological change that leads to significant system change. It was first framed by Christensen (1997) around digital technologies that changed the micro-economy of firms and then impacted the whole economy. It has since been applied at the level of the firm to a range of other sectors including the transformation of power and transport fuels (Christensen et al. 2015; Seba 2014; Green and Newman 2017a).

The demand for a new product or service is unpredictable unless firms can see the broader appeal that the market is looking for. The rapid adoption of a product leads to a whole system change such as with laptop computers (Sampire 2016). Disruptive innovations are very hard to predict by economists and modellers as the innovations can be adopted much faster than models predict as being economic feasible (Green and Newman 2017b).

The increase in roof-top solar and energy storage technology may be such a disruptive innovation in several countries (Green and Newman 2017b). One feature of disruptive innovation is that firms and utilities can be left with stranded assets as the transition created by the disruption happens very quickly (Kosoy et al. 2015; IPCC 2014b). The idea of stranded assets is mostly applied to ‘unburnable oil’ (McGlade and Ekins 2015) as well as coal-fired power plant assets (Caldecott 2017; Farfan and Breyer 2017).

4.2.3.2 *Socio-Technical Innovation*

The idea of technological transitions has been advanced by economists since Schumpeter and Kondratieff who talked about industrial change coming in waves (Šmihula 2009; Adams and Mouatt 2010). In more recent times this has been developed into a theoretical framework for understanding how technological change is associated with social change such as different business models and governance systems as well as some areas of cultural change (Freeman and Perez 2000; Perez 2002, 2009a,b) and into what is now known as Socio-Technical Innovation Theory (Geels and Schot 2007, 2010). This is now being applied to explain how energy transitions are happening and are showing how significant the socio-technical aspects of change are and will be in driving the transition to 1.5°C (Geels et al. 2016b; Geels 2014). In addition, elements of ‘transition theory’ and innovation systems theory, such as strategic niche management (Kemp et al. 1998) and functional approaches through technological innovation systems (Hekkert et al. 2007; Bergek et al. 2008) are applied in practice to develop policy responses to innovation challenges.

4.2.3.3 *Decoupling*

The socio-technical innovation changes associated with fossil fuels underpin the approach taken by a range of people and by the OECD and UNEP called *decoupling* (von Weizsäcker et al. 2014; Newman 2017). This suggests that although wealth has in the past been completely coupled to the use of fossil fuels, there are changes in technology and the economy that can enable the decoupling of wealth from a range of environmental issues, including the consumption of fossil fuels. One of the critiques of decoupling theory is that it will always be only a relative decoupling due to feedback like rebound effects (Gillingham et al. 2013; Jackson and Senker 2011). Recent data suggests that greenhouse emissions have decoupled absolutely over the past two years (International Energy Agency and OECD 2017; Peters et al. 2017). Newman (2017)

1 shows that this has been driven by declines in both coal and oil and this has been happening since the early
2 2000s in Europe, in the past seven years in the US and Australia, and has begun in China. The rate of
3 decoupling appears to depend on the socio-technical and disruptive innovations and will need to increase
4 rapidly if the 1.5°C challenge is to be met (Newman et al. 2017). It is also relevant at the city level (Swilling
5 et al. 2013).

6 7 8 *4.2.3.4 Financial Systems*

9 As investment profiles of projects in energy, land and urban systems consistent with limiting global
10 temperature rise to 1.5°C differ considerably from current practice in financial systems, more capital needs
11 to become available on a shorter term for remaining below 1.5°C than would be needed if the energy system
12 was to remain fossil-based (Miller 2008). For renewable energy options such as wind and solar, investments
13 are frontloaded and operational costs are relatively small, and also for energy efficiency, large investments
14 need to be made early on, and the revenues are generated later.

15
16 Current financial systems are not prepared to stress-test for climate change (Battiston et al. 2017b).
17 Multilateral climate finance flows are starting to warm up to climate change mitigation and adaptation and
18 are influencing other investments (Buchner et al. 2015), including in the Green Climate Fund and the Global
19 Environment Facility, but also the World Bank, regional development banks, and the Climate Investment
20 Funds. The financial literature is practically silent on climate change (Diaz-Rainey et al. 2017) and central
21 banks only recently started addressing climate change (Bank of England 2015; De Nederlandsche Bank
22 2016). Pension funds face challenges when electing to invest in climate-friendly activities (Sievänen 2013)
23 and the market provides insufficient signals to institutional investors (Haigh 2011). The literature suggests
24 that potential could still be materialised by engagement of the financial sector, but that this depends on
25 political signals that affect the bankability of climate-friendly investments.

26 27 28 *4.2.3.5 Institutional Change and Political Leadership*

29 Institutions, understood as the ‘rules of the game’ not organisations (North 1990), exert both direct and
30 indirect influence over the viability of transformation pathways required to remain below 1.5°C. Individual
31 behaviours are embedded in social institutions, institutional contexts and cultural norms and behaviours
32 emerge from socio-technical contexts made of specific material arrangements, competences and associated
33 meanings (Shove 2010). Institutions and cultural transformations are needed to support wide-scale adoption
34 of climate change mitigation and adaptation options. Considerable work remains to align the incentives,
35 aspiration, policies and finance to support the shifts required to remain below the 1.5°C threshold and the
36 level of national state and between nation states in the form of trade, finance and knowledge sharing
37 agreements (Rode et al. 2014).

38
39 Off the back of growing urban populations and the recognition that cities account for a majority portion of
40 greenhouse gas emissions, cities have emerged as the locus of institutional and infrastructural climate
41 innovation. Not only do urban centres aggregate the economic demand, capital and information required to
42 affect change, but in many instances cities are able to respond more quickly than nation states (Rode et al.
43 2014). Work remains in aligning the efforts and reporting of cities with UNFCCC goals, but the growing
44 networks of mayors and cities sharing experiences on how to cope with climate change and how to draw
45 economic and development benefit from climate change responses, represent an important institutional
46 innovation. Mayors and city managers have begun to show significant leadership in driving proactive
47 responses to climate change (Roberts 2016a). In the US, emissions are lower in states that elect legislators
48 with strong environmental records (Dietz et al. 2015).

49
50 Definitive leadership in China has given impetus to the combined transitions around urbanisation and
51 sustainability (Bai et al. 2014), and also contributed to the rise of China’s renewable energy sector. It
52 remains to be seen whether decoupling of emissions and growth in China (Newman 2017) can be sustained.

53
54 In African countries, the case for climate resilient growth has been slow to gain political traction, in part
55 because it requires perceived adjustment costs in the short-term, in expectation of future gains (Resnick et al.

2012). This may be changing since the Paris Agreement where developing countries view a climate resilient economy as offering new competitive advantage (Cartwright 2015).

4.2.3.6 Behavioural Change

Humans are at the centre of global climate change: human actions cause anthropogenic climate change, and social transformations are key to effectively respond to climate change (Hackmann et al. 2014a). To stay below 1.5°C temperature rise, substantial modification of a wide range of climate change mitigation actions by many different people in different domains is needed. Such actions include the adoption of renewable resources (e.g., solar power), the implementation of resource efficiency measures in buildings (e.g., insulation, weatherising), and the adoption and use of low carbon innovations (e.g., electric vehicles) and energy-efficient appliances. Changes in user behaviour can relate directly to energy use (e.g., walk, cycle, or use public transport rather than drive or fly; reduce room temperature) as well as to the embedded energy needed to produce, transport and dispose of products and services (e.g., reduce meat consumption or buy local seasonal food; Steg 2016; Dietz et al. 2009). Other GHG emissions can be affected via behaviour changes, such as the reduction of methane by reducing meat consumption.

Likewise, many populations already engage in climate change adaptation behaviours to protect themselves from climate change risks occurring now, or those expected to occur in the near future. These include: growing different crops or animal varieties; protecting oneself from risks due to flooding, for example, by elevating barriers between rooms, building elevated storage spaces, building drainage channels outside the home (Jabeen 2014); and protecting oneself from heat waves by staying hydrated, travelling to cool places or installing green roofs (Araos et al. 2016a; Taylor et al. 2014).

Besides changes in adoption and use of products and services, it is important to promote citizenship behaviour and behaviour in companies and other organisations that can support emissions reductions at various levels and enable pre-emptive adaptation action (Stern 2000; Stern et al. 2016). These actions can influence the implementation of climate mitigation and adaptation policies as well as decision-making that is committed to climate action. In addition to active policy choices, public expressions of acceptability of or resistance to projects and policies aimed to promote climate change mitigation and adaptation will increase the likelihood that such policies, programmes and projects will be implemented (Steg et al. 2017).

Given the urgency of meeting the 1.5°C target, options with a substantial potential for carbon emission reduction and adaptation and with a high behavioural plasticity could be prioritised, such as the adoption and use of sustainable technologies (i.e., fuel efficient vehicles, home heating and ventilation, appliances, and weatherization (Dietz et al. 2009)). These are associated with relatively low behavioural costs and can demonstrate to users that their efforts are effective. This, in turn, can strengthen environmental self-identity of users, which is likely to motivate them to engage in further mitigation actions that are consistent with those already undertaken (van der Werff et al. 2016; Lauren et al. 2016). Meanwhile, new technologies, policies and institutions can be developed that promote and facilitate further changes (see Section 4.4.5). Notably, the changes in lifestyles and behaviour needed to limit global warming within 1.5°C will be more likely when supported by changes in economic systems, social systems, infrastructure, institutions and cultural change (see Section 4.4.5).

4.3 Assessment of current and emerging (adaptation and mitigation) options

4.3.1 Assessing accelerated transitions (environmental & geophysical, technological, economic, socio-cultural, institutional)

Both the goal of remaining within a 1.5°C warming limit and the adaptation and mitigation interventions that will help achieve this target must be scrutinised for feasibility.

AR5 identified both technologically and economically feasible pathways for limiting warming to well-below 2°C. Pathways limiting warming to 1.5°C by the end of the century are also feasible, but require more

1 immediate and greater scaled initiatives than those for 2°C, including zero emissions by the 2060-2080
 2 period, roughly 20 years earlier than for a 2°C pathway (see Chapter 2).
 3

4 In its essence, feasibility in this Special Report is about the cost and speed at which options comprising the
 5 1.5°C pathway can be introduced. In practice, however, feasibility is almost always multi-dimensional, more
 6 complicated and more political than narrow definitions of cost, benefit and speed. Moreover, there are
 7 profound difficulties in including the full extent of benefits at the local scale in conventional climate change
 8 cost-benefit analyses and in identifying the distribution of benefits and costs between income groups and
 9 across regions (Cartwright et al. 2013). In discussing feasibility, AR5 recognised both physical constraints to
 10 carbon dioxide removal and the social, technical and economic dimensions of feasibility that are linked to
 11 subjective desires and human ability (Clarke et al. 2014).
 12

13 In Section 4.4, options for adaptation, mitigation and SRM cited in the literature on energy systems, land and
 14 ecosystems, cities, infrastructure and industrial systems, are reviewed in the context of the three high-level
 15 ‘dimensions’ of feasibility identified in Chapter 1 and shown in Table 4.1. These are: ‘economic and
 16 technological’, ‘environmental and geophysical’ and ‘social and institutional’. Chapter 1 disaggregates these
 17 dimensions into ‘characteristics’ and a non-exhaustive list of ‘empirical measures’ for which some data are
 18 available or being collected. Empirical measures enable a more detailed, and in some instances, a more
 19 objective, assessment of options. Recognising the multiple dimensions of feasibility becomes particularly
 20 important in the context of ‘net negative emissions’ options, such as BECCS, that are understood to be an
 21 important part of 1.5°C pathways (Smith et al. 2015).
 22
 23

24 **Table 4.1:** Dimensions and characteristics for assessing the feasibility of a 1.5°C world and options that lead to this
 25 world.
 26

Dimensions	Characteristics	Examples of empirical measures
Environmental and Geophysical	Geophysical	- Proportion of the change required - Rate of land use change
	Environmental	- Capacity of ecological systems - Limits of mitigation/adaptation in ecosystems - Risks of responsive options - Tipping points - reversibility of ecosystem change - Risks associated to irreversible changes
Technological and Economic	Technological	- How quickly different types of technologies can be implemented? - Are there technical resources available?
	Economic	- Required investment flows - Costs of response options - Financial mechanisms to enable transitions - Risks and unforeseen impacts - Differential effects of competitiveness - Benefits and trade-offs, e.g.: economic development, GDP, poverty alleviation, employment impacts
Social and Institutional	Social/cultural	- Behavioural responses (communities and private sector) - Equity, social inclusion and distributional impact - Inter-generational justice - Speed of changes in behaviour and lifestyles - Health benefits and risks - Public support for policy and changes
	Institutional	- Political support - Market structures, market failure and missing markets - Rate of institutional change - Interaction between multi-levels of governance

27

1
2 It is not the purpose of this chapter to apply a universal feasibility assessment or to select the projects or
3 programmes that will ensure warming remains below 1.5°C. Rather, the literature assessment identifies
4 important principles when accelerating change so as to remain below the 1.5°C threshold. The relative
5 feasibility of different adaptation, mitigation and SRM options is contingent upon the availability of money,
6 information, capacity and an enabling environment. As such, feasibility is likely to be location and context
7 specific. However, decision-making can be improved, and rendered more accountable and defensible, by
8 recognising principles of feasibility that tend to apply across contexts. Drawing on the literature, examples of
9 these principles are described below.

10
11 Interventions on mitigation, adaptation and SRM are not discrete and feasibility can be enhanced by options
12 that complement each other via feedback loops. Mutually enforcing responses to climate change can not only
13 accelerate transitions, but also generate self-perpetuating change through systemic influences and cost
14 reduction (Bergek et al. 2008; Hekkert et al. 2007; Geels et al. 2016b).

15
16 The feasibility of climate change responses is supported when adaptation and mitigation interventions
17 deliver simultaneously non-climate benefits that can off-set the cost of mitigation and adaptation (Schaeffer
18 et al. 2015b). There are many opportunities to align climate interventions with efforts that support
19 livelihoods (Shaw et al. 2014; Ürge-Vorsatz et al. 2014), the economy (GCEC 2014), social progress (Steg et
20 al. 2015a; Hallegatte and Mach 2016a; Ziervogel et al. 2016), and the local environment. These include
21 improving air quality, reducing the impact of flooding and reducing the effects of heat stress. This is
22 particularly true where interventions remove underlying causes of climate vulnerability such as poverty and
23 the lack of services.

24
25 Interventions presenting benefits on multiple scales are most likely to enable the transformative change,
26 especially when benefits are aligned through multi-level governance or are mutually enforcing via positive
27 feedback loops (Peters et al. 2017; Hallegatte and Mach 2016a; Geels et al. 2016b).

28
29 Feasibility has a distinct temporal component. Clarity on the timing of interventions and benefits is not only
30 critical to feasibility analysis, but also enables co-ordination and sequencing that itself can enhance
31 feasibility. Attitudes towards the future, and associated accounting for the time-lags between the short-term
32 cost of adaptation and mitigation efforts and longer-term benefits, tends to vary based on socio-economic
33 status and risk aversion (Hof 2014; Resnick et al. 2012). Unless the influence of time, and different
34 perceptions of the future is acknowledged and addressed it can lead to highly variable assessments of
35 feasibility.

36
37 Recognising that the impact of atmospheric warming is mediated through complex local contexts introduces
38 both new considerations for feasibility assessments and new possibilities for transformative change that are
39 important for the fundamental and rapid change required to remain within the 1.5°C warming threshold
40 (Ziervogel et al. 2016).

41
42 In the context of uncertainty, preventing lock-in, monitoring and adapting to technological innovation and
43 other changes (Torvanger and Meadowcroft 2011) and creating the capacity to respond to a wide range of
44 difficult to predict climate change contingencies, comprise important components of feasibility (Kowarsch et
45 al. 2017; Kalra et al. 2014). The risk and uncertainty inherent in any rapid and systemic change process
46 (Daron and Stainforth 2013) creates a premium for options that retain flexibility and reversibility (Hallegatte
47 et al. 2012).

48
49 The systemic approach implicit in this characterisation of feasibility introduces analytical complexity to the
50 need for prioritisation (Reyers et al. 2017). It is also however essential to create the potential in accelerating
51 transitions (Sovacool 2016) and in reducing unforeseen consequences and is essential in avoiding the
52 misallocation of scarce resources in the effort to limit warming to 1.5°C (Geels et al. 2016b). The means of
53 assessing and monitoring highly interconnected systems is still evolving (Markusson et al. 2012; Kowarsch
54 et al. 2017), but useful in anticipating crises, mobilizing pre-emptive responses (Battiston et al. 2017a) and
55 identifying interventions that address 'root causes' (Pelling et al.). The importance of these elements to the

1 transition to a 1.5°C world presents a case for their consideration in feasibility analyses. Whilst IAMs offer
2 many analytical strengths, they do not completely capture the dynamics and scope of these elements of the
3 required transition (Daron et al. 2015). The inference drawn from IAMs can be complemented by multi-
4 criteria analyses that include the guidelines considerations.
5

7 **4.3.2 Energy system transitions**

8
9 This section discusses the feasibility, based on the empirical measures discussed in 4.3.1 and Chapter 1, for
10 mitigation and adaptation options related to the energy transition. Only options consistent with 1.5°C and
11 with significant changes in their feasibility compared to the IPCC Fifth Assessment Report are discussed.
12 This means that for options like nuclear energy (the capacity additions of which continue to fluctuate (IEA
13 2017)), hydropower and biomass, we refer to AR5 for an assessment of their feasibility. Demand-side
14 options in the energy sector, including energy efficiency in buildings, transportation and industry, are
15 discussed in Section 4.3.4.
16

18 **4.3.2.1 Renewable energy**

19 Renewable energy options include solar energy, wind energy, hydropower, geothermal energy, tidal and
20 wave energy and osmotic energy. All these options have seen considerable advances over the years since
21 AR5, but according to the IEA (2017), only solar energy and onshore wind energy are on track to reach a
22 2°C pathway. Ocean energy, hydropower, concentrated solar power, bio-energy, offshore wind and
23 geothermal energy would all need to show faster growth rates. This applies even more strongly to a 1.5°C
24 scenario.
25

26 The largest growth factor since AR5 has been the dramatic reduction in the cost of solar PV to
27 0,41 USD Wp⁻¹ (REN21 2017), leading to costs of rooftop solar in combination with battery storage to be
28 almost competitive in sunny areas such as Australia (Green and Newman 2017b). Renewable energy in off-
29 grid or mini-grid systems are becoming a mainstream solution to improve the welfare of people in
30 developing countries, and have already provided many remote communities with energy independence,
31 allowing them to bypass the need for a transmission network and therefore remove the associated costs of
32 installing and maintaining a network (Nature 2004). Strategies for small-scale distributed energy projects are
33 now being implemented around the world (Aguar et al. 2016).
34

35 The feasibility of renewable energy options depends to a large extent on geophysical characteristics of the
36 area where the option is implemented. However, technological advances make renewable energy options
37 increasingly attractive also in areas where one would not expect it; e.g. solar energy in north-western Europe.
38 Another important factor is public acceptance, in particular for wind energy, though research indicates that
39 financial participation and serious community engagement can be effective in mitigating resistance.
40

41 Studies estimating the use of renewable energy in the future, either at the global or at the national level, are
42 plentiful and considerable debate exists on whether a fully renewable energy or electricity system, also
43 excluding biomass, is possible (Jacobson et al. 2015) or not (Heard et al. 2017; Clack et al. 2017), and by
44 what year. The estimates depend greatly on the assumptions on costs and technological developments, as
45 well as local geographical circumstances. Disruptive innovation as has been shown with roof top solar has
46 led to considerably greater growth than expected and could change the modelling based on traditional
47 assumptions (Green and Newman 2017b). Several countries have adopted targets of 100% renewable
48 electricity by e.g. 2035 (Denmark).
49

51 **4.3.2.2 Electricity storage**

52 Most current electricity storage is done by pumped hydro (150 GW), but grid-connected battery storage is
53 growing fast; by 50% between 2015 to 2016 to 1,7 GW (REN21 2017). Battery storage has been the main
54 growth feature in energy storage since AR5. The cost of battery storage has decreased significantly.

1 Although costs and technical maturity look increasingly positive, the feasibility of battery storage may be
2 negatively affected by the availability of resources and the environmental impacts of its production (Peters et
3 al. 2017). The production of lithium, a crustal element, does not appear to be restricted and large increases in
4 production have happened in recent years (Government of Western Australia 2016). One study suggests that
5 the environmental impacts of the combination of solar PV with hydrogen fuel cells as energy storage would
6 result in lower life-cycle greenhouse gas emissions (Belmonte et al. 2016).
7
8

9 4.3.2.3 *Carbon dioxide capture and storage in the power sector*

10 The IPCC Special Report on CCS (IPCC 2005) and the IPCC Working Group III Fifth Assessment Report
11 (IPCC 2014) assign great potential for mitigation to CCS in the power sector, in particular in coal-fired
12 power but also in biomass (for a discussion of CCS in non-power industry, see Section 4.3.4; for a discussion
13 of bio-energy with CCS (BECCS), see 4.3.6). CCS in the power sector has seen significant developments
14 over the past years. The technological maturity of CO₂ capture options in the power sectors has improved
15 considerably (Abanades et al. 2015), but costs have risen over the past ten years (Rubin et al. 2015). Storage
16 capacity estimates vary greatly, but there is high agreement that on the order of thousands, perhaps ten
17 thousand, GtCO₂ could be stored in underground reservoirs, of which about one thousand in well-
18 characterised oil and gas reservoirs, and the vast majority in saline formations, which are generally poorly
19 characterised (Coninck and Benson 2014). Insights on communication of CCS projects to the general public
20 and inhabitants of the area around the CO₂ storage sites (in order to prevent public resistance and increase
21 social acceptance) have been documented over the years, but not all decision-makers have taken notice
22 (Ashworth et al. 2015).
23

24 CCS in the power sector is not being realised at scale, mainly because the incremental costs are not
25 compensated by incentives (IEA 2017). One full-scale demonstration project in the power sector has come
26 online over the past years, whereby part of the capture costs were compensated with revenues from
27 Enhanced Oil Recovery (Global CCS Institute 2015), a technique that uses CO₂ to mobilise more oil out of
28 depleting oil fields. In addition, several planned CCS projects have been cancelled over the years, mainly
29 because of economic reasons (Global CCS Institute, 2017). Coninck and Benson (2014) indicate that political
30 leaders, communities and investors are key actors to provide climate change action, robust policy support,
31 favourable costs and market conditions, storage security and ensuing community support in order to make
32 CCS feasible.
33

34 4.3.2.4 *International transport options*

35 International (or intercontinental) transport is notoriously difficult to decarbonize (Sims et al. 2014).
36 Aviation emissions could be reduced by about a third by energy efficiency measures (Dahlmann et al. 2016),
37 and on shorter distances be replaced by low-carbon electricity-based high-speed trains. But for deeper
38 emission reductions and intercontinental travel, most studies indicate that biofuels are the most viable
39 alternative, given their technical characteristics, energy content and affordability (Wise et al. 2017).
40 However, the life-cycle emissions of such bio-based jet fuels can be considerable (Budberg et al. 2016; Cox
41 et al. 2014), depending on their location (Elshout et al. 2014).
42
43

44 *[International shipping yet to be included]*
45
46

47 4.3.2.5 *Options for adapting electricity systems to 1.5°C*

48 For hydroelectric plants, one of the main concerns is the decrease in reservoir reliability (Jahandideh-Tehrani
49 et al. 2014; Goytia et al. 2016; Minville et al. 2009). Hybrid renewable-based power systems with non-hydro
50 capacity, such as with high-penetration wind generation would provide the required system flexibility
51 (Canales et al. 2015).
52

53 Climate change has started to disrupt electricity generation and it is predicted these disruptions will be
54 lengthier and more frequent (Jahandideh-Tehrani et al. 2014; van Vliet et al. 2016; Bartos and Chester 2015;
55 Kraucunas et al. 2015), if climate change adaptation options are not considered, both to secure vulnerable

1 infrastructure and to ensure the necessary generation capacity (Eisenack and Stecker 2012; Schaeffer et al.
2 2012; Cortekar and Groth 2015; Murrant et al. 2015; Goytia et al. 2016; Panteli and Mancarella 2015;
3 Minville et al. 2009). Overall, there is high agreement that hybrid systems, taking advantage of an array of
4 sources and time of use strategies, will help make electricity generation more robust (Parkinson and Djilali
5 2015), given that energy security standards (Almeida Prado et al. 2016) are in place.

6
7 Water scarcity patterns and electricity disruptions will differ across regions. There is high agreement that
8 mitigation and adaptation options for thermoelectric generation and, if that remains based on fossil fuels,
9 CCS need to consider increasing water shortages. One option that both reduces emissions and lowers water
10 needs is increasing the efficiency of power plants (Eisenack and Stecker 2012; van Vliet et al. 2016). The
11 technological, economic, social and institutional feasibility of that option is very high, though improving
12 efficiency in fossil-fuelled thermoelectric power plants are insufficient to limit temperature rise to 1.5°C.

13
14 In addition, a number of options for water cooling management systems have been proposed, such as
15 hydraulic measures (Eisenack and Stecker 2012) and alternative cooling technologies (Eisenack and Stecker
16 2012; van Vliet et al. 2016; Murrant et al. 2015; Bartos and Chester 2015; Bustamante et al. 2016; Chandel
17 et al. 2011). There is high agreement on the technological, economical, and social feasibility of these new
18 cooling technologies as the lack of proper water cooling technology and guidelines can severely impact the
19 functioning of the power plant as well as safety and security standards. Water shortages are also leading to
20 new technologies that can reduce water consumption, such as for bioenergy (Gerbens-Leenes et al. 2009;
21 Yang et al. 2015), and other thermal generation sources (Fricko et al. 2016; Doll et al. 2012; Kyle et al.
22 2013; Tidwell et al. 2014).

23
24 It is expected that more options for water management and other combinations of mitigation and adaptation
25 challenges will be developed in the coming years for CCS, bio-energy and nuclear energy, that can help plan
26 for a more synergistic and robust energy sector (Schaeffer et al. 2012). Such options would create a more
27 robust and sustainable energy sector and reduce uncertainty (Parkinson and Djilali 2015). The integration of
28 possible climate impacts in the planning and development of power projects will enable them to forecast
29 future needs better (Bartos and Chester 2015).

30 31 32 **4.3.3 Land and ecosystem transitions**

33
34 Land-use transitions are driven by agriculture, deforestation, and urbanisation. Agriculture is currently
35 responsible for more than one-fourth of anthropogenic GHG emissions (Smith et al. 2014a). There is broad
36 agreement in the literature that mitigating emissions from agriculture has limits, as it will require a
37 concurrent shift in farming practices and food systems in order to simultaneously meet food security needs
38 for a growing global population (Bennetzen et al. 2016a,b). Deforestation has increased substantially in the
39 post-industrial era, driven by food production imperatives and growing demand for renewable and non-
40 renewable natural resources (Nakicenovic et al. 2000). Recent global trends show a convergence of
41 institutional arrangements, including improved protection and effective monitoring, have led to a
42 deceleration and stabilisation in deforestation in many regions, most notably in the Brazilian Amazon which
43 has seen an 80% reduction in deforestation (Aguiar et al. 2016). Studies indicate two tipping points that
44 should not be transgressed: 4°C warming or 40% deforestation (Nobre et al. 2016). This section examines
45 possible adaptation and mitigation options related to land-use and ecosystem transitions that could play a
46 role in the transition to a 1.5°C world.

47 48 49 **4.3.3.1 Agriculture and food**

50 Recent 1.5°C -specific scenarios depict a mixed picture for agriculture. While certain high-latitude regions
51 may benefit, local yields in tropical regions like West Africa, South-East Asia, and Central and northern
52 South America, which are main food growing regions of the world and support a high number of vulnerable
53 populations, are projected to reduce substantially (Schleussner et al. 2016).

54
55 The way people produce, process and transport food drives greenhouse gas emissions and is also affected by

1 elevated atmospheric greenhouse gases and higher temperatures. The humanitarian imperative of enhancing
2 global access to sufficient food holds the potential to undermine or contribute to mitigation and adaptation
3 pathways required for a 1.5°C world (Belz 2004).
4

5 Increased temperatures, even up to 1.5°C, will affect production of key cereals such as wheat and rice, thus
6 impacting food security (Schleussner et al. 2016), and elevated CO₂ concentration is also expected to change
7 the composition of food (DaMatta et al. 2010). For example, wheat and sorghum grown under elevated CO₂
8 differ in protein content and composition (Högy et al. 2009; De Souza et al. 2015).
9

10 Meta-analyses of experiments studying effects of elevated CO₂, high temperature, and drought conclude that
11 at 2°C local warming, wheat, maize, and rice will see decreased yield, but this could be reduced if adaptation
12 measures are taken (Challinor et al. 2014). As a central principle, climate resilient development pathways,
13 whether socio-economic, socio-technical or socio-ecological, leading to a 1.5°C world need to ensure access
14 to sufficient food of sufficient quality (see also Chapter 5). Three adaptation options can help lead us on this
15 path.
16

17 Behavioural shifts towards conservation agriculture refer to small changes in agricultural practices such as
18 changing crop varieties, shifting planting times, and irrigation and residue management to increase wheat
19 and maize yields by 7-12% (Challinor et al. 2014). There is growing empirical evidence that such shifts in
20 farming practices could be a key adaptation strategy (although the efficacy is still debated in the literature)
21 while other analyses show that dietary shift directed to low-impact foods along with increases agriculture
22 efficiency offer more environmental benefits than transforming conventional agricultural into organic
23 agriculture or grass-fed beef (Clark and Tilman 2017). For example, conservation agriculture has been
24 identified as an effective adaptation strategy across regions as varied as southern Africa (Thierfelder et al.
25 2017), India (Pradhan et al. 2017) and southern Spain (Varela-Ortega et al. 2016). A global meta-analysis
26 using 5,463 paired yield observations from 610 studies across 48 crops and 63 countries compared no-till
27 and conventional tillage practices (Pittelkow et al. 2014). It demonstrated that alone, no-till practices tend to
28 reduce yields. However, when combined with other two conservation agriculture principles (residue
29 retention and crop rotation), crop productivity in rain fed dry conditions increase significantly, suggesting
30 that it may become an important climate-change adaptation strategy in regions projected to face drying in a
31 1.5°C world.
32

33 Efficiency increases will be a key agricultural adaptation option to climate change. The application of
34 computational tools in precision agriculture for example, could avoid waste and increase productivity,
35 helping to cope with the decrease forecasted in production.
36

37 There is high agreement that improved climate services can play a critical role in aiding adaptation decision-
38 making (Singh et al. 2017; Wood et al. 2014; Trenberth et al. 2016; Lourenço et al. 2015). However,
39 empirical evidence suggests that there remain several technical, institutional, design-related, financial and
40 capacity barriers to applying climate information for better adaptation decision-making (White et al. 2017;
41 Jones et al. 2016b; Singh et al. 2017; Briley et al. 2015) and to scaling up current successes (Singh et al.
42 2016b).
43

44 A growing number of programs aimed at using climate services for better decisions are showing signs of
45 success: from various actors, at various scales, and using different forms of information delivery and uptake.
46 These involve participatory analysis of seasonal forecasts in East Africa (Dorward et al. 2015), NGO-driven
47 weather advisories in India (Lobo et al. 2017) and innovations in government-led agriculture extension in
48 various countries across sub-Saharan Africa and South Asia (Singh et al. 2016b).
49

50 Extreme event forecasts are transferring crop cultures to regions where lower impacts are expected, There is
51 information available about: (1) the most likely regions for extreme events associated with 2°C (Nakicenovic
52 et al. 2000) and (2) how different varieties of food, fibre and bioenergy crops can be adapted to different
53 climates (Challinor et al. 2014). These two data sets could be combined so that the costs of transference
54 could be calculated more precisely.
55

1 Improved technology, such as new molecular biology tools, have been developed and can lead to fast and
2 precise genome modification (e.g. CRISPR Cas 9, De Souza et al. 2016; Scheben et al. 2016). Such genome
3 editing tools can assist in adaptation of agriculture to climate change. For example, considering that meta-
4 analyses studying effects of elevated CO₂, high temperature, and drought concluded that at 2°C local
5 warming, wheat, maize, and rice would see decreased yield, though this could be reduced if adaptation
6 measures are taken (Challinor et al. 2014). Adjustments in plant metabolism could be enabled to avoid
7 changes in food quality (e.g. decrease in proteins). Photosynthesis could be modified to improve plant
8 growth and tolerance to drought, (De Souza et al., 2016). However, biosafety concerns and government
9 regulatory systems are likely to be a major barrier to the use of these tools as this increases the time and cost
10 of turning scientific discoveries into ready applicable technologies (Maghari and Ardekani 2011).

11
12 There is abundant knowledge on how some key crops used for food, feed and bioenergy, and livestock,
13 might respond to climate change (elevation of temperature combined with elevation of CO₂ and, drought or
14 flooding). Thus, developing new varieties with higher tolerance can minimize adverse impacts during the
15 transition to overshoot pathways to 1.5°C. Some synergy can be expected from the use of technologies to
16 increase efficiency (precision agriculture) and the use of genetics and plant transformation. Together, they
17 should be able to increase productivity to a high level compared to today's status, helping to produce enough
18 food to cope with population increase and decreasing the pressure on natural ecosystems.

19 20 21 4.3.3.2 *Ecosystems and forests*

22 Around 45% of the terrestrial carbon and 50% of the net primary production is attributed to forests. Tropical
23 forests are thought to be particularly important in climate dynamics because of their strong evaporative
24 cooling potential, as compared to temperate and boreal forests with moderate and low potentials, respectively
25 (Bonan 2008). However, the carbon sink of the Amazon is thought to be decreasing slowly due to the
26 combination of increasing mortality with a levelling off in productivity. Although some action has been
27 taken (Aguiar et al. 2016), the Amazonian tropical forests are also disappearing due to direct human action,
28 especially deforestation for agricultural land.

29
30 Land not only provides a source and potential sink of CO₂ but is also central to adaptation, for example, in
31 coastal zones (Schleussner et al. 2016) and through agriculture and forestry. Furthermore, a considerable
32 proportion of carbon is stored in soils, peatlands, wetlands and permafrost. This means that land use is
33 important to the prospects of stabilising temperature increase at 1.5°C (Davidson et al. 2006) Options such as
34 afforestation and bio-energy and carbon capture systems (BECCS) need to be carefully analysed with respect
35 to the potential competition for land in achieving the goal of food security for all, safeguarding terrestrial
36 ecosystems (Haberl 2015; Williamson 2016), and the labile nature of carbon sequestered in plants and soil
37 at higher temperatures (Ågren 2000; Davidson et al. 2006; Wang et al. 2013).

38
39 Other complementary approaches such as biochar, soil carbon sequestration and enhanced weathering (see
40 Section 3.2.2) are land-based but do not directly compete with food production and could have substantial
41 co-benefits in terms of raising crop yields (Smith et al. 2014a).

42
43 AR5 focused on 2°C stabilization pathways at the lower end of the considered spectrum and found a
44 LULUCF mitigation potential of up to 10.60 GtCO₂eq/year in 2030. For mitigation efforts, this was
45 consistent with carbon prices up to 100 USD/tCO₂-equivalent. This included both supply and demand side
46 measures, with the main sources of emissions addressed being deforestation and agricultural emissions from
47 livestock, soil and nutrient management. Demand side measures (e.g. waste reduction, diet shifts) was
48 flagged as under-researched (Smith et al. 2014a). In 1.5°C pathways emissions reductions from the AFOLU
49 sector range from [xx%-yy%] depending on the underlying assumptions about population, economic growth
50 and technical change.

51
52 The potential for sequestering atmospheric CO₂ in processes that simultaneously restore large swathes of
53 degraded land globally has been explored as a transformative climate change intervention. Smith et al.
54 (2007) report that restoring degraded grazing land could reduce atmospheric CO₂ by similar magnitudes to
55 forest and crop interventions. In the tropics, a technology for Atlantic forest restoration has been developed

1 (Rodrigues et al. 2009) and its coupling with bioenergy production has been modelled (Buckeridge et al.
2 2012). These authors concluded if the best genetic technologies for crop improvement, leading to
3 requirement of less land for the same level of production, could be combined with forest regeneration, the
4 high potential of associating both activities could be realised, since forests store 18 times more carbon than
5 sugarcane crops.

6
7 Innovations in livestock management, the use of fire regimes in savannah and rangeland ecology offer the
8 potential to remove the assumed trade-off between soil carbon restoration and stocking densities
9 (overgrazing) and shift the balance of carbon in above-ground biomass, soil carbon and animal protein in
10 support of CO₂ sequestration, reduced atmospheric CH₄ and sustainable development (Archibald and
11 Hempson 2016; Venter et al. 2017).

12
13 Several adaptation options are currently used in agriculture and associated sectors. Community-based natural
14 resource management (CBNRM) has been highlighted as a potential adaptation strategy (Fernández-
15 Giménez et al. 2015; Fook 2015). Integrated watershed management is one such CBNRM option and it has
16 moved from being restricted to soil and water management to include actions related to maintaining
17 ecosystem services, strengthening and diversifying livelihoods, and meeting food security needs (Zanzanaini
18 et al. 2017; Singh 2017).

19
20 However, cases from India demonstrate that, though such initiatives have become more participatory and
21 holistic in nature, they focus disproportionately on building hard adaptation options (check dams, earthen
22 bunds) with lower emphasis on soft options such as behavioural shifts towards reducing water demand
23 (Bharucha et al. 2014; Singh 2017). Moreover, there is high agreement in the literature from Asia that
24 integrated watershed management as it is currently implemented, will need to strengthen institutional
25 mechanisms that do not incentivize exploitative behaviour (Bharucha et al. 2014; Kale 2015; Chaudhari and
26 Mishra 2015), expand its current mandate to emphasize demand management instead of supply augmentation
27 (Bharucha et al. 2014; Singh 2017), and ensure growing irrigation and domestic water needs are met without
28 depleting water supply or causing increased damage to the watershed and the biodiversity and social and
29 economic sources it supports (Gray and Srinidhi 2013; Bharucha et al. 2014). It is also critical to enhance
30 monitoring and evaluation systems in watershed management to move away from numerical assessments of
31 ‘hectares of land treated or women in self help groups’ to a more complex adaptive systems approach that
32 focuses on forward-looking, flexible, iterative decision-making and evaluation.

33
34 Agroforestry designed to couple forest recovery with agriculture is an option providing higher carbon
35 sequestration through growing forests and the agricultural products need for human communities (Ray et al.
36 2015; Buckeridge et al. 2012).

37
38 While it is established that ecosystem restoration is essential, policy-related complexities needed to do this
39 consistently and at scale, present significant planning and management challenges. In many cases, biomes
40 cut across different countries (e.g., Amazon). This will require the development of transnational governance
41 structures and adequate finance to deal with recovery and conservation of very large bio-regions.

42
43 Reducing emissions from deforestation, forest degradation, and other forest related activities, known as
44 REDD+, has been a strategy for over two decades. Although REDD+ was designed primarily as a mitigation
45 strategy, its multiple co-benefits have made REDD+ a strategy that also benefits local communities,
46 biodiversity and sustainable landscapes (Turnhout et al. 2017). In some cases, these co-benefits have been
47 the key to the success of projects, beyond carbon pricing (Turnhout et al. 2017; Ngendakumana et al. 2017),
48 as REDD+ projects have been implemented with the joint goal of working with local communities to
49 improve their livelihoods and their sustainable use of natural resources (Dunlop and Corbera 2016). The
50 institutional financial architecture of REDD+ will require strengthened coordination, additional funding
51 sources, and access and disbursement points, especially in order to meet the commitments of the Paris
52 Agreement (Well and Carrapatoso 2016).

53
54 Besides financing, REDD+ have faced other challenges, including a lack of coherence with local forestry
55 policies (Ngendakumana et al. 2017), limited involvement of local populations and stakeholder centred

1 consultation processes (Bastakoti and Davidsen 2016), focus on the local rather than the structural causes of
2 deforestation (Ingalls and Dwyer 2016), legal problems related to property rights (especially benefits over
3 avoided or reduced emissions) (Skutsch et al. 2017), top-down distribution of funding and benefits from the
4 project (Skutsch et al. 2017; Chomba et al. 2016), and diverging perceptions of equity and ‘willingness to
5 participate’ among stakeholders (Pasgaard et al. 2016).

6
7 Most of these challenges depend on local context, policies and perceptions (Skutsch et al. 2017; Pasgaard et
8 al. 2016; Chomba et al. 2016; Ingalls and Dwyer 2016) and, as such, are best addressed at the local level to
9 unlock the enormous potential that REDD+ has in achieving a 1.5°C goal.

10 11 12 *4.3.3.3 Urban green cover*

13 Urban green spaces provide ecosystem services and associated benefits such as pollination, water retention
14 and infiltration and, in some cases, sustainable food production (Green et al., 2016). They constitute a form
15 of Ecosystem-based Adaptation (EbA) and share five linked components: ecological structures, ecological
16 functions, adaptation benefits, valuation, and ecosystem management practices Brink et al. (2016). Amongst
17 the benefits are flood control, reduction of urban heat island, pollination of numerous areas, and the
18 improvement in health and wellbeing of urban dwellers (Jennings et al. 2016; Lin et al. 2017; Sanesi et al.
19 2017).

20
21 Wellbeing is improved by passive and active means; passive related to the vegetation availability, whilst
22 active relates to the time spent in green areas (Lin et al. 2017). Although active means will bring greater
23 benefits, dense urban areas around the world tend to have smaller green area with less vegetation, meaning
24 that dwellers will benefit more from passive means (Lin et al. 2017). However, vacant lots and other
25 abandoned or degraded areas are being repurposed for green spaces in many cities (Green et al. 2016). Milan
26 in Italy has developed new policies, including the creation of an Urban Forest inventory in response to the
27 10,000 hectares of new forest and green areas created over the last two decades (Sanesi et al. 2017).

28
29 The growth of urban green spaces can lead to the concern over their governance, as they operate as small-
30 scale nodes that form part of a larger array of parks and ecological reserves (Green et al. 2016). Due to the
31 dynamics of cities and green spaces, adaptive governance has been suggested (Green et al. 2016). With the
32 expected growth of urban green areas, issues of equity, stakeholder participation, normative and ethical
33 considerations need to be accounted for. Future scenarios and the creation of new ecological structures need
34 to be thought of (Brink et al. 2016) and the evolving and growing use of ‘big-data’ can help create a better
35 understanding of the connections between these environmental services and health (Jennings et al. 2016) and
36 of urban green area dynamics and improve decision-making of natural resources management in urban
37 development (Li et al. 2017).

38 39 40 *4.3.3.4 Synergisms and the systemic approach*

41 42 43 *4.3.4 Urban, infrastructure and industrial transitions*

44
45 IPCC AR5 emphasized that much of the key and emerging climate risks and responses are concentrated in
46 cities and urban areas and the infrastructure and industries associated with those areas. Cities are complex
47 inter-dependent systems that can be leveraged to support climate mitigation and adaptation action to deliver
48 mitigation co-benefits, mainstreaming adaptation as a resource efficient strategy (Revi et al. 2014). The
49 transportation and industrial economic activities happening in urban areas increase both welfare and
50 greenhouse gas emissions. In urban areas, adaptation responses to 1.5°C will need to be integrated with the
51 mitigation transition.

52
53 In the context of the 1.5°C challenge, growing literature recognises that any likelihood of achieving a world
54 that stays within the 1.5°C temperature limit will be defined by four critical elements: what happens in cities
55 and other urban centres in the next few decades will be the defining influence on whether or not dangerous

1 climate change is avoided (Roberts 2016a; Satterthwaite and Bartlett 2016), local governments will emerge
2 as the key mediators and drivers of achieving global ambition and local action (Satterthwaite and Bartlett
3 2016), a new type of city/urban science will be desirable that bridges disciplinary boundaries and practices a
4 mix of approaches to create an evidence base for action (Solecki et al. 2013; McPhearson et al. 2016) and it
5 will be critical that prospective solutions will need to be co-designed and co-produced at the interface of
6 science and policy and these actions will often rely on the boundary roles played by local level champions
7 (Leck and Roberts 2015). Most economic growth is now being driven by urban systems (Glaeser 2012) and
8 there has been a growing awareness of the importance of urban systems as a critical part of the 1.5°C target.

11 4.3.4.1 *Options for 1.5°C transitions in urban areas*

12 The following sections outline the potential for both mitigation and adaptation action in urban areas.

15 4.3.4.1.1 *Sustainable Land Use, Urban Planning & Design*

16 There is strong evidence that indicates that a mix of land management options, such as compact development
17 and infrastructure, focusing on increased accessibility (Berke et al. 2007; Ma and Banister 2006) and
18 practicing mixed land use, create multiple co-benefits like better health outcomes (Su et al. 2016), improved
19 environmental quality and human well-being (Panagopoulos et al. 2016; Stevenson et al. 2016), promotes
20 diversity and vitality (Shi and Yang 2015) that help human and natural systems adapt to the changing climate
21 (Puppim de Oliveira et al. 2013). Some of the key benefits emerging from such a mix of strategies are:
22 improved productivity, efficient resource use and delivery, improved health impacts (Milner et al. 2012;
23 Campbell-Lendrum and Corvalán 2007) and commute savings (Day and Cervero 2010). The biggest
24 efficiencies in urban energy demand are emerging structural change in cities reflected in their urban form
25 (Goodwin and Van Dender 2013; Wee 2015; Newman and Kenworthy 2011).

26
27 Urban transitions are linked to industrial transitions (Freeman and Perez 2000; Perez 2002, 2009b,a) and
28 more specifically to transformation of transportation and energy systems (Geels et al. 2016b; Newman
29 2017). The current structure of cities across the world is very diverse, based on the level of development and
30 established infrastructure, that range from pre-industrial walking cities prevalent in the 19th and early 20th
31 century, transit cities based around trains and trams, to late-20th century automobile-based cities. These city
32 forms were and are associated with different business models, economies and governance systems (Geels
33 and Schot 2010; Hargroves and Smith 2005), with distinct urban fabrics that developed around such
34 transport systems and the economies and governance systems are associated with them (Newman et al.
35 2016).

36
37 The issues now being studied are the options available to change urban form and fabrics in response to the
38 1.5°C challenge. This is particularly shaped by the transition to new smart technology systems that enable
39 the energy and transport technologies to grow in a disruptive fashion (Adams and Mouatt 2010). There is
40 evidence that knowledge economies using smart ICT systems in cities need the space efficiencies and rapid
41 transit associated with walking and transit urban fabric. This is associated with significant urban regeneration
42 and mass transit agendas (Newman and Kenworthy 2015; Gehl 2010). A range of studies have shown how
43 oil-based greenhouse gas emissions associated with high-density, mixed-use walking city urban fabric are
44 much lower than in a medium-density, partially mixed transit city urban fabric and these are much lower
45 than low-density, highly zoned automobile urban fabric (Ewing et al. 2016; Newman et al. 2016).

48 4.3.4.1.2 *Green infrastructure & Ecosystem services*

49 There is evidence that approaches to urban mitigation and adaptation should be multi-level,
50 multidimensional and multi-sectoral. Green infrastructure and ecosystem services such as biophilic urbanism
51 are shown to reduce the need for energy and to cool the city during potentially damaging periods of hot
52 weather as it reduces the urban heat island effect (UHIE) (Beatley 2011; Newman et al. 2017). Community-
53 based adaptation (CBA) has proven to be successful, particularly in the context of enhancing local-level
54 participation in framing adaptation planning for green infrastructure, with a wider transformative potential
55 for urban governance (Archer et al. 2014). Ecosystem-based adaptation (EbA) has emerged as a potentially

1 cost-efficient, comprehensive, and multifunctional approach, in addition to conventional, ‘hard’ adaptation
2 measures (Brink et al. 2016).

3 4.3.4.1.3 *Sustainable Water and Environmental services*

4 Integrated and sustainable water resource management continues to be recognised as a promising instrument
5 for exploring mitigation and adaptation to climate change (Xue et al. 2015; Poff et al. 2015). In many cities
6 water is one of the most energy consumptive products. There are however significant barriers to sustainable
7 water management that still exist within the sector, such as lack of human and institutional capacity, lack of
8 financial resources, lack of awareness, lack of communication, inappropriate institutional structures and
9 improper management; particularly those that impede ‘participation of and collaboration between
10 stakeholders’ (Lemos 2015; Hill Clarvis and Engle 2015; Margerum and Robinson 2015; Bettini et al. 2015).
11 Significant innovation will be required to strike a balance between sustainable water supply and demand
12 (Deng and Zhao 2015).

13 14 15 4.3.4.1.4 *Sustainable Urban Agriculture & Forestry*

16 Developing countries need to meet growing demands for food, water and energy, which is further
17 compounded by climate change. Effective adaptation to climate change would require efficient use of land
18 (like zoning for agriculture as in McClintock et al. 2012), water, energy and other vital resources, and
19 coordinated efforts to minimize trade-offs and maximize synergies (Angotti 2015; Biggs et al. 2015; Yang et
20 al. 2016; Bell et al. 2015; Lwasa et al. 2015; Sanesi et al. 2017; Gwedla and Shackleton 2015). Evidence is
21 emerging (Rasul and Sharma 2016) on using a nexus approach for the integrated management of urban
22 agriculture and forestry systems (see 4.4.3 for further details).

23 24 25 4.3.4.1.5 *The urban built environment*

26 Improving the performance of buildings and housing in cities, in terms of thermal comfort, end-use service
27 efficiency and embodied energy are significant means of decarbonizing urban systems. In cities in
28 developing countries and emerging markets, the rapid pace of urbanization and new construction can imply
29 considerable emission reduction, cost-efficiency and lower climate impact if these new buildings systems,
30 end-use technologies and standards are put into place.

31
32 Climate change impacts the construction and housing sector in multiple ways: first, changing weather
33 conditions leading to delays and increased construction costs [ref]; second, climate change and associated
34 extreme weather need buildings systems and building materials to withstand an extended range of weather
35 conditions; third, changed climatic conditions that may induce building failure [ref]; fourth, a changing
36 pattern of extreme weather may imply a change in the demand for rebuilding and repair [ref] that will need a
37 range of responses around building design, material selection and resilience [ref].

38
39 Adaptation of the urban built environment in the face of a range of climate change impacts would require it
40 to protect urban populations, the urban economy, critical assets and infrastructure. Stress has been laid on
41 new emerging knowledge and innovative frameworks to adapt existing and new buildings, using a balance
42 between structural and non-structural measures, with a focus on locations where housing quality is the
43 poorest, climate risks are the greatest and economic and population exposure is the highest (UNISDR 2009,
44 2011, 2015). Adaptation in the housing sector is enabled by design, policy and implementation responses to
45 extreme weather conditions and attention to access and safety and minimizing displacement. There is strong
46 empirical evidence that poor quality housing erodes adaptive capacities in human systems (UNISDR 2009;
47 UN-HABITAT 2011; Mitlin and Satterthwaite 2013).

48 49 50 4.3.4.1.6 *Resilient Urban energy systems*

51 The heavy dependence of the urban economy, infrastructure, services and residents on electricity and fossil
52 fuels means far-reaching consequences, if supplies are unreliable or disrupted, as has been demonstrated in
53 extreme events (UNISDR 2011; IPCC 2012). Urban energy sector adaptation has received limited attention
54 [ref]. Key challenges include building redundancy into generation and distribution, negotiating policy and
55 decision-making scales and building adaptive capacity through and around local action [ref].

4.3.4.2 Sustainable and Resilient Transport systems

AR5 emphasized four key aspects of energy transitions in the transport sector (Sims et al. 2014). First, it recognized that reducing global transport GHG emissions will be challenging, owing to the projected growth in passenger and freight activity. Second, it identified key interventions that would enable decoupling of mobility and emissions in the transport sector. This included avoided journeys, modal shifts, uptake of improved vehicle and engine performance technologies, a shift to low-carbon fuels, investments in low-carbon and related infrastructure; and changes in the built environment and urban design that could alter urban form reducing travel needs, using strategies like mixed-use and transit-oriented development (IPCC 2014;Mittal et al. 2016; Li and Loo 2017; Zhang et al. 2016; IEA 2016)

There is evidence of decoupling car use and wealth since AR5, mostly in developed economies though some emerging cities are also showing this (Newman 2017). In rapidly growing cities, largely in developing and emerging economies, good opportunities exist for both structural and technological change around low-carbon transport. Yet, decoupling mobility and emissions faces critical barriers, which differ across regions: financial, institutional, cultural, and legal, particularly constraining wide deployment of low-carbon technology uptake and behavioural change (Bakker et al., 2017). Present urban form, infrastructure and urban design may facilitate or limit options for a modal shift (Geels 2014; Newman et al. 2016)

A recent study (Shi and Yang 2015) assesses the co-relation between socio-economic development, urban form and transport-sector development in China. It found a significant positive effect on per capita CO₂ emissions from transportation. The study recognized the need for planning controls, particularly around urban population density, the size of built-up areas and urban road density, to reduce the per capita CO₂ emissions from the transport sector. It also found public transport helped reduce per capita CO₂ emissions, establishing it as a key driver of altered urban GHG profile.

The major transport trend since AR5 has been towards the electrification of transport (IEA, 2016). Electric railways have been growing rapidly, especially in China, in both cities and between cities (Mittal et al. 2016; Li and Loo 2017; Zhang et al. 2016b; International Energy Agency (IEA) 2016). Electric rail policy was successful in reducing transport sector energy demand and emissions, with significant co-benefits for the oil-importing nations (Chaturvedi and Kim 2015).

Vehicle efficiency for conventional vehicles has been slowly increasing despite rebound effect of larger vehicle sizes, negating most of this improvement (Sivak and Schoettle 2016). Urban passenger vehicles have also shown a consistent growth in electric vehicles as shown in Figure 4.1.

Figure 4.1: Growth in Plug-in Electric Vehicles (PUV's) globally, 2015-16. Source: Carlin, Rader and Rucks, 2015
[Figure 4.1 to be included in the SOD]

Evidence (Mittal et al. 2016; van Vuuren et al. 2017) indicates substantial mitigation potential with electric passenger vehicles, if non-fossil energy resources are used for electricity and hydrogen production. But studies (Bauer et al. 2015; Nanaki and Koroneos 2016) caution against the associated environmental burdens across battery and fuel-electric vehicles, advocate the use of life cycle management in vehicle manufacturing chains as well as energy and transport policies, and emphasise urban planning and design interventions.

Biofuels may emerge as a viable mitigation option in some geographies. In Sao Paulo (Menezes et al. 2017), the highest potential for reducing GHG emissions is found to be via the use of biofuels, particularly ethanol, rather than through the use of public transport. This points to the need for a careful assessment of trade-offs (see also Box 4.3).

Fuel cells have been identified as a potential mitigation option, but concerns have been raised about their large-scale commercial application (Badwal et al. 2015) without adequate hydrogen storage and the almost

1 non-existence of hydrogen transportation and distribution infrastructure. Trade-offs with respect to biofuels
2 would need consideration.
3 Decarbonising the transport sector will require a range of measures, particularly in its convergence with
4 long-term climate change and sustainable development (Bakker et al. 2017). Policy co-ordination at multiple
5 scales and of multiple types, including congestion pricing, public transport improvement, pricing strategies,
6 and information and awareness campaigns have also been identified as key drivers of GHG mitigation
7 effectiveness (Menezes et al. 2017). In a recent study (Regmi and Hanaoka 2011; Mittal et al. 2016), a mix
8 of regionally differentiated low-carbon transport strategies were found to be important to India and China,
9 including improving fuel economy, promoting a low-carbon fuel mix including low carbon electricity
10 supply.

11
12 Four different transport adaptation strategies broadly define an integrated response framework for urban
13 mobility: maintain and manage; strengthen and protect; enhance redundancy; and, where needed, relocate.
14 Cities that have developed adaptation plans usually include attention to more resilient transport systems
15 (UN-HABITAT 2011).

16
17 The biggest efficiencies in transport energy demand have been due to structural change in cities, reflected in
18 the urban form associated with what is now known as ‘peak car’ (Goodwin and Van Dender 2013; Wee
19 2015; Newman and Kenworthy 2015). Although this was recognized in AR5 based on the first work by
20 Puentes and Tomer (2008) and Schipper (2011), it was not clear how global the trends would develop. Geels
21 and Schot (2010) explain the trend as a socio-technical innovation and Newman et al (2017) as a disruptive
22 innovation based on demand to reduce travel time by living closer to destinations (a change in urban form)
23 and demand for faster urban transport options (modal shift changes towards faster rail and bus options in
24 mass transit). Global data on these trends are now apparent (Newman and Kenworthy 2015) and even show
25 ‘peak car’ happening in Shanghai and Beijing (Gao and Kenworthy 2017).

26
27 Associated with peak car has been a shift towards walking and cycling in many cities (Gehl 2010; Newman
28 et al. 2016; Pucher and Buehler 2016; Colville-Anderson 2016) . These have been closely associated with
29 changes in infrastructure and amenity enabling these modes.

30
31 Transport trends in freight and air travel have not changed significantly and will probably need to be
32 decarbonized by biofuels and renewable gas.

33 34 35 *4.3.4.3 Industrial transitions - energy-intensive industry*

36 For global temperatures to remain under 1.5°C, industry will need to fully implement drastic changes in
37 three directions. First, use of bio-based feedstocks, electrification of production processes, and/or capture
38 and storage of all CO₂ emissions by 2050 (Åhman et al. 2016). Second, the substitution of materials in high-
39 carbon products with those made up of renewable materials (wood instead of steel or cement in the
40 construction sector, natural textile fibres instead of plastics). Third, an increase of the rate of recycling of
41 materials and the development of a circular economy industry (Lewandowski 2016; Linder and Williander
42 2017).

43
44 Dimensions to facilitate deep decarbonisation in energy-intensive industries on the scale to achieve a 1.5°C
45 target include addressing competitiveness, fairness, sustainable development, and technology transfer
46 (Åhman et al. 2016). Both CO₂ capture and storage and bio-based feedstock processes face barriers in public
47 acceptance (Ashworth et al. 2015) and costs (Rubin et al. 2015), but would leave the production process of
48 materials relatively untouched. Electrification of manufacturing processes and material substitutions would
49 constitute a greater technological challenge and would mean more disruptive innovation in industry,
50 potentially leading to stranded assets, and reducing the political feasibility and industry support (Åhman et
51 al. 2016). Recycling materials and developing a circular economy can be institutionally challenging as it
52 requires advanced capabilities (Henry et al. 2006) but has many advantages in terms of cost, health, and
53 environment.

4.3.4.4 *Adaptation options in urban areas*

4.3.4.4.1 *Disaster risk reduction and resilience building*

Building urban resilience to both climate change and extreme events, and enabling disaster risk reduction is an important strategy to enable the transition to a 1.5°C world (IPCC 2012; UNISDR 2009, 2011, 2015). It is now reasonably established that climate mitigation is crucial for defining the emergence of future risks and hence, defining adaptation potential (Satterthwaite and Bartlett 2016).

A recent critical debate has been around the potential of integrating climate adaptation, mitigation, disaster risk reduction and urban poverty across strategies at the city level (Revi et al. 2014). An extensive in-depth study (Satterthwaite and Bartlett 2016) examined the challenges of such an integration across multiple city types to enable successful urban adaptation. It recognized multiple barriers and enablers from: measuring socio-economic co-benefits to encourage and sustain local climate action (Durban), coherence between environmental and development concerns to lay a strong foundation for adaptation (Manizales, Rosario), fragmented governance and lack of institutional coherence that inhibits positive synergies (Bangalore) and active partnership of marginalized urban residents in the process of developing adaptation strategies (Uganda). Urban plans and actions in Manizales (and in Colombia more generally) look for coherence between disaster risk reduction and climate change adaptation and assume that capacity to adapt to future changes will increase if disaster risk and emergencies are handled well, enables by a supportive national government.

The long history of urban environmental innovation includes engaging communities and publicly monitoring environmental performance and has helped get attention to urban mitigation and to the idea of a lower carbon future. The coherence between environmental and development concerns, along with a history of disaster preparedness, has laid a durable foundation for adaptation (Satterthwaite and Bartlett 2016).

Building of local capacity and innovative institutional structures are effective measures to enable urban climate resilience (Dodman et al. 2016; Archer et al. 2017). The most meaningful outcomes emerged through interventions that emphasized knowledge, networks, information, and greater engagement of citizens with the state. This emphasis on the capacity to learn and reorganize provides a counterpoint to ideas around ‘implementation’ and ‘mainstreaming’ normally promoted within climate change adaptation practice (Reed et al. 2015).

There is enough evidence that significant overlaps between the agendas of climate adaptation, disaster risk reduction and urban poverty (Mitlin and Satterthwaite 2013; Satterthwaite and Bartlett 2016); which is critical to address sustainable development, but equally important to improve adaptation effectiveness.

4.3.4.4.2 *Migration*

4.3.5 *Short lived climate pollutants*

The main short lived climate forcer (SLCF) emissions that cause warming are black carbon (BC), methane (CH₄), other precursors of tropospheric ozone (carbon monoxide (CO) and non-methane volatile organic compounds), and a number of hydrofluorocarbons (HFCs) (Schmale et al. 2014). SLCFs thus can be gases as well as aerosols, and are defined as substances that remain in the atmosphere for between a couple of days and roughly a decade. SLCFs also include emissions that lead to cooling, such as sulphur and nitrogen dioxide, organic carbon and ammonia. Here, we focus on the primary warming agents, black carbon, HFCs and methane, often referred to as short-lived climate pollutants (SLCPs).

Box 1.2 provides a discussion of the emission metrics around SLCPs and their long-lived counterparts. Modelling indicates that implementing full SLCP mitigation would delay crossing the 2°C threshold in an RCP 4.5 scenario by 68 years, in an RCP 6 scenario by 17 years and in RCP 8.5 by nine years

(Pierrehumbert 2014) and could increase the CO₂ budget for a >66% chance of staying below 2°C by 25% compared to a case without dedicated SLCP mitigation (Rogelj et al. 2015). We note that BC is rarely emitted alone, and so mitigation strategies target BC-rich sectors and consider the impacts of all co-emitted SLCPs.

The AR5 concluded that SLCPs have comparable contributions to CO₂ for short-term time horizons and that the atmospheric lifetimes of SLCPs are better matched with the political lifetime of decision-makers than those of long-lived GHG, thus potentially resolving intergenerational barriers to interventions to reduce the emission of SLCPs.

Table 4.2: Overview of main characteristics of SLCPs (based on Pierrehumbert (2014) and Schmale et al. (2014))

SLCP compound	Atmospheric lifetime	Annual global emission	Main anthropogenic emission sources	Options to reduce emissions consistent with 1.5°C
Methane (gas)	On the order of 10 years	0,3 GtCH ₄ (2010) (Pierrehumbert 2014)	Fossil fuel extraction and transportation Land-use change Livestock and rice cultivation Waste and wastewater	See Sections 4.3.2 and 4.3.3 managing manure from livestock; Intermittent irrigation of rice; Capture and usage of fugitive methane; Dietary change
HFCs (gas)	Months to decades, depending on the gas	0,35 GtCO ₂ -eq (2010) (Velders et al. 2015)	Air conditioning Refrigeration Construction material	Alternatives to HFCs in air-conditioning and refrigeration applications
Black carbon (solid)	Days	~7 Mt (2010) (Klimont et al. 2017)	Incomplete combustion of fossil fuels or biomass in vehicles (esp. diesel), cook stoves or kerosene lamps	See Section 4.3.4: Fewer and cleaner vehicles; Cleaner cook stoves, gas-based or electric cooking; Replacing brick and coke ovens; Solar lamps

Mitigating SLCPs leads to a cooler climate more quickly (because of the front-loaded warming effect; Myhre et al. (2013)) and more permanently as compared to scenarios where SLCPs are not reduced, but if CO₂ emissions are not reduced in parallel to SLCPs, rapidly accumulating warming due to CO₂ will overwhelm any SLCPs mitigation benefits over a time span of a couple of decades.

Sources of methane are manifold and include both fugitive and deliberate releases during fossil fuel extraction, transportation and storage, as well as wastewater treatment, rice paddy cultivation, livestock, biomass burning and landfill (Schmale et al. 2014; Finn et al. 2015). As such, the options to reduce emissions of SLCPs are also many and varied. This was extensively discussed in various sections in AR5 (IPCC 2014b).

Reducing black carbon and co-emissions from vehicles has numerous co-benefits, in particular for health, avoiding premature deaths and increasing crop yields (Scovronick et al. 2015; Peng et al. 2016). A consequence of this is that interventions to reduce black carbon offer tangible local benefits, increasing the likelihood of local public support (Venkataraman et al. 2016; Eliasson 2014). Limited interagency co-ordination, poor science-policy interactions (Zusman et al. 2015), weak policy and absence of inspections and enforcement (Kholod and Evans 2016) are among barriers that reduce feasibility of options to reduce vehicle-induced black carbon emissions. Switching from biomass cook stoves to cleaner gas stoves (based on liquefied petroleum gas or natural gas (LPG/PNG) or to electric cooking stoves is technically and economically feasible in most areas, but faces barriers in user preferences, costs and the organisation of supply chains. Similar feasibility considerations emerge in switching in lighting from kerosene wick lamps

1 to solar lanterns, from current low efficiency brick kilns and coke ovens to cleaner production technologies,
2 and from field burning to agricultural practices using deep-sowing and mulching technologies.
3 HFC emissions are currently small, but growing rapidly (Myhre et al. 2013). Mitigation options are to
4 transition to climate-friendly alternatives, ideally in combination with improved energy efficiency so as to
5 simultaneously reduce both CO₂ and co-emitted air pollutants as well (e.g. Shah et al. 2015). Technical,
6 social, institutional and environmental feasibility of alternatives is likely to be high, but costs are estimated
7 to be in the same range as other mitigation options; the majority of emission reductions can be done below
8 60 €/tCO₂eq, and the remainder below roughly double that number (Höglund-Isaksson et al. 2017). This
9 indicates that economic feasibility is more limited.

10
11 Most very low-carbon emissions pathways include a transition away from use of coal and natural gas in the
12 energy sector and oil in transportation, leading to a substantial overlap with SLCP mitigation strategies in
13 such scenarios. However, SLCP reductions may be achieved later in such scenarios.

14
15 Reductions in SLCPs can also provide large benefits towards sustainable development. These have been well
16 characterized in terms of improvements in air quality (e.g. Schmale et al. 2014) and crop yields (e.g. Shindell
17 et al. 2012). Benefits would also be realized in terms of energy access, gender equality, and poverty
18 eradication (e.g. Shindell et al. 2017). There is an information deficit, however, with the absence of
19 international frameworks for integrating SLCPs into emissions accounting and reporting mechanisms being a
20 significant barrier for policy-making to address SLCP emissions (Venkataraman et al. 2016).

21 22 23 **4.3.6 Carbon dioxide from the atmosphere and CO₂ capture, utilisation and storage**

24
25 While there are some 2°C pathways that manage to achieve their emissions reductions targets without
26 relying on negative emissions (Clarke et al. 2014; Rogelj et al. 2015), 1.5°C pathways typically feature
27 removal of carbon dioxide from the atmosphere (CDR) to either limit overshoot or to bring emissions down
28 again from a temporary overshoot.

29
30 Complementing the analysis of the pathways assessed in Chapter 2 (Section 2.2.2), this section provides a
31 bottom-up assessment of the different CDR options already embedded in the pathways (bioenergy with
32 carbon capture and storage, i.e. BECCS), direct air capture and storage (DACS) and afforestation &
33 reforestation). Other options that have not yet been integrated in the assessment models, but could also
34 contribute towards augmenting the mitigation potential, include enhanced (ocean and terrestrial) weathering,
35 soil carbon sequestration (SCS), biochar, blue carbon, ocean iron fertilization, and other greenhouse gas
36 removal (GGR) techniques (e.g. of methane). Exponential growth in the literature since the IPCC's last
37 assessment cycle (Minx et al. 2017) demonstrates that the knowledge landscape has significantly expanded
38 in recent years and needs to be assessed and synthesized to serve as input for the development of 1.5°C
39 strategies.

40
41 Another strand of options assessed here concerns carbon capture, utilization and storage (CCUS). In the
42 absence of carbon pricing, the argument is that regarding the captured CO₂ as a resource (e.g. for usage in
43 greenhouses; to produce synfuels or enhanced oil recovery (EOR) can be an entry point for negative
44 emissions, fostering learning and eventually upscaling, even though the technology does not *per se* lead to
45 negative emissions.

46 47 48 **4.3.6.1 Bioenergy with carbon capture and storage**

49 There have been bottom-up assessments of BECCS components in previous IPCC reports (IPCC 2005;
50 Smith et al. 2014) and different BECCS technologies have been incorporated into integrated assessment
51 models (IAMs) for a long time (Clarke et al. 2014; Fuss et al. 2016). The 1.5°C pathways assessed in
52 Chapter 2 remove about 5 (median, 1-16 full range) Gt CO₂ per year by mid-century and 15 (median, 3-32
53 full range) Gt CO₂ per year by 2100 through BECCS, which corresponds to 68 (median, 19-296 full range)
54 and 175 (median, 54-404 full range) EJ per year of bioenergy for CCS, respectively. Note that bioenergy
55 (Section 4.3) can play an even larger role when BECCS use is constrained, as biofuels are then needed at

1 larger scale to decarbonize the transport sector.

2
3 There is now large agreement that bioenergy potentials in 2050 are restricted to 100 EJ per year (Creutzig et
4 al. 2015; Slade et al. 2014), which is less than what is usually assumed to be available in the scenarios
5 (Chapter 2). While bioenergy potentials depend very much on assumptions about future yields, the type of
6 technology deployed, the land available for the cultivation of biomass and grazing intensity and diets (Klein
7 et al. 2014), these restrictions appear to be mostly due to sustainability concerns, with respect to the
8 requirements for land that would also be needed for food production for a growing population, to safeguard
9 ecosystems and biodiversity and potential limitations with respect to other inputs such as water and nutrients
10 (Williamson 2016; Haberl 2015; Smith et al. 2013).

11
12 Synthesizing bottom-up literature to perform an ex-post assessment of the implications of BECCS
13 deployment consistent with the aim of limiting global warming to below 2°C, Smith et al. (2016) estimate a
14 land use intensity of BECCS between 1–1.7 ha per ton of C-eq. per year when forest residues are used as
15 feedstock, about 0.6 ha of C-eq. per year for agricultural residues, and 0.1–0.4 ha of C-eq. per year when
16 purpose-grown energy crops are used. Putting this into perspective, the average amount of BECCS deployed
17 in 2°C pathways would thus require an area of land amounting to 25–46% of arable plus permanent crop area
18 in 2100. Other assumptions can, however, lead to a percentage of up to 80% (Monfreda et al. 2008).

19
20 There is low agreement on the exact land areas required for BECCS deployment, which is also reflected in
21 the ranges across models (Chapter 2). Importantly, the area of land is not necessarily a good indicator for
22 competition with food production or threats to ecosystems. On the contrary, requiring a large area of land for
23 the same potential could indicate that low-productivity marginal land is used to avoid such potential conflicts
24 (Schueler et al. 2016). It is thus important to complement global assessments with regional, geographically
25 explicit bottom-up studies of biomass potentials to get more precise insights into the implications of large-
26 scale biomass cultivation. Other implications are the energy that would on average be produced by the
27 BECCS infrastructure in a 2°C pathway (170 EJ per year by 2100) and the water footprint (720 km³ per year
28 by 2100). Smith et al. (2016) find low agreement on global impacts on nutrients and albedo.

29
30 Combined 2050 bioenergy and CCS potentials are found to be of the order of magnitude of 10 Gt CO₂ per
31 year (Kemper 2015), 18 Gt CO₂ per year (NAS 2015) and 20 Gt CO₂ per year (combined with ocean liming
32 and DACS, Caldecott et al. 2015), which partially exceeds pre-AR5 estimates. As these potentials are not
33 homogeneously distributed across regions, pertinent knowledge gaps around distributional impacts and
34 governance mechanisms need to be addressed more systematically in the future literature (Fuss 2017).

35
36 On the CCS side, large technological advances have been made over the last years (see Bui et al.) for an
37 extensive assessment: there is now injection of CO₂ at rates exceeding 1 Mt CO₂ per year at individual sites
38 with 14 currently operating industrial scale projects, including three injecting into saline aquifer systems
39 (Global CCS Institute 2015). Coninck and Benson (2014) and (Bui et al.) provide an in-depth review of the
40 latest CCS literature identifying a better characterisation and prediction of plume migration, lowering of
41 uncertainty around and managing the risks of leakage, and evaluation of the global role of CO₂ storage in
42 energy systems as the current cutting-edge research activities addressing knowledge gaps in the field. They
43 furthermore find large agreement in the literature that pore space exceeds the amounts of CO₂ that are stored
44 for climate change mitigation in below 2°C pathways by far. The capture rate ranges reported by the model
45 inter-comparison presented in Koelbl et al. (2014) are 5–23 Gt CO₂ per year in 2050 and 8–50 Gt CO₂ per
46 year in 2100. Recent assessments (Cook and Zakkour 2015) reconfirm this conclusion from previous
47 assessments (e.g. Benson et al. 2012).

48
49 There is lower agreement on whether this storage capacity can also be exploited to achieve ambitious climate
50 targets. For example, Scott et al. (2015) assess permanent (>100,000 years) storage potential for CO₂. While
51 they also find that overall capacity is adequate to *technically* match current fossil fuel reserves, they
52 emphasize that *rates of storage creation* cannot balance current and expected rates of fossil fuel extraction
53 and CO₂ consequences. Coninck and Benson (2014) point out that not only the availability of storage
54 capacity, but also the required infrastructure of the size of the oil industry poses an obstacle to the rapid
55 upscaling.

1
2 This uncertainty about feasibility of timely upscaling is exacerbated by CCS being largely absent from the
3 Nationally Determined Contributions (Spencer et al. 2015) and CCS deployment having lagged significantly
4 behind roadmaps in line with a 2°C or even 1.5°C target (Peters et al. 2017; IEA 2016). Furthermore,
5 economic incentives for ramping up a large BECCS infrastructure are weak in the absence of carbon pricing
6 or other policies that could support an accelerated uptake of the technology. Smith et al. (2016) cite US\$138
7 billion and \$123 billion per year by 2050 as the average investment costs for a BECCS infrastructure
8 compliant with keeping temperature increase below 2°C by 2100 for bio-electricity and biofuels respectively.
9 However, BECCS unit costs vary widely in the literature, ranging between US\$ 60–250 per ton of CO₂
10 according to Kemper (2015) and McLaren (2012). The latter further specify the range of US \$70-250 per ton
11 of CO₂ to apply to BECCS from combustion and co-firing and provide an estimate of only US \$45 per ton of
12 CO₂ for BECCS from ethanol fermentation. Kemper (2015) also discusses different policy instruments and
13 gives an overview of negative emissions and CCS in different GHG accounting frameworks finding
14 relatively little agreement in the literature on the appropriate policies for rapid upscaling of BECCS, but
15 identifying important interactions across sectors (e.g. by affecting the wood price, incentive schemes targeted
16 at the energy sector could then affect the pulp and paper industry).

17
18 Limited public acceptance is one barrier related to large-scale BECCS deployment. Indeed, BECCS is
19 affected by this challenge on two fronts. First, CCS is problematic (Benson et al. 2012) as there is concern
20 that it is a strategy in favour of prolonging the profitability of the fossil fuel industry (Shackley et al. 2009;
21 Upham and Roberts 2011; Wallquist et al. 2012). Further factors lowering acceptance relate to safety and
22 environmental issues (de Best-Waldhober et al. 2009; Ha-Duong et al. 2009; Reiner et al. 2006). On the
23 other hand, bioenergy has come under scrutiny in the aftermath of the food price hikes in 2007 and 2008
24 with concerns relating to competition for resources like land and water (see above). Most importantly, the
25 assumption that bioenergy can be carbon-neutral has been under special scrutiny. Studies raising concern
26 over the carbon-neutrality assumption can inter alia be found in the literature on indirect land use change,
27 site-specific barriers, and challenges of implementing at scale without impacts on the environment (Plevin et
28 al. 2010; Fargione et al. 2008; Searchinger et al. 2009; Havlík et al. 2011; Popp et al. 2014). While policies
29 have tried to account for indirect land use change by formulating sustainability criteria, for example in the
30 European Union, these have been found to be insufficient (Frank et al. 2013).

31 32 33 *4.3.6.2 Direct air capture and storage*

34 Direct air capture from ambient air through chemical processes with subsequent storage of the CO₂ in
35 geological formations is another option to remove CO₂ from the atmosphere. Alternatively, the captured CO₂
36 could be disposed of in carbonate minerals (Lackner et al. 1995). Compared to BECCS, DACS has the
37 advantage of being independent of source and timing of point emissions, but can capture CO₂ independently
38 of these factors and thus also offset emissions from aviation, for example. On the other hand, this is also the
39 main challenge. While the maximum theoretical potential for DACS is probably only limited by the
40 availability of safe and accessible storage, the concentration of CO₂ in ambient air is 100-300 times lower
41 than at gas- or coal-fired power plants (Keith et al. 2016) and thus still requires about three times more
42 energy than flue gas capture (Pritchard et al. 2015), for which the agreement in the literature appears to be
43 relatively high, with the most extreme range given by NAS (2015) as two to ten times as much.

44
45 Newer studies therefore explore alternative techniques, which can help to reduce the parasitic load (van der
46 Giesen et al. 2017). In their ex-post assessment of DAC energy requirements based on previous bottom-up
47 technology studies (Socolow et al. 2011), Smith et al. (2016) estimate that energy consumption could be up
48 to 45 GJ per ton C-eq. This translates into an average of 156 EJ per year by 2100 corresponding to an
49 average 2°C pathway. Water requirements are estimated to average 10–300 km³ per ton C-eq. per year.
50 Nutrients and albedo would not be affected.

51
52 However, as Broehm et al. (2015) point out in their DAC review, the body of literature is extremely
53 fragmented without a frame of reference or system of analysis for the different studies in the field, which
54 makes assessment difficult. This fragmentation is also reflected in a large variety of cost estimates, which
55 range from US\$ 20 to US\$ 1000 per ton of CO₂ (Goepfert et al. 2012; Sanz-Pérez et al. 2016). This includes

1 both the range by Socolow (2011) of US\$ 600–800 per ton of CO₂ and at the upper end the US\$ 1000 per ton
2 of CO₂ estimate by House et al. (2011). Many of the lower estimates come from commercialisation projects,
3 cover different systems designs or only parts of the system (Ishimoto et al. 2017; National Academy of
4 Sciences 2015; Lackner et al. 2012). For example, Holmes and Keith (2012) only consider capture costs and
5 provide an estimate of US\$ 60 per ton of CO₂. Mazzotti et al. (2013) also include regeneration and arrive at
6 an estimated range of US\$ 376-600 per ton of CO₂. We can thus establish that there is lower agreement in
7 the literature at the lower end of the cost range assessed here, higher agreement for the higher cost estimates
8 and strong support for the conclusion that DACS is significantly more expensive than conventional CCS
9 (Bui et al.).

10
11 While the same barriers to implementation that apply for capture and storage combined with bioenergy apply
12 to DACS in terms of public opposition to storage and lack of an incentive scheme, DACS obviously suffers
13 less from concerns about competition for scarce land resources and negative side effects on ecosystems and
14 biodiversity compared to BECCS, as it can be flexibly placed.

15
16 Current research and efforts by small-scale commercialization projects are focused on overcoming the lack
17 of incentives by considering the captured CO₂ as a resource (see Section 4.3.6.7). Other priorities should
18 include the incorporation of DACS into IAM scenarios alongside BECCS, which has so far only rarely been
19 done (Chen and Tavoni 2013).

20 21 4.3.6.3 *Afforestation and reforestation*

22 The potential for mitigation in the forest sector was evaluated to be up to 9.5 Gt CO₂-eq per year in 2030 at a
23 CO₂ price of US\$ 50 per ton and up to 13.8 Gt CO₂-eq per year at US\$ 50 per ton of CO₂ in AR5 based on
24 post-AR4 literature (Smith et al. 2014b). More than 60% of this potential is provided by forest management
25 options and avoided deforestation, which do not lead to a removal of CO₂ from the atmosphere and are thus
26 assessed in Section 4.3.3. The remainder of the forest mitigation potential can be attributed to afforestation,
27 the share of which is relatively stable across escalating carbon prices, but differs by region: while reduced
28 deforestation dominates the forestry mitigation potential in Latin America and Caribbean and Middle East
29 and Africa, there is very little potential in the OECD-1990 and Economies in Transition (Eastern Europe and
30 part of former Soviet Union), which on the other hand have higher potentials in forest management and
31 afforestation with (non-OECD) Asia featuring a more even distribution (Smith et al. 2014b).

32
33 New literature since AR5 includes e.g. Houghton et al. (2015), note that afforestation is more challenging
34 than avoiding deforestation and relying on natural regrowth because of higher costs per hectare, but they
35 estimate that about 500 Mha could be available (low to medium agreement, see e.g. Dinerstein et al., 2014)
36 for the re-establishment of forests on lands previously forested but not currently used productively. This
37 would sequester at least 3.7 Gt CO₂ per year for decades. Smith et al. (2016) find that it is possible to reach
38 the 12 Gt CO₂ that are on average removed in the 2°C pathways by 2100 with afforestation and reforestation.
39 However, even though the unit costs are estimated to be low compared to other CDR options, US \$18–29 per
40 ton of CO₂-eq, realizing such large potentials comes at an even larger land and water footprint than BECCS
41 – up to 970 Mha and 1000 km³ of water per year, respectively. The nutrient impact would be at 16.8 kt N per
42 year, while the energy requirement would be negligible.

43
44 Many caveats apply when comparing afforestation and reforestation to BECCS and DACS because the
45 biogenic storage has typically much shorter permanence, as forest sinks saturate, a process which typically
46 occurs on the scale of decades to centuries compared to the thousands of years of residence time of CO₂
47 stored in geological formations (Smith et al. 2016) and is subject to disturbances, for example to drought,
48 forest fires and pests that can be exacerbated by climate change (Chapter 3). These issues require careful
49 forest management also after the actual afforestation process and make afforestation and reforestation less
50 effective as a CDR option over time. In the context of reaching the 1.5°C target, it also needs to be stressed
51 that even though there is a lot of practical experience with afforestation and reforestation, which also does
52 not involve ramping up large infrastructures like BECCS and DACS, the pace at which removal will be
53 taking place will still be slow, as forests need to grow to their full potential. Further issues arise from the
54 heterogeneous geographical distribution of afforestation and reforestation potentials, where CDR
55 effectiveness of afforestation and reforestation is limited by its impact on the albedo in higher latitudes

(Jones et al. 2015; Bright et al. 2015), and the lack of governance structures and monitoring capacities to protect forests in the first place (Wehkamp et al. 2015), which is not considered when modelling baselines. Finally, even though forest mitigation options appear to be more accepted than options that involve geological storage, there is relatively low agreement in the literature whether avoiding deforestation and pursuing afforestation and reforestation necessarily have a positive impact on ecosystems and biodiversity, in particular (Phelps et al. 2012). Such co-benefits would need to be actively considered in the design of incentive schemes.

Moving from trade-offs to opportunities, current research is also focusing on exploiting synergies with other policy goals. For example, Rööß et al. (2017) explore how much land would be spared by shifting to healthier diets in Western Europe, which could then be afforested, finding that the yearly carbon storage potential arising from spared agricultural land ranges from 90 to 700 Mt CO₂ in 2050. More research like this will be needed by countries seeking to ratchet up their climate change mitigation ambitions in the context of other policy goals.

4.3.6.4 *Soil carbon sequestration and biochar*

Mitigation through SCS has been included in AR5 AFOLU mitigation potentials and the option of biochar – both for replacing fossil fuels and for sequestering CO₂ – has been presented in AR5 as well (Smith et al. 2014b). However, the full potential to extract CO₂ from the atmosphere to meet ambitious temperature targets has not been assessed for these options. A bottom-up analysis such as that conducted in Smith et al. (2016) finds that 2.6–4.8 Gt CO₂ could be removed each year using either of the two options. The mitigation potential of biochar is, therefore, less than that assessed for BECCS, DACS and afforestation and reforestation, but could make a substantial contribution. For biochar, this range is less than previous estimates e.g. by Woolf et al. (2010) because earlier studies also consider the displacement of fossil fuels through biochar, which is not considered as carbon-negative here. In their review, McGlashan et al. (2012) quote a range of 5.5–9.5 Gt CO₂ per year by 2100 (Gaunt and Lehmann 2008). Caldecott et al. (2015) report a yearly sequestration potential of biochar of 2.2 Gt CO₂ by 2100, under the assumption that any additional biomass would be used for BECCS, and 1.3–3.9 Gt CO₂ for SCS, under the assumption of ongoing restoration. Despite the wide range, there is high agreement in the literature on the magnitude of these potentials, also considering pre-AR5 studies.

Total costs of exploiting the full biochar potential estimated by Smith (2016) would amount to US\$ 130 billion, while SCS is cost-negative on average: it is estimated that much of the negative emissions could be delivered at negative cost (US\$ -16.9 billion per year), and the rest at low (US\$ 9.2 billion per year) cost, with an overall saving of US\$ 7.7 billion per year. This is connected to the multiple co-benefits of SCS, for example on productivity and resilience of soils (Smith et al. 2014b). Water requirements are close to zero for both options, which is also true for the energy requirement of SCS, while biochar could at full theoretical deployment generate up to 65 EJ per year. Both options affect nutrients favourably, but the disadvantage of biochar is that it affects the albedo if applied at large scale: 14 Mha are needed for implementation at 2.6 Gt CO₂-eq. per year, which could reduce the albedo by up to 12% thus partially offsetting the mitigation benefit. Concerning land requirements, biochar would consume less than 3.67 ha per ton of CO₂ (Smith 2016). However, since SCS and biochar addition can be applied to all managed land without changing its current use, there are no problems with respect to competition for land. Still, not all land is suitable for SCS and biochar (Caldecott, B.; Lomax, G.; Workman 2015) and there is also a constraint for biochar in the maximum safe holding capacity of soils (Lenton 2010). The disadvantage of SCS is similar as for AR: saturation will eventually diminish its effect, thus also requiring subsequent management.

4.3.6.5 *Ocean Alkalinisation (OA), marine and terrestrial Enhanced Weathering (EW)*

Many recent assessments have highlighted the substantial uncertainty about the potential storage capacity, environmental impact, and cost of sequestration of inorganic carbon in the ocean (NAS 2015; IPCC 2014a). More recent literature (Renforth and Henderson 2017) provides a thorough review of the state-of-the-art knowledge on OA for large-scale carbon removal to fill this knowledge gap. Ocean alkalinity increases due to rock weathering, thereby naturally sequestering about half a billion tons of CO₂ each year. The idea

1 behind OA is to enhance this natural process e.g. by accelerated weathering of limestone, enhanced
2 weathering, electrochemical promoted weathering, ocean liming, potentially sequestering hundreds of
3 billions of tons of carbon according to Renforth and Henderson (2017) at cost ranges like those of other CDR
4 options. Hartmann et al. (2013) specifically examine enhanced weathering based on ground olivine applied
5 to the ocean or land. The latter would not only help to sequester large amounts of carbon, but would have
6 significant co-benefits amongst which higher agricultural productivity due to the fertilization effect and
7 increased alkalinity of natural waters which decreases ocean acidification if performed at large scale. Taylor
8 et al. (2016) use simulations and find that distributing pulverised silicate rocks throughout the tropics has the
9 potential of sequestering hundreds of Gt of CO₂ by 2100 with significant negative impacts on ocean
10 acidification. Another important advantage is that – at smaller scales – it could be started relatively quickly
11 and thus complement other CDR options without the downside of raising competition for land for other
12 policy goals such as ensuring food security. Yet, exploiting more of the large potentials cited above would
13 require an enormous upscaling of mining, transportation and monitoring that could imply prohibitive costs.
14 In addition, terrestrial EW could also have negative side effects such as an increase in air-borne dust that
15 could impair health (Hartmann et al. 2013). Finally, terrestrial EW potentials are concentrated in the tropics
16 and so huge investments would be needed in less developed regions posing distributional and governance
17 challenges. Smith et al. (2016) estimate more conservatively that between 0.7 and 3.7 Gt CO₂ per year could
18 be sequestered by terrestrial EW, spreading ground olivine on 2-10 Mha of agricultural land and requiring
19 46 EJ of energy per year, mainly for the grinding of the minerals. The corresponding water use is 0.3-
20 1.5 km³ per year. These potentials compare to the NAS (2015) number of 2 Gt CO₂ per year for the US only
21 at US\$ 20-1,000 and are very dependent on the underlying assumptions about the applied technology (cf.
22 (Renforth and Henderson 2017)).
23
24

25 4.3.6.6 *Ocean Fertilization*

26 Another option to remove CO₂ from the atmosphere involving the oceans is by adding iron or other nutrients
27 to them, either from external sources or via enhanced ocean mixing. However, there is currently low
28 confidence on the amount of carbon that could be removed from circulation on a long-term basis
29 (Williamson et al. 2012). This is because so far, only small-scale field experiments and theoretical modelling
30 have been conducted to assess this question, thereby also resulting in low confidence concerning the
31 readiness of this technology to contribute substantially to rapid decarbonisation (e.g. (McLaren 2012), who
32 also makes this point for mineralization techniques). There is broad agreement that OF as a negative
33 emissions technique is likely to play a modest role in offsetting current or future climate forcing (Williamson
34 et al. 2012). Williamson et al. (2012) also assess the literature on unintended impacts of large-scale OF,
35 which represent considerable bottlenecks to its rapid and effective implementation: (a) an increase in upper
36 ocean concentrations of a range of climate-relevant gases associated with phytoplankton growth; (b)
37 potential impacts on subsurface waters and sediments into which the fertilized biomass sinks; (c) a decrease
38 oxygen levels in the ocean interior; (d) unclear impact of an increased carbon flux on ecosystems at the sea
39 floor; and (e) in spite of reduced ocean acidification in the upper ocean, an increased rate of acidification of
40 ocean interior waters.
41

42 The implications of these findings are that impacts would need to be adequately monitored over large space
43 and time-scales. Along with the fact that the greatest theoretical potential for the application of ocean
44 fertilization is the Southern Ocean, this would pose grand challenges for governance, especially when
45 considering the oceans as global commons. Williamson et al. (2012) therefore recommend international
46 governance of further field-based research on ocean fertilization.
47

48 Previous assessments have nevertheless provided estimates for potentials. NAS (2015) bases its range of 1-
49 4 Gt CO₂ per year (through ocean iron fertilization) at US\$ 500 per ton of CO₂ on the work of Aumont and
50 Bopp (2006) and Harrison (2013). McLaren (2012) considers fertilization with nitrogen (0.2-0.5 Gt CO₂ per
51 year) and phosphate (0.5 Gt CO₂ per year), with the caveat of resource limitations. For ocean iron
52 fertilization, he quotes a potential of up to 1 Gt CO₂ per year.
53
54

4.3.6.7 Carbon capture utilization & storage

Carbon dioxide has large potential as synthetic feedstock for chemical material because of its abundance, non-toxicity, and low cost. Among CO₂, the chemical utilization for producing Poly Propylene Carbonate (PPC) has been assessed to represent the best opportunity for rapid scale-up and commercialization (Qin et al. 2015). Other applications include carbon mineralization, Enhanced Oil Recovery (EOR), biodiesel and synfuel production and other chemical applications. These have varying potentials and limitations and more research and piloting are needed to demonstrate their large-scale viability (Cuéllar-Franca and Azapagic 2015). However, von der Assen et al. (2013) warn that most Life Cycle Analyses (LCA) suffer from at least one of the three following pitfalls shedding doubt on whether CCUS can really contribute much to achieving large-scale CDR: 1) utilized CO₂ might intuitively be considered as carbon-negative without actually being so; 2) accounting problems with respect to the allocation of emissions to the individual products and 3) negligence of CO₂ storage duration. There is now more critical research, lowering the confidence of CCUS as an entry point for negative emissions. In particular, MacDowell et al. (2017) voice serious concern about scale issues: comparing the scale and rate of CO₂ production to that of utilization allowing long-term sequestration, they assess it to be highly improbable the chemical conversion of CO₂ will contribute more than 1% to the mitigation needed to achieve the Paris goals. Even scaled-up EOR will account for 4–8% only according to their estimates. So while they agree that EOR may be an economic incentive for early CCS projects, CCU may prove to be a costly distraction from the real task of mitigation.

4.3.6.8 Removal of non-CO₂ greenhouse gases

Another recent strand of literature discusses the possibilities of not only removing CO₂ from the atmosphere, but to also consider the removal of non-CO₂ GHGs (GGR) such as methane. This is very relevant for the 1.5°C target, as the remaining carbon budget is already almost exhausted (see Chapters 1 and 2) and methane is a much more potent GHG than CO₂ (Montzka et al. 2011), which is associated with difficult-to-abate emissions in the food sector, but also outgassing from lakes, wetlands, and oceans (Stolaroff et al. 2012), two processes for which there are no quick solutions at sufficiently large scale in the next few years. Enhancing processes that naturally remove methane, either by chemical or biological decomposition (Sundqvist et al. 2012), has been proposed to lead to negative emissions. Boucher and Folberth (2010) review several existing technologies for methane removal (cryogenic separation, molecular sieves or gates, and adsorption filters based on zeolite minerals) and find low confidence that any of these are currently economically or energetically suitable for large-scale air capture. Further, their review highlights several co-benefits of methane removal: reduced tropospheric ozone production, decreased stratospheric forcing, energy recycling by exploiting the methane chemical energy, and a possible further reduction in atmospheric CO₂ (during the methane oxidation process). Still, they consider it only part of a larger negative emissions portfolio, mainly because of the very small concentration of methane in the atmosphere and its low chemical reactivity at ambient conditions, which would require more research. Current work (e.g. (de Richter et al. 2017)) examines other technologies that go beyond methane and also consider non-CO₂ GHGs like N₂O. More literature is needed, however, to arrive at more robust global GGR potentials.

4.3.6.9 Blue Carbon

There have been some publications hitherto left out from assessments that can be summarized under the label of, which refers to the carbon stored in sea grasses, mangroves, and salt marshes along coasts. Enhancing seagrass meadows has been suggested to remove CO₂ from the atmosphere. Macreadie et al. (2017) assess the literature for three different routes of BC and find that reducing nutrient inputs, avoiding unnaturally high levels of bioturbation, and restoring natural hydrology will maximize carbon sequestration and minimize carbon losses – with the latter featuring the highest confidence in the scientific literature. While there are no quantifications of what a global CDR potential from BC could look like, all three options are found to reduce human and environmental impacts on coastal ecosystems and the ecosystem benefits go beyond the pure benefit of carbon sequestration. Johannessen and Macdonald (2016) report the BC sink at 0.4-0.8% of global anthropogenic emissions and point out that protocols have been developed to quantify BC potentials to include BC credits into the Verified Carbon Standard. However, they warn that these do not adequately account for post-depositional processes and therefore significantly overestimate BC CDR. Seagrass beds will likely not contribute significantly to the meeting the 1.5°C target, according to the review by Johannessen

1 and Macdonald (2016), even though they acknowledge that seagrass meadows provide valuable habitat, are
2 disappearing rapidly and thus warrant intervention for other ecosystems services than carbon storage. There
3 is thus general agreement in the literature that the main knowledge gap is to further investigate the
4 contribution and costs of BC in reaching the 1.5°C target. Otherwise, overestimated carbon offsets could lead
5 to a net increase in CO₂ emissions Johannessen and Macdonald (2016).

6
7 Finally, there are knowledge gaps affecting any technique removing CO₂ at large scale (Section 4.5.1) Jones
8 et al. (2016a) show, for example, that on sufficiently long time scales, natural sinks could even reverse.
9 However, much more research is needed to be able to make robust quantitative statements about this.

10
11 *[Table (or figure) giving a systematic overview of potentials, costs, side effects, governance implications*
12 *planned either here or in synthesis section]*

13 14 15 **4.3.7 Solar Radiation Management**

16
17 Several recent papers have asserted that SRM could reduce some of the global risks of climate change
18 related to temperature rise (Keith and Irvine 2016; Keith et al. 2016; Irvine et al. 2016; Izrael et al. 2014;
19 Heutel et al. 2016; Lloyd and Oppenheimer 2014; Moreno-Cruz and Smulders 2017; Tilmes et al. 2016).
20 However, SRM also presents a number of risks and concerns (Robock 2016; Visionsi et al. 2016; Smith et al.
21 2017; Pitari et al. 2014; Suarez and van Aalst 2017; Svoboda 2017). If SRM is employed, it will have
22 implications for geophysical characteristics (precipitation, cloudiness, ozone, etc.) that are key for
23 livelihoods and economies.

24
25 Those impacts, as well as a full discussion of all SRM options currently proposed, and their implications for
26 sustainable development, are discussed in Chapter 3 and in Box 4.13. In this section, we assess the
27 feasibility, mainly from a governance, economic and ethical viewpoint, of two SRM options: stratospheric
28 aerosols injection (SAI) and marine cloud brightening (MCB). Amongst the SRM options that have been
29 proposed, SAI and MCB at the moment appear to be the technologies that could become most effective.

30
31 Although SRM is sometimes considered alongside CDR (see Section 4.3.6) under the header
32 ‘geoengineering’, this report separates the two. This is because their technical characteristics, risks,
33 governance and even their classification as a mitigation, adaptation or another category, are different. In this
34 report, we consider CDR as mitigation. SRM is neither adaptation nor mitigation.

35 36 37 **4.3.7.1 Governance and institutional feasibility**

38 SRM governance and incentives differ from governance commonly proposed for climate change mitigation
39 or adaptation (Sandler 2017; Ricke et al. 2013). If risks of negative effects and trade-offs are ignored, SAI
40 and MCB may be relatively cheap compared to carbon emission reduction (Crutzen 2006). This makes
41 unilateral deployment by one or several countries or even non-state actors possible (Lloyd and Oppenheimer
42 2014; Sandler 2017; Rabitz 2016; Weitzman 2015). Governance of field experimentation to help clarify the
43 many uncertainties surrounding SRM is also needed (US National Academy of Sciences 2015; Long and
44 Shepherd 2014; Lawrence and Crutzen 2017; Caldeira and Bala 2017).

45
46 In addition to global SRM, regional radiation management has potential since marine cloud brightening and
47 thinning or dissolution of cirrus clouds could be operated at a local scale (Quaas et al. 2016). From a
48 governance perspective, it is desirable to avoid any substantial climate effects of regional SRM outside the
49 target region (Quaas et al. 2016).

50
51 Preventing unilateral action, so as to avoid international conflict, may be the most difficult SRM governance
52 issue (Sandler 2017). ‘Predatory geoengineering’ may emerge if self-concerned actions to manage climate
53 change through SRM result in harmful consequences to others (Suarez and van Aalst 2017). Any
54 international governance instrument would have to reflect views of different countries, because it is likely
55 that SRM implementation will create winners and losers (Izrael et al. 2014; Heyen et al. 2015; Robock

2016). Different countries view SRM differently (Harnisch et al. 2015; Huttunen et al. 2015) making the formulation of an international governance instrument for SRM difficult to formulate and follow (Sandler 2017).

Several possible institutional arrangements have been mentioned for governance in regards to SRM: through the United Nations, by a single state, or through a consortium of states (Sandler 2017; Bodansky 2013). Agreements through the United Nations can be very time consuming, governance by a single country is rapid, but the interests of the pivotal country are favoured, a third structure – coalition governance – involves a small number of countries that include those capable of SRM and those most affected by such modification (Sandler 2017).

4.3.7.2 Economics and cost

Cost estimates of SRM deployment (not taking into account indirect and social costs) are mostly focussed on stratospheric aerosols injection (SAI), and have varied over the years and between studies. Robock et al. (2009) and The Royal Society (2009) put the costs of injecting 1-5 megatons of sulphur per year into the stratosphere between \$0.225-30 billion depending on the implementation method. McClellan et al. (2012) arrive at a cost range of \$1-8 billion depending on the delivery system. Ryaboshapko and Revokatova (2015) estimate a capital cost of SAI implementation at \$ 3.8 billion and annual cost at \$ 3.2 billion. According to Moriyama et al. (2016), the annual cost of SAI to achieve cooling of 2 W m^{-2} (with injection of 10 Mt H_2S) could reach \$10 billion. Authors also noted that it is important to recognize that costs could increase rapidly as cooling exceeds 2 W m^{-2} .

Only a single cost study exists for marine cloud brightening (Salter et al. 2008). According to this research, MCB need \$32 million for more research and development. Once there is operational experience and MCB technology has matured, it would cost approximately \$38 million annually.

However, the true economic cost of SRM must incorporate not just deployment expenses but also any externalities or a social cost in addition to just engineering costs (Mackerron 2014; Moreno-Cruz and Keith 2013). Recently economists began to delve deeper and discover the various risks, uncertainties, and problems with international politics of implementation (Harding and Moreno-Cruz 2016; Heutel et al. 2016).

Most of the studies examined benefits and costs of SRM by using integrated assessment models (Metcalf and Stock 2015; Heutel et al. 2016; Bickel and Agrawal 2013; Kosugi 2013; Manoussi and Xepapadeas 2015). Depending on the criteria used, SRM could be economically optimal or suboptimal (Sugiyama et al. 2017). Recent studies examined game-theoretic, strategic interactions of states under heterogeneous climatic impacts of SRM (Ricke et al. 2013; Weitzman 2015; Manoussi and Xepapadeas 2015; Moreno-Cruz 2015). Manoussi and Xepapadeas (2015) attribute asymmetries between countries to two main sources: differences in the impacts of climate change and SRM activities across countries, and differences in the prevailing economic conditions. When the asymmetry is in the cost of global warming to each country, the country with the lower costs substantially increases emissions and reduces SRM (Manoussi and Xepapadeas 2015).

A recent paper (Aaheim et al. 2015) addresses the economic impacts of implementing two SRM technologies: SAI and MCB. It was found that economic benefits of SRM under a moderate emission pathway (RCP4.5) can be questioned. In particular, under the set of assumed conditions and processes, the economic impacts of SRM are clearly positive for Sub-Saharan Africa, Latin America and Former Soviet Union, while East Asia would lose out. However, authors concluded that usage of RCP8.5 could change their results significantly (Aaheim et al. 2015).

There is no literature supporting the complete substitution of mitigation by SRM. This suggests that SRM would be used sparingly, which would decrease the potential side-effects, including the termination effect, and could address some of the societal issues (Sugiyama et al. 2017). Some studies indicate for how much forcing or temperature reduction goal they prefer to use SRM; for example Kosugi (2013) for 1 W/m^2 and Keith & MacMartin (2015) for half the temperature rise. A small amount of deployment could make economic sense (Keith and MacMartin 2015) assuming climate change remains gradual, and no run-away, tipping point climate impacts are happening – a risk that Crutzen (2006) warned could happen.

4.3.7.2.1 *Social acceptability and ethics*

SRM research and deployment is connected with variety of ethical issues (Preston 2013), and literature seems polarised (Linnér and Wibeck 2015). The so-called ‘moral hazard’, sometimes described as ‘mitigation obstruction’, asserts that SRM research (preceding SRM implementation) might lead policy-makers to reduce mitigation efforts (Klepper and Rickels 2014; Morrow 2014a; McLaren 2016; Lin 2013).

Klepper and Rickels (2014) indicate that any successful SRM application would significantly reduce the chances of ever reversing the impacts of anthropogenic interventions and reverting Earth back to its natural state. Reynolds (2015) argues that, so far, the consideration of SRM has meant that more mitigation is done, and that SRM may lead to mitigation because of income effects, if uncertainties about the impacts and risks of SRM are addressed. Some of these conclusions are supported by Moreno-Cruz (2015), who in a game-theoretic exercise finds that in asymmetric interests between countries (i.e., reality), the prospect of SRM may lead to inefficiently high levels of mitigation. Chen and Xin (2017) argue that the Paris Agreement means that SRM research must be done and propose guidance for China to engage in SRM (and CDR) research, as well to integrate natural and social sciences in SRM research. Preston (2013) discusses the ambiguity on the moral hazard and calls attention to ‘moral corruption’, basing himself on Gardiner (2010), who contests that considering SRM an alternative to mitigation is ‘culpable self-deception’ and shows ‘just how far we are prepared to go to avoid confronting climate change directly’ (Gardiner 2010 as quoted in Preston (2013)). Other ethical concerns include those of intergenerational equity, the rights of women and those concerned with the rights of non-human species (Burns 2010; Morrow 2014a; Buck et al. 2014).

To address ethical concerns for SRM researchers, frameworks have been proposed, including the Oxford principles (Rayner et al. 2013) and a ‘Draft Code of Conduct’ (Hubert and Reichwein 2015) for researchers in the field of SRM. An investigation into public perception of SRM research indicates that the perception of controllability is key to legitimacy and public acceptability of SRM experiments (Bellamy et al. 2017).

More ethical concerns are connected with maintenance of SRM. Even if SRM would be effective and morally permissible, and all distributive and compensatory issues associated with costs, risks, harms and benefits connected with implementation have been satisfactorily addressed, the normative questions related to maintenance of SRM would remain (Wong 2014). Other researchers argue that while it is technically possible for SRM to reduce unjust harms from climate change, its side-effects and unevenly distributed benefits and costs make it unlikely that any particular SRM policy would be both morally permissible and politically feasible (Morrow and Svoboda 2016). Compensation schemes for SRM could be constructed in order to address injustices, in instances where a party has experienced disproportionate harm (Lambini 2016; Svoboda and Irvine 2014).

A final issue of SRM is connected with concerns about who gets to participate in decisions about SRM. Illustrated by a case of coastal management by a large city that severely harmed a small coastal community, Suarez and van Aalst (2017) worry that voices of vulnerable populations will not be heard, and that insufficient weight is given to affected communities in decision-making around SRM. Whyte (2012) argues that the concerns, sovereignties, and experiences of indigenous peoples must be addressed in SRM governance.

Despite the growing literature on the concerns and considerations around SRM (Lawrence and Crutzen 2017), more research is needed to understand a morally permissible decision on whether, when, where, and how SRM might be done, to construct compensation system of SRM and to be able to take precautions against objectionable mitigation obstruction (McLaren 2016; Svoboda and Irvine 2014; Morrow 2014b).

4.4 Implementing far-reaching and rapid change

4.4.1 *Enabling environments*

1 The far-reaching and rapid change required to remain below 1.5°C and allow societies to cope with the
2 associated climate changes will depend on circumstances that enable and cohere innovations in technology
3 (Creutzig et al. 2015), buildings and infrastructure (most obviously in urban areas) (Rode et al. 2014;
4 Roberts 2016b), finance (Campiglio 2016; Pauw 2017; Diaz-Rainey et al. 2017) and human behaviour (Steg
5 2016; Moloney et al. 2010).

6
7 An enabling environment is the product of these circumstances and describes the institutional context as the
8 ‘rules of the game’ (North 1990) that incentivise and support change. This section describes in some detail
9 the sustainable development (Section 4.4.2), governance (Section 4.4.3), institutional capacity (Section
10 4.4.4), behaviour and lifestyle (Section 4.4.5), innovation (Section 4.4.6), policy instruments (Section 4.4.7)
11 and finance (Section 4.4.8) components that are key to implement the actions needed for the transition to a
12 1.5°C world.

13
14 While enabling environments show considerable variation across regions, sectors and contexts (Creutzig et
15 al. 2015), there are also common features to contexts that are capable of rapid change. Recognising and
16 establishing the preconditions of rapid and far reaching change forms an important part of efforts to limit
17 warming and adapt effectively to a warmer world. Infrastructure, governance, information and finance are
18 clearly important inputs to any innovation process, but the sections below draw on the literature to synthesise
19 across these inputs and identify the dynamic features of an environment that will enable the transition to a
20 1.5°C world.

21 22 23 *4.4.1.1 Dynamic features of enabling environments*

24 Transformative change is seldom an insular or discrete pursuit. Aligning incentives, regulations and
25 relationships at different spatial and temporal scales is critical to accelerated and substantive change (Daron
26 et al. 2015; Ostrom 2009). We briefly discuss accountable governance, policy instrumentation, partnerships,
27 inclusivity and education.

28
29 **Accountable governance** is a prerequisite for policies and programmes that will drive the transition to a
30 1.5°C world. Beyond this prosaic point, it is important that governments and corporations at various scales
31 begin providing the information that will enable them to account for their progress against the 1.5°C
32 threshold (James et al. 2017; Diaz-Rainey et al. 2017).

33
34 **Guiding policies and policy instruments**, of which carbon pricing is currently most discussed, can be
35 applied at various scales, but ultimately requires a global consensus as part of an enabling environment.
36 Pricing instruments are unlikely to succeed on their own (Campiglio et al. 2014), but stronger carbon pricing
37 signals hold the potential to internalise the negative externality of greenhouse gas emissions and contribute
38 to a useful reallocation of resources (Schaeffer et al. 2015a).

39
40 **Partnerships**, characterised by a shared vision and trust, between different spheres of government and
41 between the public and private sector, enable collaboration, shared investment and a sharing of risks during
42 ambitious innovation (Mazzucato and Semieniuk 2017; Geels et al. 2016b). For example, National Urban
43 Policies that bring coherence to the business of nation states, cities and state-owned enterprises create the
44 type of environment in which ambitious change can be undertaken. The example of Manizales below (Box
45 4.4.1.2) illustrates the importance of a national framing of the development-climate interface that empowers
46 local individuals and action. Similarly, Shenzhen’s decarbonisation is enabled by local incentives and the
47 national context. Important in the national context is China’s swing in coal consumption from 3.7% growth
48 in 2013 to 3.7% decline in 2015 (Hsu et al. 2017; BP Global 2016; Zhang 2010). The local context involves
49 a New-type Urbanisation Plan that seeks to resolve difficult connections between ecological progress,
50 urbanisation quality, expanding domestic demand and rural-urban coordination across scales
51 (Cheshmehzangi 2016).

52
53 The Manizales example further suggests that enabling environments function better when they are inclusive.
54 Aligned household, community and city interactions within the global policy regime can enable rapid
55 innovation and change (Ziervogel et al. 2016; Blanchet 2015). Given the tenacity with which poor and

1 vulnerable people hold onto their hard-won livelihoods, the ability to partner and enfranchise these
2 communities in climate programmes is important in establishing the type of enabling environment that is
3 also inclusive. Seen through this lens, informal settlements in the cities of the developing world that are
4 characterised by rapid growth in consumption and population growth become important loci for climate
5 action and the capacity to engage these settlements with governments programmes becomes critical (Freire et
6 al. 2014).

7
8 **Education** does not explain all views on climate change. It does, however, support resilience and increase
9 the efficacy of climate policies (Wamsler 2009). As such, education and female education, in particular,
10 form a key component of an enabling environment for a 1.5°C world. There are strong two-way links
11 between female education and climate risk. These links manifest through decisions on fertility, ability to
12 access information and other resources, and the vulnerability to climate change that arises from multiple
13 deprivation (Wamsler et al. 2012). Better educated communities are more enabled to adapt and take long-
14 term decisions regarding their futures.

15 16 17 *4.4.1.2 Systemic elements of enabling environments*

18 **Public awareness** and support are important in creating pressure for socio-technological change (Blanchet
19 2015). The decoupling of emissions and economic growth in select economies (Newman 2017) is enabled by
20 a growing social concern around climate change that generates incentives for policy and technological
21 change (Geels et al. 2016b). It is, however, the alignment of public awareness, policy driven change,
22 technological efficiencies and economic and finance factors that holds the greatest potential (Peters et al.
23 2017).

24
25 **Systemic approaches** that combine adaptation and mitigation can unlock synergies, avoid side-effects and
26 accelerate change by mainstreaming and integrating climate policy (Locatelli et al. 2015), keeping in mind
27 the differences between mainstreaming and integration (Abeygunawardena et al. 2003) (see Box 4.4).
28 Switching generation sources in the energy sector, for example, can be strengthened by a consideration of the
29 energy-water-food nexus (van Vliet et al. 2016; Rasul and Sharma 2016). Studies highlight the growing
30 importance of geothermal energy sources, both to generate clean energy and as a cleaner source for
31 desalination, especially in areas that are water constrained (Manju and Sagar 2017; Loutatidou and Arafat
32 2015; Chandrasekharam et al. 2015). Policies that recognise and deal with spill-over effects can form an
33 important part of an enabling environment (Cosbey and Tarasofsky 2007; Higham et al. 2016; Åhman et al.
34 2016).

35
36 **Bold political leadership** and a clear vision, as is illustrated by Bhutan (see Box 4.1) can give direction to
37 innovation efforts and accelerate the pace of change through appropriate regulation, the allocation of public
38 money and associated mobilisation of investment (Roberts 2016b). Appropriate and targeted government
39 spending can send a clear signal to investors, particularly when aligned to taxes (Mazzucato and Semieniuk
40 2017). Committing to the removal of perverse subsidies and to ‘sun-rise’ and ‘sun-set’ sectors industrial
41 policies can assist the smooth reallocation of assets (Battiston et al. 2017b; Hallegatte et al. 2013).

42
43 **Harnessing mega-trends** can provide momentum. Enabling environments draw on, rather than resist, the
44 global mega-trends such as ICT, financialisation and urbanisation, so as to harness and direct behaviour
45 change trends. It is, for example, difficult to imagine how a 1.5°C world will be attained unless the SDG on
46 cities and sustainable urbanisation is attained in developing countries, given the scale of the urbanisation
47 trend (Revi 2016), or without major reforms in the global financial system (Pauw 2017).

48
49 **Knowledge partnerships** and science-policy interactions provide the information, skill and technologies
50 required for the challenging and complex transition to a 1.5°C world (Figueres et al. 2017; Roberts 2016b).
51 An enabling environment for a 1.5°C world will not only encourage research that describes pathways to this
52 world, but will align national commitments and economic policies with the science of how to remain within
53 the 1.5°C warming threshold (Rockström et al. 2017).

1 **A durable rights framework** is a necessary, if insufficient, precondition for navigating the difficult trade-
2 offs between interest groups and avoiding perverse outcomes in the context of rapid change (Ziervogel et al.
3 2016) and can enable inclusive and more durable change (Annecke and Swilling 2012).

4
5 **Integrated climate and development planning.** The ability to anticipate and prepare for extreme weather
6 events can greatly enhance a community's ability to cope with climate risks, as can effective disaster relief
7 efforts when these risks manifest. Effective enabling environments will combine weather forecasting and
8 communication with programmes that alleviate the underlying causes of climate vulnerability, such as
9 poverty (Pelling et al.) and inadequate access to employment, food, mobility, energy and housing (Hallegatte
10 and Mach 2016b).

11
12
13
14 **Box 4.1:** Case Study: Bhutan - mutually enforcing economic growth, carbon neutrality and happiness

15
16 Bhutan has three national goals: Gross National Happiness index (GNH), economic growth (GDP) and
17 carbon neutrality (NEC 2015). These goals clearly interact. Whether they can all be maintained into the
18 future depends on the creation of a suitable enabling environment. This case study gives a cursory discussion
19 of how Bhutan integrates and pursues its three goals.

20
21 Bhutan is well known for its GNH, which contains a variety of indicators covering psychological well-being,
22 health, education, cultural and community vitality, living standards, ecological issues and good governance
23 (RGoB 2012; Schroeder and Schroeder 2014; Ura 2015). In many ways the GNH is an expression of the
24 SDG's (Allison 2012; Brooks 2013) and reflects enabling environments as discussed in this section. The
25 GNH has been measured twice, 2010 and 2015, and this showed an increase of 1.8% (Ura et al. 2015). Like
26 most emerging countries, Bhutan wants to increase its wealth to become a middle-income country by 2020
27 (RGoB 2013, 2016) and aims to remain carbon-neutral, which was reiterated in its INDC (NEC 2015).
28 Bhutan achieves its current carbon-neutral status through hydropower and forest cover (Yangka and
29 Diesendorf 2016).

30
31 However, Bhutan faces rising GHG emissions. Transport and industry are the largest growth areas (NEC
32 2011). Modelling [ref] has shown that the carbon-neutral status would be broken by 2037 or 2044 depending
33 on rates of economic growth, if business-as-usual approaches continue. Increases in hydropower are being
34 planned based on climate change scenarios that suggest sufficient water supply will be available (NEC
35 2011). The biggest challenge involves electrifying the transport system. Plans are being developed to
36 electrify both freight and passenger transport (ADB 2013). If this succeeds, Bhutan would be a model for
37 achieving economic growth consistent with limiting climate change to 1.5°C and improving its Gross
38 National Happiness. In this case it will point to the importance of an enabling macro-environment for
39 balancing the difficult trade-offs involved in realising a national contribution to a 1.5°C world.

40
41
42
43 **Box 4.2:** Case study: Manizales, Colombia - Supportive national government and localised planning and
44 integration as an enabling condition for managing climate and development risks

45
46 The case on the city of Manizales, Colombia assists in identifying three important features of an enabling
47 environment: integrating climate change adaptation, mitigation and disaster risk reduction at the city-scale;
48 the importance of decentralised planning and policy formulation within a supportive national policy
49 environment; the role of a multi-sectoral framework in mainstreaming climate action in development
50 activities.

51
52 Manizales is exposed to risks caused by rapid development and expansion in a mountainous terrain exposed
53 to seismic activity and periodic wet and dry spells. Local assessments expect climate change to amplify the
54 risk of disasters. The city is widely recognized for its longstanding urban environmental policy

1 (Biomanizales) and local environmental action plan (Bioplan), and has been integrating environmental
2 planning in its development agenda for nearly two decades (Velasquez and Stella 1998; Hardoy and
3 Velasquez Barrero 2014). When the city's environmental agenda was updated in 2014 to reflect climate
4 change risks, assessments were conducted in a participatory manner at the street and neighbourhood level
5 (Hardoy and Velasquez Barrero 2016).

6
7 The creation of a new Environmental Secretariat assisted in coordination and integration of environmental
8 policies, disaster risk reduction, development and climate change (Leck and Roberts 2015).

9 Planning in Manizales remains mindful of steep gradients through the longstanding Slope Guardian
10 programme that trains women and keeps records of vulnerable households. Planning also looks to include
11 mitigation opportunities and enhance local capacity through participatory engagement (Hardoy and
12 Velasquez Barrero 2016).

13
14 The cities' Mayors emerged as important champions for much of the early integration and innovation efforts.
15 Their role, however, was enabled by Colombia's history of decentralised approach to planning and policy
16 formulation, including establishing environmental observatories (for continuous environmental assessment)
17 and the participatory tracking of environmental indicators. Multi-stakeholder involvement has both enabled
18 and driven progress, and has enabled the integration of climate risks in development planning (Hardoy and
19 Velasquez Barrero 2016).

20 21 22 23 **4.4.2 Implementing SD and the SDGs**

24
25 One of the questions emerging from the Paris Agreement is whether the transition to a 1.5°C world is
26 compatible with the UN commitment to end poverty and meet the 17 Sustainable Development Goals by
27 2030 (United Nations 2016b). Endogenous to this SDG set is one on climate change (SDG13), which
28 provides direct linkage between the Paris Agreement and 2030 Sustainable Development Agenda.

29
30 Another important related goal is SDG7 on universal access to affordable and clean energy, which has a
31 strong convergence with the climate SDG and the transition pathway to a 1.5°C world. In principle, the
32 expansion of renewables, energy efficiency, and fuel switching - all implicit in the achievement of SDG7 -
33 could be made compatible with 1.5°C pathways. This also holds true for the achievement of other SDGs for
34 which energy is an enabler.

35
36 There are however, other implicit challenges. These exist especially around the imperatives of achieving
37 decent work and economic growth (SDG8) with expanding populations; the implicit drive towards
38 industrialisation and infrastructure development (SDG9) without decoupling of energy intensity and
39 decarbonisation; and simultaneous movement towards sustainable production and consumption (SDG12).
40 Additionally, the universal commitment of the SDGs to 'leave no one behind' (United Nations 2016b) could
41 challenge the triggering and feasibility of market-based instruments and innovation in introducing new
42 emission reduction or carbon dioxide removal technologies, as Box 4.3 on bio-ethanol in Brazil illustrates.

43
44 Strengthening the implementation of the Sustainable Development Goals requires governments,
45 communities, and businesses to address synergies, trade-offs, and spill-over effects inherent within the goals
46 (Barbier et al. 2017; Åhman et al. 2016). This not only requires coordinated policy interventions, but needs
47 to address considerations of equity and access. The Addis Ababa slum clean energy provision case (Box 4.4)
48 highlights the complexity of simultaneously meeting multiple goals and delivering sustainable outcomes to
49 poor and vulnerable people.

50
51 The case studies and literature shows that there is no simple answer to the question of what can be done to
52 strengthen implementation of the 1.5°C transition and the SDGs simultaneously. Responses for both 1.5°C
53 and the SDGs need to be locally appropriate. If initiatives emerge from communities, this aspect is generally
54 covered. But neither the 1.5°C challenge nor the world's poverty problems will be resolved by community
55 action alone.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54

Box 4.3: Case Study: Bio ethanol in Brazil

The use of sugarcane as a bioenergy source started in Brazil in the 1970s. Government and multinational car factories modified engines nationwide so that pure ethanol running cars could be produced while making production and distribution systems more efficient to meet the growing demand (de Souza et al. 2014).

After a transition period in which ethanol only and gasoline only cars were used across the whole country, the flex-fuel era started in the 1990s, when all gasoline became E25%, that is, with blend of 25% ethanol. Brazil became the first country in the world where pure gasoline was no further available for transportation. Over the next two decades, around 80% of the light car fleet in Brazil was converted to use flex-fuel (Goldemberg 2011).

Despite the intensive use of sugarcane as a bioenergy crop, no significant effects on food production or forests was observed, although some adverse effects of bioenergy production were reported, related to debts created by forest substitution by croplands (Searchinger et al. 2008). More recently, Searchinger and Heimlich (2015) examined the impact of the competition between bioenergy and food production, and claimed that bioenergy feedstocks potentially undercut efforts to minimize the climate change impact in Brazil. This was not observed by other studies, which show that the energy matrix had become more sustainable, both economically and environmentally (Smeets et al. 2008; Macedo et al. 2008; Buckeridge et al. 2012).

More than 40 years of R&D led to the deployment of ethanol production, transportation and distribution systems across Brazil and integration of climate-compatible policies, leading to a significant decrease in CO₂ emissions (Macedo et al. 2008). Pollution reduction was an important co-benefit, leading to a 30% decrease in the emission of ultrafine particles (Salvo et al. 2017).

Brazil's bioethanol potential is high. Some modelling exercises have indicated the potential to reduce up to 6% of net emissions by 2045 without a reduction in forest area or food production [ref]. Brazil is currently expanding its land-area under bioethanol production, but there is a need to carefully study the potential impacts of bioethanol induced displacement and consequent social movements (McKay et al. 2016). As a new generation of biofuels is being developed, feasibility and LCA studies need to consider 'all aspects of environmental, economic, and social factors, especially the impacts on biodiversity, water resources, human health and toxicity, and food security' (Rathore et al. 2016).

One open question is whether the Brazilian bioethanol experience and its climate mitigation potential could be extended to other sugarcane growing countries. Attempts made over the last decade to take that experience to Africa met with little success (Afionis et al. 2014; Favretto et al. 2017). Nevertheless, lessons learned from these experiences, could perhaps be applied in the future expansion of bioenergy production and use in land-surplus tropical countries.

Box 4.4: Case Study: Slum Regeneration in Addis Ababa: Can Carbon Reduction Work with SDGs?

Addis Ababa, like many developing country cities, has a high level of informal settlements, perhaps up to 80% (Assefa and Newman 2014; EMUJDC 2014). The question facing many such cities is how these informal settlements can be upgraded to achieve a reduction in GHG emissions (SDG 13) while enabling economic and social goals to be achieved as set out in the other SDGs (United Nations 2016b).

Two approaches are in play in Addis Ababa. One is urban renewal based on slum clearance and transfer to high rise dwellings; the other is urban regeneration based on *in situ* upgrading of infrastructure using solar

1 energy and other community-based distributed infrastructure (Satterthwaite 2016; OECD 2011). Data from
2 three existing slums have been compared to two urban renewal high rise complexes in Addis Ababa, where
3 residents were transferred from slums (Teferi).

4
5 Communities in the informal settlements before in situ upgrade are exposed to physical, socio-economic, and
6 health hazards because of poor quality housing, poor environmental sanitation, and inadequate social
7 services. This situation is improved for relocated apartment dwellers, who have better housing and living
8 environments (SDG11), and better sanitation and water supply (SDG6). Yet, they have lost the all-important
9 community cohesion that is a hallmark of informal settlements that provides the social safety net that
10 underpins access to other SDGs, and the end of extreme poverty (SDG1).

11
12 Small-scale distributed infrastructure like roof-top solar PV not only enables access to clean and modern
13 energy (SDG7) but also enables the achievement of climate goals (SDG13) and maintains the strength of
14 informal community life (Teferi). Governance of these informal settlements is currently maintained by *Idir*,
15 a community-led self-help system. The *Idir* are elected by the residents and provide support for people in
16 need through a local fund based on a monthly contribution. Giving *Idir* more responsibility to manage
17 community-based infrastructure through training and job creation can not only improve the quality of life
18 meeting several SDGs, but also facilitate required emission reduction that will contribute to 1.5°C agenda.
19

20
21
22 AR5 outlined the development of climate resilient pathways for sustainable development (IPCC 2014a), in
23 advance of the full definition of the SDGs that emerged a year later. In addition, transitions to a 1.5°C world
24 could involve considerable overshoot, not only of the temperature goal but also of linked precipitation and
25 extreme events (IPCC 2012). This has a direct bearing on two issues: First, is the delivery of core SDGs on
26 extreme poverty reduction (SDG1) and food security (SDG2) as an outcome of either rapid decarbonisation
27 or the impacts of overshoot. Second, is that lack of long-term scenarios outside of IAMs for mid- or late-
28 century sustainable development, that define in a consistent manner the interaction between economic and
29 social development and environmental protection.

30
31 The next case study on bioethanol production for transport in Brazil explores the non-trivial challenge of
32 assessing the long-term feasibility of a proven biofuel-led emission reduction at scale, keeping into
33 consideration its consonance with food security (SDG2), forest protection (SDG15), and health co-benefits
34 due to lower air pollution (SDG3). Chapter 5 and the feasibility screening of both mitigation and adaptation
35 options (see Section 4.5.3) explore these questions in more detail.

36 37 38 **4.4.3 Enhancing multi-level governance**

39
40 Addressing climate change and implementing sound responses for 1.5°C transitions will need to engage with
41 various levels of governance – local, regional, national and supranational – in a mutually reinforcing effort to
42 curb emissions and to increase resilience to the unavoidable impacts of climate change (Betsill and Bulkeley
43 2006; Kern and Alber 2009; Christoforidis et al. 2013). The effectiveness of these outcomes also depends on
44 innovative, effective and strengthened governance structures, that work along with other policy and financial
45 instruments, lifestyle and behaviour change

46
47 AR5 highlighted the significance of governance as a means of strengthening climate change adaptation and
48 mitigation responses and advancing sustainable development (Fleurbaey et al. 2014). Governance was
49 defined in the broadest sense as the, ‘processes of interaction and decision making among actors involved in
50 a common problem. It goes beyond notions of formal government or political authority and integrates other
51 actors, networks, informal institutions, and incentive structures operating at various levels of social
52 organization’ (Fleurbaey et al. 2014, p. 297).

53
54 This section will discuss what dimensions of governance are relevant for 1.5°C transitions from both a
55 mitigation and an adaptation perspective, and how governance at multiple levels can be enhanced to

1 strengthen the implementation of responses to 1.5°C.

2
3 Section 4.4.3.1 will discuss institutions and their capacity for change. Section 4.4.3.2 will discuss recent
4 findings on the roles of different governance levels for staying below, and adapting to, 1.5°C. Section 4.4.3.3
5 will discuss findings on what interactions between actors in governance structures work and what effective
6 approaches to enhancing multi-level governance can be identified.
7

9 *4.4.3.1 Institutions and their capacity to invoke far-reaching and rapid change*

10 Institutions, the rules and norms that guide human interactions (analysed in more detail in Section 4.4.4),
11 play a key role within governance by enabling the structures, mechanisms and measures that guide climate
12 change mitigation and adaptation. Institutions and governance structures are strengthened when the principle
13 of ‘commons’, under which the global climate system falls, are explored as a way of sharing management
14 and responsibilities (Chaffin et al. 2014; Ostrom et al. 1999; Young 2016a).
15

16 Institutions need to be strengthened to interact amongst themselves, and to share responsibilities for the
17 development and implementation of rules, regulations, and policies that will more likely ensure their
18 compliance (Craig et al. 2017; Wejs et al. 2014; Ostrom et al. 1999). The goal for strengthening
19 implementation is to ensure that these policies, rules and regulations embrace poverty alleviation and
20 sustainable development, enabling a 1.5°C world through mitigation and building adaptive capacity (Wood
21 et al. 2017; Reckien et al. 2017). Literature also suggests building a synergy between sustainable
22 development and climate change goals within each institutional mandate and within each policy domain (e.g.
23 clean energy, sustainable transportation and cities, education and health) will be a step forward (Eizenberg
24 and Jabareen 2017; Wood et al. 2016).
25

26 Capacity for change will have to be strengthened across multiple scales: from the individual and household;
27 communities and at the local level; in organisations and business; and at national and global level. Multi-
28 level governance in climate change has emerged as a key enabler for systemic transformation and effective
29 governance, combining decisions at global (i.e. UNFCCC), regional (e.g. EU), national, subnational (e.g.
30 state/region) and local (i.e. cities, municipalities and communities) levels in a productive way, as well as a
31 cross-sectorally and across various types of institutions, at the same level. For example networks of cities
32 like C-40 or ICLEI, that are attempting to accelerate a climate response (Ringel 2017; Hsu et al. 2017; Kemp
33 et al. 2005).
34

35 Several authors have identified different modes of cross-stakeholder interaction in climate policy. Horizontal
36 and vertical interaction across state levels and between public and non-public actors requires considerable
37 policy coordination (Ingold and Fischer 2014; Kern and Alber 2009). Kern and Alber (2009) recognise
38 different forms of collaboration relevant to successful climate policies beyond the local level. Horizontal
39 collaboration (e.g. national and transnational city networks learning from others and sharing best practices)
40 and vertical collaboration within nation-states can play an enabling role with national governments and
41 funding schemes. Hsu et al. (2017) affirm that vertical and horizontal alignment require synergistic
42 relationships between stakeholders.
43
44

45 *4.4.3.2 Multiple levels of governance: from global to local*

46 Strengthening solutions and policy change requires both a bottom-up approach to engaging citizens,
47 businesses, municipalities and local communities and a more traditional top-down approach, enacted by
48 national or supranational governmental institutions. A bottom-up approach provides information and a local
49 perspective on what are viable actions and targets, and can respond to short-term political interest linked to
50 electoral cycles (Maor et al. 2017). A 1.5°C transition needs long-term planning, solutions and instruments
51 such as legislation and international cooperation (Oberthür and Groen 2017), which are often better enacted
52 from the top down. Actions by nation states are discussed in Section 4.4.7 on policy instruments.
53
54

1 4.4.3.2.1 Global governance

2 Governance models or supranational authorities and treaties can help strengthen policy implementation,
3 providing a guide to transition in periods between election cycles to ensure a medium and long-term vision is
4 being considered and followed [ref]. Global governance is organized via many mechanisms, including
5 international treaties and conventions. Climate change is governed by the UNFCCC, through the Kyoto
6 Protocol and the Paris Agreement, with an important contribution on HFCs coming from the Montreal
7 Protocol that operates under the Vienna Convention.

8
9 While binding targets are seen by some as the strongest and most effective form of global climate
10 governance, the failure to negotiate binding targets in the Paris Agreement (Patt 2017) is because a new
11 temperature target does not only need emission reductions. It ideally needs the elimination of all GHG
12 emissions and going beyond the traditional framing of climate as a ‘tragedy of the commons’ to be addressed
13 via cost-optimal allocation rules – which have a low probability of enable a transition to a 1.5°C world.
14 Emerging literature suggests the Paris Agreement will be strengthened under conditions that enable effective
15 monitoring and timely reporting on national contributions, international scrutiny and persistent efforts of
16 civil society to encourage greater and faster action (Allan and Hadden 2017; Bäckstrand and Kuyper 2017;
17 Höhne et al. 2017; Maor et al. 2017). International climate governance also includes multi-actor engagement.
18 Recently, the importance of non-state actors, such as civil society and citizens, business and environmental
19 organisations, has been recognized (Hsu et al. 2017; Hale 2016).

20
21 International climate governance has some profound differences between governance of mitigation and
22 adaptation. Mitigation tends to be global by its nature and it is based on the principle of the climate systems
23 as a global commons (Ostrom et al. 1999). Hence, emissions can be allocated by country and carbon markets
24 can be established with some international intermediation. Adaptation, which has a local or national
25 dimension, often involves local authorities and stakeholders, with a less central role for international actors.
26 For instance, international treaties bridge the short-term vision of emergency response and disaster
27 reconstruction with longer-term sustainable development goals, which is key as short-term disaster
28 reconstruction programs and risk mitigation. Short to medium-term disaster responses can strengthen climate
29 mitigation and adaptation when embedded within longer term sustainable development processes (de Leon
30 and Pittock 2016).

31
32 So far, work on international climate governance at the interface between political science, law, geography,
33 sociology and political economy (Aykut, 2016) focused on the nature of ‘climate regimes’, coordinating the
34 action of nation-states. Most discussions were on whether this coordination should rely on carbon prices,
35 emissions quotas or pledges and review of policies and measures (Pizer 2002; Newell and Pizer 2003; Grubb
36 1990; Stavins 1988). Carbon prices and emission quotas were envisaged via a top-down approach where the
37 decentralised coordination of efforts was operated through market instruments in view of equating marginal
38 costs of global GHG abatement. This was the basic principle behind the Kyoto Protocol (Aldy and Stavins
39 2007).

40
41 Literature about the failure of the Kyoto Protocol (KP) gives two important insights from a 1.5°C
42 perspective. First, the major cause of failure of the KP was the absence of agreed rules to allocate emissions
43 quotas under the Common but Differentiated Responsibility (Shukla 2005; Winkler et al. 2011; Gupta 2014;
44 Méjean et al. 2015). A burden sharing approach led to an adversarial game among nations to decide who
45 shall be allocated ‘how much’ of the remainder of the emissions budget. The second is the impasse of a
46 climate-centric vision of a climate regime (Shukla 2005; Winkler et al. 2011; Shukla 2006; Jayaraman et al.,
47 2011) disconnected from development issues.

48
49 The paradigm shift enabled at Cancun by fixing the objective of ‘equitable access to sustainable
50 development’ (Hourcade et al. 2015) now underpins the Paris Agreement. This consolidates the attempts,
51 after COP15 in Copenhagen to define a governance approach that relies on National Determined
52 Contributions (NDCs) and on means for a ‘facilitative model’ (Bodansky and Diring 2014, p. 6) to
53 reinforce them. Beyond a general consensus on the necessity of Measuring, Reporting and Verification
54 (MRV) mechanisms as a key element of a climate regime, the literature explores different governance
55 approaches to implement the Paris Agreement. For example, convergence toward a uniform carbon price and

1 the progressive integration of different regional mechanisms (Metcalf and Weisbach 2012; Bodansky et al.
2 2014) under the Art 6 of the PA (e.g. Internationally transferred mitigation outcomes (ITMOS) (6.3) and
3 joint credit mechanism (JCM) (Art 6.4 and 6.7), and speeding up climate action as part of ‘climate regime
4 complex’ (Keohane and Victor 2011) of loosely interrelated global governance institutions.
5

6 These two approaches contain useful elements to meet the transition to a 1.5°C world. This objective
7 demands an acceleration of cooperation and action on three key barriers to more ambitious nationally
8 determined policies: evolution of the finance and monetary system; trade organisation to tackle distortions of
9 competitiveness; and intellectual property rights to accelerate access to technology. They expect to expand
10 and revisit the CBDR principle out of a ‘sharing the pie’ paradigm (Ji and Sha 2015) as a tool to open a
11 world innovation process towards alternative development pathways.
12

13 Enabling the 1.5°C transition requires further exploration into conditions of trust and reciprocity amongst
14 nation states (Ostrom and Walker 2005; Schelling 1991). Seminal suggestions are made, for example to
15 depart from the Nash based vision of games with actors acting individually in the pursuit of their self-interest
16 to a Berge based vision of games (Colman et al. 2011; Courtois et al. 2015) where actors can exchange
17 information to avoid the prisoner’s dilemma, where the outcome is the worst for all stakeholders.
18

19 Literature on climate regimes has only started exploring ways of articulating markets, state and non-state
20 actors like the search of coalitions of transnational actors as a substitute to states (Nordhaus 2015; Hermwille
21 et al. 2017; Hovi et al. 2016) or club of countries as complement to the UNFCCC (Abbott and Snidal 2009;
22 Biermann 2010; Bulkeley et al. 2012; Zelli 2011). However, these will not replace deep ‘top-down’
23 evolution in financial institutions and governance (Hourcade et al. 2015), trade organization (Jegou 2015)
24 and intellectual property rights (Zhuang 2017; Abdel-latif 2015) as preconditions for regimes built on trust
25 and reciprocity.
26
27

28 4.4.3.2.2 *Community and local governance*

29 Local governments can play a key role among other actors, influencing climate mitigation and adaptation
30 strategies. It is important to understand how cities, communities and other actors might intervene to reduce
31 climate impact (Bulkeley et al. 2011), either by implementing climate objectives defined at higher
32 government levels or to take initiative autonomously (Aall et al. 2007). Local government are a key to
33 coordination and developing effective local responses and more effective policies around energy and
34 environmental issues (Fudge et al. 2016). Fudge et al. (2016) indicate that policy makers, academics and
35 practitioners recognise that local authorities are well-positioned to involve the wider community in designing
36 and implementing climate policies, engaging with both the technological aspects of energy generation and
37 the delivery of sustainable demand-side energy management strategies. Carney and Shackley (2009) show
38 that in several policy areas excessive centralisation has led to failure and that sustainable policies could be
39 better designed nearer to the intended beneficiaries, hence more focused at the local scale.
40

41 Rutherford and Jaglin (2015) acknowledge that ‘while cities are often seen as the source of many energy
42 issues and problems [...] they may also be part of the ‘solution’, offering potential, wide-ranging
43 opportunities for contributing to shifting energy policies onto more ‘sustainable’ pathways’. Several
44 initiatives have been launched to help cities to implement climate change mitigation and adaptation measures
45 at local level, for example the Covenant of Mayors (Melica et al. 2017; Kona et al. 2017). The Covenant of
46 Mayors serves to test new models of governance, including citizens and stakeholders and other neighbouring
47 cities, and on the vertical dimension regions and countries (see Box 4.5). The need to have local context or
48 place in the governance of global problems is illustrated by MacGillivray (2015).
49
50

51 **Box 4.5:** Multi-level governance in the EU Covenant of Mayors: the example of the Provincia di Foggia

52 The EU Covenant of Mayors (CoM) is an initiative of the European Union in which municipalities
53 voluntarily commit to CO₂ emission reduction via energy efficiency and renewable energy targets. It has
54
55

Do Not Cite, Quote or Distribute

4-50

Total pages: 134

1 allowed the testing of a model of multi-level governance involving Covenant Territorial Coordinators
2 (CTCs), i.e. public authorities such as Provinces and Regions, which commit to providing strategic guidance,
3 financial and technical support to municipalities in their territories willing to deploy climate policies
4 (Covenant of Mayors 2017).

5
6 As a CTC, the Province of Foggia (Italy) enabled 36 municipalities (most of them with a population below
7 10,000 inhabitants) to participate in the CoM and to prepare Sustainable Energy Action Plans (SEAPs). The
8 Province developed a common approach to prepare SEAPs, provided data to compile municipal emission
9 inventories and guided Mayors to identify an appropriate combination of measures to curb GHG emissions,
10 including energy efficiency actions in public buildings, and public lighting. Financial support for the
11 implementation of these actions was found through the European Local Energy Assistance (ELENA)
12 programme (EIB 2015), a joint initiative of the European Investment Bank and the European Commission.
13 ELENA provided the Province with support for preparing an energy baseline study and 1.7 M€ procurement
14 support for the selection of the ESCos. The local Chamber of Commerce had a key role in the
15 implementation of these projects by the municipalities.

16
17 The expected results are (Lombardi et al. 2016):

- 18 • Energy savings in buildings of about 30 GWh yr⁻¹ (almost 55% of the total consumption)
- 19 • Energy savings in public lighting of about 21 GWh yr⁻¹ (60% of total demand)
- 20 • GHG emission reduction of 20,375 tCO₂eq yr⁻¹
- 21 • Investment to be mobilized: 81 M€

22 Besides contributing to the EU Climate and energy targets and the Paris Agreement, this highlights a new
23 form of collaboration among different actors, both governmental and non-governmental, which could
24 potentially be replicated elsewhere. A wider involvement of Chambers of Commerce could help to bring the
25 business community and local and regional governments, closer together to address the challenge of climate
26 change.

27
28
29
30 Researchers have investigated local forms of collaboration within local government, with the active
31 involvement of citizens and stakeholders, and acknowledge that public acceptance is key to the successful
32 implementation of policies (e.g. Lee and Painter 2015; Christoforidis et al. 2013; Musall and Kuik 2011;
33 Pollak et al. 2011; Pasimeni et al. 2014; Larsen and Gunnarsson-Östling 2009).

34
35 Emerging literature since AR5 on governance for a 1.5°C warmer world indicates that achieving this
36 ambition will take leadership, vision and widespread participation in transformative change (Castán Broto
37 and Bulkeley 2013; Wamsler 2017; Fazey et al. 2017). However, authors disagree over the extent to which
38 implementing transformative governance must involve large scale, top-down, fast and far reaching action
39 including reliance on negative emissions (Anderson 2015; Biermann 2014; Busby 2016); incremental yet
40 significant voluntary changes amplified through community networking, poly-centric partnerships and long-
41 term change to governance systems at multiple levels (Termeer et al. 2017; Pichler et al. 2017; Stevenson
42 and Dryzek 2014; Lövbrand et al. 2017); or the allying of “deep and early reductions in energy demand with
43 rapid substitution of fossil fuels by zero-carbon alternatives” and policy initiatives that focus on the highest
44 carbon emitters (Anderson 2015; Knutti et al. 2015).

45 46 47 *4.4.3.3 Interactions and processes for multi-level governance*

48 It is still unclear how multiple actors with varied motivations and agendas will come together to undertake
49 action towards enabling a 1.5°C transition. There is growing evidence on some aspects of climate
50 governance: a study on 29 European countries showed that the rapid adoption and diffusion of adaptation
51 policymaking is largely driven by internal factors, at the national and sub-national levels (Massey et al.
52 2014). However, Jordan and Huitema (2014) highlight that subnational policy makers are often relatively
53 poorly connected to international climate governance agendas, represented on global fora or on in contact

1 with their counterparts in other countries. Kivimaa et al. (2017) conclude that systematic deliberation of
2 combinations of diverse types of experiments, each contributing to slightly different processes, can facilitate
3 the emergence and diffusion of new technologies, test several types of governance innovations, and change
4 existing policies and institutions.

5
6 There is agreement in the literature that national processes to prepare integrated climate and development
7 plans must be leveraged to meet adaptation and mitigation goals. The NDCs have been identified as one such
8 institutional mechanism (Peters et al. 2017; Kato and Ellis 2016; Magnan, A., Ribera, T., Treyer et al. 2015);
9 see also Box 1 on NDCs. In addition, adaptation policy has seen growth: Massey et al. (2014) found that,
10 between 2005 and 2010, the total number recorded adaptation policy measures in the EU grew by 635%.
11 However, current emission reductions pledged in the NDCs are inadequate to remain below the Paris
12 Agreement temperature limits (Höhne et al. 2017). To strengthen responses, national governments must raise
13 their level of ambition and for many developing countries, achieving this will require ‘financial,
14 technological and other forms of support’ to build capacity for effective climate governance (Höhne et al.
15 2017), which has been promised in the Paris Agreement but has not been delivered (e.g., de Coninck and
16 Sagar, 2015).

17
18 To overcome barriers to policy implementation, local conflict of interests (building of roads and parking
19 space that favour the usage of private vehicles) or vested interests (e.g. construction of buildings in area
20 prone to flooding), strong leadership and agency is needed by political leaders. As shown by the Covenant of
21 Mayors initiative (Box 4.5), political leaders with a vision for the future of the local community (e.g., zero
22 emissions by 2050) are more likely to succeed in reducing GHG emissions (Kona et al. 2017; Rivas et al.
23 2015; Croci et al. 2017). This vision needs to be translated into an action plan, describing the policies and
24 measures needed to achieve the target, the human and financial resources needed, key milestones, and
25 appropriate measurement and verification process (Azevedo and Leal 2017). Discussing the plan with
26 stakeholders, including citizens, and having them endorse it is found to increase the likelihood of success
27 (Wamsler 2017; Rivas et al. 2015). Effective plans also describe the financial tools for implementation.
28 However, as described in Nightingale (2017) and Green (2016), struggles over natural resources and
29 adaptation governance both at national and community level need addressing too, ‘in politically unstable
30 contexts, where power and politics shape adaptation outcomes’.

31
32 Multilevel governance for adaptation refers to adaptation activity across administrative levels, consistent
33 with the notion that adapting to climate change involves a range of decisions across local, regional, and
34 national scales (Adger et al. 2005). Different actors have different responsibilities and interdependencies
35 across administrative levels. National governments, for example, have been associated with enhancing
36 adaptive capacity through building awareness of climate impacts, encouraging economic growth,
37 establishing legislative frameworks conducive to adaptation, and communicating climate change information
38 (Austin et al. 2015). Local governments, on the other hand, are responsible for delivering basic services and
39 utilities to the urban population, and protecting their integrity from the impacts of extreme weather (Adger et
40 al. 2005; Austin et al. 2015).

41
42 Hoppe and Wesselink (2014) propose that multilevel governance can manifest as two different arrangements.
43 One arrangement disperses authority across general-purpose and non-intersecting jurisdictions, where
44 jurisdictional units are arranged around territorial communities and are separated from each other. The
45 second assigns distinct functions to different jurisdictions, so that each level of government deals with a
46 specific policy problem, but with overlapping territorial coverage.

47
48 A multilevel approach considers that adaptation planning is affected by scale mismatches between the local
49 manifestation of climate impacts and the diverse scales at which the problem is (Shi et al. 2016). Multilevel
50 approaches are particularly relevant in low-income countries where limited financial and human resources
51 within local governments, often lead to greater dependency on national governments and other (donor)
52 organizations to strengthen adaptation responses. A multilevel approach seeks to determine how different
53 levels of government contribute to or obstruct the process of adaptation planning. National governments or
54 international organizations, for example, may motivate urban adaptation externally through broad policy
55 directives or projects by international donors taking place in a city. Municipal governments on the other hand

1 work within the city to spur progress on adaptation. Individual political leadership in municipal government,
2 for example, has been cited as a municipal-level factor driving adaptation policy of early adapters in Quito,
3 Ecuador, and Durban, South Africa (Anguelovski et al. 2014), and for adaptation more generally (Smith et
4 al. 2009).

5
6
7
8 **Box 4.6:** Watershed management in response to drought and El Niño Southern Oscillation (ENSO) in
9 Southern Guatemala.

10 Central America has suffered from the impacts of hydrometeorological events (Chang et al. 2015; Maggioni
11 et al. 2016), especially of the El Niño Southern Oscillation (Steinhoff et al. 2014). The 2014-2016 ENSO
12 was especially devastating for agriculture and rural communities in Southern Guatemala. The country has
13 experienced a drop in productivity of staple crops, including sugar cane, banana, and palm (Vargas et al.
14 2017; Sain et al. 2017) and loss of cattle (Shannon and Motha 2015) due to drought. A lack of proper water
15 infrastructure (Vásquez and Aksan 2015; Mekonnen et al. 2015) and water policies and regulations (Vásquez
16 and Aksan 2015; Vásquez and Espaillat 2014; Mekonnen et al. 2015) have created some conflicts amongst
17 watershed users (Hileman et al. 2015). Conflicts over water use have been predominant, especially due to
18 mining and hydroelectrical projects (Aguilar-Støen and Hirsch 2015; Haslam and Ary Tanimoune 2016) and
19 competing agricultural uses (Mingorría 2017).

20
21
22 In February 2016, the Climate Change Institute (ICC, for its acronym in Spanish), together with the
23 government, private and public sectors, communities and human rights organizations, created technical
24 dialogue tables in different watersheds to mitigate the effects of the drought and the social tension it had
25 created. These tables were created by the users of the Achiguate, Madre Vieja, and Ocosito watersheds and
26 led by the respective State Governors. Identification of all water users and the measurements of river levels
27 to ensure availability of the ecological flow, were focal concerns. The goal of these dialogues was to enable
28 better management of water resources, through improved communications, transparency, and coordination
29 amongst users, was met this year when all previously affected rivers didn't run dry and reached the Pacific
30 Ocean with at least their minimum ecological flow (Guerra 2017). This initiative is planned to be expanded
31 to other watersheds at risk.

32
33
34
35 **4.4.4 Enhancing institutional capacities**

36 The implementation of sound responses and strategies for a 1.5°C world will require strengthening
37 governance and scaling up institutional capacities particularly in developing countries (Rosenbloom 2017).
38 This section examines what is required in terms of changes in institutional capacity to implement actions to
39 make the transition to a 1.5°C world, and adapt to its consequences. This takes into account a plurality of
40 responses based on the jurisdiction, as institutional capacity is highly context-dependent (North 1990;
41 Lustick et al. 2011).

42
43
44 Institutions need to interact with one another and align across scales to ensure that rules and regulations are
45 followed (Chaffin and Gunderson 2016; Young 2016b). The institutional architecture required for a 1.5°C
46 world must try to include the growing proportion of the world's population that live in peri-urban and
47 informal settlements and engage informal economic activity (Simone and Pieterse). This population,
48 amongst the most exposed to perturbed climates in the world (Hallegatte et al. 2017), is also beyond the
49 direct reach of some policy instruments (Jaglin 2014; Thieme 2017). Strategies that accommodate the
50 informal rules of the game adopted by these people are more likely to succeed (McGranahan et al. 2016;
51 Kaika 2017).

52
53 The goal for strengthening implementation is to ensure that these rules and regulations embrace equity,
54 equality, poverty alleviation along a pathway that leads to a 1.5°C world (mitigation) and enables the

1 building of adaptive capacity (adaptation) and sustainable development.

2
3 Rising to the challenge of a transition to a 1.5°C world requires enhancing institutional climate change
4 capacities along multiple dimensions presented below.

7 *4.4.4.1 Capacity for policy design and implementation*

8 The enhancement of institutional capacity for integrated policy design and implementation has long been
9 among the top of the UN agenda to addressing global environmental problems and sustainable development
10 (UNEP 2005).

11
12 Access to a knowledge base, the availability of resources, political stability, and a regulatory and
13 enforcement framework (e.g. institutions to impose sanctions, collect taxes and to verify building codes) are
14 needed at various governance levels to address a wide range of stakeholders, and their concerns. There is a
15 need to support these with different interventions (Pasquini et al. 2015).

16
17 Given the amount of change required to achieve 1.5°C, it is critical that strengthening the response capacity
18 of relevant institutions be addressed in ways that take advantage of existing decision-making processes at
19 lower governmental levels and within cities (Romero-Lankao et al. 2013). Examples of successful
20 institutional networking at the local level and the integration of local knowledge in climate change related
21 decisions making is provided in Box 4.5 and 4.6.

22
23 Additionally, implementing 1.5°C-relevant strategies would require well-functioning legal frameworks to be
24 in place in conjunction with clearly defined mandates, rights and responsibilities to enable the institutional
25 capacity to deliver (Romero-Lankao et al. 2013). As an example, current rates of urbanization occurring in
26 cities with a lack of institutional capacity for proper land use planning, zoning and infrastructure
27 development, result in unplanned, informal urban settlements which are vulnerable to climate impacts. It is
28 common for 30-50% of urban populations in low-income nations to live in informal settlements with no
29 regulatory infrastructure (Revi et al. 2014). In Huambo, Angola, a classified ‘urban’ area extends 20 Km
30 west of the city and is predominantly ‘unplanned’ urban settlements (Smith and Jenkins 2015).

31
32 Internationally, the Paris Agreement process enhanced the capacity of decision making institutions in many
33 developing countries to support the effective implementation. These efforts are particularly reflected in
34 Article 11 of the Paris Agreement on capacity building, as well as Article 15 on compliance.

37 *4.4.4.2 Monitoring, reporting, and review institutions*

38 The availability of independent private and public reporting and statistical institutions is integral to
39 oversight, effective monitoring, reporting and review. One of the central and novel features of the new
40 climate governance architecture emerging from the 2015 Paris Agreement is the transparency framework
41 committing countries to provide regular progress reports on national pledges to address climate change (Paris
42 Agreement, Article 13). Many countries will rely on public policies and existing national reporting channels
43 to deliver on their NDCs under the Paris agreement. Scaling up the efforts to be consistent with 1.5°C would
44 put significant pressure on the need to enhance and streamline local, national and international GHGs
45 reporting and monitoring methodologies and institutions (Schoenefeld et al. 2016). Consistent with this
46 direction the Paris Agreement has invented two mechanisms: progression and the global stock, to scale up
47 international efforts (Paris Agreement, Article 14).

50 *4.4.4.3 Financial institutions*

51 IPCC AR5 assessed that to get the world on a 2°C pathway, both the volume and patterns of climate
52 investments need to be transformed. The report argued that annually up to a trillion dollars in additional
53 investment in low-carbon energy and energy efficiency measures may be required through to 2050 (Blanco
54 et al. 2014). Financing of 1.5°C would present even a greater challenge and would require significant
55 transitions to the type and structure of financial institutions as well as to the method of financing (Ma 2014).

1 Both the public and private financial institutions would be needed to mobilize resources for 1.5°C. Yet, in
2 the ordinary course of business private finance is not expected to be sufficiently forthcoming, given the risks
3 associated with commercialization and scaling up of renewable technologies (Hartley and Medlock 2013).
4 Private financial institutions such as carbon markets could face risks of carbon price volatility and supportive
5 political will. In contrast, traditional public financial institutions are limited by both structure and
6 instruments and concessional financing requires taxpayers subsidization Hoch (2017) suggest the creation of
7 special institutions that underwrite the value of emission reductions using auctioned price floors.
8

9 Financial institutions are equally important for adaptation. Linnerooth-Bayer and Hochrainer-Stigler (2015)
10 discuss the benefits of financial instruments in adaptation, including the provision of post-disaster finances
11 for recovery and pre-disaster security necessary for climate adaptation and poverty reduction. These benefits
12 often come at a cost. Pre-disaster financial instruments and options include insurance including index-based
13 weather insurance schemes; catastrophe bonds; and laws to encourage insurance purchasing. At the local
14 level, the development and enhancement of microfinance institutions have been useful to ensure social
15 resilience and smooth transitions in the adaptation to climate change impacts (Hammill et al. 2008).
16

17 In addition to the private and public financial institutions, there are the global multilateral financial
18 institutions such as the World Bank, the IMF, IFC, and regional development banks that are currently
19 leading the mobilization of green finance and which need to assume an even greater role during the low-
20 carbon transition. Further, there are the specialized multi-lateral financial intuitions such as the Green
21 Climate Fund and the Global Environmental Fund whose functions and level of operations need upscaling to
22 address the 1.5°C challenge.
23

24 25 *4.4.4.4 Co-operative institutions and social safety nets*

26 Effective Co-operative institutions and social safety nets may be useful to address distributional impacts
27 during the transition to low-GHG emissions societies and enabling sustainable development. Social capital
28 (in the form of bonding, bridging, and linking social institutions) has proved to be very effective in dealing
29 with climate crises at the local, regional, and national levels (Aldrich et al. 2016).
30

31 Transitioning economies towards sustainable energy models could impact the livelihoods of large
32 populations. The transition of select EU economies to biofuels, caused anxiety among farmers, who lacked
33 confidence in the biofuel crop market. Contracts between farmers and energy companies, involving local
34 governments were enabled, to create an atmosphere of confidence during the transition (McCormick and
35 Kåberger 2007).
36

37 How do broader socio-economic processes influence urban vulnerabilities and thereby underpin climate
38 change adaptation? This is a systemic issue originating from the lack of collective societal ownership of the
39 responsibility for climate risk management. Literature exploring this issue provides numerous explanations,
40 from competing time-horizons due to self-interest of stakeholders (Moffatt 2014) to a more ‘rational
41 conception of risk assessment, where risk is noted on a spectrum of tolerability for the party involved.
42

43 Compared to traditional social forms where energy technology and resource systems are either owned and
44 administered individually in market settings or via a central authority (e.g. the state), self-governing and self-
45 organized institutional settings where equipment and resource systems are owned and managed in common
46 by people can potentially generate a much higher diversity of administration solutions. They can also
47 increase the adaptability of technological systems, while reducing their burden on the environment (Labanca
48 2017). Educational, learning and awareness-building institutions help strengthen the societal response to
49 climate change (Thi Hong Phuong et al. 2017; Butler et al. 2016).
50

51 The strengthening of institutional capacity to accelerate the transition to 1.5°C requires special attention to
52 capacity building efforts, especially in developing countries. Article 11 in the Paris Agreement has made a
53 positive step in this direction through its emphasis on capacity building.
54
55

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53

Box 4.7: Institutions for integrated policy design and implementation

The presence of multinational networks and scientific groups help guide local governments in climate policy creation and provide access to knowledge in the urban context. In Mexico, the World Mayors Council on Climate Change helped develop the Mexico City Climate Action Plan for 2008-2012. Climate Adaptation Santiago played integral role in launching 'Climate Adaptation Plan for the Metropolitan Region of Santiago 2012' (Romero-Lankao et al. 2013). In Huambo, Angola, collaboration between Centre for Environment & Human Settlements, Development Workshop, and the City Administration of Huambo in an urban planning project supplemented the weak institutional capacity of the local government in such projects (Smith and Jenkins 2015).

Box 4.8: Case: Indigenous Knowledge

For centuries, indigenous communities have observed the behaviour of flora, fauna, and climate phenomena on their crops and their communities (Mistry and Berardi 2016; Green and Raygorodetsky 2010). This indigenous knowledge can now contribute towards climate research (Reyes-Garcia et al. 2016) and adaptation strategies (Altieri et al. 2015).

Mayan indigenous traditional knowledge has been transferred from one generation to the next, since ancestral times. The changing climate is a growing concern amongst indigenous populations, who depend on their climate knowledge for a livelihood. In Guatemala, the Mayan K'iché population of the Nahuatlac river basin and the Climate Change Institute (ICC, in Spanish) have systematized traditional and ancestral knowledge and identified indicators used for watershed meteorological forecasts (Yax 2016). These indicators need to be scientifically validated to determine if they are still viable, in an effort to link this indigenous knowledge to current science (Nyong et al. 2007; Alexander et al. 2011; Mistry and Berardi 2016).

For more than ten years, Guatemala has had an Indigenous Table for Climate Change that ensures indigenous concerns are taken into consideration in national policies and, more importantly, that indigenous knowledge play a role in the different disaster management and adaptation policies that take place, as it constitutes a part of their livelihood.

The Arctic is experiencing some of the earliest and most rapid impacts of climate change (Ford et al. 2012; Hinzman et al. 2005; Kirtman et al. 2013), exacerbating pre-existing high health burdens in the region (Ford et al. 2014b). However, Indigenous communities in the Arctic have historically adapted to environmental change, and traditional knowledge systems are recognized as being key to resilience in the region (Arctic Council 2013a; Ford et al. 2015). They have shifted the timing of harvesting activities, and, more recently, adapted and diversified economic systems (Einarsson 2014a; Wenzel 2009). In the present, community and regional capacities are driving adaptation initiatives across the Arctic, with the potential to reduce vulnerability (Arctic Council 2013b). Adaptation initiatives are increasingly observed at local to national scales in the Arctic, with communities responding and reducing current damages and future risks, and capitalizing on new opportunities presented by climate change (Ford et al. 2014a; Labbe et al. 2016; Arctic Council 2013b). Arctic communities have used traditional knowledge to conduct community-based monitoring initiatives and risk assessments centred on the needs and interests of communities (Rosales and Chapman 2015; Johnson et al. 2015; Alessa et al. 2015), and several recent initiatives have combined indigenous knowledge with technology to record and assess the safety of sea ice for hunters and community members (Bell et al. 2015; Eicken et al. 2014).

4.4.5 *Enabling lifestyle & behavioural change*

Substantial changes in behaviours and lifestyles are needed to stay below 1.5°C. Climate change mitigation and adaptation efforts will be more effective when they address key factors influencing climate-related actions, and consider behavioural anomalies that affect how decisions that affect climate change are made. A wide range of policy approaches can be employed to encourage and facilitate climate-related actions. We refer to climate-related action when factors and policies affect both climate change mitigation and adaptation actions; otherwise we refer to mitigation and adaptation actions specifically.

4.4.5.1 *Factors related to climate change actions*

Individual preferences, choices and behaviour have major implications for anthropogenic climate change and for the effectiveness of mitigation and adaptation strategies (Dietz et al. 2013; Hackmann et al. 2014b; ISSC and UNESCO 2013; Sovacool 2014; Weaver et al. 2014; Vlek and Steg 2007). The likelihood that individuals act on climate change depends on many contextual factors that define their opportunities to engage, influencing motivations and cost and benefits of their actions. These include economic, spatial, institutional, social and cultural factors, and available infrastructure and technology, discussed earlier in this chapter. These factors can both pose serious barriers to action on climate change, or encourage and facilitate them.

Mitigation and adaptation strategies that aim to realise economic, physical or technological change involve behaviour changes. It is important to understand under which conditions these strategies are most likely to realise their potential and what social and psychological factors enhance their effects. Further, individuals need to accept these proposed policies and changes, and use new technologies and infrastructure in the intended way. Hence, it is important to understand which individual and social factors promote action on climate change and the acceptability of climate change policy.

Behaviour is affected by a wide range of factors that shape which behavioural options are feasible and considered by individuals. These include abilities and the motivation to engage in relevant mitigation and adaptation behaviour (Steg et al. 2015a), and behavioural anomalies incentives (Shogren & Taylor 2008).

Abilities depend on, among others, income and knowledge. A higher income is related to higher CO₂ emissions; higher income groups can afford more energy intensive lifestyles (Lamb et al. 2014; Vringer and Blok 1995; Wang et al. 2015; Dietz et al. 2015; Abrahamse and Steg 2009) (Gatersleben, Steg & Vlek 2002). At the same time, low-income groups may lack the financial resources to invest in energy efficient technology, refurbishments (Andrews-Speed and Ma 2016) and climate change adaptation options (Takahashi et al. 2016; Fleming et al. 2015).

Lack of knowledge can inhibit engagement in actions on climate change, even when people would be motivated to do so. Knowledge of the causes and consequences of climate change and ways to reduce greenhouse gas emissions is not always accurate (Bord et al. 2000; Whitmarsh et al. 2011; Tobler et al. 2012). For example, people overestimate savings for low-energy activities, while they underestimate savings for high-energy activities. Besides, people know little about the energy use ‘embedded’ in products and services (Tobler et al. 2011), such as the mitigation potential of limiting meat consumption (de Boer et al. 2016). They also hold misperceptions of the environmental impact of energy sources. For example, some individuals think natural gas is a renewable energy source or think bioenergy is a fossil fuel as it involves burning materials (Butler et al. 2013; Devine-Wright 2003). Similarly, some people conflate risks posed by climate change impacts with different hazards, which may be a barrier to adequate adaptation (Taylor et al. 2014). People may also hold misperceptions of the pros and cons of behaviour options, which may inhibit climate change actions. For example, people tend to overestimate the disadvantages of public transport. Yet, perceptions can become more accurate when people are triggered to try out public transport, which can motivate them to continue using public transport rather than driving a car (Fujii et al. 2001; Fujii and Kitamura 2003).

1
2
3 While knowledge is important, it is seldom sufficient to motivate action (Trenberth et al. 2016). Indeed,
4 climate change knowledge and perceptions are not strongly related to climate change mitigation actions
5 (Hornsey et al. 2016). Similarly, while providing information on climate change and possible mitigation and
6 adaptation actions generally does increase knowledge and awareness, their effects on climate change actions
7 are typically weak (Ünal et al., *submitted*; Abrahamse et al. 2005). Direct experiences of events related to
8 climate change influence climate concerns and actions more than second-hand information (Demski et al
9 2017; Myers et al. 2012; Spence et al. 2011). Individuals with particular political views and those who
10 emphasise individual autonomy are likely to reject climate science knowledge and believe that there is
11 widespread scientific disagreement about climate change (Kahan et al. 2010; O'Neill et al 2013), which
12 inhibits support for climate change policy (Ding et al. 2011; McCright et al. 2013). Economic recession can
13 also reduce climate change concerns (Scrugg and Benegal 2012).

14
15 Climate change mitigation and adaptation actions are more strongly related to motivational factors such as
16 values, ideology and worldviews than to knowledge (Hornsey et al. 2016). People particularly consider
17 consequences that have implications for their key values (Dietz 2013; Steg 2016). This implies that different
18 individuals consider different types of consequences when making choices. For example, endorsement of a
19 market-friendly perspective is associated with weaker climate change beliefs (Hornsey et al. 2016), and
20 capital-oriented culture tends to promote economic expansion and activity associated with GHG emissions
21 (Kasser et al. 2007). People who strongly value protecting nature, the environment and other people are more
22 likely to act on climate change than those who strongly endorse hedonic and egoistic values (Dietz et al.
23 2005; Steg, 2016; Taylor et al. 2014). Furthermore, people are more likely to adopt sustainable innovations
24 when they are more open to new experiences and ideas (Jansson 2011; Wolske et al. 2017).

25
26 Individuals are more likely to act on climate change when such actions have more individual benefits relative
27 to individual costs (Steg and Vlek 2009; Bamberg and Möser 2007; Wolske et al 2017), including prices,
28 time, convenience, and safety. Yet, many other costs and benefits play a role that are often more predictive
29 of actions than financial costs and convenience. These include social costs and benefits (Farrow et al. 2017).
30 People are more likely to act on climate change when they think others expect them to do so and when others
31 act as well (Bamberg and Möser 2017; Dang et al. 2014; Nolan et al. 2008; Rai et al. 2016; Truelove et al.
32 2015), when they experience social support (Burnham and Ma 2017; Wolske et al. 2017; Singh et al., 2016)
33 and when they discuss about effective actions with their peers (Esham and Garforth 2013), particularly when
34 they strongly identify with the relevant groups (Biddeau et al 2016; Fielding & Hornsey 2016).

35
36 Actions on climate change are more likely when individuals think doing so would enhance their reputation
37 and social status, and signals something positive about them to others and self (Kastner and Stern 2015)
38 (Griskevicius et al. 2010; Milinski et al. 2006; Noppers et al. 2014; Schuitema et al 2013). Furthermore,
39 individuals are more likely to act upon climate change when they worry about climate change (Verplanken &
40 Roy 2013), while positive affect associated with a climate related threat may inhibit protection behaviour
41 (Lefevre et al., 2015). People are more likely to act on climate change when they expect to derive positive
42 feelings from such actions (Taufik et al. 2016; Pelletier et al. 1998), either because engagement is
43 pleasurable or because they feel meaningful when engaging in actions that benefits others and the
44 environment (Venhoeven et al. 2013, 2016; Taufik et al. 2015).

45
46 Besides individual consequences, collective consequences affect climate change actions (Dóci and
47 Vasileiadou 2015; Bamberg and Möser 2007; Kastner and Stern 2015; Balcombe et al. 2013). Individuals are
48 motivated to see themselves as morally right and to do the right thing, such as protecting the environment,
49 which encourages actions on climate change (Steg et al., 2015), particularly when long-term goals and
50 motives are salient (Zaval et al. 2015). The more individuals are aware of environmental problems caused by
51 their behaviour, the more they think they can reduce these problems by acting responsibly, which
52 strengthens their feelings of moral obligation to act accordingly and promotes actions on climate change (De
53 Groot and Steg 2009; Jakovcevic and Steg 2013; Steg and De Groot 2010; Stern 2000; Stern et al 1999;
54 Wolske et al. 2017). Individuals are less likely engage in climate change actions when they believe others are
55 responsible for climate change problems (Fielding and Head 2012). Climate change mitigation actions are

1 more likely among those who see themselves as supportive of the environment (i.e. strong environmental
2 self-identity; Barbarosa et al. 2017; Fielding, McDonald & Louis, 2008; Gatersleben et al. 2014; Kashima et
3 al. 2014; Van der Werff et al. 2013, 2014). Environmental self-identity is strengthened when people realise
4 they engaged in climate mitigation actions, which may in turn promote further actions on climate change
5 (Van der Werff et al. 2014).

6
7 Individuals are more likely to engage in climate adaptation and mitigation behaviour when they believe
8 climate change is happening and perceive climate change and variability, when they are aware of threats
9 caused by climate change and the problems caused by their inaction, and when they feel capable to engage in
10 actions that will reduce the relevant threats (Esham and Garforth 2013; Arunrat et al. 2017; Chatrchyan et al.
11 2017).

12
13 Personal experience with climate change hazards strengthens motivation to protect oneself (Jabeen 2014),
14 although this does not always translate into proactive adaptation (Taylor et al. 2014). Adaptive capacity
15 depends on contextual factors and individual abilities, including income, knowledge and technical capacities
16 (Eakin et al. 2016; Feola et al. 2015; Singh et al. 2016), and on gender roles (Jabeen 2014). Individuals are
17 less likely to engage in climate adaptation behaviour when they rely on protection measures undertaken by
18 the government (Burnham and Ma 2017; Armah et al. 2015; Grothmann and Reusswig, 2006) and when they
19 believe ‘God’ will protect them from any harm (Dang et al. 2014; Mortreux and Barnett, 2009). Moreover,
20 individuals with a strong attachment to their community may be unwilling to migrate to protect themselves
21 from climate change risks as they are reluctant to leave behind their social and emotional support groups
22 (Adger et al. 2013).

23 24 25 4.4.5.2 *Behavioural anomalies*

26 Decisions are not always based on weighing costs and benefits, but are also based on feelings (Taufik et al.
27 2016; Finucane et al 2000), habit (Aarts and Dijksterhuis 2000; Klöckner et al. 2003), and behavioural
28 anomalies. Behavioural anomalies imply individuals do not have well-defined preferences, do not use all
29 available information, and do not maximize utility with perfect foresight and impeccable optimization skills
30 under budget constraints. Behavioural anomalies challenge theory on rational choice and on how individuals
31 respond to incentives (Shogren and Taylor 2008).

32
33 Behavioural anomalies can lead to systematic difference between decision utility (i.e. expected or intended
34 utility at the time of choice) and experienced utility (i.e. utility experienced after the choice) (Kahneman &
35 Thaler 2006). Behavioural anomalies that result in sub-optimal choices in climate change mitigation and
36 energy use include the endowment effect, loss aversion, reference-dependency, status quo bias, heuristics,
37 limited attention, framing effects, procrastination and satisficing (Frederiks et al. 2015; Gillingham & Palmer
38 2014; Gowdy 2008; Lopes et al. 2012; Steg et al. 2015; Tietenberg 2009). Behavioural anomalies in the
39 context of adaptation are heuristics, such as the availability heuristic that imply that risk perceptions are
40 influenced by recent or recurrent events that are more cognitively available (Preston et al. 2013; Clayton et
41 al. 2015). Besides, biases such as status quo bias, omission bias and action bias play a role. For example,
42 farmers in Mozambique were unwilling to take an action with potentially negative consequences, in order to
43 avoid personal responsibility for the losses (an omission bias), while policymakers displayed action biases,
44 wanting to demonstrate positive action even though it might lead to negative consequences (Patt and
45 Schröter 2008). Another example is around mismatches between perceived and actual risks: For example,
46 farmer adaptation decisions in India were shaped by collectively constructed notions of risk, experiences of
47 past events, and expectations of future variability which often differed from measured shifts in climatic
48 variables, leading to a mismatch between risk and response behaviour (Singh et al. 2016). A brief review of
49 these behavioural anomalies is presented below.

50
51 Loss aversion is the tendency to place greater value on relative losses and disadvantages than on gains or
52 advantages (Kahneman 2003). Perceived gains and losses depend on a *status quo* or reference point
53 (Kahneman et al. 1991; Kahneman 2003). Indeed, energy-related information or recommendations are more
54 effective to promote energy conservation, load shifting in electricity use and sustainable travel choices when
55 framed in terms of losses rather than gains (e.g. via performance contracts, dynamic pricing, energy audits)

1 (Bradley et al. 2016; Gonzales et al. 1988; Wolak 2011). Loss aversion prevents consumers to switch to
2 time-of-use electricity tariffs (Nicolson et al. 2017). Combined with uncertainty, loss aversion also leads
3 consumers to over-discount the value of future energy savings (Greene 2011). Training energy auditors in
4 loss-aversion to recommend efficiency improvements was effective in motivating households to invest in
5 retrofits (Gonzales et al. 1988).

6
7 The endowment effect (Thaler 1980) refers to individuals attaching greater value to goods they already own
8 and that the (selling) value is much higher than the buying price. Owned inefficient appliances and fossil
9 fuel-based electricity are likely to act as instant endowments, which increases the value of a default option
10 compared with alternative options (Dinner et al. 2011; Pichert and Katsikopoulos 2008).

11
12 Loss aversion also drives individuals to stick to the *status-quo*, as new options are perceived to have more
13 drawbacks than benefits (Samuelson and Zeckhauser 1988). The *status quo* affects households decisions to
14 switch to a new electricity supplier (Ek and Söderholm 2008) and to accept changes in energy systems
15 (Leyten et al. 2014). Field experiments show that consumer inertia towards energy conservation activities or
16 renewable energy can be reduced if participation is set as default ‘opt-out’ option, rather than as ‘opt-in’
17 (Ebeling and Lotz 2015; Ölander and Thøgersen 2014; Pichert and Katsikopoulos 2008).

18
19 Procrastination leads to delayed decisions, failure to act or acceptance of the *status quo* (Anderson 2003).
20 Individuals with a higher tendency to procrastinate are less likely to participate in energy saving activities
21 (Lillemo 2014). Uncertainties about the performance of products and illiquidity of investments can also drive
22 consumers to postpone energy efficient investments, even when this would be profitable (Van Soest and
23 Bulte 2001; Sutherland 1991).

24
25 People are ‘rationally bounded’ in problem solving capacities (Simon 1955, 1979). This results in satisficing
26 outcomes (‘good enough’, a mix of ‘satisfying’ and ‘sufficing’ as opposed to ‘maximising’; (Gigerenzer and
27 Goldstein 1996), rather than finding the ‘best’ or ‘optimal’ solution (Simon 1979). Satisficing often takes
28 over utility maximisation in energy related decisions of individuals and firms (Klotz 2011; Wilson and
29 Dowlatabadi 2007), which can prevent them from investing in energy efficient measures (Decanio 1993;
30 Frederiks et al. 2015). Energy consumers appeal to intuition as balancing all costs and benefits of energy-
31 using products is challenging (Allcott 2013; Frederiks et al. 2015). Heuristics (or ‘rules of thumb’) are
32 simplified intuitive decision-making rules that often lead to immediate but suboptimal choices and inaccurate
33 perceptions. For example, people tend to think that larger and visible appliances use more energy, which is
34 not always accurate (Steg et al. 2015). They also underestimate the amount of energy used for water heating
35 and overestimate the energy used for lighting (Stern 2014). Relying on heuristics demands less cognitive
36 efforts, knowledge and time. When facing choice overload, heuristics can make people focus on the most
37 important information and drive individuals to choose the easiest or first available option, which can inhibit
38 energy saving behaviour (Frederiks et al. 2015; Stern and Gardner 1981) and drive energy consumers to
39 systematically undervalue the savings from energy efficient technologies (Kolstad et al. 2014). Consumers
40 are also careless about additional delivery costs if they are added to the end of transaction (Hossain and
41 Morgan 2006).

44 4.4.5.3 Strategies to promote actions on climate change

45 To encourage wide-scale changes in behaviour and lifestyles, policy and changes need to be implemented
46 that empower and enable people to engage in climate change mitigation and adaptation actions. More rapid
47 and far-reaching implementation efforts are needed to scale-up mitigation and adaptation responses.

48
49 In both rural and urban areas, adaptation efforts tend to focus on infrastructural and technological solutions
50 with relatively lower emphasis on socio-cognitive and finance aspects involved in adaptation action (Boyd
51 2017; Mortreux and Barnett 2017). For example, flooding policies in cities currently focus on infrastructure
52 projects and amendments to regulation such as the building code, but do not target the behaviour of
53 households or individuals (Georgeson et al. 2016; Araos et al. 2016a).

54
55 Policies can influence mitigation and adaptation behaviour through different instruments: informational or

1 awareness campaigns that rely on voluntary compliance; using the government's authority to command
2 behaviour; using public funds to (disc)incentivise behaviours; and leveraging physical and human capital of
3 the government to deliver programmes and services that affect behaviour (Adger et al. 2003; Henstra, 2016;
4 Steg and Vlek 2007). Climate policy will be more effective when important antecedents of climate change
5 actions are targeted, including contextual factors, abilities, perceptions and motivations. These may differ
6 across contexts and individuals (Stern 2011). When people perceive serious barriers or constraints to act
7 upon climate change, the context in which decisions are made needs to be changed, as to make climate
8 mitigation and adaptation actions more feasible and attractive. Besides, various strategies can be employed to
9 target individuals' perceptions and motivations to act on climate change.

10
11 Current policy approaches largely derived from rational choice models emphasize infrastructural and
12 technology development, regulation, financial incentives and information provision. These approaches target
13 only some of the many (motivational) factors and processes influencing actions on climate change. They also
14 fall short of their true potential if their social and psychological implications are overlooked and when
15 behavioural anomalies are not considered (Stern et al. 2016). For example, promising energy-saving devices
16 or low carbon technology may not be adopted, or not be used as intended (Pritoni et al 2015). People may
17 lack cognitive resources to make well-informed decisions or not know where to find trustworthy advice or
18 competent technical help (Balcombe et al. 2013; Stern 2011).

19
20 Financial incentives, financial appeals and feedback on financial savings are not always effective (Bolderdijk
21 et al, 2013; Delmas et al. 2013), and can be less effective than emphasizing benefits for other humans and the
22 environment (Asensio and Delmas 2015; Bolderdijk et al. 2013; Handgraaf et al. 2013; Schwartz et al.
23 2015). This can happen when financial incentives, appeals and feedback reduce a focus on environmental
24 concerns and crowd out intrinsic motivation to engage in climate change actions (Agrawal et al. 2015; Evans
25 et al. 2013; Schwartz et al. 2015). Besides, pursuing small financial gains is perceived to be less worth the
26 effort than pursuing similar reductions in CO₂ emissions (Bolderdijk et al. 2013; Dogan et al. 2014). Also,
27 people may not respond to financial incentives e.g. to improve home energy efficiency because they do not
28 trust the organisation sponsoring incentive programmes or because it takes too much effort to receive the
29 incentive (Stern et al. 2016).

30
31 While providing information on the causes and consequences of climate change or on effective action to
32 mitigate or adapt increases knowledge - it often does not result in behaviour change (Abrahamse et al. 2005).
33 To promote climate mitigation and adaptation actions, it is particularly important to provide credible and
34 targeted information at the point of decision (Stern et al. 2016). For example, communicating the impacts of
35 climate change is more effective when provided right before adaptation decisions are taken (e.g. before the
36 agricultural season) rather than just making climate change visible by providing information on change itself
37 (e.g., weather forecasts, seasonal forecasts, decadal climate trends, Dorward et al. 2015; Singh et al. 2017).
38 Information provision is more effective when it is tailored to the personal situation of consumers,
39 demonstrates clear impacts, and when it resonates with their core values (Abrahamse et al., 2007; Bolderdijk
40 et al. 2013; Lokhorst et al 2013; Singh et al., 2017; Jones et al., 2016); tailored information prevents
41 information overload, and people are more motivated to consider and act upon information that aligns with
42 their core values and beliefs (Hornsey et al. 2016; Campbell and Kay 2014). Tailored information can, for
43 example, be provided *via* energy audits that are effective to promote energy savings (Abrahamse et al. 2005),
44 and *via* participatory deciphering of climate information and planning based on forecasts that have been
45 shown to promote climate change adaptation actions (Dorward et al. 2015; Singh et al. 2017). Tailored
46 information is key to target the most vulnerable individuals, such as elderly during heat waves. To maximise
47 impact; care should be taken to remove barriers faced by vulnerable groups to receive and interpret such
48 information (Keim 2008; Vandentorren et al. 2006).

49
50 Provision of simple, salient and relevant information is more effective than detailed and technical data (Ek
51 and Söderholm 2010; Frederiks et al. 2015; Wilson and Dowlatabadi 2007). Energy labels (Banerjee and
52 Solomon 2003; Stadelmann 2017), visualisation techniques (Pahl et al. 2016) and ambient persuasive
53 technology (Midden and Ham 2012) can motivate climate change mitigation action by providing information
54 and feedback in a format that immediately makes sense and mostly not requires users' conscious attention.
55 For example, feedback through a lamp that changes colour depending on one's actual energy consumption is

1 more effective than numeric feedback (Maan et al. 2011). Such lighting feedback is particularly effective
2 when colours are used that are associated with energy savings (Lu et al. 2016). Prompts can be effective as
3 they serve as reminders to perform a certain action (Osaldiston and Schott 2012). Furthermore, feedback is
4 generally effective in promoting sustainable energy behaviour (Abrahamse et al, 2005; Delmas et al., 2013;
5 Karlin et al. 2015), particularly when provided in real-time or immediately after the behaviour has been
6 performed (Darby 2006; Tiefenbeck et al. 2017) as this makes the implications of one's behaviour more
7 salient.

8
9 Social influence approaches that emphasise what other people do or think are effective to promote actions on
10 climate change (Clayton et al. 2015), particularly when they involve face-to-face interaction with consumers
11 (Abrahamse and Steg 2013). For example, block leader approaches, where local volunteers initiate or help
12 deliver an intervention are effective in promoting actions on climate change (Abrahamse and Steg 2013),
13 particularly when community ties are strong (Weenig and Midden 1991). Similarly, community approaches
14 where change is initiated from the bottom-up and community members are actively engaged are effective to
15 promote action on climate change (Middlemis 2011; Seyfang and Haxeltine 2012). Furthermore, goal setting
16 and commitment strategies where people make a pledge to engage in climate change actions promote
17 behaviour change (Lokhorst et al. 2013; Abrahamse et al. 2005; Abrahamse and Steg 2013), even more so
18 when individuals additionally indicate how and when they will engage in the relevant actions and anticipate
19 how to cope with possible barriers when they occur (i.e., implementation intentions, Bamberg 2000, 2002).

20
21 Goal setting and commitment strategies take advantage of individuals' desire to be consistent (Steg 2016).
22 Similarly, hypocrisy strategies, in which case people are made aware of inconsistencies between their
23 attitudes and behaviour proved to be effective in encouraging actions on climate change (Osaldiston and
24 Schott 2012; Steg 2016). Moreover, providing social models of desired actions can encourage behaviour
25 change (Abrahamse & Steg 2013; Osaldiston & Schott 2012). Social influence approaches that do not
26 involve face-to-face interaction, such as social norm information, social comparison feedback and group
27 feedback, are less effective to change behaviour, but are more easily administered on a large scale enabling
28 targeting large groups at relatively low costs (Abrahamse & Steg 2013; Alcott 2011).

29
30 Sustainable behaviour can be rewarded and facilitated or unsustainable behaviour can be punished and
31 inhibited (i.e. carrots versus sticks), and behaviour change can be voluntarily (e.g., via information) or
32 imposed (e.g., by law); voluntary changes that involve rewards are more acceptable than imposed changes
33 that restrict choices (Dietz et al. 2007; Eriksson et al. 2006, 2008; Steg et al. 2006). Policies punishing
34 maladaptive behaviour can be inappropriate when they reinforce socio-economic inequalities that typically
35 produce the maladaptive behaviour in the first place (Adger et al. 2003). Strategies can target intrinsic versus
36 extrinsic motivation. It may be particularly important to enhance intrinsic motivation so that people
37 voluntarily engage in behaviour that is both sustainable and reduces sensitivity to climate impacts over and
38 again. Change can be initiated by governments at various levels, but also by individuals, communities,
39 profit-making organisations, trade organisations, and other non-governmental actors (Lindenberg and Steg
40 2013; Robertson & Barling 2015; Stern et al., 2016).

41
42 Individuals across the world need to engage in many different behaviours to meet the 1.5°C target and to
43 adapt to climate change already occurring, and support climate change policy. Endorsement of mitigation
44 and adaptation are positively related (Brügger et al. 2015; Carrico et al. 2015); both are more likely when
45 people are more concerned about climate change (Brügger et al. 2015). Overall, energy efficiency rebound
46 effects are limited, and energy efficiency improvements are not reversed by the rebound effect (Gillingham,
47 Rapson, & Wagner, 2016). Consistent actions on climate change are more likely when strategies target
48 general antecedents that affect a wide range of actions, such as values, identities, worldviews, climate change
49 beliefs, general awareness of climate change caused by one's actions and feelings of responsibility to reduce
50 climate change (Hornsey et al. 2016; van der Werff et al. 2016; Steg 2016; Van Der Werff and Steg 2015).
51 Besides, initial climate related actions can lead to further commitment to climate mitigation and adaptation
52 behaviour (Juhl et al 2017) when people learn that such actions are easy and effective (Lauren et al. 2016),
53 and when initial actions make them realise they are an environmentally-sensitive person, motivating them to
54 act on climate change and support climate change policies in subsequent situations to be consistent (Lacasse
55 2015, 2016; Van der Werff et al., 2014).

4.4.5.4 *Acceptability of policy and system changes*

Policy and system changes need public support. Public support will be higher when people expect more positive and less negative implications of policy and system changes (Demski et al. 2015; Perlaviciute & Steg 2014; Shwom et al. 2010). Because of this, people generally prefer adoption of energy-efficiency measures above behaviour changes and shift in consumption patterns to reduce their overall energy consumption (Poortinga et al. 2003). Besides, climate change policy and energy system changes are more acceptable when people strongly value other people, nature and the environment (Dietz et al. 2007; Perlaviciute & Steg 2014, 2015; Perlaviciute, Steg, & Hoekstra, 2016; Shwom et al. 2010). Also, public support for climate change policy is higher when people are concerned about climate change, when they think they can engage in effective actions to reduce its negative impacts, and when they feel responsible to act on climate change (Eriksson et al. 2006; Jakovcevic & Steg 2013; Steg et al. 2005).

Besides, perceived distributive and procedural fairness affect climate change policy support (Gross 2007): acceptability is higher when costs and benefits are distributed equally and when nature and future generations are protected (Schuitema et al. 2011; Sjöberg & Drottz-Sjöberg, 2001), and when fair decision-making procedures have been followed, including active public participation (Bidwell 2016; Bernauer et al. 2016; Dietz 2013; Wolsink 2007). Public support for global climate policy is higher when public society organisations have been involved in the process (Bernauer & Gampfer 2013; Bernauer et al. 2016). Providing community benefits to compensate affected communities for losses to ensure distributional fairness enhanced public acceptability of energy projects in some cases (Perlaviciute & Steg, 2014). Yet, people may disagree on what would constitute a worthwhile compensation (Aitken 2010; Cass et al. 2010). For example, offering compensation does not enhance acceptability of the siting of wind farms when procedural fairness is challenged (Cowell et al. 2011) or when people suspect they are being bribed (Cass et al. 2010; Perlaviciute & Steg, 2014).

Public support will be higher when individuals trust responsible parties (Perlaviciute & Steg 2014). Public support is not higher for multilateral climate policy than for unilateral policy (Bernauer & Gamfer 2015); in fact, public support for unilateral, non-reciprocal climate policy is rather strong and robust (Bernauer et al. 2016). Public opposition may result from a culturally valued landscape being affected by adaptation or mitigation options, such as renewable energy development (Warren et al. 2005), particularly when people have formed strong emotional bonds with the place (Devine-Wright 2009, 2013; Devine-Wright & Howes 2010; Perlaviciute & Steg 2014). Also, people may not support adaptation policies that affect their attachment to their place (Adger et al. 2013). Yet, a strong global place attachment promotes climate change concerns and beliefs (Devine-Wright et al. 2015). Public support can increase when people experience positive effects after a policy has been implemented (Schuitema et al. 2010; Weber 2015; Wolsink 2007). It is often believed that climate change adaptation and mitigation actions reduce quality of life, as these actions involve some costs, effort or discomfort (Venhoeven et al. 2013). Yet, this is a limited view of what constitutes quality of life, as it focuses on hedonic and neglects eudemonic aspects. Action on climate change can enhance quality of life as doing so is meaningful. Pursuing meaning and purpose (i.e. eudaimonia) by acting on climate change makes people feel good about themselves (Venhoeven et al. 2013, 2016; Taufik et al. 2015), which enhances long-term wellbeing (Aristotle, 2000; Steger, Kashdan, & Olshi, 2008), more so than merely pursuing pleasure. Indeed, pro-environmental actions are related to higher quality of life (Kasser & Sheldon, 2002; Schmitt et al. 2017; Xiao & Li, 2011), and both are higher when people care about the community (Brown & Kasser 2005), suggesting that improvements in wellbeing can be attainable without adverse effects on the environment (Dietz et al. 2009).

Box 4.9: How transport behaviour in Singapore, Stockholm and London has changed

Policy can promote behaviour change. In Singapore, Stockholm and London, significant shares of the city population have changed their travel behaviour, with a noticeable effect on car ownership, pollution and GHG emissions, as a consequence of pricing and regulatory policies combined with flanking policies that support and facilitate behavioural changes. Notably, support for such policies increases when people

1 experience positive effects of policies.

2
3 For example, Singapore implemented a combination of policies including electronic road pricing (ERP), a
4 vehicle quota and registration fee system, and investments in mass transit. As a result, per capita transport
5 emissions are approximately 1.25 tonnes of CO₂, which is much lower than cities with comparable income
6 levels. Modal share of public transport was 63% during peak hours in 2013 (LTA 2013), and car ownership
7 of 107 vehicles per 1000 capita (LTA 2017) is substantially lower than in comparable cities. The ERP
8 scheme covers the central business district and major expressways. The vehicle quota system implies that
9 registration of new vehicles is conditional upon a successful bid for a Certificate of Entitlement (Chu 2015),
10 the costs of which were about 50,000 US\$ in 2014 (LTA 2015). In addition, a registration tax aims to
11 incentivize purchase of low-emission vehicles through a feebate system.

12
13 The Stockholm congestion charge implemented in 2007 (after a trial period in 2006) resulted in a 16%
14 reduction of kilometres driven in the inner city, and a 5% reduction outside the city; traffic volumes reduced
15 by 20% and remained constant across time despite economic and population growth (Eliasson 2014). This
16 resulted in a 2-3% reduction of CO₂ emissions from traffic in the county of Stockholm. The charge implied
17 that vehicles entering or leaving the Stockholm city centre were charged during the day (except for weekends
18 and holidays). Charges varied between 1 and 2 € (with a maximum of 6 € per day) and were higher during
19 peak hours; some vehicles like taxis, emergency vehicles and busses were not charged. Before the
20 introduction of the charge, public transport was extended, and new parking places were created near mass
21 transit stations. The aim and effects of the charge were extensively communicated to the public *via* different
22 channels. Acceptability of the pricing scheme was initially low, but increased substantially after the
23 implementation of the scheme gaining support of about two thirds of the population and all political parties
24 (Eliasson 2014); the initially hostile media became more positive during the trial period and eventually
25 declared the scheme to be a success story. After the trial period, people believed that the congestion charge
26 had more positive effects on environmental, congestion and parking problems and cost increases were lower
27 than they anticipated beforehand (Schuitema et al. 2010).

28
29 In 2003, the London congestion charge was implemented in the Greater London area, together with an
30 enforcement and compliance scheme and public information campaigns. All vehicles entering, leaving,
31 driving or parking on a public road in the zone at daytime and weekdays pay a congestion charge of initially
32 £ 8 (till 2005 it was £ 5); some exemptions and discounts are at place. The total number entering the zone
33 decreased by 18% in 2003 and 2004. Vehicle kilometres driven inside the charging zone decreased by 15%
34 in the first year and a further 6% a year later (Santos 2008), and a 20% CO₂ emission reduction from road
35 traffic was observed in the charging zone (Santos 2008).

36 37 38 39 **4.4.6 Enabling technological change and enhancing innovation**

40 41 **4.4.6.1 Recent innovations and their impact on 1.5°C**

42 Several innovations affect the feasibility of a 1.5°C pathway, and the ability to adapt to 1.5°C or higher
43 temperature scenarios. A few telling examples are explained for illustrative reasons and include the costs of
44 solar PV and batteries, as well as advances in artificial intelligence and in computing power.

45
46 The cost of the solar PV sharply declined, and the bid price dropped to as low as three cents per kilowatt-
47 hour (kWh) in the United Arab Emirates (UAE) where solar energy conditions are most favourable
48 (IEA/IRENA 2017). The rapid cost decline – more rapid than projections by mainstream models including
49 those assessed in Chapter 2 of this volume – happened due to a combination of policy instruments (primarily
50 feed-in tariffs and feed-in subsidies), mostly in Europe, fast innovation in China, which is now the world's
51 largest manufacturer of solar PV, and spill-over from general technological progress notably from
52 semiconductor industries (Nemet 2014). In addition, the cost of battery sharply declined, thanks to research
53 and development and mass production for portable equipment applications. This resulted in cheaper electric
54 vehicles (Nykqvist and Nilsson 2015).

1
2 Advances in Artificial Intelligence (AI), by the invention of ‘deep learning’ technology, in combination with
3 other Information and Communication Technologies (ICT), if deployed for the benefit of mitigation and
4 adaptation, may result in emission cuts that could help reaching 1.5°C. For example, energy management
5 systems have been drastically improved and put in use in factories, offices, and homes (IEA 2017). In
6 addition, the rapid and steady improvement of computing power enabled detailed simulation of material
7 science, and development of highly functional yet inexpensive materials. This, for example, has had impacts
8 on the cost of hydrogen fuel cell vehicles, which have declined (IEA 2017, Iguma and Kidori 2016).

9
10 The common thread of the above innovations is that general progress of technology, such as in computers,
11 ICT, semiconductors, AI, the Internet of Things (IOT), and robotics, has contributed to innovation relevant
12 to mitigation and adaptation. The performance of mitigation technologies has improved, and the costs of
13 mitigation technologies dropped thanks to a combination of specific and more general technological progress
14 (Laitner et al. 2010, IEA 2017).

15 16 17 *4.4.6.2 Emerging trends and 1.5°C-compatible technologies and innovation policy*

18 Technology systems evolve over time by combination of existing technologies like biological ecosystems
19 (complex systems theory: see Arthur 2009; Kauffman 2000 for more). The enabling condition for a new
20 technology is sufficient accumulation of prior technologies (called adjacent possibilities). As such, advances
21 in mitigation technologies are often not directly related to dedicated mitigation technology policy. Instead,
22 they have been greatly benefited from the advance of technology in general. For example, utilizing deep
23 learning, a wide range of climate mitigation and adaptation technologies such as intelligent energy saving
24 and precision agriculture are becoming possible. As such, some expect that, in the future, the development of
25 AI and IOT will expand the range of adjacent possibilities. For example, deep learning is used for refining
26 estimates and control of the load of air-conditioning equipment by image analysis of a room and save energy
27 in the office (IEA 2017). Furthermore, by combination of self-driving, car-sharing and electric vehicle
28 technologies, to all of which ICT contributes, it is estimated that significant emission cuts are possible (ITF
29 2017). For a wider range of ICT-enabled mitigation technologies, see (IEA 2014).

30
31 However, to reap the benefits of such innovations, three issues have to be addressed. First, care should be
32 taken that the rebound effects may be as large as the potential emission cuts. Policy intervention may be
33 necessary to reduce such rebound effects (IEA 2017; ITF 2017). Second, climate policy and economic
34 growth or other economic priorities must be compatible, as innovation occurs in virtuous cycle with
35 economic growth (Bresnahan et al 1995) or prosperity. This consideration is important when nations aim at
36 deep emissions cuts such as 1.5°C, as ambitious mitigation policy might undermine economic progress if
37 inadequately implemented. On the other hand, the general notion of economic growth as a necessary
38 condition of addressing climate change and of innovation is contested (e.g., Klein 2014). Third, regulatory
39 systems must be supportive of innovation. It was argued that ICT innovation in Europe had been greatly
40 delayed compared to the United States due to heavy security regulations that impeded free corporate
41 activities (Thierer 2016). However, ‘permissionless innovation’, as argued by Thierer (2014) is not generally
42 favoured though; other authors argue for a greater directional role in governmental support and regulation
43 around innovation (e.g., Mazzucato 2013).

44
45 Although ICT, including AI, may enable emission cuts through various channels mentioned above, it is very
46 difficult to predict the pace and potential in quantitative manner, since we do not know how fast ICT and
47 how wise AI will be at all beyond 2020, let alone 2050. AI may outperform human-beings to the extent it
48 replaces labour at most workspace known today (Brynjolfsson and McAfee 2011; Ford 2009). Furthermore,
49 it may improve the manufacturing process of the solar cell, and the installation work of photovoltaic systems
50 (PV) may be carried out by robots, cutting so-called Balance of Systems costs. As such the cost of the PV
51 may further be reduced (IEA/IRENA 2017).

52 53 54 *4.4.6.3 1.5°C-relevant insights from innovation policy*

55 Although mitigation and adaptation technology depends on broader technological advances and

1 developments in the broader innovation system, innovation policy directed at mitigation or adaptation can
2 make a difference. Dedicated policies for mitigation technologies remain important. In this light, there have
3 been many calls for increasing R&D funding for climate mitigation and adaptation (examples). In 2015,
4 twenty countries responded by an initiative called ‘Mission Innovation’, and committed to doubling their
5 energy R&D funding, although at this point it is difficult to evaluate its effectiveness (Sanchez and Sivaram
6 2017). At the same time, the private sector started an initiative called the ‘Breakthrough Energy Coalition’.
7

8 The climate-resilient pathways in Chapters 2 and 5 require new technology and more widely-applicable,
9 lower-cost, existing technology. This will not sufficiently come about autonomously (IPCC WGII 2014
10 Chapter 15, GEA 2012). Governments have employed various different innovation policies. Revenues for
11 R&D could come from the general budget, but could also be generated by carbon pricing schemes (see also
12 section 4.4.7) or, for instance, energy or resource taxation. Investing in climate-related R&D has as an
13 additional benefit in building up of capabilities to implement climate mitigation and adaptation technology
14 (Coninck and Sagar, 2015), see also Section 4.4.4.
15
16

17 4.4.6.4 *Technology and the implementation of the Paris Agreement*

18 Technology transfer and innovation are recognized as enablers of both mitigation and adaptation in the Paris
19 Agreement, and well before that in the UNFCCC (UNFCCC 1992:Article 4.5). It is obvious that technology
20 transfer and innovation can help adapting technologies to local circumstances, reduce costs, develop
21 indigenous technology, and build capabilities globally (Ockwell et al. 2014). A 1.5°C world is hard to
22 imagine without a significant increase in global R&D expenditures, and development of innovation systems
23 and associated capabilities around technologies for mitigation and adaptation in all countries (Coninck and
24 Sagar, 2017, forthcoming).
25

26 The international institutional landscape around technology transfer and innovation includes the UNFCCC
27 (via its technology framework and technology mechanism), the UN (a technology facilitation mechanism for
28 the SDGs) and a huge variety of non-UN multilateral and bilateral cooperation initiatives, such as Mission
29 Innovation (founded in 2015), the Consultative Group on International Agricultural Research (CGIAR,
30 founded in the 1970s) and numerous initiatives of companies, foundations, governments and non-
31 governmental and academic organisations. By far most technology transfer is happening driven by human
32 needs and markets, in particular in areas with growing institutional and innovation capabilities (Glachant and
33 Dechezleprêtre 2016), and the current landscape does leave gaps, in particular in least-developed countries,
34 adaptation and innovation capabilities (de Coninck and Puig 2015). Literature suggests that the management
35 or even monitoring of all these initiatives will fail to lead to better results; it is more cost-effective to ‘let
36 a thousand flowers bloom’, while at the same time challenge and entice researchers in the public and the
37 private sector to direct innovation towards low-carbon options (Haselip et al. 2015).
38

39 For adaptation specifically, Olhoff (2015) argues that networks can build capabilities globally on adaptation
40 technologies (and options and policies), that a balance should be found between technology development and
41 transfer for the short- and medium-term compared to the long term, and that, like mitigation, technology
42 development and transfer around adaptation is crucially dependent on socio-cultural, economic and
43 institutional contexts.
44

45 At COP 21, the UNFCCC requested the Subsidiary Body for Scientific and Technological Advice (SBSTA)
46 to initiate the elaboration of the technology framework established under the Paris Agreement (UNFCCC,
47 2015: Article 10), which, among other things, should facilitate the undertaking and updating of technology
48 needs assessments (TNAs), as well as the enhanced implementation of their results. An enhanced guidance
49 issued by the Technology Executive Committee (TEC) for preparing a technology action plan (TAP)
50 supports the new technology framework as well as Parties’ long-term vision on technology development and
51 transfer reflected in the Paris Agreement.
52
53

54 4.4.7 *Strengthening policy instruments*

55

1 The immediate policy challenge raised by the transition to a 1.5°C world is to trigger drastic and almost
2 immediate changes in technical choices, land-use patterns, urbanisation, lifestyles, consumption and
3 behaviour. This will need to be enabled without negative socio-cultural and political responses that could
4 block the transformation process, from the outset.

5
6 This builds on an old debate in public economics about the relative weight and effectiveness of ‘command
7 and control’ measures and price signals to coordinate individual and collective behaviour. The first entails
8 the risk of political arbitrariness and of raising the costs of climate policies to politically infeasible levels.
9 The second can lower arbitrariness and policy costs but are limited by potential market and governance
10 failures that are not easy to mitigate against. The core challenge of the Paris Agreement of realizing a 1.5°C
11 world, may require the effective use and design of ‘price signals’, various forms of ‘market-based
12 instruments’, along with appropriate regulation and financial incentives, depending on the region and
13 country in question.

14 *The nature of the challenge: questions of costs and equity*

15
16 Whatever the content of the policy-mix, the low-carbon transition will imply higher short-run energy costs,
17 owing to off-setting existing infrastructure lock-ins and making a transition out of climate incompatible path
18 dependencies. Negative cost measures exist (Section 4.3.6) and some lifestyle changes can take place
19 without price signals (Section 4.4.5) but their pace of deployment will be constrained by the inertia of
20 existing capital stocks, market structures and lack of enabling conditions, cultural habits and behaviour.
21 Therefore, a range of policy and market incentives will be needed to accelerate the deployment of carbon
22 neutral technologies, before they are more cost-effective than conventional fossil energy.

23 The order of magnitude envelope for the worldwide marginal abatement costs for a 2°C target in AR5 was:
24 35-60 \$ t⁻¹ in 2020, 62-140 \$ t⁻¹ in 2030 and 140-260 \$ t⁻¹ in 2050. While, these estimates can be
25 challenged, their lower bound relies on optimistic technical assumptions, coming from models assuming
26 least-cost planning with neither market imperfections, including missing or informal markets, nor uncertainty
27 for decision-makers and in some cases.

28 Technical change can be accelerated by learning-by-doing processes and R&D, to accelerate the cost-
29 effectiveness of low carbon technologies. However, in all these processes, the deployment of the new
30 techniques implies higher costs at its early phase. This is why the German energy transition, resulted in the
31 highest consumer prices for electricity in Europe, and needed to be supported by strong non-price policy
32 measures. At the global level high energy costs tend to propagate from one sector to another amplifying
33 overall production costs, depending on the structure of the economy under consideration. This is important
34 for developing countries that are building their infrastructure that is dependent upon energy intensive
35 products like cement and steel (Crassous et al. 2006; Luderer et al. 2012). Ultimately, during the early stage
36 of a low-carbon transition, both energy prices and the prices of non-energy goods will typically increase,
37 causing lower purchasing power of wages and lower final demand for non-energy goods.

38
39 Higher energy prices may thus have adverse effects on the distribution of welfare, potentially exacerbated by
40 slower economic growth in the absence of accompanying policies. The negative welfare impact is typically,
41 inversely correlated with the level of income (Harberger 1984; Fleurbaey and Hammond 2004) and with the
42 share of energy in the households budget for low - and middle - income households in temperate and cold
43 countries (Hourcade et al. 2012; Guivarch and Hallegatte 2011; Chiroleu-Assouline et al. 2011;
44 CORNWELL and CREEDY 1996; Cremer et al. 2003; West and Williams 2004) (Proost, et al. 1995, Barker
45 et al. 1998). Here, vulnerability to high energy prices depends upon heating and mobility needs in the
46 suburbs, remote and low-density regions can be as vulnerable as low income areas in urban areas. Poor
47 households with low-levels of energy consumption will also be impacted by an overall price increase of non-
48 energy goods.

49
50 A unique global carbon price is hard to implement because of the huge discrepancies in *per capita* income
51 and the difficulty of large international compensatory transfers, exacerbated by purchasing power parity
52 (PPP) exchange rates in poorer countries (e.g. 1.8 in China and Brazil, 2.3 in South Africa and 3.8 in India).
53 Hence, a second matter of concern, in a minority of regions, is the distortion of international competition by

1 heterogeneity of carbon constraints (Demailly et al. 2009) in highly energy intensive industries. Some of
2 them are not very exposed to international competition because they entail very high transportation costs per
3 value added (Demailly and Quirion 2008; Sartor 2013) while others could suffer a sufficiently severe shock
4 to generate ‘carbon leakage’ that is cheaper imports of goods from countries with lower carbon constraint
5 (Branger et al. 2016). This can weaken the surrounding industrial fabric with serious economy wide and
6 employment implications.
7

8 A third challenge during the carbon transition, weakly reflected in scientific literature, is the depreciation of
9 assets whose value is based on carbon-intensive capital stocks, like coal-fired power which become stranded
10 assets, as they were built under the assumption of low energy prices (Guivarch and Hallegatte 2011;
11 OECD/IEA/NEA/ITF 2015) (Pfeiffer et al. 2016). This raises challenges of changes in industrial and
12 employment structure, retraining and deployment of workers and the potential instability of financial and
13 social security systems (e.g. based on the asset holding of pension funds). This could impact the valuation of
14 resources not yet transformed into economic production as in the case of coal, gas and oil production, where
15 future revenues may decline precipitously with higher carbon prices (Waisman et al. 2013; Jakob and,
16 Hilaire 2015; McGlade, and Ekins 2015).
17
18

19 4.4.7.1 *Mastering the cost-efficiency-equity challenge*

20 After a quarter century of policy experimentation and economic literature on carbon pricing (IPCC TAR,
21 AR4 and AR5) a huge gap persists between aspirational and explicit carbon prices. Today, only 15% of the
22 emissions are covered by carbon pricing schemes, three quarters of which have prices below \$ 10 ton⁻¹ of
23 CO₂ (World Bank 2016).

24 A dominant share of climate and energy policies mobilize non-price instruments (technical regulations and
25 standards, financial instruments, infrastructure projects, information and training) but these policies also
26 entail mobilization of economic resources at higher energy costs, at least in a first phase, when there may be
27 a major difference between the explicit price and implicit cost of carbon.
28

29 A transition to a 1.5°C world requires, even more than for less stringent targets, the prioritization of policies
30 that enable a minimisation of social costs. In principle, this implies that: (1) that marginal costs of abatement
31 are equated across all sources of emissions; (2) investors *a priori*, make the right financial and technical
32 choices, without any information asymmetry; and (3) the general equilibrium effects of higher energy prices
33 are managed to minimize their negative impact and potentially to even transform it a positive gain. Many
34 low carbon transition assessments are primarily based on partial equilibrium frameworks with very attention
35 to economy wide implications.
36

37 In a frictionless world, explicit carbon prices equal to marginal abatement costs could secure the cost
38 efficiency of climate policies sending a clear signal in favour of decarbonisation to all economic actors
39 provided the adverse distributive impacts of higher energy costs are offset through compensating transfers.
40 Off-setting mechanisms will be a critical challenge for which a transparent institutional and governance
41 architecture will be required to be set up. Balancing distributional implications are usually inter-temporal
42 affairs with large cost-benefit uncertainties in space and time.
43

44 In practice, explicit carbon pricing can offset the propagation effect of high energy costs because they raise
45 significant revenue, that can be recycled using a ‘revenue neutrality’ condition into reducing more
46 distortionary taxes (Stiglitz et al. 2017). They could help lower technical abatement costs by reducing social
47 charges imposed on production, a challenge if a major part of the market transaction happens informally.
48 Even setting up such frameworks will be challenging, particularly in developing countries, from the
49 perspective of informational access cost and reliance on voluntary disclosures.
50

51 Substitution of direct income taxes with carbon taxes is a positive measure, both in countries with a high
52 level of social security as well as those that are building their social welfare system, like China (Li and Wang
53 2012). This substitution, *via* an effective fiscal transfer from energy intensive sectors, could lead to lower
54 energy intensity and hence lower production costs in decarbonising economic sectors.

1
2 Explicit carbon taxes can also help in offsetting the adverse redistributive effects of higher energy costs.
3 They can do this by redistributing part of their revenues through direct rebates or cash transfers to
4 households. If rebates are divided equally, adjusted for household size, then most people, especially poor
5 households, would be even better off after the imposition of a carbon tax. These positive distributional
6 effects are typically due to the larger share of wages in the total income of poor households compared to
7 high-income households who have other sources of income from capital, such as interest and rents. Even
8 though their carbon fee burden may be a relatively smaller share of their overall income, higher income
9 people pay more in absolute terms and the revenue would be redistributed across all households (Arze del
10 Granado, Coady, and Gillingham 2012). The balance between the share of the revenues of carbon taxes that
11 can be used to offset redistributive, reduce the inflationary effect of higher energy prices, is country specific,
12 depending on its income and production structure (Combet et al. 2010); (Combet et al. 2015). The efficiency
13 of this recycling depends on a country specific market and potential local institutional distortions.
14

15 Explicit carbon pricing offers a good tax base, as it is difficult to evade, thereby decreasing the gap between
16 the tax burden across the formal and the informal labour market (Bovenberg 1999; Goulder 2013). This
17 could lead to lower labour cost, potentially reducing unemployment, helping to increase real wages, thus
18 counteracting the recessive effect of higher energy prices. Therefore, recycling carbon tax revenues may
19 lead to a double dividend of fostering the decarbonization transition while simultaneously promoting
20 economic growth and social development (Combet et al., 2015; Grottera, William, and La Rovere 2016; La
21 Rovere et al. 2017; Goulder 1995). This is why numerous studies highlight the potential benefits from such
22 reforms to turn technical costs into economic gains (IPCC 2007, 2001) under certain conditions (Goulder
23 2013; R. A. de Mooij 2000) offering a ‘double dividend’ by providing both environmental benefits and an
24 aggregate economic gain.
25

26 27 4.4.7.2 *Coordinating long run expectations: a matter of credibility and consistency of incentives*

28 Explicit cross-sectoral and global carbon prices could be the necessary ‘lubricant’ to accommodate the
29 general equilibrium effects of higher energy prices. They are also needed to control the rebound effect of
30 emissions due to a higher consumption of energy services enabled by energy efficiency gains, if energy
31 prices do not change (Greening et al. 2000; Sorrell et al. 2009).
32

33 An ‘implementation gap’ is likely to persist between medium-run carbon prices calculated in models that
34 align them with levelled costs of technologies and the ‘switching carbon prices’ needed to trigger abrupt
35 changes in behaviour or innovation (180). First, their level should be higher than in climate models because
36 they need to outweigh the ‘noise’ from: the volatility of oil markets (in the range of \$ 100 tCO₂⁻¹ over the
37 past decade), other price dynamics (interest rates, currency exchange rates and real estate returns) and
38 regulatory uncertainties in the energy, transportation and industrial sectors. As an example, the dynamics of
39 mobility depends to a great extent upon ‘commuting costs’, the trade-off between housing prices and
40 transportation costs (Lampin et al. 2013) and ‘spatial planning’.
41

42 Second, they have to be embedded in a consistent set of fiscal and social policies, so that a carbon price can
43 be perceived as a desirable signal instead of an arbitrary burden. When systemic changes are at play on
44 many dimensions of development, switching carbon prices are contingent upon other policy means. This
45 is the old lesson that prices levels ‘depend on the path and the path depends on political decisions’
46 (Drèze and Stern 1990).

47 These considerations have been reflected in attempts to secure a minimum carbon price in existing emissions
48 trading systems (Fell et al 2012; Wood et al 2011; Fuss et al 2017) and *via* pricing mechanisms like fee-bates
49 or ‘bonus-malus’ that foster the penetration of low carbon options (Butler and Neuhoff 2008). It also applies
50 to the reduction of fossil fuel subsidies, which are estimated at \$ 548 billion in 2013, or 5% of the GDP and
51 25-30 percent of government revenues in forty mostly developing countries (IEA 2014). The OECD
52 estimates that its member countries spent \$ 55-90 billion a year subsidizing fuels over 2005-2011 (OECD
53 2013) and \$ 650 billion in 2015 (Coady et al. 2016). Banning these subsidies is urgent from a below 2°C
54 perspective, but raises the same issues as carbon pricing with long-term benefits and short-term social costs

1 (Jakob et al. 2015; Zeng et al 2016).

2
3 Any transition to a 1.5°C world may therefore, require coordinating a complex set of ‘signals’ to shape long
4 term expectations, and align a low carbon transition with equitable access to development opportunities,
5 entitlements and benefits.

6
7 The potential of implementing policy packages, rather than discrete policies, was indicated in AR5. For
8 example, to enable a 1.5°C transition, carbon pricing may need to be combined with non-price policies
9 including efficiency standards, due to high consumer discount rates and price inelasticity (Parry et al. 2014).
10 Over the past two decades, regulatory instruments have been effective, cost-effective and primary tool of
11 achieving energy efficiency improvements, enhancing renewable energy penetration and enabling increased
12 energy savings in OECD countries (e.g., US, Japan, Korea, Australia, the EU) and more recently in other
13 countries (e.g., China) (Scott et al. 2015; Brown et al. 2017). Many developing countries are adopting these
14 policy instruments to avoid import of products banned in other countries, but there is still a large
15 technological efficiency potential (Knoop and Lechtenböhmer 2017) in equipment and buildings to be
16 captured.

17
18 For energy efficiency, these instruments include end-use standards and labelling for equipment like domestic
19 appliances, lighting, electric motors, water heaters and air-conditioners. Often, mandatory efficiency
20 standards are complemented by mandatory efficiency labels to attract consumers’ attention to the most
21 efficient products in the market and to stimulate manufacturers to innovate (Girod et al. 2017) and to offer
22 the most efficient products. Experience shows that two policy instruments are effective only if they are
23 regularly reviewed to follow technological developments, such as in the successful ‘Top Runner’ programme
24 for domestic appliances in Japan.

25
26 Regulation and standards have been effectively used in the transport sector, for light and heavy-duty vehicles
27 by imposing efficiency requirements (e.g. miles/gallon or level of CO₂ emission per km). In the EU,
28 regulatory instruments are imposed on manufacturers (Ajanovic and Haas 2017), which require them to meet
29 a certain target of annual fleet CO₂ emissions for new vehicles. A similar instrument exists in the US - the
30 CAFE standard (Sen et al. 2017). A fleet target allows manufacturers to continue selling high emission
31 vehicles to be compensated by the entry of low emission vehicles, into the fleet, with a gradual reduction of
32 fleet emissions over time. This regulatory instrument assures more efficient vehicles, but does not limit the
33 driven distance. Nevertheless, ‘rebound’ effects, of increased emissions, driven by efficiency gains can take
34 place in the absence of high carbon prices, which can offset the expected savings (Freire-González 2017;
35 Chitnis and Sorrell 2015).

36
37 Building codes that prescribe efficiency requirements for new and existing buildings have been adopted at
38 national and local level in many OECD countries (Evans et al. 2017). Building codes are regularly revised
39 prescribing an increased level of efficiency, either through the prescriptive use of efficient technologies and
40 insulation levels or through energy or CO₂ limits per unit floor space. This instrument is very relevant for
41 countries with rapid urbanisation and a large share of new construction, to avoid the lock-in effect of new
42 poorly performing buildings remaining in use for the next 50-100 years. As the rate of new building
43 construction is low in many OECD countries, it is important to incentivize the retrofit of existing buildings,
44 to adopt energy efficiency and renewable energy measures. As indicated in Section 4.3.4 on Net Zero Energy
45 Buildings is where Building codes for both new and existing buildings should converge (D’Agostino 2015).
46 Expanding consumption and emission levels need to be addressed for equipment, vehicles and buildings.
47 (Bertoldi). In the context of a 1.5°C world these policy instruments will require public and private co-
48 ordination including with urban policies.

49
50 Another set of policies to foster investment in low carbon-technologies, are grants, subsidies, loans and feed-
51 in tariffs. Grants are mainly used to support R&D, where risk and long-term perspectives reduce the private
52 sector’s willingness to invest (e.g. nuclear fusion research). Subsidies are used to fostering market
53 penetration of low-carbon technologies and can take the form of tax rebates (e.g. lower VAT or a rebate on
54 income tax), subsidies for investments (e.g. renewable energy or refurbishment of existing buildings),
55 rebates for consumers and manufacturers, and feed-in tariffs (Mir-Artigues and del Río 2014). Subsidies may

1 be provided from the public budget or via consumption levies (e.g. on kWh); carbon taxes or via a cap-and-
2 trade systems. To have a neutral impact of national budgets the feebates instrument, to incentivise low-
3 emission vehicles, products and buildings and penalise high-emissions ones, has been introduced in some
4 countries (e.g. for cars) (de Haan et al. 2009).

5
6 An alternative form of subsidy is the feed-in tariff that is based on the quantity of renewable energy
7 produced or by energy saving resulting from efficiency improvements and/or energy conservation ‘nega-
8 watts’ (Ritzenhofen and Spinler 2016; Pablo-Romero et al. 2017; García-Álvarez et al. 2017; Bertoldi et al.
9 2013).

10
11 Information campaigns are a common instrument used by national and local governments to foster
12 investment in clean technologies and change end-user behaviour. These campaigns have different forms:
13 from general campaigns (e.g. TV ads) to tailored information provided to specific groups of end-users.
14 Although some authors report large savings obtained by such campaigns [ref], most agree that their effect
15 have a short life and tends to decrease over time (Bertoldi et al. 2016). Recently, focus has been placed on
16 the use of social norms, as a way of motivating citizens and altering behaviour (Allcott 2011; Alló and
17 Loureiro 2014)(Also see Section 4.4.5 for more details).

18
19 Efficiency standards are not disconnected from the use of market based instruments (Haoqi et al. 2017). Such
20 a combination has been introduced in US and in some EU member states to improve energy efficiency by
21 imposing Energy Savings Obligations or Energy Resources Standards (Haoqi et al. 2017) for energy retailers
22 and to promote renewable energy via Green Certificates or renewable energy portfolio standards (Upton and
23 Snyder 2017). Thomas et al. (2017) propose to cap the utilities energy sales and others scholars have
24 investigated emission caps at a personal level (Sioshansi et al. 2010). A key to the success of these policies is
25 stringent obligations (i.e. the cap), as well different options to set the cap according to the interaction
26 between energy markets and other policy instruments (García-Álvarez et al. 2017; Bhattacharya et al. 2017).

27
28 Voluntary actions by non-governmental actors are gaining importance and could make a, important
29 contribution to achieving a 1.5°C world. Commitments by local authorities and cities, as in the Covenant of
30 Mayors in the EU and the US, where many cities have committed to long-term targets of 60% to 80%
31 emissions reductions, some becoming carbon-neutral by 2050 (Kona et al. 2017).

32
33 There is thus a diversity of policy packages available to coordinate decarbonisation decisions. The core
34 challenge is how to secure their consistency and their credibility. Literature shows that conflict between
35 poorly articulated policies can undermine their efficiency (Lecuyer and Quirion 2013). See also Box 4.4
36 for evidence from case studies.

37
38 The simultaneous launch of multiple policies in many domains in a regional context where carbon prices
39 are too low to hedge against their arbitrariness is challenging. A well-established tradition in public
40 economics is to resort to implicit (notional) prices representing the social values of public goods, to hedge
41 against such a risk. Such notional carbon prices have been adopted in countries like the US, the UK and
42 France, but do have the volume, price level nor the degree of systematic application required to accelerate an
43 ambitious decarbonisation programme. Shukla et al (2017) argue that, to secure the alignment of climate
44 policies with an equitable access to development, these notional prices should (following the article 108 of
45 the Paris Agreement) represent the Social Value of Mitigation Activities (SVMA) including co-benefits in
46 terms of health, security, adaptation and sustainable development. These notional prices could be higher than
47 the explicit carbon prices because they redirect new equipment without an immediate impact on existing
48 capital stocks and vested interests.

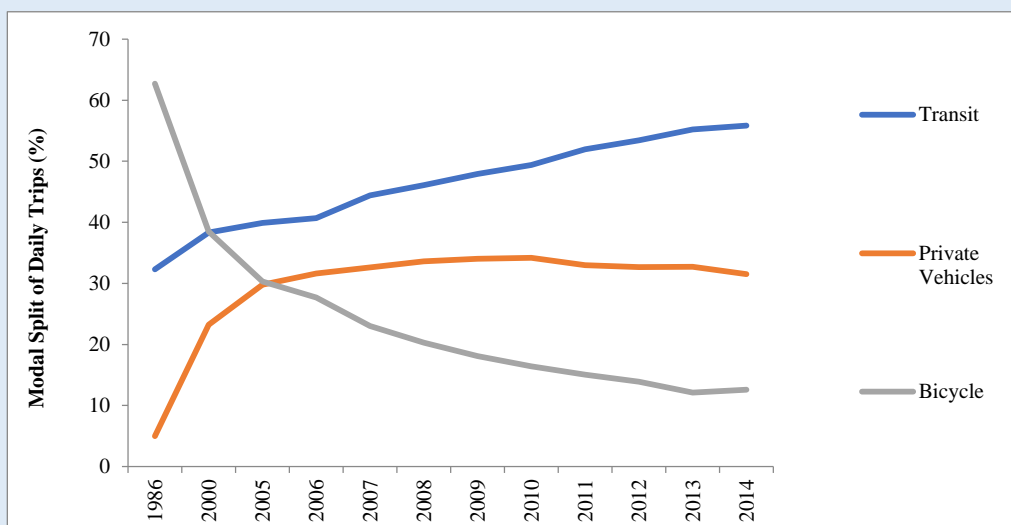
49
50 A new strand of post-AR5 literature, examines a set of policy packages that combine carbon pricing, non-
51 price policies and financial incentives to catalyse savings towards low carbon investments. One sign of
52 success of these policy packages will be to ‘make finance flows consistent with a pathway towards low
53 greenhouse gas emissions and climate-resilient development’ (Paris Agreement, Art. 2). This will depend
54 upon their capacity to resist regulatory uncertainty (Laffont and Tirole,1993), which cannot be completely

1 overcome. Even well-designed policies will have to be adapted in response to implementation experience, as
 2 empirical evidence from case studies in Box 4.10 underline.

3 **Box 4.10: Emerging Cities and Peak Car Use: Evidence from Shanghai and Beijing**

4 The phenomenon of ‘peak car’, reductions in per capita car use, provide hope for continuing reductions in
 5 greenhouse gas from oil consumption (Millard- Ball and Schipper 2011; Goodwin and Van Dender 2013;
 6 Newman and Kenworthy 2011). The phenomenon has been mostly associated with developed cities, though
 7 apart from some early signs in Eastern Europe, Latin America and China (Newman and Kenworthy 2015)
 8 there is great need in emerging economies (Gao and Kenworthy 2017). New research is indicating that peak
 9 car is now underway in China [ref].

10 China’s rapid urban motorisation has resulted from strong economic growth, rapid urban development and
 11 the prosperity of the Chinese automobile industry (Gao and Kenworthy 2015). However, recent data [ref]
 12 suggests that the first signs of a break in the growth of car use is now underway as the growth in mass transit,
 13 primarily caused by the expansion of Metro systems, is becoming more significant (see Box 4.10, Figure 1).

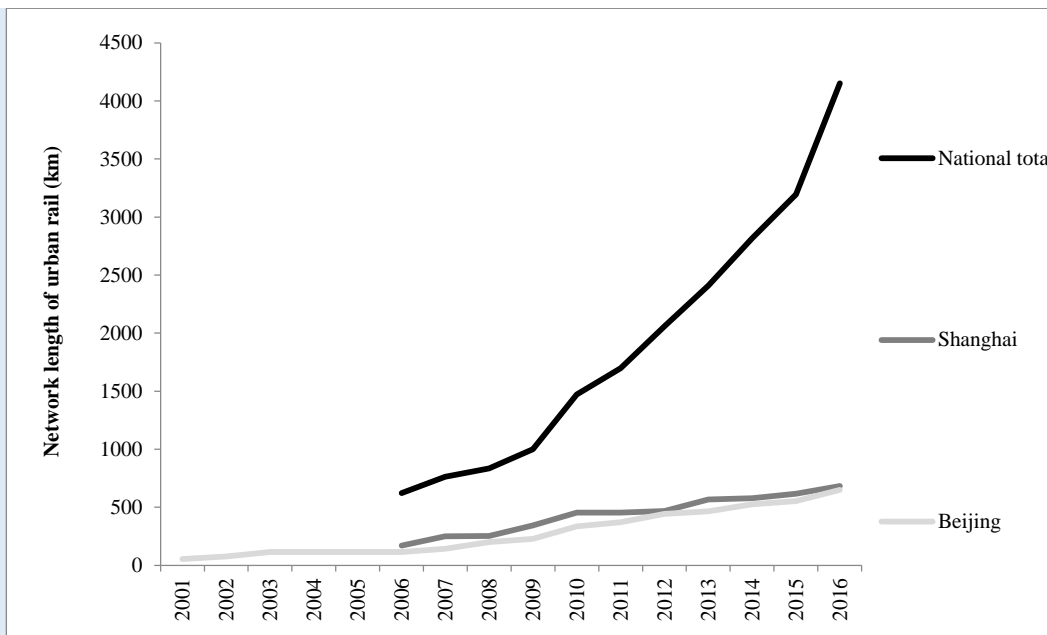


14

15 **Box 4.10, Figure 1:** The modal split data in Beijing indicating the peaking in car use as mass transit growth takes over.
 16 Source: (Gao et al. 2017)

17

18 Similar trends are observable in Shanghai (Gao et al. 2017). This is explained by Gao et al (2017) by
 19 understanding how Chinese urban fabrics, featuring traditional dense linear forms and mixed land
 20 use, favour such mass transit systems over automobiles. However, it does require investment and as shown
 21 by Box 4.10, Figure 2 there has been rapid investment in urban Metro systems in recent years. By the end of
 22 2016 there were 133 operational metro lines within 30 cities of mainland China, totalling 4,153 km of
 23 operational length (Gao et al. 2017).



Box 4.10, Figure 2: Operational length of urban rail transport in Beijing, Shanghai and China by the end of 2016 (km). Source: Compiled from data provided by National Bureau of the People’s Republic of China and China Association of Metros (Gao et al. 2017)

The dramatic growth of intercity Fast Rail (now by far the largest system in the world) (UIC 2017) has also been a feature of recent Chinese investment and in the use of electric vehicles (both cars and motor cycles/bikes) with 250 million EV and 194 million EV cars in 2017 (Gao et al. 2017). The transition to an all-electric transport system is well underway in China, suggesting there is a model for emerging cities and nations that can enable this important dimension of the 1.5°C agenda [ref].

Box 4.11: Climate Policy to enhance Deep Decarbonisation

As policies are context-specific, many case studies have emerged in the social science literature providing a source of empirical evidence of the effectiveness of different policy instruments to deliver on climate, other sustainability and economic development goals. Due to the heterogeneity of contexts and approaches, it is usually difficult to systematically assess a large diversity of case studies and distil synthetic lessons that can serve policymakers in optimizing their portfolio of policy instruments and ratcheting up on existing policies. The effectiveness of climate policies can often not be assessed, due to a lack of explicit targets and indicators. However two comparative projects have been conducted on a number of national case studies.

The Deep Decarbonisation Pathways Project (DDPP) provides a common frame for designing country-driven low-emission scenarios (Bataille et al. 2016). This analysis, conducted for 16 countries covering 70% of world emissions helped identifying country-specific policy packages and obstacles to a transformation consistent with domestic socio-economic priorities (DDPP Network 2016).

The CD-LINKS project has developed guidelines for 17 national-level case studies of past and ongoing policies at the interface of climate and development with a balanced regional coverage across the G-20. Pahle et al. (under review) present the synthesis with findings based on three criteria: (1) policy effectiveness; (2) policy robustness; and (3) ability to monitor and evaluate performance.

A common finding of these two projects is that the effectiveness of policy-packages depend upon their

1 capacity to align climate and development objectives. For example, the Indian analysis presented in (Shukla
2 et al, 2015) shows that domestic sustainable development objectives could impact the design of climate
3 policies by decreasing the cost of ambitious mitigation and dependence on high-risk technologies.

4 Complementary policies are found to systematically improve policy effectiveness for example support for
5 infrastructure and capacity building to enable effectiveness of incentive schemes. This is shown in the
6 Canadian case (Bataille et al. 2015) which considers a diversified policy package, with a hybrid and
7 differentiated carbon pricing policy, mandatory carbon intensity regulations in buildings and transport,
8 mandatory control of landfill and industrial methane, and a specific land-use package. This is especially
9 important to accelerate the transition to a 1.5°C world, which can be triggered by such incentives.

10
11 Examining four coal dependent country cases (Australia, South Africa, India and China) on the potential of
12 current policies to contribute to a rapid exit from coal, necessary to enable the 1.5°C transition (Spencer
13 *under review*), assesses the lack of complementary policies as a major bottleneck to policy effectiveness.
14 This is necessary to address stakeholders impacted by a coal phase out, for example energy-intensive
15 industry in Australia or resource-poor families and small-scale business in China. Policies not accompanied
16 by the means to mitigate financial risk, were found to be ineffective in triggering targeted investments,
17 across all relevant case studies (Pahle et al. *under review*).

18
19 Another lesson is that a rise of energy prices has a proportionally greater impact on developing economies,
20 because price-elasticities are higher at lower incomes and because they have a higher ratio of the energy to
21 labour cost, which is the core driver of general equilibrium effects of higher costs of energy (Waisman et al.
22 2012). This is illustrated by scenarios developed under DDPP for South Africa (Altieri et al, 2016) and
23 Brazil (LA Rovere et al. 2016). Both scenarios achieve ambitious decarbonisation, of an 80% decrease of the
24 ratio of carbon emissions to GDP between 2010 and 2050. But this is achieved with lower ranges of absolute
25 carbon prices compared to those reached in other developed countries. One co-benefit of such low-carbon
26 policies, like the improvement of energy security permitted by the decreased reliance on imported fossil fuels
27 in the Japanese case (Oshiro et al. 2016).

28
29 Durability and robustness of policies were found to critically depend on their flexibility to adjust to new
30 objectives and new situations in a context of uncertainties. This requires attention to a combination of long-
31 lived incentives to form consistent expectations, like a pre-announced escalating carbon price; and adaptive
32 policies which can evolve over time (Mathy et al. 2016). This is the case in Germany, where renewables
33 were first supported as an alternative to nuclear power, but were still supported despite a nuclear phase-out
34 with the new objective of reducing emissions. This is also true in the French case where the low-carbon
35 transition in France envisages a steep rise of building retrofits, but should envisage regular revisions if the
36 impact of this action is limited, and requires future adjustments to the overall strategy.

37
38 From a governance perspective, the involvement of different governing bodies with varying objectives was
39 found to systematically lead to efficiency losses. The Swedish and Brazilian experiences examined by
40 (Silveira and Johnson 2016) support this finding and illustrate the importance of coordinating policies
41 between local and national levels and across sectors to advance modern bioenergy platforms. Especially
42 interesting for a 1.5°C transition is the robust finding across case studies that ratcheting up of ambition leads
43 to an increase in policy costs, so that cost effectiveness becomes more important (Pahle et al. *under review*).

44
45 Other lessons concerns the performance of market mechanisms. In a case study on China's wind power
46 program, a gradual shift to market mechanisms is considered necessary to sustain the promotion of wind
47 power. Yet, commitment problems and lack of credibility and transparency of regulation have consistently
48 led to low carbon prices, for example in the case of the European Emissions Trading Scheme (Koch et al.
49 2014, 2016). (Hoch 2017) examine the cases of the UK's Contracts for Difference Program to support
50 renewable energy and the World Bank's Pilot Auction Facility, which supports methane and N₂O mitigation
51 projects, and conclude that auctioned price floors for emission reductions could provide an alternative to
52 existing public climate finance strategies.

53
54 Finally, a common lesson identified (Pahle et al. *under review*) is that the lack of data on policy performance
55 and cost observed in almost all case studies, along with frequent changes of policies in many assessed cases,

1 undermine the ability to monitor and evaluate policies. A better ex-ante policy design and ex-post
2 management would greatly help policymakers to monitor performance and steer potential policy reforms. In
3 addition, this would enable more rigorous ex-post analysis effectiveness and impact - a serious knowledge
4 gap in climate policy.
5

6 7 8 **4.4.8 Enabling climate finance** 9

10 Finance plays a critical role in governing long-term market responses. There are however, some concerns
11 about the short-term bias of climate finance (Black and Fraser 2002; Bushee 2001; Miles 1993). This has
12 been previously explained by the way compensation schemes are designed (Tehrani and Waeglein 1985),
13 by herd behaviour (Bikhchandani and Sharma 2000), credit constraints and arbitrage costs (Shleifer and
14 Vishny 1990), and the risks of debt accumulated via leverage-by-outs.
15

16 This bias typically leads to chronic under-investment in long-term projects and unrealistic expectations on
17 financial returns from low-carbon investments. It therefore, needs more than direct carbon pricing to deliver
18 this transition. At a minimum, it will require the building of appropriate financial intermediation to make
19 low-carbon assets attractive for savers and tempering the current market preference for liquidity.
20

21 22 **4.4.8.1 The quantitative challenge**

23 Many assessments have been made by expert groups of the investment needs for a 2°C target. The World
24 Economic Forum (WEF 2013) estimates that \$ 85 trillion in investment in low-carbon infrastructure is
25 required by 2030 to meet a 2°C target. The Global Commission on the Economy and Climate (GCEC 2014)
26 has a higher estimate, of \$ 94 trillion, for the same target and period. Restricting emissions sufficiently to
27 meet a goal of 1.5°C and the SDGs demands an acceleration of action required, that is an additional
28 \$ 10 trillion per year in the ‘two to three years after 2018’ (Wolf et al. 2017).
29

30 One difficulty is that, while investments in the energy sector and energy efficiency are well identified,
31 investments needs to decarbonize transportation and other infrastructure are poorly defined. The Cities
32 Climate Finance Leadership Alliance e.g. notes that ‘global demand for low-emission, climate-resilient
33 urban infrastructure will be in the order of \$ 4.5 trillion to \$ 5.4 trillion annually from 2015 to 2030’
34 (CCFLA 2016). There is also large uncertainty about upstream investments in the material transformation
35 and manufacturing sectors. One first attempt to assess them suggests a multiplier effect of 1.2 (Aglietta et al.
36 2015b).
37

38 *[A consolidated table to clarify the orders of magnitude at stake will be presented in the SOD]*
39

40 Whatever their uncertainty, these figures amount to about 0.5% to 0.8% of world GDP for the 2°C target and
41 an increase of between 2-3% of the total Gross Capital Formation in comparison with a non-climate policy
42 scenario. This increase is higher in most developing countries (IEA 2014) because they typically are in a
43 catch-up development phase, with heavy dependence on energy and energy-intensive sectors.
44

45 A critical issue is whether the low-carbon transition will imply a drain on consumption (Bowen et al. 2017).
46 The consumption response can be influenced by the use of appropriate policies, for example drawing upon
47 savings allocated to the real-estate sector and liquid financial products, or enabling the redirection of savings
48 to productive carbon-sensitive investments (Summers 2016; Teulings and Baldwin 2014; King 2010).
49

50 The financial flows for 1.5°C transitions seem to more significant that estimated by most climate models.
51 First, the up-front investment costs are 1.9-3.2-fold higher than estimates relying on levelized costs (World
52 Bank 2016). Second, the amount of redirected investments in mitigation is far higher than incremental
53 investments because most of low-carbon technologies are not end-of-pipe equipment, and may involve
54 significant incremental capital investments over conventional carbon-based options. Aglietta et al. (2015b)
55 estimate the redirected investment to be around three times higher than the incremental investments. Third,

1 the notion of incremental costs is not relevant in a below 2°C world because the first priority is to reduce the
2 funding gap for low-carbon, climate resilient infrastructures in many developing countries (Arezki et al.
3 2016). Once that gap has disappeared, so have incremental costs. Fourth, funding needs depend upon the
4 magnitude of the risk-weighted capital costs, which are higher than the typical capital costs.
5

6 Ultimately, whether the transition to a 1.5°C world will be confronted by insurmountable macroeconomic
7 challenges or will help regional and global economic recovery will depend on the evolution of a financial
8 system that bridges the regional and temporal gap between short-term cash balances and long-term low-
9 carbon assets.
10

11 4.4.8.2 *Redirecting savings and de-risking low-carbon investment*

12 The financial community's attention for climate change grew after COP 15 in Copenhagen in 2009 (Gros et
13 al. 2016). The three-risk alert by the Governor of the Bank of England on the Tragedy of the Horizons
14 (Carney 2016) is confirmed by literature: the physical risk of the impact of climate events on the value of
15 financial assets (Battiston et al. 2017), the liability risk (Heede 2014) and the transition risk due to
16 devaluation of entire classes of assets (Platinga and Scholtens 2016). These factors represent a potential
17 threat to the stability of the global financial system (Arezki et al. 2016; Christophers 2017). The transition
18 risk will be exacerbated by the 1.5°C imperative, while physical risk would be mitigated.
19

20
21 The UNEP-Inquiry (2015), the G20 Green Finance Study Group and the Financial Stability Board
22 (2015) also focus on the importance of transparency and of the disclosure of climate-related risks in
23 financial portfolios. For instance, France adopted a mandatory disclosure (see Article 173 in its 2015
24 Energy Transition Law). Such disclosure obligations might lead to the creation of low-carbon financial
25 indices that investors could consider as a 'free option on carbon' and as a hedge against a cap on emissions
26 (Andersson et al. 2016).
27

28 With the possible exception of REDD+ for forest protection, which tried to leverage private finance (Laing
29 et al. 2015), the movement to accelerate the emergence of climate friendly financial products is too recent
30 to have been analysed by scientific literature. Estimates of green bonds issuance, largely due to the
31 momentum of private capital, are about \$ 200 billion in 2017 according to Moody (BNEF 2017). However,
32 there is an accounting challenge due to the lack of standardization of what is a 'green bond' and of the
33 control of their 'greenness'. Another is that relying on climate-related information alone assumes that the
34 'efficient market hypothesis' applies, that is integrating all climate uncertainties into an ex-ante probability
35 distribution to enable the financial system to allocate capital in an optimal way (Christophers 2017). It is
36 argued that climate change is unhedgeable by individual strategies (Kelly and Reynolds 2016) and is a
37 systemic risk (Schoenmaker and Tilburg 2016). The debate on this theme is only just starting.
38

39 The voluntary disclosure approach may be a first step to encourage financial actors to stop investing in
40 fossil fuels (Ayling and Gunningham 2017; Platinga and Scholtens 2016). In the absence of structural
41 incentives, asset managers might not resist the attractiveness of carbon-intensive investments in many
42 regions. Decarbonizing an investment portfolio is not synonymous with investing in a low-carbon
43 development path.
44

45 The crux of the challenge is to: (1) link the emergence of climate-friendly financial products with the
46 reduction of the risk-weighted capital costs of low-carbon projects; and (2) increase the quantity of bankable
47 projects at a given carbon price. The specific barrier problem of low-carbon investment is a low 2 to 4
48 leverage compared with a degree of leverage of 3-15 range for other public funding mechanisms (Maclean et
49 al. 2008; Ward et al. 2009). This weak financial performance is due to the interplay between the intrinsic
50 uncertainty of low-carbon technologies in the mid-term of their learning-by-doing cycle, of future revenues
51 because of the volatility of oil and gas prices (Gross et al. 2010; Roques et al. 2008), and of the very
52 regulatory risks about carbon pricing policies. This is not only an inhibiting factor for corporations
53 functioning under a 'shareholder value business regime' (Berle and Means 1932; Roe 2001; Aglietta 2015;
54 Froud et al. 2000), but also for cities and local authorities, SMEs with restricted access to capital, and
55 households with high discount rate preferences (when they invest in energy efficiency). For these

1 economic actors the expected ‘reward’ of carbon taxes or carbon prices on the current carbon market come
2 too late to compensate for uncertainty about the technical performance of low-carbon projects and about the
3 ‘reward’ itself.

4
5 Recent literature therefore places a focus on policy instruments aimed at de-risking, ranging from interest
6 rate subsidies, feebates, tax breaks on low-carbon investments, concessional loans from development banks,
7 and public investment funds. These instruments will need to incorporate an agreed Social Value of
8 Mitigation Activity to reduce the risk of arbitrariness and ensure the overall economic efficiency of climate
9 policies (Hourcade et al. 2015; La Rovere et al. 2017).

10
11 Many proposals have been made around the use of public guarantees to secure high leverage public
12 financial support to reduce regulatory uncertainty for example Green Infrastructure Funds managed by a
13 multilateral development fund (Studart & Gallagher, 2015; De Gouvello and Zelenko 2010; Emin et al.)¹.
14 An advantage of public guarantees is that they imply a direct burden on taxpayers only in case of default of
15 the project; a risk that can be mitigated by strong Monitoring Reporting and Verifying systems (MRV)
16 (Bellassen 2015). Another advantage is a lower risk-weighted capital cost of low-carbon investment
17 supported by public guarantees compared to the present value of project SVMA (Hourcade et al. 2012).
18 Hirth and Steckel (2016) show the substitution curve between carbon price and decreasing capital costs that
19 could trigger a given amount of investments, which is important for developing and emerging economies,
20 where capital costs tend to be higher than in high-income countries (Steckel 2016; De Gouvello and Zelenko
21 2010).

22
23 Combining public guarantees and a predetermined value of avoided emissions would improve the
24 consistency of non-price measures by using a common notional price in projects’ selection and support the
25 emergence of financial products backed by a new class of certified assets to attract savers in search of safe
26 and ethical investments (Aglietta et al. 2015b). It could dispel suspicions about the ‘green-washing’ of
27 financial flows and hedge against the fragmentation of climate finance initiatives. However, these market-
28 based mechanisms may not be appropriate to respond to non-market priorities like the provision of
29 infrastructure for basic needs and the enhancement of adaptive capacities, which may need overseas
30 development assistance, innovative removal of fossil fuel subsidies (Jakob 2016) and introduction of
31 carbon taxes (Jakob 2016).

32 33 4.4.8.3 *Public commitments and evolution of the financial systems*

34 Public guarantees have been a privileged national tool to enable systemic transformations like the
35 deployment of the railway systems at the end of the 19th century. Such guarantees in the climate case
36 amount to quantitative easing of monetary policy with money issuance backed by the low carbon projects as
37 collateral. Amongst suggested international mechanisms are the use of Special Drawing Rights of the IMF
38 to fund the paid-in capital of the Green Climate Fund (Bredenkamp and Pattillo 2010), and public
39 guarantees at a pre-determined face value per tonne to refinance low-carbon loans (Aglietta et al.
40 2015 a,b). All these proposals are tentative and demand further scrutiny. Yet, they might be needed to
41 accelerate on three aspects, which are outlined below.

42
43
44 First, the access of developing countries to affordable loans *via* bond markets and lower exchange rate risk,
45 which constitutes a barrier for large classes of long-term investments. Given lowering support for ODA
46 in developed countries, such loans might be the only way of establishing a burden sharing mechanism
47 between rich and poor countries that enhances reciprocity and enables countries to deploy ambitious NDCs,
48 including the increase of their domestic carbon prices (Edenhofer et al. 2015; Stern-Stiglitz 2017).

49
50 Second, the emergence of new asset classes may be necessary to redirect financial flows worldwide;
51 compensate for ‘stranded’ assets caused by divestment in carbon-based activities; and that back part of the
52 assets of financial and insurance institutions. This new class of assets could facilitate the low carbon
53 transition for fossil fuel producers and help them to overcome the ‘resources curse’ syndrome (Venables

¹ One prototype is the World Bank’s Pilot Auction Facility on Methane and Climate Change

1 2016; Ross 2015)

2
3 Third, the involvement of non-state public actors like cities and regional public authorities that govern
4 infrastructures investments are critical for the penetration of low-carbon energy systems, shaping the urban
5 dynamics (Cartwright 2015), fostering changes in agriculture and food systems.

6
7 Public guarantees and the involvement of non-state actors are also important for investments enhancing the
8 adaptive capacity of societies to climate change. However, the economic rationale of these investments
9 differs from mitigation investments because (1) their social value cannot be expressed in a ‘per tonne’
10 metric; (2) climate models are not very good in predicting the consequences of global warming at regional
11 scales; (3) the challenge to reduce investment deficits on basic infrastructure; and (4) they concern non
12 market-based services. This implies that adaptation investments could remain in the domain of domestic or
13 overseas development assistance, also given the recent decline of the CER prices.

14
15 One issue under debate is the premise that money should remain neutral (Annicchiarico and Di Dio, 2015;
16 Annicchiarico and Di Dio, 2016 Nikiforos and Zezza, 2017). This implies that central banks could act as a
17 facilitator of low-carbon financing instruments, while ensuring better the stability of the financial system.
18 This might lead to the use of carbon-based monetary instruments to diversify reserve currencies (Jaeger et al.
19 2013) and to differentiate reserve requirements (Rozenberg et al., 2013) in a prospective Climate Friendly
20 Bretton Woods (Sirkis 2015; Stua 2017).

21
22 An unresolved macro-economic debate is whether investing in low-carbon programmes or adaptation
23 projects would ultimately be cost-saving (NCE 2016) and could unlock new economic opportunities (GCEC)
24 2014), without crowding out private or public investments (Pollitt and Mercure, 2017). This could be done
25 injecting liquidity into the low-carbon transition *via* underinvested infrastructure sectors (IMF, 2014) that
26 have a potential ripple effect large enough to trigger a new growth cycle (Stern 2015, 2013). This could,
27 if managed appropriately, assist managing the dangerous waters between stranded assets and green financial
28 bubbles (Safarzynska and Van den Bergh, 2017).

29
30 A transition to a 1.5°C world that is aligned with SDGs, implies a move to shift the ‘production frontier’ of
31 the global economy over both the short- and the long-term. A key strategy to successfully enable this is to
32 reducing the regional and temporal gap between the ‘propensity to save’ and the ‘propensity to invest’ thus
33 mitigating some of the ‘fault lines’ of the global economy (Rajan 2016).

34 35 36 **4.5 Integration and enabling transformation**

37 38 **4.5.1 Knowledge gaps and key uncertainties**

39
40 Concerning the pathways keeping global warming to 1.5°C by 2100, new scenarios show how mitigation
41 would need to respond – both in terms of an increased scale and a more rapid pace. Different methodologies
42 reviewed in Section 4.2 have been developed to put this into historical context and thereby test the realism of
43 the pathways. For a more comprehensive assessment, more knowledge would be needed on historical rates
44 of change in land transitions. Furthermore, while there are rates of change in energy and land transitions
45 available, they do not reflect short-term changes and tipping points that are emerging for some renewable
46 energy options. Finally, current studies on rates of change are focused on generic economic parameters or on
47 technology, but do not take into account realistic behaviour and lifestyle parameters, nor political and
48 institutional (capacity) change.

49
50 However, when looking at impacts and adaptation, to date large literature gaps remain with respect to the
51 assessment of incremental economic and climate impacts between end-of-century warming levels of 1.5°C
52 and 2°C, especially when overshooting the target during the century. In particular, there is a lack of
53 knowledge on how much climate damage at the global level is reduced as a result of being more ambitious
54 and an absence of information on avoided adaptation investments associated with keeping warming to 1.5°C

1 compared to business-as-usual or keeping warming to 2°C. The available evidence outlined in Section 4.2 is
2 mostly on specific impacts in specific regions that will not allow any sort meaningful comparisons or
3 generalization aiding implementation. Furthermore, relatively literature has been published on individual
4 adaptation options since AR5 – as evident from the assessment in Section 4.3 - and neither are there any
5 1.5°C-specific case studies. In addition, the literature on effectiveness of current adaptation is very scant and
6 regional information on some options does not exist at all, especially in the case of land use transitions. Even
7 though strong claims are made with respect to synergies and trade-offs, there is little knowledge of co-
8 benefits by region.

9
10 Considering the three main systems for which mitigation and adaptation options have been assessed in this
11 chapter, urban systems feature major gaps in knowledge pertaining to innovation desirable within local
12 governance arrangements that may act as key mediators and drivers for achieving global ambition and local
13 action. An uncovering of the heterogeneous mix of actors, settings, governance arrangements and
14 technologies involved in the governance of climate change in cities in different parts of the world is needed
15 for this. Similarly, including the criteria of justice in climate responses is a key omission in the current
16 literature. Furthermore, the possibility of a new city/urban science that bridges disciplinary boundaries and
17 practices a mix of approaches to create an evidence base for action should be explored. In this context, it is
18 also important to better understand processes and mechanisms linked to co-design and co-production of
19 climate knowledge (across practice and research, across multiple actors), particularly at the science-policy
20 interface. On the economic side, regional and sectoral adaptation cost assessments are missing, particularly
21 in the context of welfare losses at household level, across time and space. Related to this, the political
22 economy of adaptation needs to be better understood, particularly addressing the cost-benefit asymmetry,
23 adaptation performance indicators which could stimulate investment, and distributional aspects of adaptation
24 interventions. For concrete planning, more evidence is then needed on hot-spots, for example the growth of
25 peri-urban areas, populated by large informal settlements. Finally, major uncertainties emanate from the lack
26 of knowledge on integration of climate adaptation and mitigation, disaster risk reduction, and urban poverty
27 alleviation.

28
29 For the land system, land-based mitigation will play a major role in 1.5°C stabilization pathways and more
30 knowledge is needed with respect to how this can be reconciled with land demands for adaptation and
31 development. However, while there is now more literature on the underlying mechanisms at work here, data
32 are often more than insufficient to draw robust conclusions, with disagreements between the main land use
33 map products being substantial. New efforts using hybrid strategies based on remote sensing, data sharing
34 and crowd-sourcing are emerging, which can help to fill this gap. This lack of data counts especially also for
35 social and institutional information, which is therefore also not integrated in large-scale land use modelling.

36
37 For the energy system, it is important to note the special challenges that a 1.5°C target brings with it: energy
38 demand has very little scope for further growth, while at the same time providing universal access to energy,
39 as many people still suffer from no access or energy poverty at least. Whilst combinations of new smart
40 technologies and sustainable design are showing how overall reductions in energy demand can be applied to
41 buildings, transport and industrial processes, there is a lack of knowledge about how this can be applied at
42 scale in settlements. Furthermore, the shift to intermittent renewables that many countries have implemented
43 are just reaching levels where large scale storage systems are required to enable resilient grid systems, thus
44 new knowledge on the opportunities and issues associated with scaling up zero carbon grids is now needed.
45 Knowledge about how zero carbon electric grids can also integrate with the full scale electrification of
46 transport systems is also needed. One outstanding feature of the 1.5°C scenarios is their increased reliance on
47 negative emissions or removal of CO₂ from the atmosphere. However, the bottom-up analysis of the
48 available options in Section 4.3 indicates that there are still key uncertainties around the individual
49 technologies, with ocean fertilization, for example, needing much more robust results rather than a reliance
50 on few experiments and theoretical modelling, and land-used-based options like BECCS and afforestation
51 and reforestation having environmental implications that have hitherto not been systematically assessed and
52 quantified. In order to thus obtain more information on realistically available and sustainable potentials,
53 more bottom-up, regional studies are needed. These can then inform the larger models again with their
54 insights. Other knowledge gaps pertain to issues of governance and public acceptance, the impacts of large-
55 scale removals on the carbon cycle and potential hysteresis, the potential to accelerate deployment and

1 upscaling, and means of incentivisation in the absence of carbon pricing and public support. Finally, the use
2 of captured CO₂ is not per se generating negative emissions and needs further scrutiny as a mitigation option.
3 Reducing Short-Lived Climate Pollutants (SLCPs) could be one way to reduce the reliance on negative
4 emissions in a 1.5°C pathway, but in the absence of economic incentives, more evidence is needed,
5 particularly from developing countries, to support the argument that targeting SLCP reduction also generates
6 significant co-benefits (for e.g., better health outcomes, agricultural productivity improvements). New
7 research that helps articulate how SLCP reduction policies can be aligned with concerns at scale would
8 facilitate such an integration. Further challenges arise on the international level, where frameworks are
9 needed that help integrate SLCPs into emissions accounting and reporting mechanisms and a better
10 understanding of the links between Black Carbon, air pollution, climate change and agricultural productivity
11 must be achieved.

12
13 Another strategy assessed in Section 4.3 that is increasingly discussed in the face of our dwindling emissions
14 budgets is Solar Radiation Management (SRM). Yet, on spite of increasing attention to the different
15 concerns of SRM, knowledge gaps remain not only on the SRM options themselves, but also on ethical
16 issues in general and the governance structure for SRM. In particular, we do not know when, where, and how
17 ‘moral hazard’ might appear, how to construct a compensation system of SRM and what precautions to take
18 against objectionable mitigation obstruction.

19
20 Finally, turning to the implementation of the options to mitigate and adapt, Section 4.4 has generally
21 identified a lack of 1.5°C-specific literature, for example on institutions and on lifestyle and behavioural
22 change. Even relying on 2°C-specific literature and extrapolating assuming an increased pace and scale of
23 change, some uncertainties remain: in particular, whereas mitigation pathways studies address (implicitly or
24 explicitly) the reduction or elimination of market failures (e.g. external costs, information asymmetries) *via*
25 climate or energy policies, no study seems to address behavioural anomalies and behavioural change
26 strategies in relation to mitigation and adaptation actions in the 1.5°C context. From a modelling point of
27 view, a paramount challenge is to what extent a representation of (empirically estimated) behavioural
28 determinants of technology choice or adoption is actually feasible in detailed process IAMs (Chapter 2).
29 These aspects continue to limit our understanding and treatment of behavioural change and the potential
30 effects of related policies in ambitious mitigation pathways. Furthermore, behaviour and lifestyle change are
31 hardly addressed in modelling, and mitigation behaviour tends to be studied more extensively than
32 adaptation behaviour, even though Section 4.4.5 points to a growing body of recent literature on adaptation
33 behaviour in agriculture. The literature appears to be moving towards an understanding that adaptation action
34 has focused too much on assets (e.g. finances for adapting, access to resources, access to information etc.) as
35 barriers or enablers of adaptation, but tends to underplay the role of cognition (through perceived self-
36 efficacy, risk perception etc.). Finally, most research has been conducted in Western countries (far less in
37 e.g. LMIC and former Soviet bloc countries) and the focus is often on changing individuals - far less on
38 changing groups (e.g. communities), organizations and political systems.

39
40 For implementation of adaptation options, there is a lack of monitoring & evaluation of adaptation measures,
41 with most studies enumerating the M&E challenges and emphasizing the importance of context and social
42 learning. Very few studies seek out to evaluate whether an adaptation initiative has been effective or not.
43 One of the challenges of M&E for both mitigation and adaptation is that some communities lack high quality
44 information and data for models; this is especially seen for IWRM.

45
46 Concerning policies, there is also very little literature that is 1.5°C -specific in the area of mitigation, yet
47 building on knowledge from the 2°C -specific literature and taking into account the shorter time window for
48 policies to take effect, many lessons could be drawn in Section 4.4.7. In addition, some case studies are
49 emerging that allowed Section 4.4.7 to study the effectiveness of policies and policy packages for
50 accelerated change and across multiple objectives. Yet, much more empirical research is needed to derive
51 robust conclusions on what works and what does not in order to provide aid to decision-makers seeking to
52 ratchet up their national commitments in 2018. Adaptation policy meanwhile has focused more on
53 engineering and the built environment and institutions, however, ‘social’ adaptation, such as social
54 protection initiatives have been critiqued because they don’t address climatic risk specifically. So there is a
55 need for adaptation initiatives that address social vulnerability (social protection, cohesion, capacity) while

1 addressing climatic risk at the same time.

2
3 For climate finance assessed in Section 4.4.8, there is now a better understanding of the flows of finance and
4 where they can come from. Also here, knowledge gaps persist with respect to the vehicles to match this
5 finance to its most effective use in mitigation and adaptation.

6
7 Generally speaking, an upscaled and more rapid transition introduces new challenges for efforts to assess the
8 feasibility of projects and programmes that would deliver this change. Conventional metrics such as cost-
9 benefit analysis and internal rate of return are prone to quantification bias and limited in the extent to which
10 they capture the relative merits of the available options in the context of the 1.5°C target. Equally, however,
11 multi-criteria assessments and expert opinion are subjective and difficult to apply in a consistent manner
12 across all contexts. Additional work is therefore required to develop assessment methodologies that prioritize
13 the types of options that will deliver on these challenges in consonance with sustainable development, while
14 simultaneously factoring in the implications of innate uncertainty and the risks of lock-in to options that
15 produce unforeseen negative consequences.

16 17 18 **4.5.2 Implementing mitigation**

19 *[Synthesis of 4.2, 4.3 and 4.4 relevant to mitigation to be included in the SOD]*

20 21 22 **4.5.3 Implementing adaptation**

23 *[Synthesis of 4.2, 4.3 and 4.4 relevant to adaptation to be included in the SOD]*

24 25 26 **4.5.4 Convergence with sustainable development**

27 *[Synthesis of 4.2, 4.3 and 4.4 relevant to sustainable development to be included in the SOD]*

30 31 **Box 4.12: Consistency between NDCs and 1.5°C scenarios**

32 33 **Mitigation**

34
35 The COP21 Paris Agreement seeks to strengthen the global response to the threat of climate change, limiting
36 the increase of global average temperature to ‘well below 2°C above pre-industrial levels and pursuing
37 efforts to limit the temperature increase to 1.5°C above pre-industrial levels’, with the ‘aim to reach global
38 peaking of greenhouse gas emissions as soon as possible’ and ‘achieve a balance between anthropogenic
39 emissions by sources and removals by sinks of greenhouse gases in the second half of this century’
40 (UNFCCC 2015).

41
42 The Paris Agreement departs from the top-down approach of the Kyoto Protocol, which assigns mandatory
43 reduction limits to Annex I countries, and it adopts a bottom up approach in which each country determines
44 its contribution to reach the common target. These national targets, plans and measures are called ‘nationally
45 determined contributions’ (NDCs). NDCs shall be revised and increased every five years through a global
46 stocktaking mechanism established by the UNFCCC, supported by a facilitative dialogue in 2018, and a first
47 formal review in 2023. According to Article 4.2 of the Paris Agreement, each party is obliged to ‘prepare,
48 communicate and maintain successive NDCs’ as well as to pursue domestic mitigation measures to achieve
49 the NDC’s objective’ (van Asselt and Kulovesi 2017). Subsequent NDCs must increase in ambition and be
50 based on the principles of ‘highest possible ambition’ as well ‘common but differentiated responsibilities and
51 respective capabilities, in the light of different national circumstances’.

52
53 There is high agreement in the literature that NDCs provide an important part of the global response to
54 climate change and represent an innovative instrument, which has all countries committed to contributing to
55 mitigation (Rogelj et al. 2016; Robiou du Pont et al. 2016; Vandyck et al. 2016; Hof et al. 2017; Iyer et al.

2015; Fujimori et al. 2016; Sanderson et al. 2016; Pan et al. 2017; Jiang et al. 2017; den Elzen et al. 2016). NDCs represent in any case an improvement compared to the Business as Usual pathway to 2030 (Rogelj et al. 2016; Hof et al. 2017; den Elzen et al. 2016). According to the UNFCCC by the end of 2016, a total number of 190 Parties, or 96% of all Parties to the UNFCCC, have submitted 162 NDCs. In May 2016, the UNFCCC completed a full analysis on the NDCs, reporting that the temperature would continue to rise to reach 2.2°C to 3.4°C above preindustrial levels in 2100, even with a full implementation of NDCs policies and measures (UNFCCC 2016). This range has been broadly confirmed by other analyses from UNEP (UNEP 2016), or the peer-reviewed literature (Fawcett et al. 2015; Rogelj et al. 2016).

Several studies estimate global emission levels that would be achieved under the NDCs, for example, (Fujimori et al. 2016; Vandyck et al. 2016; Sanderson et al. 2016; Iyer et al. 2015; Hof et al. 2017; Rose et al. 2017; Rogelj et al. 2017; Luderer et al. 2016; Rogelj et al. 2016; Fawcett et al. 2015).

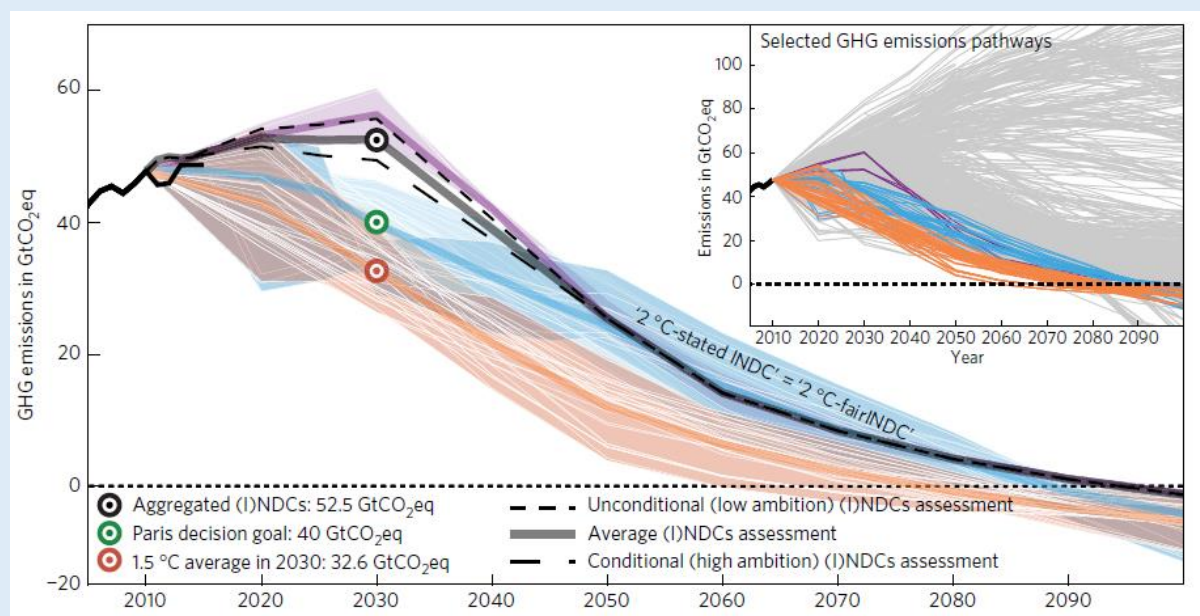
The key question related to current NDCs and 1.5°C pathways is whether the implied emissions reductions are in line with a 1.5°C consistent pathway. As the time horizon of NDCs is maximally until 2030, most of the NDCs do not include long-term targets (Fujimori et al. 2016), with only a few countries such (e.g. US and the EU) have included indicative targets or ranges for 2050 (Rose et al. 2017) and 1.5°C pathways require a deep decarbonisation over multiple decades to reach carbon neutrality by around mid-century, the NDCs by themselves cannot be sufficient. However, an analysis of their implied measures and emissions reductions can provide insights into whether a transition towards the required transition for a 1.5°C pathway is already envisaged. Several authors (Rogelj et al. 2016; Robiou du Pont et al. 2016; Vandyck et al. 2016; Hof et al. 2017; Iyer et al. 2015; Fujimori et al. 2016) have run integrated assessment models to assess the contribution of NDCs to achieve the 1.5°C targets in the Paris agreement. Different assumption for the period post 2030 have been made. The multiple assessments that have looked into this question find that current NDCs are not in line with pathways that limit warming to 1.5°C by the end of the century (Fujimori et al. 2016; Vandyck et al. 2016; Sanderson et al. 2016; Rogelj et al. 2016; Iyer et al. 2015; Hof et al. 2017; Rose et al. 2017; Fawcett et al. 2015; Rogelj et al. 2017; Luderer et al. 2016). The latter 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 conditions related to finance and technology transfer. However, as the measures proposed in NDCs are not legally binding under the Paris Agreement, on the one hand, there is no strong guarantee that they will be implemented or that will achieve the proposed national 2030 targets (Nemet et al. 2017), and, on the other hand, there are also indications that in some regions there could be over-delivery on emissions reductions compared to what is indicated in their NDCs. This would further impact estimates of anticipated 2030 emission levels.

Estimates of 2030 emissions levels in line with the current NDCs fall outside the range of 2030 emissions found in 1.5°C pathways (see Section 2.3.3 in this report, Figure 2.10). Earlier studies indicated important trade-offs of delaying global emissions reductions in the context of trying to limit global mean temperature increase to 1.5°C (Sections 2.3.5 and 2.5.1). AR5 identified some flexibility in 2030 emission levels when pursuing a 2°C objective (Clarke et al. 2014) indicating that the strongest trade-offs for 2°C pathways could be avoided if emissions are limited to below 50 GtCO₂-eq yr⁻¹ in 2030 (here computed with the GWP-100 metric of the IPCC SAR). However, no such flexibility has been found for 1.5°C pathways (Rogelj et al. 2017; Luderer et al. 2016) indicating that the post-2030 emissions reductions required to still remain within a 1.5°C compatible carbon budget during the 21st century (Section 2.2) are not within the feasible operating space of state-of-the-art process-based global integrated assessment models of the energy-economy-land system. This indicates that the risks of failure to reach a 1.5°C pathway are significantly increased (Riahi et al. 2015b). Some studies show that if the current decarbonisation trends of the NDCs is continued after 2030, this most probably will result in a very late achievement of carbon neutrality (Sanderson et al. 2016), thus resulting in a higher effort of negative emissions and higher costs (Iyer et al. 2015).

Implementing deeper emissions reductions by 2030 towards the levels identified in Section 2.3.3, either as part of NDCs or by over-delivering on NDCs, would significantly reduce this risks of failure. The mechanisms for stock-taking and ratcheting-up of the targets can help in reinforcing the national pledges (Wakiyama and Kuramochi 2017).

Assessment frameworks have been proposed to analyse, benchmark and compare NDCs between countries. The variation in compliance with particular equity principles across NDCs and countries is large, an aspect which will be further elaborated in the Second Order Draft. Various assessment frameworks have been proposed to analyse, benchmark and compare NDCs (Jiang et al. 2017; Wakiyama and Kuramochi 2017; Postic et al. 2017; Fridahl and Johansson 2016; den Elzen et al. 2016). Most of the authors agree on a multi-criteria assessment framework (Höhne et al. 2017; Jiang et al. 2017; Pan et al. 2017) based in six equity principles of effort sharing to allocate emission targets most of the NDCs are ambitious apart India (Pan et al. 2017), while Robiou du Pont (2016) in a similar analysis based on equity allocation of cost-optimal scenarios, shows that all NDCs analysed fail on some equity principles used in the authors' assessment framework. Alternatively authors (Vandyck et al. 2016; Robiou du Pont et al. 2016) have allocated emission allowance to countries for the different pathways (e.g. at 2030 year) and have assessed the country gap between the pathways and the emissions in the NDCs.

In any case, the NDCs are also recognised by authors as increasing the transparency and credibility of the process (Nemet et al. 2017), even if in the present very open format and by using different types targets (Rodríguez and Pena-Boquete 2017), the aggregation of targets results in very high uncertainty (Rogelj et al. 2017). This uncertainty could be reduced with more focused energy accounting and clearer guidelines for compiling the future NDCs (Rogelj et al. 2017).



Box 4.12, Figure 1, (Robiou du Pont et al. 2016)

Adaptation

The National Adaptation Plans (NAPs) and Nationally Determined Contributions (NDCs) of each country already indicate the main areas of risk and vulnerability, and the flexibility allowed by the adaptation pathways allows for different options to be considered and changed as monitoring is carried out at each phase.

The Paris Agreement stipulates that adaptation communications shall be submitted as a component of or in conjunction with other communications, such as a Nationally Determined Contribution (NDC), National Adaptation Plans, or National Communication. Of the 190 Parties, there are a total of 160 NDCs submitted, out of which 140 have an adaptation component. NDC adaptation components can be an opportunity for enhancing adaptation planning and implementation by highlighting priorities and goals (Kato and Ellis 2016). At an international level, they signal political will for enhancing action on adaptation and ensure

1 accountability. At national the level they provide momentum for the NAP process and raise the profile of
2 adaptation (Sanchez-Ibrahim et al. 2017).

3
4 NDC adaptation goals have been presented quantitatively and qualitatively. A percentage of countries use
5 the NDCs to communicate their adaptation goals in quantitative terms. Adaptation cost estimates in the
6 NDCs aggregated to the global level are at \$ 653.2 billion (reporting from 35% of NDCs with adaptation
7 component). Estimated costs for activities that are already planned, in USD, are at \$ 146.2 billion (reporting
8 from 221% of NDCs with adaptation component). Quantified requested support for general adaptation
9 implementation in USD: \$ 38,024,480,000 (\$38 billion – reporting from 4% of NDCs with adaptation
10 component). Quantified committed for support for specific adaptation measures and/or sectors is, in USD,
11 \$ 19 billion (only 5% of NDCs with adaptation component).

12
13 Adaptation measures presented in qualitative terms, include sectors, risks, and vulnerabilities are seen as
14 priorities by the Parties. Sectoral coverage of adaptation actions identified in NDCs is uneven, with
15 adaptation primarily reported to focus on water sector (71% of NDCs with adaptation component),
16 agriculture (63%), and health (54%), and biodiversity/ecosystems (50%) (Sanchez-Ibrahim et al. 2017). The
17 table below shows a complete breakdown of sectors targeted in the NDCs:

18
19 **Box 4.12, Table 1:** NDC Targeted sectors.

Sectors specified	% of NDCs mentioning sector
Water	71%
Agriculture	63%
Health	54%
Biodiversity/Ecosystems	50%
Infrastructure/Transport	42%
Forestry	41%
Energy	27%
DRR	50%
Coastal protection	42%
Fishery	33%
Food Security	33%
Finance and Insurance sector	18%
Human settlement/Landuse	39%
Waste	9%
Education	13%
Tourism	22%

21
22 In order to strengthen the NDCs framework to deliver on adaptation goals, improving the structure, content,
23 and planning processes is essential (Magnan, A., Ribera, T., Treyer et al. 2015). This will involve better
24 adaptation communication (Kato and Ellis 2016), which will need a strong national and sub-national
25 infrastructure that identifies, collates and reports adaptation-related progress.

26
27 The NAPs are country-owned and country-driven, they seek to enhance coherence between adaptation and
28 development planning, and they are designed so countries can monitor and review them on regular bases.
29 Out of 54 countries mentioning the NAP process in their NDC, 22 indicate that they have started the process
30 and 32 say they plan to do so prior to 2020. Around 45% of developing countries and more than 80% of
31 LDCs have started process of formulation and implementation of NAPs.

32
33 Linking the NDC and NAP process will be key to strengthening adaptation response (Magnan, A., Ribera,
34 T., Treyer et al. 2015). The NDCs should inform and mirror the processes on the ground as countries
35 operationalize national adaptation policy through the NAP. From a reporting perspective, then, it is
36 important that progress on the NAP is fully reported in the NDCs.

37
38 Other benefits of linking the reporting on the NAP through the NDC process are (Smithers, R., Holdaway,

1 E., Rass, N., and Sanchez Ibrahim 2017):

- 2
- 3 • Coordination between NDC and NAP development establishes coherent governance structures at national
- 4 level to avoid duplication of adaptation efforts and make efficient use of limited resources.
- 5 • Linking the NAP process with the NDCs can support adaptation/mitigation co-benefits and synergies.
- 6 The NAP process can inform development of the NDC's adaptation goals and how these goals are
- 7 implemented.
- 8 • Linkages between the NDCs and NAP process can emphasize countries' transparency frameworks
- 9 regarding adaptation policy.
- 10

11

12

13

14 **Box 4.13: Solar Radiation Management: Methods, effectiveness and technical feasibility**

15

16 **Solar Radiation Management methods**

17 Solar radiation management (SRM) refers to the modification of the Earth's albedo to increase the reflection

18 of incoming solar radiation. Several SRM technologies have been proposed to reduce global mean

19 temperature:

- 20 • Stratospheric aerosol injection (SAI) (Crutzen 2006; Keith and Irvine 2016; Irvine et al. 2016) which
- 21 would involve injecting of sulphates or other reflecting particles into the stratosphere continuously using
- 22 airplanes, tethered balloons, or other delivery technologies
- 23 • Marine cloud brightening (MCB) (Latham et al. 2014; Wang et al. 2011) (Alterskjær et al. 2013) which
- 24 would involve spraying sea salt or other particles into marine clouds, making them more reflective.
- 25 Spraying sea salt may also increase effective radiative forcing in clear-sky conditions (Ahlm et al. 2017)
- 26 • Cirrus cloud thinning (Jackson and Webster 2016; Muri et al. 2014) through seeding to promote
- 27 nucleation, reducing optical thickness and cloud lifetime, to allow more outgoing infrared radiation to
- 28 escape into space
- 29 • Sunshade geoengineering or 'space mirrors' which can be set in orbit in order to reflect sunlight back into
- 30 space (Angel 2006); Gaidos 2016)

31

32 Ground-based albedo modifications have also been suggested but are generally of smaller spatial footprint

33 and do thus not strongly affect the global temperature (Irvine et al. 2011, Seneviratne et al. *submitted*). These

34 include *white roofs* (Akbari et al. 2012; Jacobson and Ten Hoeve 2012), planting *more reflective crops*

35 (Irvine et al. 2011), *changes in land use management (e.g. no-till farming)*, which increase the reflectivity of

36 crop areas (Davin et al. 2014). *Change of albedo at a larger scale* (Irvine et al. 2011)(Seidel et al., 2014)

37 could involve covering glaciers or deserts with reflective sheeting with significant impacts on circulation

38 patterns and global temperature.

39

40 **Impacts on global temperature**

41 SRM approaches are generally discussed in the context of counteracting global climate change and reducing

42 warming. However, a world with 1.5°C mean global warming achieved with SRM is unlikely to have the

43 same characteristics, especially at the regional level, as a world where 1.5°C is reached through a fast

44 decrease of greenhouse gas emissions and a net zero CO₂ budget (Chapter 3). Among the SRM methods

45 listed above the ones that could most strongly affect global mean temperature are stratospheric aerosol

46 injection (SAI) and marine cloud brightening (MCB). Sunshade geoengineering could be effective in

47 temperature reduction also but is not feasible.

48

49

50 The idea of stratospheric aerosol injection (SAI) in the tropical lower stratosphere (a layer of the atmosphere

51 that begins between 10 and 18 km above the surface), was originally proposed by Budyko (1974, 2013) and

52 further developed by Crutzen (2006). The direct effect of aerosols injection is an increase in the local

53 concentration of optically active aerosol particles in the lower stratosphere. These particles increase the

54 amount of back-scattered solar radiation, resulting in less radiation arriving at the Earth's surface and cooling

1 the troposphere. Reviews of the current knowledge on SAI are found in Visionsi et.al. (2017), MacMartin
2 (2016) Keith and Irvin (2016) and Irvin et al. (2016).

3
4 The most often used SAI approach is sulphate geoengineering which mimics a volcanic eruption by injecting
5 sulphate aerosol precursors. Following the Mount Pinatubo eruption of June 1991, when 7–10 Tg S were
6 injected into the stratosphere, a sharp reduction in the net radiative flux at the top of atmosphere was
7 observed (2.5 Wm^{-2}), as well as a significant drop in global surface temperatures of about 0.5°C (Visioni
8 et.al. 2017).

9
10 Marine cloud brightening (MCB) would inject sea salt aerosols into the marine boundary layer to directly
11 scatter light, and increase the albedo of low-lying clouds. While the radiative forcing from stratospheric
12 aerosols is potentially relatively uniform in space and time, marine cloud brightening would create spatially
13 heterogeneous forcing and potentially more spatially heterogeneous climate effects (Latham et al. 2012).

14
15 Numerous recent simulation experiments assess the effectiveness of different SRM techniques. Comparison
16 of SAI and MCB effectiveness based on G3 GeoMIP experiment (Kravitz et al. 2011; Niemeier et al. 2013)
17 made by Aswathy et al. (2015) shows that both schemes reduce temperature increases by about 60% globally
18 compared with the baseline RCP4.5 scenario, but are more effective in the low latitudes and exhibit some
19 residual warming in the Arctic. The change in shortwave radiative forcing at the top-of-the-atmosphere for
20 the MCB experiment is smaller than the one for SAI over both ocean and land, but, for the MCB top-of-the-
21 atmosphere short wave fluxes are slightly larger over ocean relative to land. This reflects the more local
22 nature of MCB, since it is applied only over tropical oceans. The long-wave fluxes of both SRM schemes are
23 similar, with less difference between SRM techniques.

24
25 In case of MCB, the injection strategy is critical in determining the spatial distribution of injected particles
26 and the effectiveness of radiative forcing. The radiative effects from different simulated MCB experiments
27 summarized by Kravitz et al. (2013) vary depending on geoengineering technique and level and aerosols
28 injection area. The influence of ocean albedo increase on stabilization of global air temperature varies
29 spatially with most effective decrease is observed for ocean temperatures in the tropics and mid latitudes,
30 with less success in reducing temperature over land areas and the Arctic. The sea salt injection technique
31 under RCP4.5 forcing, starting in 2021, needs a uniform distribution of about 212 Tg a^{-1} dry sea-salt aerosol
32 emissions in the marine boundary layer between 30°S and 30°N by, to produce a global-mean effective
33 radiative forcing (ERF) of -2.0 Wm^{-2} (Kravitz et al. 2013). The largest ERF values are generally confined
34 within the 30°S to 30°N injection area.

35
36 Cirrus cloud thinning is well studied. Generally the effects of cirrus cloud thinning depends on the degree of
37 cloud optical depth modification (Schmidt et al. 2014). The estimated global cooling effect varies from 1°C
38 (Crook et al. 2015; Muri et al. 2014) to 1.4°C (Storelvmo et al. 2014).

39
40 The effectiveness, advantages and disadvantages comparison of SRM techniques are summarized in the Box
41 4.13 Table 1 (MacMartin et.al., 2017).

Box 4.13, Table 1: Effectiveness, advantages and disadvantages of SRM techniques.

SRM method	Ability to achieve global temperature stabilization	Advantages	Disadvantages	Application burden	Climatic response	Reference
Stratospheric aerosol injection	Very high Current technologies can likely be adapted to loft materials and disperse SO ₂ at relevant scales. Other aerosols injection: lofting similar to sulphate but aerosol dispersal much more uncertain	Similarity to volcanic sulphate gives empirical basis for estimating efficacy and risks. Some other solid aerosols may have less stratospheric heating and minimal ozone loss	Limited ability to adjust zonal distribution; ozone loss; stratospheric heating	Baseline – RCP8.5; start in 2040; max. injection 8.5 Tg S yr ⁻¹ (in form of SO ₂) in 2100	RF = -2.5 W m ⁻² Temperature stabilization +2 °C above pre-industrial	Tilmes et al., 2016
				Baseline – RCP8.5; start in 2049; max. injection 4.5 Tg S yr ⁻¹ (in form of H ₂ S) in 2100	Temperature stabilization +2°C above pre-industrial	Izrael et al., 2013
				Baseline – RCP4.5; start in 2020; equal annual injection 2.5 Tg S yr ⁻¹ (in form of SO ₂) till 2069	RF = from -1.6 to -3.6 W m ⁻²	Kravitz et al. 2011; Kashimura et al., 2017
				Baseline – RCP8.5; start in 2020; max. injection 45 Tg S yr ⁻¹ (in form of SO ₂)	RF = -5.5 W m ⁻²	Niemeier, Timmreck, 2015
Marine cloud brightening	Uncertain: observations support wide range of CCN impact on albedo; no system-level analysis of cost of deployment	Ability to make local alterations of albedo; and modulate on short timescales. Can also be used in clear-sky conditions	Mostly applicable on marine stratus covering -10% of Earth means RF inherently patchy.	Baseline – RCP4.5; start in 2020; 212 Tg a ⁻¹ dry sea-salt aerosol emissions in the marine boundary layer 30°S - 30°N	RF = -2 W m ⁻²	Kravitz et al., 2013
				11000 Tg a ⁻¹ dry sea-salt aerosol emissions over all open ocean	RF = -4.8 W m ⁻²	
Cirrus thinning	Uncertain: deep uncertainty about fraction of cirrus strongly dependent on homogeneous nucleation; no studies examining diffusion of CCN	Works on longwave radiation so could provide better compensation	Maximum potential cooling limited; zonal distribution of RF constrained by distribution of cirrus			
Sunshade geoengineering or “space mirrors”	Low physical uncertainty, but deep technological uncertainties	Possibility of near “perfect” alteration of solar constant	Likely prohibitively expensive			
Based on MacMartin et al., 2017 (forthcoming)						

Technical implementation and feasibility of the deployment

Most studies of technical implementation are focused on SR through stratospheric aerosol injection. Sulphur dioxide (SO₂) is most often used as a precursor of sulphate aerosol (Crutzen, 2006; Kravitz et al. 2011; Izrael et al. 2014; Vioni et al. 2017; Keith and Irvin 2016), however, other sulphate precursors (such as hydrogen sulphide (H₂S) can also be effective and may be preferable technologically and economically (Ryaboshapko et al. 2015). Different scattering aerosols (silicon carbide (SiC), synthetic diamond, aluminium oxide (Al₂O₃), titanium dioxide (TiO₂), zirconium dioxide (ZrO₂), calcium carbonate) could also be chosen that have less stratospheric heating potential relative to sulphate (Dykema et al. 2016) or that might reduce other side effects of SAI (Keith et al. 2016).

The highest burden to injection ratio is modelled for stratospheric injections between 30° N and 30° S (English et al. 2012). The altitude also plays a significant role in determining the aerosol lifetime, due to a faster sedimentation removal in the upper troposphere when the sulphur injection is closer to the tropical tropopause layer (Aquila et al. 2014). The SO₄ stratospheric lifetime in the simulations of Aquila et al. (2014) was approximately 1.2 and 1.8 years for sulphur injection in the altitude layers 16–25 and 22–25 km, respectively. The lifetime of sulphur aerosols erupted by Pinatubo was about four years.

The Geoengineering Model Intercomparison Project (GeoMIP) G4 experiment (Kravitz et al. 2011) used the RCP4.5 scenario as a baseline and injected SO₂ every year from 2020 to 2069 with a fixed SO₂ injection rate 5 Tg yr⁻¹. The mean values of radiation forcing (RF) reduction vary widely from approximately -3.6 to -1.6 Wm⁻². Significant feedback mechanisms exist among the magnitude and location of SO₂ injection, aerosol microphysics, background stratospheric dynamics, aerosol induced surface cooling and stratospheric heating rates, and induced changes in the stratospheric circulation and stratosphere–troposphere exchange (Vioni et al. 2017; Kashimura et al. 2017). The sum of all direct and indirect radiative forcing (RF) with an injection of 5 Tg SO₂ yr⁻¹ accounts for -1.4±0.5 Wm⁻², which means a compensation of the projected positive RF in 2100 relative to 2011 by 64, 38, and 23% for the IPCC scenarios RCP4.5, RCP6.0 and RCP8.5, respectively (Vioni et al. 2017).

SRM for global temperature stabilization at the level of 1.5°C above pre-industrial level has been proposed as a possible emergency switch if mitigation efforts do not produce global climate stabilization or if there is a temporary temperature overshoot (Keith and Irvin 2016; MacMartin et al. 2017; Chen and Xin 2017). The level of stratospheric sulphur burden required to meet the stabilization target may significantly depend on radiative response of different simulation models, injection height and technology (Izrael 2013; Tilmes et al. 2016; Niemeier and Timmreck, 2015).

SRM implementation requires lifting millions of tons of material to the stratosphere each year (Robock et al. 2009; Davidson et al. 2011; McClellan et al. 2012; Ryaboshapko et al. 2015; Irvine et al. 2016). The literature suggests the most feasible are (Irvine et al. 2016): high-altitude aircraft or tethered balloons (Davidson et al. 2011; McClellan et al. 2012). All assessments agree that aircraft have the potential to deliver millions of tons of material to the lower stratosphere (~20 km or 60 hPa) at a cost on the order of 1–10 billion US dollars per mega-ton of material per year (Robock et al. 2009; Davidson et al. 2011; McClellan et al. 2012). Tethered balloons offer a potentially cheaper alternative especially for large injection amounts, with estimated costs ranging from an order of magnitude less to an order of magnitude more than delivery by aircraft; (Davidson et al. 2011). Balloon borne injections would rely on less certain technologies, and as such, assessments disagree on its potential feasibility. (Davidson et al. 2011; McClellan et al. 2012).

Implications for regional climate and impacts of generally considered SRM techniques

The regional climate impacts of Global-scale Solar Radiation Management (SRM) are mostly assessed for Sunshade Geoengineering (SG) (which is mostly hypothetical but easier to implement in climate model simulations), and Stratospheric Aerosol Injections (SAI). (Rasch et al. 2008; see also previous subsections). These global SRM approaches are designed to offset the global mean warming induced by a certain level of increase in GHG. SG can be considered as a highly idealized model experiment, which represents some of the first-order climatic effects of SAI, but with significant differences in climate response (e.g., Robock 2014; Irvine et al. 2016). Both SG and SAI are set up to balance a particular radiative forcing (e.g., 4xCO₂ or RCP4.5), but SAI may produce a non-uniform forcing depending on where and in what form aerosols are

1 inserted in stratosphere (e.g. Muri et al. 2014; Laakso et al. 2012). For the same global mean temperature
2 reduction, SAI produces a greater change in the hydrological cycle than SG and would lead to greater
3 regional change in climate, particularly in the tropics (e.g., Irvine et al. 2016). For both SG and SAI an
4 abrupt termination of employment would lead to a ‘termination-shock’ with rapid global warming and
5 unknown consequences for the Earth system (Jones et al. 2013; for more information see Section 3 of this
6 Box).

7
8 In general, global model experiments suggest, that in case of a global SRM implementation, surface
9 temperatures would be reduced most in regions and lead to more moderate temperature and precipitation
10 extremes (Curry et al. 2014). However, this would be accompanied with an overcooling of tropical ocean
11 (Curry et al. 2014), a shift in the diurnal cycle (i.e. shift in night-time vs. day-time warming) (Lunt et al.
12 2008) and a residual temperature increase over high-latitude land regions and in Polar Regions (Curry et al.
13 2014). SRM model experiments indicate a reduction in the intensity of the hydrological cycle compared to a
14 4xCO₂ warming, with substantial regional differences in the hydrological cycle patterns, for instance, a
15 reduction of precipitation on land, particularly in monsoon regions, and more low-intensity rainfall events
16 (e.g., Bala et al. 2008; Tilmes et al. 2013). SRM methods may further induce shifts in ITCZ, Walker, and
17 Hadley cell circulations, with implications for precipitation changes in affected regions and towards
18 prevailing La Niña like conditions. (Niemeier et al. 2013). The weakening of tropical circulation as projected
19 under increased GHG would not be reduced by SAI (Ferraro et al. 2014). Atlantic hurricane storm surges
20 may be reduced by half (but only marginally statistically significant) with further implications for coastal
21 flood levels due to reduced sea level rise (Moore et al. 2015).

22
23 Ricke et al. (2010) point out that it would not be physically feasible for SRM to simultaneously stabilize
24 global precipitation and temperature if GHG continue to rise. While SRM, deployed along with emissions
25 cuts, could make it possible to reach a 2.0°C or even 1.5°C global-mean temperature warming, the associated
26 climate would be very different from a 2.0°C or 1.5°C climate associated only with greenhouse gas
27 mitigation (see Box 3.12). Tilmes et al. (2016) emphasize that the climate impacts by stringent emissions
28 cuts would be different from those of moderate emissions cuts supplemented by SRM cooling. This means
29 that global mean temperature would not be a good proxy for aggregate climate risks if solar geoengineering
30 were to be deployed (Irvine et al. 2017). The changes in spatial and temporal distributions of temperature,
31 precipitation and wind conditions induced by SRM would affect regions in different ways with recognizable
32 economic consequences. Specifically, under RCP4.5, SRM economic benefits are small, and may become
33 negative. While global GDP may increase with lower warming, regions with negative benefits (i.e. losses)
34 from SRM cannot be avoided (Aaheim et al. 2015), and thus SRM would inevitably create winners and
35 losers (e.g., Kravitz et al. 2014; Hegerl and Solomon 2009).

36
37 Because of these recognized shortcomings and risks associated with SRM, more recent publications have
38 also discussed more moderate deployments of SRM as potentially more realistic options (Keith and
39 MacMartin 2015). Nonetheless, a main issue remains that traditionally considered SRM implementations
40 such as SAI do not have scope for regional adjustment of the applied radiative forcing (MacMartin et al.
41 2012).

42
43 Beside SAI, modifications of the land surface reflectivity, for example *via* changes in the albedo of
44 agricultural land or urban areas (Irvine et al. 2011; Davin et al. 2014; Seneviratne et al. *submitted*) may be
45 considered. These land-surface radiation management methods have a smaller spatial footprint than SAI or
46 SG, because the forcing is more restricted in space. The land-surface radiation management approaches are
47 potentially better suited than SAI to affect local and regional temperature but would have at most only a
48 negligible effect on global temperature (e.g. Seneviratne et al. *submitted*). They should therefore be
49 considered as a different strategy than traditional SRM approaches, and may have more direct relevance in
50 the context of regional-scale adaptation (Boucher et al. 2013), although such regional effects may be relevant
51 in the development of realistic global socio-economic pathways (Chapter 2, and Box 3.12).

52
53 It is important to note that independently of any regional footprint of application, changes in temperature that
54 result from changes in radiative forcing (such as with SAI-based SRM, but also land-based changes in
55 surface albedo) do not address non-temperature impacts of greenhouse-gas concentrations, and in particular

1 ocean acidification (see Chapter 3, Section 3.3.1.1, IPCC 2014).

2
3 Other risks of SAI include: 1) the lack of testing of the proposed schemes (e.g. Schäfer et al. 2013); 2)
4 potential associated depletion of stratospheric ozone (Tilmes et al. 2008) which remain very uncertain (Irvine
5 et al. 2016); 3) possible tropospheric impacts (Irvine et al. 2016); and 4) effects on vegetation and crop
6 production (for more information see Section 4 of this Box). This last point is uncertain and has important
7 implications for sustainable development (see the Sustainable Development and SRM section of this Box
8 and Chapter 5).

9
10 The overall impacts on food production and ecosystems would result from the combined effects of 1)
11 changes in regional climate (with potential benefits, Pongratz et al. 2012, but also negative modifications on
12 regional scale in particular with respect to the water cycle); 2) changes in the ratio of incoming direct and
13 diffuse radiation (Pongratz et al. 2012); and 3) the extent of CO₂ effects on plant photosynthesis (Wenzel et
14 al. 2016; Mystakidis et al. 2017) and their possible reduction through nutrient or water limitation (Ciais et al.
15 2013, Reichstein et al. 2013).

16
17 Given the level of uncertainty in the various underlying processes, and the lack of comprehensive
18 assessments in the literature, it is not possible at the present time to confidently assess the effects of SAI
19 deployment on food production and ecosystem health. The precautionary principle and the potential regional
20 inequalities leads to the assessment, with *medium confidence* (expert judgment), that the risks of SAI
21 deployment for global food security and ecosystem health would outweigh the benefits, even for low levels
22 of application, at the present state of knowledge.

23 24 **Implications of terminating SRM**

25 A ‘Termination shock’ or ‘termination effect’ has been discussed in (Robock 2016; Izrael et al. 2014; Jones
26 et al. 2013a) (McCusker et al. 2014) and also highlighted in AR5 (Boucher et al. 2013). All model results
27 concur that a sudden stop of SRM SAI deployment will lead to rapid temperature rise, accompanied by
28 increases in global-mean precipitation rate toward the levels they would have reached without SRM. This
29 happens because SRM would not reduce atmospheric GHG concentrations, it would only mask their
30 warming effect by blocking sunlight (Jones et al. 2013) examine changes in sea-ice cover and global-mean
31 plant net primary productivity due to abrupt suspension of SRM SAI. Results show considerable agreement
32 regarding the distribution of reductions in Arctic sea-ice, but no agreement on the impact to the global-mean
33 plant net primary productivity. (McCusker et al. 2014) show that increased net primary productivity on land
34 is one of potential positive impact of SRM cessation, however there is disagreement among global climate
35 models on the sign of the response (Jones et al. 2013). According to (McCusker et al. 2014) food production
36 could be severely reduced in many regions concurrently under a scenario of high GHG emissions and SRM
37 termination and many species suddenly reach their survival limits due to SRM cessation.

38
39 Some recent studies indicate that the risks and benefits of SRM including “termination effect” depend on
40 assumptions about SRM implementation (Keith and MacMartin 2015; Reynolds et al. 2016). They showed
41 that the termination shock could be avoided or reduced under well-orchestrated deployment and cessation of
42 SRM (for example, scenario in which SRM cooling is ramped up and then slowly ramped back down again)
43 although this would require strong governance and institutional arrangements. (Kosugi 2013) demonstrates
44 that if the SRM cooling remained below a certain threshold, it would be hard to detect the effects of
45 termination against the natural variations in temperature. When SRM starts, it exerts a high degree of
46 cooling, and it cannot be stopped suddenly, but could be phased out over a long period (Reynolds et al.
47 2016). SRM should be used only in combination with emission reduction and CDR (Irvine et al. 2016).

48 49 **Implications for other geophysical quantities**

50 Stratospheric water vapour

51 Upper-tropospheric ice and cirrus clouds

52 Stratospheric and tropospheric ozone and other stratospheric chemistry (ch5 address only in context of
53 health)

54 Glacier evolution under SRM

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48

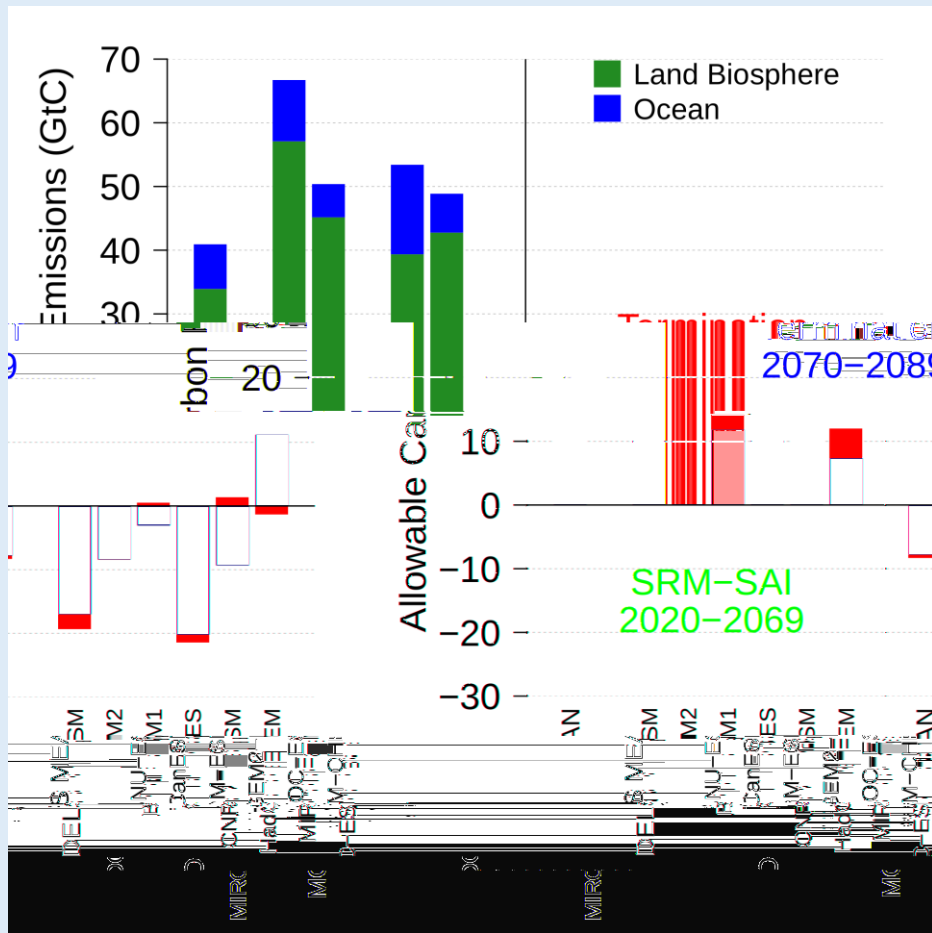
Impact of SRM on carbon budget

The global carbon cycle can be affected by the deployment of SRM because of effects on ecosystems and take up of carbon (Matthews and Caldeira 2007; Govindasamy et al. 2002; Eliseev 2012; Keller et al. 2014; Muri et al. 2015; Lauvset et al. 2017) and may affect carbon budget estimates compatible with 1.5°C or 2°C (see Section 2.2.2 for further details). SRM may enhance the natural carbon uptake by land, biosphere and the ocean based on analysis of model results (Box 4.13 Figure 1) and natural analogues such as major volcanic eruptions (Macmartin et al. 2016; Rothenberg et al. 2012; Brovkin et al. 2010; Tjiputra and Otterå 2011; Wang et al. 2013). In both cases the same mechanism is at play: the global carbon cycle responds to the thermal adjustment of the climate system following a decrease in incoming solar energy. Over the land surface, SRM would cause a decrease in soil respiration driven by a reduction in surface temperature. The difference between photosynthesis and respiration then results in a potential increase of the net carbon uptake by land and biosphere under SRM. The ocean carbon sink could also be enhanced (but less so) because decreasing sea surface temperatures increase CO₂ solubility in sea water.

A quantitative assessment of the potential efficiency of SRM to draw down atmospheric CO₂ is hampered by many large uncertainties. First, uncertainties in our understanding arise from the differences between modelled SRM experiments (intensity, time-scales etc.), modelling set-up, and emissions pathways (Edenhofer et al. 2011; Govindasamy and Caldeira 2000; Matthews and Caldeira 2007; Glienke et al. 2015; Tjiputra et al. 2015; Lauvset et al. 2017; Muri et al. 2015). These differences result in a wide range of estimated CO₂ reductions in response to SRM, from 15 ppm (Tjiputra et al. 2015) to 110 ppm (Matthews and Caldeira 2007). However, studies agree that SRM reduces more CO₂ when the duration of SRM is increased or the background level of CO₂ concentrations is increased, or both.

Second, important uncertainties remain in understanding the driving processes governing the global carbon cycle response to SRM. SRM is expected to modify the ratio between diffuse and direct radiation, leading to an enhancement of photosynthesis and hence greater gross uptake of carbon by vegetation (Xia et al. 2016b; Mercado et al. 2009b; Eliseev 2012). But SRM is also expected with a high confidence to reduce total incoming solar radiation, decreasing the amount of photosynthetically available radiation for photosynthesis, leading to a decrease in gross carbon uptake by vegetation (Ramachandran et al. 2000). These two competing effects of SRM on vegetation photosynthesis could ultimately balance each other out so that the land-biosphere response to SRM remains uncertain. Furthermore, the availability of water and nutrients to the biosphere can be modified under SRM. For example, AR5 indicated that rising atmospheric CO₂ leads to enhanced water-use efficiency of the land biosphere and reducing the water requirement to fix a given amount of atmospheric CO₂ in vegetation biomass. However, a number of studies have shown that SRM might lead to modified precipitation patterns and ultimately alter the water available for land biosphere and for specific biomes (Muri et al. 2015; Glienke et al. 2015).

There are also large uncertainties about how the carbon cycle will respond to termination effects of SRM. Although models agree in terms of temperature change following termination (in both geographical structure and amplitude), the associated change in net primary productivity remains unclear (Jones et al. 2013b). Yet, due to the response of soil respiration and ocean solubility to temperature change (Friedlingstein et al. 2006; Friedlingstein and Prentice 2010), the termination effect might release carbon previously stored in the soil and in the upper ocean layers to the atmosphere, undoing the earlier enhanced CO₂ uptake. Uncertainties in climate-carbon cycle feedbacks (as documented in Friedlingstein et al. 2013) currently hamper a quantitative determination of the amount of carbon which could be released to the atmosphere in response to the abrupt warming induced by the stoppage of SRM.



Box 4.13, Figure 1: Change in cumulated allowable carbon emissions (in GtC) due to the use of solar radiation management by stratospheric aerosol injection (SRM-SAI) as simulated in the experiment G4 of GeoMIP for each of six Earth system models and the models mean. Allowable carbon emissions are estimated from cumulated carbon fluxes over the geoengineered period (2020-2069, left) and over the twenty years after the cessation of geoengineering (2070-2089, right) using the approach of Jones et al. (2013). Land biosphere and ocean carbon uptake are represented respectively in green and blue.

Changes in solar energy resources

SRM through SAI is expected to have adverse effects for solar power on the Earth’s surface (Robock et al.2009) and thus on solar energy which is a key mitigation technology. The only detailed study assesses the impacts on solar photovoltaics (PV) and concentrating solar power (CSP) (Smith et al. 2017). According to this study, SAI at a rate of 10 Tg yr⁻¹ SO₂ is likely to result in negative changes in CSP output in most regions of the world. The global land mean decrease in annual energy output is 4.5% and 5.9% compared to the RCP4.5 and to the historical simulation. Marine cloud brightening will reduce solar transmission through clouds, but also reduce solar transmission in clear-sky areas where sea-salt aerosol is generated. Cirrus cloud thinning will increase the incoming solar radiation slightly. The implementation of space mirrors is likely to be more homogeneous in its negative impacts for solar energy. Increasing the surface albedo is unlikely to have a direct negative impact on solar energy technologies and may be slightly positive due to additional solar radiation being reflected upwards from the ground (Smith et al. 2017).

Sustainable Development and SRM

In terms of sustainable development, some see SRM as a relatively cheap way to bring down global temperatures, with resulting benefits for SD and equity from reduced climate impacts in terms of food, water, health and ecosystems and could be a controversial response to humanitarian emergencies associated with rapid climate change (Morrow 2014; Al-sabab and Brien 2015; Anshelm and Hansson 2014; Harding and Moreno-Cruz 2016; Heutel et al. 2016; Nicholson 2013)(Buck 2012). But because SRM/SAI has uncertain effects on precipitation, may damage the ozone layer, and does not address ocean acidification

1 there are also negative risks to SD (Heyen et al. 2015; Irvine et al. 2017; Robock 2012; Nicholson 2013).
 2 For example, some models, and analogues with historic volcanic eruptions, produce results that reduce
 3 temperatures but include a weakening of tropical circulation, drought in the Sahel, and a weaker monsoon
 4 with droughts in Asia (Ferraro et al. 2014; Irvine et al. 2017). A small number of studies examine ecosystem,
 5 hydrological, and agricultural effects are inconclusive and emphasize regional uncertainties (Ito 2017; Parkes
 6 et al. 2015; Russell et al. 2012; Xia et al. 2014; Irvine et al. 2017). SAI does not solve the problems of
 7 ecosystem and fishery decline associated with acidification, may increase health effects of ozone depletion,
 8 and, if it reduces mitigation and adaptation efforts will modify the SD side benefits of these actions. For
 9 more information about SAI impacts on ecosystems, regional patterns of precipitation, circulation regime,
 10 ozone, cloudiness and stratospheric chemistry see Chapter 3, the Impacts on global temperature section, and
 11 the Implications for regional climate and impacts of generally considered SRM techniques section of this
 12 Box.

14 **Governance, public perception and ethics of SRM**

15 SRM research and implementation faces considerable challenges when it comes to governance and potential
 16 impacts on sustainable development. The literature mostly suggests that SRM requires multilateral
 17 governance because of the high costs and impact on the global commons, because of the risk of termination,
 18 and because of risks that implementation or unilateral action by one country or organization will produce
 19 negative side effects for others, especially in terms of precipitation, extreme events, and photosynthesis
 20 (Horton 2011; Bodansky 2013; Virgoe 2009; Bracmort et al. 2010; Low et al. 2013; Dilling and Hauser
 21 2013; Lempert and Prosnitz 2011; US National Academy of Sciences 2015; Al-sabah and Brien 2015). Even
 22 in the case of modest implementation or impacts, public perceptions may begin to attribute a wide range of
 23 negative environmental changes to SRM, whether or not a link can be made, creating fear, political tensions
 24 and social unrest (Boyd 2009). There is evidence that the public is confused and concerned about
 25 geoengineering, with those in developing countries unaware of the issue (Bellamy et al. 2017; Burns et al.
 26 2016; Carr et al. 2013; Parkhill et al. 2013; Visschers et al. 2017). Key ethical questions discussed in the
 27 research literature include those of international responsibilities for implementation, financing, and
 28 compensation for negative effects, privatization and patenting, informed consent by affected publics,
 29 intergenerational ethics (because SRM requires sustained action in order to avoid termination hazards), the
 30 rights of indigenous people and women, and the moral hazard that SRM could reduce mitigation and
 31 adaptation efforts (Buck et al. 2014; Burns 2011; Whyte 2012; Morrow 2014). For more detailed information
 32 about governance, economics and ethics of SRM (including “moral hazard”) see Chapter 4 (Section 4.3.7).
 33

35 **Box 4.14: Cities**

39 **Box 4.15: Adaptation**

40 This Box presents five case studies from different climate regions to provide a holistic example of definitions
 41 and key adaptation typologies from physical and human impacts (Chapter 3); implementation challenges
 42 including governance issues (Chapter 4); and poverty, livelihoods consequences and sustainability (Chapter
 43 5). The case studies were selected to highlight specific issues, for example, the Arctic due to its rapid
 44 changing climate, the Caribbean for its potential sea level rise and numerous extreme hydro-meteorological
 45 events, the Mekong Delta for impacts on a ‘food-basket’ region, urban adaptation, and the Amazon for its
 46 adaptation efforts at scale.

47 *[A map that locates these case locations will be included in the SOD]*

48 Each case study first presents climate impacts, then explores adaptation strategies and their implementation,
 49 and concludes with poverty alleviation and sustainable development implications.
 50
 51
 52
 53
 54

Adaptation in the Arctic

Climate change vulnerability in the Arctic reflects the elevated rate of environmental change occurring in polar regions in combination with social and economic stresses (IPCC 2014a). Current high health burdens in the region, such as food insecurity, unintentional injury and mental health issues, are linked in part to environmental systems and have the potential to worsen with climate change (Ford et al. 2014b; Arctic Council 2017). Ice-free Septembers by 2100 are very unlikely if global warming is limited to 1.5°C, although permafrost melt, increased instances of storm surge, and extreme weather events are still anticipated (Ford et al. 2016; Melvin et al. 2016; Screen and Williamson 2017). Environmental changes are projected to have negative short-term impacts on health, housing availability, transportation, and economy across the Arctic (Larsen et al. 2008; Ford et al. 2015, 2016; Melvin et al. 2016; Arctic Council 2017). Human systems in the Arctic are also recognized for their resilience, a function of traditional knowledge systems, diversified livelihoods, and governance systems that include institutions for collective action (Arctic Council 2013b; Ford et al. 2015; Arctic Council 2017). Indeed, community and regional capacities are driving adaptation initiatives across the Arctic, with potential to reduce vulnerability (Arctic Council 2013b).

Communities across the Arctic, many with indigenous roots, have a history of adapting to environmental change, developing or shifting harvesting activities and patterns of travel and, more recently, transitioning economic systems (Wenzel 2009; Einarsson 2014b). Present economic and social conditions can limit a family or community's capacity to undertake necessary adaptations to environmental change without resources and cooperation from public and private sector actors (Ford et al. 2014b, 2015; Clark 2016; Arctic Council 2017). Further, for many Arctic communities, climate change is only one of the many dynamics that may constrain social and economic wellbeing. Adaptation initiatives, including managing future risks, reducing and responding to damages, and capitalizing on new opportunities, have been increasingly observed at community, regional, and national scales in the Arctic (Arctic Council 2013b; Labbe et al. 2016; Ford et al. 2014a; Arctic Council 2017). Across the region, investments aimed at reducing vulnerability may doubly serve to address current social and economic needs, such as improving an airport's runways, enhancing telecommunications, or reducing food insecurity (Arctic Council 2013b). These 'no-regrets' adaptations are seen as having fewer political or institutional hurdles and are socially or economically beneficial external to climatic change (Heltberg et al. 2009). Transformative adaptations, such as restructuring the education system to improve opportunities and sustain indigenous knowledge, have also been identified as having significant opportunity to reduce vulnerability by addressing root causes, but generally take more resources and political will (Kates et al. 2012; Ribot 2011).

Adaptation actions are being noted in all Arctic nations, with the highest number occurring in the Canadian Arctic (Ford et al. 2015). Further, most documented adaptation initiatives are occurring at local levels and are in response to both observed and projected environmental changes as well as social and economic stresses. In a recent study of adaptations in Nunavut, Canada, most adaptations were found to be in the planning stages, lacking coordinated effort within and between the territorial governments, and largely driven by a select few institutions and individuals (Labbe et al. 2016).

It has been argued that sufficient information on vulnerability exists for adaptation implementation in some sectors and countries, but research gaps remain (Arctic Council 2013b; Ford et al. 2016). Moving beyond community case studies to fine resolution system modelling, larger scale climate models that include projections for variables such as permafrost melt, surface winds, and sea level rise are demanded in conjunction with linked economic and demographic projections (Ford et al. 2016; Arctic Council 2017). Continued assessments of potential regional economic and social benefits are important and will need to be built into regional projections and adaptation plans (Arctic Council 2013). Addressing knowledge gaps, and incorporating Indigenous knowledge and stakeholder views is essential to the development of much-needed adaptations policies and initiatives across the Arctic (Boyle and Dowlatabadi 2011; Hansen and Larsen 2014). Studies have suggested that a number of the adaptation actions in the region are not sustainable, lack evaluation frameworks, and hold potential for maladaptation (Loboda 2014; Ford et al. 2015; Larsson et al. 2016). More proactive, empirically driven, and regionally coherent adaptation plans and actions have been identified as important in Arctic nations to address the impacts from 1.5°C level climate change scenario (Larsson et al. 2016; Melvin et al. 2016; Arctic Council 2017).

Adaptation in the Caribbean

Key climatic risks and vulnerabilities

Damage from hurricanes and their increased frequency and severity is the largest risk facing Caribbean island nations. It is estimated that average damage from each hurricane since the mid-20th century has been 4.8% of GDP for Caribbean island nations (Acevedo Mejia 2016). By 2100, average hurricane damage in the Caribbean is expected to increase between 22% and 77%, with large variations in damage across islands (Acevedo Mejia 2016; Bertinelli et al. 2016). The damage from hurricanes is manifested through a range of socioeconomic and ecological impacts: loss of life and GDP (Pielke et al. 2003), negative impact on agricultural products and crops (Beckford and Rhiney 2016; Lashley and Warner 2015; Mohan 2017), and loss of biodiversity such as localised extinction of sea turtles (Laloë et al. 2016).

Vulnerability to the impacts of hurricanes and sea level rise is driven by multi-scalar social and economic factors. High levels of poverty (Rhiney 2015; Beckford and Rhiney 2016), limited institutional capacity (Pittman et al. 2015), lack of reliable data (Muis et al. 2016), land use change (Cashman and Nagdee 2017), and food security instability (Pemberton and Patterson-Andrews 2016) have negative impacts on Caribbean nations' ability to cope and recover from the impacts of hurricanes and sea level rise.

An assessment of adaptation readiness done by Deklu (Deklu 2015), identified 3 countries as having high adaptation readiness scores (Cuba, Grenada, and St. Lucia), 8 countries with moderate adaptation readiness (Antigua and Barbuda, Bahamas, Barbados, Dominican Republic, Jamaica, St. Kitts and Nevis, St. Vincent and the Grenadines, and Trinidad and Tobago), and 2 countries with low adaptation readiness (Dominica and Haiti) (Deklu 2015).

Adaptation mechanisms

Institutional: Studies have found that governance to address climate change in the Caribbean relies on holistic, integrated management systems, improving flexibility in existing collaborative decision-making processes, increasing capacity of local authorities with support from higher-level government, private-social partnerships, and adequate social-environmental monitoring programs (Pittman et al. 2015). Social work programs to promote human and community well-being have also been proposed to reduce social vulnerability to climate change impact in the Caribbean (Joseph 2017). Robust institutions with proper technology, such as information and communication technologies (ICT's) can help in the use of early warning systems, as well as help in the exchange of information required for decision-making and emergency situations (Eakin et al. 2015; Ley 2017).

Social: Settlement relocation or migration have been documented as social responses to climate change risks in the Caribbean islands (Rivera-Collazo et al. 2015; Betzold 2015). However, retreating from coastal areas at risks has also been argued to be problematic, as islanders have close ties to home and strong place-based identities, so islands becoming uninhabitable poses important consequences for global justice, human rights, and cultural heritage (Betzold 2015). Micro-landscape modification is also viewed as a strategy which, together with relocation, can strengthen community bonds that lead to social resilience or vulnerability (Rivera-Collazo et al. 2015).

Engineering and built environment: Studies of resilient housing design for low income households with limited resources, for example, proposes several design modifications to make homes more resistant to high winds and flying debris during hurricanes (Prevatt et al. 2010). Moreover, building codes and standards haven't been updated in many cases to account for the extreme weather events that are now occurring (Garsaball and Markov 2017). Urbanization in low-lying areas has also increases potential run-off and flash-flood events, such as in the case of St. John's in Grenada (Pratomo et al. 2016). Therefore, engineering applies not only to buildings but also to other infrastructure such as coastal defences, ports, docks, marinas, bridges, and water supply (Sammy et al. 2016; Boyce 2016). The Blue Urban Agenda has emerged as a solution, especially for urban coastal adaptation (Donovan 2017).

Implementation gaps and challenges

Awareness and perceptions: Local residents and decision makers often have limited knowledge and

1 understanding of climate change, and in more remote communities, climate change is even more unfamiliar.
2 Other seemingly more pressing problems like poverty and food security compete for attention of locals and
3 decision makers (Betzold 2015). Perceptions are important to consider when designing adaptation measures,
4 and need to be included in vulnerability assessment. Stakeholder perceptions of climate change can have
5 implications on local adaptation plans and strategies and can help to a more unified implementation of
6 adaptation measures (Altschuler and Brownlee 2016). Until there is better awareness and understanding of
7 climate change and its risks, it will be difficult for risk management needs to be institutionalised as part of
8 the planning process, which is increasingly required (Boyce 2016).

9
10 *Lack of resources:* After Hurricane Ivan struck in 2004 with estimated losses of as much as twice the GDP in
11 the case of Grenada (Joyette et al. 2015), a regional catastrophe insurance scheme was created. The lack of
12 financial resources after a disaster has been a major constraint for most of the islands, but the hazard models
13 used in different schemes have low levels of acceptability, which impede financial schemes from being truly
14 beneficial (Joyette et al. 2015).

15
16 So far, donors have funded adaptation measures to a substantial extent, with the national government also
17 contributing significant amounts. However, donors fund what they see as a priority, not necessarily reflecting
18 community priorities. Short funding cycles on donor projects also leave the local community paying for
19 maintenance or repair of adaptation interventions, e.g. seawalls (Betzold 2015). It has also been reported that
20 development programs have focused attention on climate change adaptation (Donovan 2017), however,
21 there is still more integration needed between the development and climate change sectors, especially when
22 understanding trade-offs and synergies. Vergara (Vergara et al. 2015) estimate that damages to climate
23 impacts in LAC will be about US\$100 billion by 2050 (Vergara et al. 2015), indicating that rapid adaptation
24 needs to happen now to reduce the magnitude of future events and to avoid the permanent loss of natural and
25 cultural capital, some of which is already being lost.

26 **Adaptation in the Mekong food-basket region**

27 **Status and transitions**

28
29 The Mekong Basin is a climate change hotspot (de Sherbinin 2014; Lebel et al. 2014) and home to a
30 population of nearly 20 million (Chapman et al. 2016). The largest riverine wetland complex in South-east
31 Asia, it plays a critical role in regional economy and food security (Smajgl et al. 2015) contributing to 90%
32 of Vietnam's rice production (Kontgis et al. 2015). It is witnessing several transitions which have
33 implications for climate adaptation.

34
35 *Land use transitions* are rapidly shifting from forest to agriculture (especially rice which is a regional staple
36 food) and increasing development of highlands through increasing hydropower and road networks (Kura et
37 al. 2017; ICEM 2013). Agriculture has also seen a shift towards greater commercialization with a concurrent
38 degradation of ecosystems and associated services (Sebesvari et al. 2017) which have raised sustainability
39 concerns (Anthony et al. 2015). While this agricultural transition has alleviated poverty and improved food
40 security (Schipper et al. 2010), long-term distributive effects and implications for adaptation remain poorly
41 examined (Ling et al. 2015). Some studies note that such transitions exacerbate risks of vulnerable
42 populations to climate change and extreme event (ICEM 2013) and may even be maladaptive (Chapman and
43 Darby 2016).

44
45 *Economic expansion and demographic shifts* are transforming the economies and environment but rural
46 populations remain significantly dependent on natural resources and ecosystem services for livelihoods: 75%
47 of peoples' livelihoods in the Lower Mekong basin are dependent on agriculture, fishery, livestock, and
48 forestry (Sebesvari et al. 2017). There is also significant urbanisation in pockets within the Mekong Deltaic
49 region: for example, SocTrang province in Vietnam has seen a 50% increase in urban dwellers between 1992
50 and 2011 (Smith et al. 2013).

51
52 Analyses of past climate data have shown a fluctuating upward trend for temperature and annual mean
53 precipitation in the Lancang-Mekong River basin from 1980 to 2009 (Wu et al. 2011). However, this
54 increase in precipitation is primarily in the wet season. Drought incidence and severity has increased
55

1 significantly in the Lancang River Basin during 1991-2010 (Yu et al. 2015).

2
3 In the Lower Mekong Basin, under the A1B scenario (moderate emissions), temperature increases are
4 expected to reach an average 3-5°C by 2100 while in some pockets such as eastern Cambodia and regions in
5 the Mekong Delta of Vietnam and Cambodia, increases of 2-3°C may be reached before 2050 and up to 5°C
6 by 2010 (ICEM 2013). Under the same scenario, a basin wide temperature increase of 0.79°C, with greater
7 increases for colder catchments in the north are projected (Eastham et al. 2008). Importantly, under all RCPs,
8 the Mekong River Basin is projected to see an increase in annual average temperature with the largest
9 increases in upstream areas. Annual precipitation is also projected to increase except for a weak decreasing
10 trend during early-21st century under RCP4.5 and RCP8.5 scenarios (Zhang et al. 2016a). The persistent
11 rising of summer temperature might accelerate melting of glaciers, and impact the local freshwater
12 availability. Summer precipitation will most certainly increase in the short, medium and long terms, which
13 would increase the risk of flood-related disasters (Zhang et al. 2016a). While higher flows (due to warming-
14 induced intensification of the hydrological cycle) can reduce dry season water shortages and control
15 downstream salinization, higher and more frequent peak discharges will exacerbate flood risk in the basin
16 (Hoang et al. 2016).

17
18 The region is also highly susceptible to flooding (Ling et al. 2015), with 75% of Vietnam's areas at risk
19 located in the Mekong Delta (Smith et al. 2013). Finally, sea level rise and saline intrusion are ongoing risks
20 agricultural systems are facing and adapting to (Renaud et al. 2015).

21 22 **Adaptation Interventions**

23 The main implications of these transitions will be on ecosystem health through salinity intrusion, biomass
24 reduction and biodiversity losses (Le Dang et al. 2013; Smajgl et al. 2015); agricultural productivity and
25 food security (Smajgl et al. 2015); livelihoods such as fishing, farming (Wu et al. 2013); and disaster risk
26 (Hoang et al. 2015; Wu et al. 2013) with implications for human mortality and economic and infrastructure
27 losses.

28
29 Main adaptation strategies in the Mekong include technical, behavioural, financial and institutional shifts in
30 agriculture, coastal management and ecosystem services (Schipper et al. 2010). The region also sees several
31 landscape-based initiatives (Zanzanaini et al. 2017) that have potential adaptation implications through
32 livelihood strengthening, agriculture development and ecosystem conservation.

33
34 Adaptation related to agriculture including improving water use technology (e.g. pond capacity
35 improvement, rainwater harvesting), shifting farming systems or crops, soil management and diversification,
36 and strengthening allied sectors such as livestock rearing and aquaculture (ICEM 2013).

37 Several ecosystem-based approaches have been suggested and implemented in the Mekong River Basin. For
38 example, integrated water resources management (IWRM) has demonstrated successes in mainstreaming
39 climate adaptation into existing basin strategies and water management (Sebesvari et al. 2017).

40
41 Coastal adaptation strategies include dyke construction and mangrove restoration to reduce the impacts of
42 sea level rise and storm surge (Smith et al. 2013) and ecological engineering such as densification of coastal
43 vegetation (Renaud et al. 2014). However, some of these adaptation measures have been identified to have
44 negative impacts as well: a study in the Vietnamese Mekong Delta suggests that dyke construction and
45 resultant sedimentation has increased agricultural productivity but sharpened the divide between land-rich
46 and land-poor farmers and reshaped the socioeconomic system (Chapman et al. 2016). The entry of high
47 dykes ushered triple-cropping which benefits land-wealthy farmers but forces debt on poorer farmers
48 (Chapman and Darby 2016). Thus, when seen holistically and over a longer time frame, certain seemingly
49 adaptive strategies (dyke construction) can be maladaptive and cause new risks. Studies have repeatedly
50 called for an ensemble of hard and soft policies where focus on hard options such as building water
51 infrastructure are balanced by investment in soft adaptation measures such as land-use change to deal with
52 impacts of rising sea levels and salinity intrusion in the Mekong (Smajgl et al. 2015).

53
54 The Mekong River Commission (MRC) is an intergovernmental body established in 1995 by agreement of
55 the governments of Cambodia, Lao PDR, Thailand and Viet Nam. In the face of growing impacts of climate

1 variability and change, the MRC responded to a call for regional cooperation to share knowledge and build
2 capacities, and implemented the Climate Change and Adaptation Initiative (CCAI) in 2009. This politically
3 backed institution has facilitated impact assessment studies, regional capacity building and local project
4 implementation (Schipper et al. 2010), demonstrating a workable template.

5
6 The region also sees significant civil society presence and communities of practice such as the Asia-Pacific
7 Adaptation Network, Adaptation Knowledge Platform and Asian Cities Climate Change Resilience Network
8 (Schipper et al. 2010).

9
10 National governments have also undertaken action to deal with climate change but their progress varies
11 substantially (Gass et al. 2011). Laos PDR and Cambodia have NAPAs, Thailand has a Climate Change
12 Master Plan (2015-2050) and Viet Nam launched a ‘National Target Program to Respond to Climate
13 Change’ in 2008 with full implementation in 2015. However, overall, the region has been critiqued for
14 inadequate mainstreaming of adaptation into development policies and low adaptation action (Gass et al.
15 2011). However, these are explained by significant capacity barriers and other national priorities that limit
16 adaptation progress (Gass et al. 2011).

17
18 Adaptation funding in the Mekong region is typically project-based and channelled through national projects
19 financed by the Asian Development Bank (ADB), Global Environment Facility (GEF), LDCF, Special
20 Climate Change Fund (SCCF), United Nations Development Programme (UNDP), World Bank and World
21 Health Organization (WHO). The Adaptation Fund (managed by the GEF) is currently funding two projects
22 in the region focusing on climate resilience of communities in protected areas (Cambodia) for \$3 million and
23 enhancing climate and disaster resilience rural and emerging urban settlements (Lao PDR) for \$45 million.
24 Some bilateral assistance from developed countries is also directed towards adaptation though this varies by
25 country.

26
27 To strengthen current adaptation action in the Mekong, there needs to be more investment in developing
28 drought and saline-tolerant rice varieties and shifts towards crop diversification and integrated agriculture-
29 aquaculture practices (Renaud et al. 2014). Putting in place more flexible institutions dealing with land use
30 planning and agricultural production, improved monitoring of saline intrusion, setting up early warning
31 systems that can be directly and instantly accessed by the local authority or farmers are also recommended
32 (Renaud et al. 2014). Finally, it is critical to identify and invest in synergistic strategies from an ensemble of
33 hard options (building dykes) and soft adaptation measures (land-use change) (Smajgl et al., 2015), to
34 combinations of top-down government-led strategies such as the Living With the Flood (LWF) program to
35 relocate residents from flood areas and bottom-up household strategies such as increasing house height (Ling
36 et al. 2015).

37 38 **Urban Adaptation**

39 40 **Status**

41 Studies tracking progress on urban adaptation report that between 18% (from total n=401 of cities >1m
42 population) (Araos et al. 2016b) and 25% of city governments (from total of n=468 surveyed ICLEI member
43 cities) (Aylett 2014) are developing a climate change adaptation plan. An additional 18% report already
44 having implemented a plan (Aylett 2014). In Europe, a 2014 study of 200 cities found that 28% (from total
45 n=200 cities >500k population) have an adaptation plan (Reckien et al. 2014, 2015).

46
47 High-income regions such as Europe, North America, and Australia report higher levels of engagement with
48 adaptation than developing regions, yet within these regions less than half of the cities have a plan (Reckien
49 et al. 2014). Several cities in low-income countries are currently reporting extensive adaptation activity such
50 as Quito, Ecuador, Durban, South Africa, and Semarang, Indonesia. These cities represent focal points for
51 learning from their success. In these cities, the emergence of policy entrepreneurs and champions has
52 enabled an emphasis on urban adaptation. While urban adaptation is in the early stages, there are substantive
53 examples of governments taking leadership regardless of wealth levels and institutional barriers (Roberts
54 2008).

Adaptation measures

Across studies, the most frequently addressed urban adaptation measures are protection of the built environment, coastal protection, and green infrastructure (Araos et al. 2016b; Austin et al. 2015). Only a small portion of initiatives have targeted health and social services, while the rest focus on protecting physical infrastructure (Araos et al. 2016b).

A study of 10 megacities' spending on adaptation found that protection of the built environment is the sector where cities spend the most on adaptation (~35% of global expenditure), followed by transport infrastructure (~13% of total spend on average) (Georgeson et al. 2016).

Implementation gaps and challenges

Lack of funding is reported as the most significant challenge for implementing urban adaptation projects and programs by 78% of 350 surveyed ICLEI member cities (Aylett 2014). Competing priorities such as health, housing, sanitation, and economic growth are also cited as a significant challenge by cities planning adaptation. Finally, cities report difficulties incorporating climate change, a relatively new issue, into existing departmental functions and procedures (Aylett 2014).

Adaptation mechanisms

Mainstreaming adaptation into spatial planning: Spatial planning in cities offers the potential to support cross-sectoral urban adaptation, where climate change concerns can be integrated into urban policy and planning. This means mainstreaming climate change projections and considerations into city plans, including land use planning, public health, transportation, and social services (Archer et al. 2014; Chu 2016; Chu et al. 2016; Friend et al. 2014; Lehmann et al. 2015; Rivera and Wamsler 2014).

Community-based adaptation (CBA): As adaptation tends to be a more localised approach in dealing with climate change effects, there is increasing focus of placing local communities at the heart of forming policy and adaptation plans. CBA presents opportunities for local participation in the design and implementation of adaptation activities and yields greater transformative potential for urban governance (Archer et al. 2014). It can also offer a cost-effective, sound way to tackle climate change by capturing the wealth of knowledge, skills and experience that communities have on dealing with climate variability and change (Fenton et al. 2014; Brink et al. 2016; Mitchell and Borchard 2014; Reid and Huq 2014; Tran 2014).

In Dhaka, for example, the city's largest informal settlement Korail, has created a community savings group which provides loans to residents to rebuild their housing structures with more durable material in the event of flood destruction (Jabeen 2014). Of the informal households in the community, 50% save regularly with the CBA project and in 2009, 30% of households withdrew loans for repairs.

Ecosystem based adaptation (EbA): In recent years, policy makers and planners are increasingly promoting integrated 'EbA' and CBA approaches. EbA is defined as the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change (Wamsler et al. 2014; Wamsler 2015; Reid 2016).

With the increasing uptake of green infrastructure such as green roofs and street trees, ecosystems and their services can increase local resilience and adaptive capacity, most notably as a substitute to built infrastructure. Examples of EbA in urban spaces include coastal mangroves providing protection against cyclone damage and storms, wetlands acting as floodwater reservoirs and well-vegetated hillsides reducing risks from erosion, landslides and downstream flooding during heavy downpours of rain (Brink et al. 2016; Reid et al. 2009; Wamsler 2015; Wamsler et al. 2014).

City networks and learning partnerships: Transnational networks of cities such as C40, Resilient Cities, and ICLEI have also played a key role supporting accelerated learning and action local adaptation. The growth in membership of transnational networks signals an interest in learning and experimentation with more flexibility than through mandated government policy (Spaans and Waterhout 2017; Heidrich et al. 2016; Fünfgeld 2015).

Adaptation in the Amazon

The highest terrestrial carbon dioxide uptake on Earth is due to tropical forests (Beer et al. 2010). The Amazon photosynthetic system is responsible for a significant amount of the CO₂ uptake of the planet and stores an enormous amount of carbon, mainly in trees. At the same time, the Amazon is quite sensitive to changes in the climate, especially to drought (Laurance and Williamson 2001). According to Nobre et al. (2016), there are two “tipping points” that should not be transgressed: 4C warming or 40% or total deforested area. Thus, the danger of crossing these tipping points come from two directions: human activities, mainly related to land use change for food production, and global warming. Depending on the choices taken during the first quarter of this century, the Amazon may or may not survive to the warming effects.

Because climate change is closely associated with GHG emissions, and mitigation is vital to maintaining Earth temperature well below 2°C (Rogelj et al. 2015), the Amazon is thought to play a critical role in future strategies to avoid global warming. Crossing the tipping points mentioned above (Nobre et al. 2016) would lead to significant changes in the climate of the region, possibly leading to a backfiring effect that could affect the whole agricultural and settlement systems established at the expense of the forest. The devastation of the Amazon, even advancing slowly as it is today, would increase CO₂ emissions and contribute to warming, preventing most of the actions that could be taken towards a 1.5°C.

Deforestation of the Amazon has been discussed since the 1980s. Authors have pointed out to several adverse consequences such as loss of habitats and biodiversity, loss of indigenous people and culture, and climate change (Fearnside 1985; Shukla et al. 1990; Malhi et al. 2008; Nobre et al. 2016). The consequences of human activity in the region through burning with the purpose of freeing land for agriculture has been quite drastic, leading to loss of biodiversity and increasing CO₂ emissions (Tasker and Arima 2016; Numata et al. 2017).

Because the Amazon forest has a key role in the climate equilibrium at regional and global levels, whatever happens to that forest will potentially affect not only the local biodiversity and people, but also produce teleconnections that may influence the world in many ways (Bonan 2008). Burning has been decreased dramatically over the last two decades (Magrin et al. 2014), but has not been eliminated (Tasker and Arima 2016). Even though it was a significant governance intervention in a large forest and quite successful, the threat continues as the forest is slowly disappearing. Human activity that leads to deforestation is complex and depends on national government policies as well as on possible coalitions of countries that could work together towards preservation, sustainable use and the possible recovery of lost areas. Although the biodiversity loss is irreversible (Oliver and Morecroft 2014), the complete arrest in burning and clearing of the forest along with the restoration of part of the biodiversity would be an important action to help to stay in a 1.5°C scenario. The governance and finance mechanisms to implement such a coalition hardly exist, but one agreement made in 2008 between Norway and Brazil generated investment of US\$ 1 billion in projects (REDD+) for reforestation of the Amazon. According to a study of the Centre for Global Development, the investment is generating successful results, but there are challenges and lessons learned that can be used as guides for other agreements of the type in the Amazon region. This will probably be one of the main challenges to cope with the Amazon forest during this century.

Conclusion

The case studies presented here are representative of multiple climate impacts that are being felt in key regions and hot-spots worldwide, along with the array of adaptation options and strategies as well as the multiple challenges that remain to be met. Each case study presents the importance of local circumstances and contexts, which are important to consider when implementing an adaptation option. While describing planned or implemented adaptation strategies, there is a lack of empirical studies and monitoring and evaluation of current efforts to generalise across regions and themes. It is not yet possible to determine how effective these efforts have been. Determining the appropriate adaptation strategy also depends on having the proper data at the local level, appropriate governance and institutional capacity and ensuring citizen participation.

References

- 1 Aaheim, A., B. Romstad, T. Wei, J. E. Kristjánsson, H. Muri, U. Niemeier, and H. Schmidt, 2015: An economic
2 evaluation of solar radiation management. *Sci. Total Environ.*, **532**, 61–69, doi:10.1016/j.scitotenv.2015.05.106.
- 3 Aall, C., K. Groven, and G. Lindseth, 2007: The Scope of Action for Local Climate Policy: The Case of Norway. *Glob.*
4 *Environ. Polit.*, **7**, 83–101, doi:10.1162/glep.2007.7.2.83.
- 5 Abanades, J. C., and Coauthors, 2015: Emerging CO₂ capture systems. *Int. J. Greenh. Gas Control*, **40**, 126–166,
6 doi:10.1016/j.ijggc.2015.04.018.
- 7 Abbott, K. W., and D. Snidal, 2009: Strengthening International Regulation Through Transnational New Governance:
8 Overcoming the Orchestration Deficit. *Vanderbilt J. Transnatl. Law*, **42**, 501–578.
9 [http://search.ebscohost.com/login.aspx?direct=true&profile=ehost&scope=site&authtype=crawler&jrnl=0090259](http://search.ebscohost.com/login.aspx?direct=true&profile=ehost&scope=site&authtype=crawler&jrnl=00902594&AN=38898483&h=FcHKpjlRaCHDVVmzUx5GsfirEVtMCzXfpZn+BKPfKr61aGsI4kjR5T+bllAuuZW0Cp1bcWe82r5oqYeY3qu4xw==&crl=c)
10 [4&AN=38898483&h=FcHKpjlRaCHDVVmzUx5GsfirEVtMCzXfpZn+BKPfKr61aGsI4kjR5T+bllAuuZW0Cp1](http://search.ebscohost.com/login.aspx?direct=true&profile=ehost&scope=site&authtype=crawler&jrnl=00902594&AN=38898483&h=FcHKpjlRaCHDVVmzUx5GsfirEVtMCzXfpZn+BKPfKr61aGsI4kjR5T+bllAuuZW0Cp1bcWe82r5oqYeY3qu4xw==&crl=c)
11 [bcWe82r5oqYeY3qu4xw==&crl=c](http://search.ebscohost.com/login.aspx?direct=true&profile=ehost&scope=site&authtype=crawler&jrnl=00902594&AN=38898483&h=FcHKpjlRaCHDVVmzUx5GsfirEVtMCzXfpZn+BKPfKr61aGsI4kjR5T+bllAuuZW0Cp1bcWe82r5oqYeY3qu4xw==&crl=c) (Accessed July 21, 2017).
- 12 Abdel-latif, A., 2015: Intellectual property rights and the transfer of climate change technologies: issues, challenges,
13 and way forward. *Clim. Policy*, **15**, 103–126, doi:10.1080/14693062.2014.951919.
14 <http://www.tandfonline.com/doi/abs/10.1080/14693062.2014.951919> (Accessed July 21, 2017).
- 15 Abeygunawardena, P., and Coauthors, 2003: *Poverty and Climate Change: Reducing the Vulnerability of the Poor*
16 *through Adaptation*. Washington, 56 pp.
- 17 Abrahamse, W., and L. Steg, 2009: How do socio-demographic and psychological factors relate to households' direct
18 and indirect energy use and savings? *J. Econ. Psychol.*, **30**, doi:10.1016/j.joep.2009.05.006.
- 19 Acevedo Mejia, S., 2016: *Gone with the Wind: Estimating Hurricane and Climate Change Costs in the Caribbean*. 40
20 pp.
- 21 Adams, C., and S. Mouatt, 2010: The information revolution: information systems and the 6th Kondratieff cycle. *MCIS*
22 *2010 Proceedings* <http://aisel.aisnet.org/mcis2010/3>.
- 23 ADB, 2013: *Bhutan transport 2040: integrated strategic vision*. 24 pp.
- 24 Adger, W. N., N. W. Arnell, and E. L. Tompkins, 2005: Successful adaptation to climate change across scales. *Glob.*
25 *Environ. Chang.*, **15**, 77–86.
- 26 Afionis, S., L. C. Stringer, N. Favretto, J. Tomei, and M. S. Buckeridge, 2014: Unpacking Brazil's Leadership in the
27 Global Biofuels Arena: Brazilian Ethanol Diplomacy in Africa. *Glob. Environ. Polit.*, **14**, 82–101,
28 doi:10.1162/GLEP.
- 29 Aglietta M., Hourcade J.C., Jaeger C., Perrissin-Fabert B. (2015a) : Financing transition in an adverse context : climate
30 finance beyond carbon finance, International environmental agreements: politics, law and economics, 15:403-420,
31 DOI 10.1007/s10784-015-9298-1 Ågren, G. I., 2000: Temperature dependence of old soil organic matter. *AMBIO*
32 *A J. Hum. Environ.*, **29**, 55–55, doi:10.1579/0044-7447-29.1.55.
- 33 Aguiar, A. P. D., and Coauthors, 2016: Land use change emission scenarios: anticipating a forest transition process in
34 the Brazilian Amazon. *Glob. Chang. Biol.*, **22**, 1821–1840, doi:10.1111/gcb.13134.
- 35 Aguilar-Støen, M., and C. Hirsch, 2015: Environmental Impact Assessments, local power and self-determination: The
36 case of mining and hydropower development in Guatemala. *Extr. Ind. Soc.*, **2**, 472–479,
37 doi:10.1016/j.exis.2015.03.001. <http://linkinghub.elsevier.com/retrieve/pii/S2214790X15000532> (Accessed July
38 20, 2017).
- 39 Åhman, M., L. J. Nilsson, and B. Johansson, 2016: Global climate policy and deep decarbonization of energy-intensive
40 industries. *Clim. Policy*, **0**, 1–16, doi:10.1080/14693062.2016.1167009.
- 41 Aldrich, D. P., C. Page, and C. J. Paul, 2016: *Social Capital and Climate Change Adaptation*. Oxford University Press,
42 1-36 pp.
- 43 Aldy, J. E., and R. N. Stavins, 2007: *Architectures for agreement : addressing global climate change in the post-Kyoto*
44 *world*. Cambridge University Press, 380 pp.
- 45 Alessa, L., A. Kliskey, J. Gamble, M. Fidel, G. Beaujean, and J. Gosz, 2015: The role of Indigenous science and local
46 knowledge in integrated observing systems: moving toward adaptive capacity indices and early warning systems.
47 *Sustainability Science*.
- 48 Alexander, C., and Coauthors, 2011: Linking indigenous and scientific knowledge of climate change. *Bioscience*, **61**,
49 477–484, doi:10.1525/bio.2011.61.6.10.
- 50 Allan, J. I., and J. Hadden, 2017: Exploring the framing power of NGOs in global climate politics. *Env. Polit.*, **26**, 600–
51 620, doi:10.1080/09644016.2017.1319017.
52 <https://www.tandfonline.com/doi/full/10.1080/09644016.2017.1319017>.
- 53 Allcott, H., 2013: The Welfare Effects of Misperceived Product Costs: Data and Calibrations from the Automobile
54 Market. *Am. Econ. J. Econ. Policy*, **5**, 30–66, doi:10.1257/pol.5.3.30.
- 55 Allison, E., 2012: Gross National Happiness. *Berksh. Encycl. Sustain. Meas. Indic. Res. Methods Susrainability*, 180–
56 184.
- 57 Almeida Prado, F., S. Athayde, J. Mossa, S. Bohlman, F. Leite, and A. Oliver-Smith, 2016: How much is enough? An
58 integrated examination of energy security, economic growth and climate change related to hydropower expansion
59 in Brazil. *Renew. Sustain. Energy Rev.*, **53**, 1132–1136, doi:10.1016/j.rser.2015.09.050.
- 60

- 1 <http://linkinghub.elsevier.com/retrieve/pii/S1364032115010205> (Accessed July 16, 2017).
- 2 Altieri, M. A., C. I. Nicholls, A. Henao, and M. A. Lana, 2015: Agroecology and the design of climate change-resilient
3 farming systems. *Agron. Sustain. Dev.*, **35**, 869–890, doi:10.1007/s13593-015-0285-2.
- 4 Altschuler, B., and M. Brownlee, 2016: Perceptions of climate change on the Island of Providencia. *Local Environ.*, **21**,
5 615–635, doi:10.1080/13549839.2015.1004165.
- 6 Anderson, C. J., 2003: The psychology of doing nothing: Forms of decision avoidance result from reason and emotion.
7 *Psychol. Bull.*, **129**, 139–167, doi:10.1037/0033-2909.129.1.139.
- 8 Anderson, K., 2015: Talks in the city of light generate more heat. *Nature*, **528**, 437–437, doi:10.1038/528437a.
- 9 Andonova, L., T. N. Hale, and C. Roger, 2017: National Policies and Transnational Governance of Climate Change:
10 Substitutes or Complements? *Int. Stud. Q.*, 1–16, doi:10.1093/isq/sqx014.
- 11 Andrews-Speed, P., and G. Ma, 2016: Household Energy Saving in China: The Challenge of Changing Behaviour.
12 *China's Energy Efficiency and Conservation*, B. Su and E. Thomson, Eds., Vol. 31 of, SpringerBriefs in
13 Environment, Security, Development and Peace 31, 23–39.
- 14 Angotti, T., 2015: Urban agriculture: long-term strategy or impossible dream? *Public Health*, **129**, 336–341,
15 doi:10.1016/j.puhe.2014.12.008.
- 16 Anguelovski, I., E. Chu, and J. Carmin, 2014: Variations in approaches to urban climate adaptation: Experiences and
17 experimentation from the global South. *Glob. Environ. Chang.*, **27**, 156–167,
18 doi:10.1016/j.gloenvcha.2014.05.010.
- 19 Annecke, E., and M. Swilling, 2012: *Just transitions: Explorations of Sustainability in an Unfair World*. United Nations
20 University Press, 448 pp.
- 21 Anthony, E. J., G. Brunier, M. Besset, M. Goichot, P. Dussouillez, and V. L. Nguyen, 2015: Linking rapid erosion of
22 the Mekong River delta to human activities. *Sci. Rep.*, **5**, srep14745.
- 23 Araos, M., L. Berrang-Ford, J. D. Ford, S. E. Austin, R. Biesbroek, and A. Lesnikowski, 2016a: Climate change
24 adaptation planning in large cities: A systematic global assessment. *Environ. Sci. Policy*, **66**, 375–382,
25 doi:10.1016/j.envsci.2016.06.009.
- 26 —, —, J. D. Ford, S. E. Austin, R. Biesbroek, and A. Lesnikowski, 2016b: Climate change adaptation planning in
27 large cities: A systematic global assessment. *Environ. Sci. Policy*, **66**, 375–382, doi:10.1016/j.envsci.2016.06.009.
- 28 Archer, D., F. Almanshi, M. DiGregorio, D. Roberts, D. Sharma, and D. Syam, 2014: Moving towards inclusive urban
29 adaptation: approaches to integrating community-based adaptation to climate change at city and national scale.
30 *Clim. Dev.*, **6**, 345–356, doi:10.1080/17565529.2014.918868.
- 31 —, W. Monteith, H. Scott, and S. Gawler, 2017: Developing city resilience strategies: lessons from the ICLEI-
32 ACCCRN process. *IIED Work. Pap. Ser.*, **41**, doi:10.13140/RG.2.2.18761.13928.
- 33 Archibald, S., and G. P. Hempson, 2016: Competing consumers: contrasting the patterns and impacts of fire and
34 mammalian herbivory in Africa. *Philos. Trans. R. Soc. B Biol. Sci.*, **371**, 20150309, doi:10.1098/rstb.2015.0309.
- 35 Arctic Council, 2013a: *Arctic Resilience Interim Report 2013*. Stockholm Environment Institute and Stockholm
36 Resilience Centre, Stockholm, 134 pp.
- 37 —, 2013b: *Taking stock of adaptation programs in the Arctic. Adaptation Actions for a Changing Arctic, Part B*. 59
38 pp. <https://www.amap.no/documents/doc/aaca-part-b-taking-stock-of-adaptation-programs-in-the-arctic/1060>.
- 39 —, 2017: *Adaptation actions for a Changing Arctic - Barents Area Overview Report*.
- 40 Arezki, R., F. Samama, J. Stiglitz, P. Bolton, and S. Peters, 2016: *From Global Savings Glut to Financing*
41 *Infrastructure: The Advent of Investment Platforms*. Washington DC,.
- 42 Arunrat, N., C. Wang, N. Pumijumnong, S. Sreenonchai, and W. Cai, 2017: Farmers' intention and decision to adapt
43 to climate change: A case study in the Yom and Nan basins, Phichit province of Thailand. *J. Clean. Prod.*, **143**,
44 672–685, doi:10.1016/j.jclepro.2016.12.058.
- 45 Ashworth, P., S. Wade, D. Reiner, and X. Liang, 2015: Developments in public communications on CCS. *Int. J.*
46 *Greenh. Gas Control*, **40**, 449–458, doi:10.1016/j.ijggc.2015.06.002.
47 <http://dx.doi.org/10.1016/j.ijggc.2015.06.002>.
- 48 Assefa, Z., and P. Newman, 2014: Older Slums in Addis Ababa: How do they work? *UNHabitat Conference:*
49 *Responsive Urbanism in Informal Areas*, Cairo, Egypt.
- 50 van Asselt, H., and K. Kulovesi, 2017: Seizing the opportunity: tackling fossil fuel subsidies under the UNFCCC. *Int.*
51 *Environ. Agreements Polit. Law Econ.*, **17**, 357–370, doi:10.1007/s10784-017-9357-x.
- 52 von der Assen, N., J. Jung, and A. Bardow, 2013: Life-cycle assessment of carbon dioxide capture and utilization:
53 avoiding the pitfalls. *Energy Environ. Sci.*, **6**, 2721–2734, doi:10.1039/C3EE41151F.
- 54 Aumont, O., and L. Bopp, 2006: Globalizing results from ocean in situ iron fertilization studies. *Global Biogeochem.*
55 *Cycles*, **20**, doi:10.1029/2005GB002591.
- 56 Austin, S. E., J. D. Ford, L. Berrang-Ford, M. Araos, S. Parker, and M. D. Fleury, 2015: Public health adaptation to
57 climate change in canadian jurisdictions. *Int. J. Environ. Res. Public Health*, **12**, doi:10.3390/ijerph120100623.
- 58 Aylett, A., 2014: Progress and challenges in the urban governance of climate change: results of a global survey.
- 59 Azevedo, I., and V. M. S. Leal, 2017: Methodologies for the evaluation of local climate change mitigation actions: A
60 review. *Renew. Sustain. Energy Rev.*, **79**, 681–690, doi:10.1016/j.rser.2017.05.100.

- 1 Bäckstrand, K., and J. W. Kuyper, 2017: The democratic legitimacy of orchestration: the UNFCCC, non-state actors,
2 and transnational climate governance. *Env. Polit.*, **0**, 1–25, doi:10.1080/09644016.2017.1323579.
3 <https://www.tandfonline.com/doi/full/10.1080/09644016.2017.1323579>.
- 4 Badwal, S. P. S., S. Giddey, A. Kulkarni, J. Goel, and S. Basu, 2015: Direct ethanol fuel cells for transport and
5 stationary applications – A comprehensive review. *Appl. Energy*, **145**, 80–103,
6 doi:10.1016/j.apenergy.2015.02.002.
- 7 Bai, X., P. Shi, and Y. Liu, 2014: Realizing China’s urban dream. *Nature*, **509**, 158.
- 8 Bakker, S., and Coauthors, 2017: Low-Carbon Transport Policy in Four ASEAN Countries: Developments in
9 Indonesia, the Philippines, Thailand and Vietnam. *Sustainability*, **9**, 1217, doi:10.3390/su9071217.
- 10 Bamberg, S., and G. Möser, 2007: Twenty years after Hines, Hungerford, and Tomera: A new meta-analysis of psycho-
11 social determinants of pro-environmental behaviour. *J. Environ. Psychol.*, **27**, 14–25,
12 doi:10.1016/j.jenvp.2006.12.002.
- 13 Bank of England, 2015: The impact of climate change on the UK insurance sector - A Climate Change Adaptation
14 Report by the Prudential Regulation Authority. *Prudent. Regul. Auth.*, 1–87.
- 15 Barbier, E. B., J. C. Burgess, A. B. Edward Barbier, and C. B. Edward Barbier, 2017: The Sustainable Development
16 Goals and the systems approach to sustainability. *Econ. Discuss. Pap.*, 1–24.
- 17 Barker, T., Köhler, J., 1998. Equity and ecotax reform in the EU: achieving a 10 per cent reduction in CO2 emissions
18 using excise duties. *Fiscal Studies* 19, 375–402
- 19 Bartos, M. D., and M. V. Chester, 2015: Impacts of climate
20 change on electric power supply in the Western United States. *Nat. Clim. Chang.*, **5**, 748–752,
21 doi:10.1038/nclimate2648.
- 22 Bastakoti, R. R., and C. Davidsen, 2016: Nepal’s REDD+ Readiness Preparation and Multi-Stakeholder Consultation
23 Challenges. *J. For. Livelihood*, **13**, 30, doi:10.3126/jfl.v13i1.15364.
- 24 Battiston, S., A. Mandel, I. Monasterolo, F. Schütze, and G. Visentin, 2017a: A climate stress-test of the financial
25 system. 106–112, doi:10.1038/NCLIMATE3255.
- 26 ———, ———, ———, F. Schütze, G. Visentin, F. Schütze, and G. Visentin, 2017b: A climate stress-test of the financial
27 system. *Nat. Clim. Chang.*, **7**, 283–288, doi:10.1038/NCLIMATE3255.
- 28 Bauer, C., J. Hofer, H.-J. Althaus, A. Del Duce, and A. Simons, 2015: The environmental performance of current and
29 future passenger vehicles: Life cycle assessment based on a novel scenario analysis framework. *Appl. Energy*,
30 **157**, 871–883, doi:10.1016/j.apenergy.2015.01.019.
- 31 Beatley, T., 2011: *Biophilic cities : integrating nature into urban design and planning*. Island Press, 191 pp.
- 32 Beckford, C. L., and K. Rhiney, 2016: Future of Food and Agriculture in the Caribbean in the Context of Climate
33 Change and Globalization: Where Do We Go from Here? *Globalization, Agriculture and Food in the Caribbean*,
34 Palgrave Macmillan UK, London, 267–295.
- 35 Beer, C., and Coauthors, 2010: Terrestrial Gross Carbon Dioxide Uptake: Global Distribution and Covariation with
36 Climate. *Science (80-.)*, **329**, 834–838, doi:10.1126/science.1184984.
- 37 Bell, T., R. Briggs, R. Bachmayer, and S. Li, 2015: Augmenting Inuit knowledge for safe sea-ice travel - The SmartICE
38 information system. *2014 Oceans - St. John’s, OCEANS 2014*.
- 39 Bellamy, R., J. Lezaun, and J. Palmer, 2017: Public perceptions of geoengineering research governance: An
40 experimental deliberative approach. *Glob. Environ. Chang.*, **45**, 194–202, doi:10.1016/j.gloenvcha.2017.06.004.
41 <http://www.sciencedirect.com/science/article/pii/S0959378016302230> (Accessed July 23, 2017).
- 42 Bellassen, N. Stephan (eds), Accounting for carbon. Monitoring, reporting and verifying emissions in the climate
43 economy / V., 2015. Cambridge University Press. 561 p
- 44 Belmonte, N., V. Girgenti, P. Florian, C. Peano, C.
45 Luetto, P. Rizzi, and M. Baricco, 2016: A comparison of energy storage from renewable sources through batteries
46 and fuel cells: A case study in Turin, Italy. *Int. J. Hydrogen Energy*, **41**, 21427–21438,
47 doi:10.1016/j.ijhydene.2016.07.260. <http://linkinghub.elsevier.com/retrieve/pii/S0360319916323151> (Accessed
48 July 22, 2017).
- 49 Belz, F.-M., 2004: A Transition Towards Sustainability in the Swiss Agri-Food Chain (1970–2000): Using and
50 Improving the Multi-level Perspective. *System Innovation and the Transition to Sustainability*, Edward Elgar
51 Publishing, Cheltenham, UK, 97–114.
- 52 Bennetzen, E. H., P. Smith, and J. R. Porter, 2016a: Decoupling of greenhouse gas emissions from global agricultural
53 production: 1970-2050. *Glob. Chang. Biol.*, **22**, 763–781, doi:10.1111/gcb.13120.
- 54 Bennetzen, E. H., P. Smith, and J. R. Porter, 2016b: Agricultural production and greenhouse gas emissions from world
55 regions—The major trends over 40 years. *Glob. Environ. Chang.*, **37**, 43–55.
- 56 Benson, S. M., and Coauthors, 2012: Chapter 13 - Carbon Capture and Storage. Cambridge University Press,
57 Cambridge, UK and New York, NY, USA and the International Institute for Applied Systems Analysis,
58 Laxenburg, Austria, 993–1068 www.globalenergyassessment.org.
- 59 Bergeek, A., S. Jacobsson, B. Carlsson, S. Lindmark, and A. Rickne, 2008: Analyzing the functional dynamics of
60 technological innovation systems: A scheme of analysis. *Res. Policy*, **37**, 407–429,
doi:10.1016/j.respol.2007.12.003.
- Berke, E. M., L. M. Gottlieb, A. V. Moudon, and E. B. Larson, 2007: Protective Association Between Neighborhood

- 1 Walkability and Depression in Older Men. *J. Am. Geriatr. Soc.*, **55**, 526–533, doi:10.1111/j.1532-
2 5415.2007.01108.x.
- 3 Bertinelli, L., P. Mohan, and E. Strobl, 2016: Hurricane damage risk assessment in the Caribbean: An analysis using
4 synthetic hurricane events and nightlight imagery. *Ecol. Econ.*, **124**, 135–144,
5 doi:10.1016/j.ecolecon.2016.02.004.
- 6 de Best-Waldhober, M., D. Daamen, and A. Faaij, 2009: Informed and uninformed public opinions on CO₂ capture and
7 storage technologies in the Netherlands. *Int. J. Greenh. Gas Control*, **3**, 322–332,
8 doi:10.1016/j.ijggc.2008.09.001.
- 9 Betsill, M. M., and H. Bulkeley, 2006: Cities and the Multilevel Governance of Global Climate Change. *Glob. Gov.*, **12**,
10 141–159, doi:10.2307/27800607.
- 11 Bettini, Y., R. R. Brown, and F. J. de Haan, 2015: Exploring institutional adaptive capacity in practice: examining water
12 governance adaptation in Australia. *Ecol. Soc.*, **20**, art47, doi:10.5751/ES-07291-200147.
- 13 Betzold, C., 2015: Adapting to climate change in small island developing states. *Clim. Change*, **133**, 481–489,
14 doi:10.1007/s10584-015-1408-0.
- 15 Bharucha, Z. P., D. Smith, and J. Pretty, 2014: All paths lead to rain: explaining why watershed development in India
16 does not alleviate the experience of water scarcity. *J. Dev. Stud.*, **50**, 1209–1225.
- 17 Bickel, J. E., and S. Agrawal, 2013: Reexamining the economics of aerosol geoengineering. *Clim. Change*, **119**, 993–
18 1006, doi:10.1007/s10584-012-0619-x.
- 19 Biermann, F., 2010: Beyond the intergovernmental regime: Recent trends in global carbon governance. *Curr. Opin.*
20 *Environ. Sustain.*, **2**, 284–288, doi:10.1016/j.cosust.2010.05.002.
- 21 Biermann, F., 2014: The Anthropocene: A governance perspective. *Anthr. Rev.*, **1**, 57–61,
22 doi:10.1177/2053019613516289. <http://anr.sagepub.com/lookup/doi/10.1177/2053019613516289>.
- 23 Biggs, E. M., and Coauthors, 2015: Sustainable development and the water–energy–food nexus: A perspective on
24 livelihoods. *Environ. Sci. Policy*, **54**, 389–397, doi:10.1016/j.envsci.2015.08.002.
- 25 Blanchet, T., 2015: Struggle over energy transition in Berlin: How do grassroots initiatives affect local energy policy-
26 making? *Energy Policy*, **78**, 246–254, doi:10.1016/j.enpol.2014.11.001.
- 27 Blanco, G., and Coauthors, 2014: Drivers, Trends and Mitigation. M. Gomes and A. Verbruggen, Eds., Cambridge
28 University Press, Cambridge, UK and New York, NY, USA, p. 98.
- 29 Bodansky, D., 2013: The who, what, and wherefore of geoengineering governance. *Clim. Change*, **121**, 539–551,
30 doi:10.1007/s10584-013-0759-7.
- 31 ———, and E. Diringer, 2014: Alternative Models for the 2015 Climate Change Agreement. *FNI Clim. Policy Perspect.*
32 **13**, **October**. [http://re.indiaenvironmentportal.org.in/files/file/Alternative Models for the 2015 climate change](http://re.indiaenvironmentportal.org.in/files/file/Alternative%20Models%20for%20the%202015%20climate%20change%20agreement.pdf)
33 [agreement.pdf](http://re.indiaenvironmentportal.org.in/files/file/Alternative%20Models%20for%20the%202015%20climate%20change%20agreement.pdf) (Accessed July 21, 2017).
- 34 ———, S. A. Hoedl, G. E. Metcalf, and R. N. Stavins, 2014: *Facilitating Linkage of Heterogeneous Regional, National,*
35 *and Sub-National Climate Policies Through a Future International Agreement*. 62 pp.
- 36 de Boer, J., A. de Witt, and H. Aiking, 2016: Help the climate, change your diet: A cross-sectional study on how to
37 involve consumers in a transition to a low-carbon society. *Appetite*, **98**, 19–27, doi:10.1016/j.appet.2015.12.001.
38 <http://dx.doi.org/10.1016/j.appet.2015.12.001>.
- 39 Bonan, G. B., 2008: Forests and climate change: forcings, feedbacks, and the climate benefits of forests. *Science (80-*
40 *),* **320**, 1444–1449, doi:10.1126/science.1155121. <http://www.ncbi.nlm.nih.gov/pubmed/18556546> (Accessed
41 July 21, 2017).
- 42 Bord, R. J., R. E. O’Connor, and A. Fisher, 2000: In what sense does the public need to understand global climate
43 change? *Public Underst. Sci.*, **9**, 205–218. <http://pus.sagepub.com/content/9/3/205.short> (Accessed February 18,
44 2013).
- 45 Bosomworth, K., A. Harwood, and P. Wallis, 2015: *Adaptation Pathways : a playbook for developing options for*
46 *climate change adaptation in NRM*. Nathan, QLD, 26 pp.
- 47 Boucher, O., and G. A. Folberth, 2010: New Directions: Atmospheric methane removal as a way to mitigate climate
48 change? *Atmos. Environ.*, **44**, 3343–3345, doi:10.1016/j.atmosenv.2010.04.032.
- 49 Boyce, D., 2016: Assessment of Disaster Risk Management in Sectoral Planning within the Caribbean Community. *J.*
50 *Assoc. Prof. Eng. Trinidad Tobago*, **44**, 42–48.
51 [http://www.apett.org/journal/vol44_n1_April2016/JAPETT_v44n1_April2016\(Completed_v2b\).pdf#page=44](http://www.apett.org/journal/vol44_n1_April2016/JAPETT_v44n1_April2016(Completed_v2b).pdf#page=44)
52 (Accessed July 23, 2017).
- 53 Boyd, E., 2017: Climate adaptation: Holistic thinking beyond technology. *Nat. Clim. Chang.*, **7**, 97–98,
54 doi:10.1038/nclimate3211.
- 55 Boyle, M., and H. Dowlatabadi, 2011: Anticipatory adaptation in marginalized communities within developed
56 countries. *Climate Change Adaptation in Developed Nations: From Theory to Practice*, Springer, Dordrecht,
57 461–473.
- 58 BP Global, 2016: *BP Statistical Review of World Energy*. [https://www.bp.com/content/dam/bp/pdf/energy-](https://www.bp.com/content/dam/bp/pdf/energy-economics/statistical-review-2016/bp-statistical-review-of-world-energy-2016-full-report.pdf)
59 [economics/statistical-review-2016/bp-statistical-review-of-world-energy-2016-full-report.pdf](https://www.bp.com/content/dam/bp/pdf/energy-economics/statistical-review-2016/bp-statistical-review-of-world-energy-2016-full-report.pdf).
- 60 Bradley, P., A. Coke, and M. Leach, 2016: Financial incentive approaches for reducing peak electricity demand,

- 1 experience from pilot trials with a UK energy provider. *Energy Policy*, **98**, 108–120,
2 doi:10.1016/j.enpol.2016.07.022.
- 3 Bright, R. M., K. Zhao, R. B. Jackson, and F. Cherubini, 2015: Quantifying surface albedo and other direct
4 biogeophysical climate forcings of forestry activities. *Glob. Chang. Biol.*, **21**, 3246–3266, doi:10.1111/gcb.12951.
- 5 Briley, L., D. Brown, and S. E. Kalafatis, 2015: Overcoming barriers during the co-production of climate information
6 for decision-making. *Clim. Risk Manag.*, **9**, 41–49, doi:10.1016/j.crm.2015.04.004.
7 <http://dx.doi.org/10.1016/j.crm.2015.04.004>.
- 8 Brink, E., and Coauthors, 2016: Cascades of green: A review of ecosystem-based adaptation in urban areas. *Glob.*
9 *Environ. Chang.*, **36**, 111–123, doi:10.1016/j.gloenvcha.2015.11.003.
- 10 Broehm, M., J. Streffer, and N. Bauer, 2015: Techno-Economic Review of Direct Air Capture Systems for Large Scale
11 Mitigation of Atmospheric CO₂. doi:<http://dx.doi.org/10.2139/ssrn.2665702>.
- 12 Brooks, S. J., 2013: Avoiding the Limits to Growth: Gross National Happiness in Bhutan as a Model for Sustainable
13 Development. *Sustainability*, **5**, doi:10.3390/su5093640.
- 14 van der Brugge, R., and R. Roosjen, 2015: An institutional and sociocultural perspective on the adaptation pathways
15 approach. *J. Water Clim. Chang.*, **6**, 743–758, doi:10.2166/wcc.2015.001.
- 16 Buchner, B. K., and Coauthors, 2015: *Global Landscape of Climate Finance 2015*. Venice, 17 pp.
- 17 Buck, H. J., A. R. Gammon, and C. J. Preston, 2014: Gender and geoengineering. *Hypatia*, **29**, 651–669,
18 doi:10.1111/hypa.12083.
- 19 Buckeridge, M. S., A. P. de Souza, R. A. Arundale, K. J. Anderson-Teixeira, and E. Delucia, 2012: Ethanol from
20 sugarcane in Brazil: A “midway” strategy for increasing ethanol production while maximizing environmental
21 benefits. *GCB Bioenergy*, **4**, 119–126, doi:10.1111/j.1757-1707.2011.01122.x.
- 22 Budsberg, E., J. T. Crawford, H. Morgan, W. S. Chin, R. Bura, and R. Gustafson, 2016: Hydrocarbon bio-jet fuel from
23 bioconversion of poplar biomass: life cycle assessment. *Biotechnol. Biofuels*, **9**, 170, doi:10.1186/s13068-016-
24 0582-2. <http://biotechnologyforbiofuels.biomedcentral.com/articles/10.1186/s13068-016-0582-2> (Accessed July
25 22, 2017).
- 26 Bui, M., and Coauthors, (Under Review) Carbon capture and storage (CCS): The way forward.
- 27 Bulkeley, H., H. Schroeder, K. Janda, J. Zhao, A. Armstrong, S. Y. Chu, and S. Ghosh, 2011: The Role of Institutions,
28 Governance, and Urban Planning for Mitigation and Adaptation. *Cities and Climate Change*, The World Bank,
29 125–159.
- 30 ———, and Coauthors, 2012: Governing climate change transnationally: Assessing the evidence from a database of sixty
31 initiatives. *Environ. Plan. C Gov. Policy*, **30**, 591–612, doi:10.1068/c11126.
- 32 Burnham, M., and Z. Ma, 2017: Climate change adaptation: factors influencing Chinese smallholder farmers’ perceived
33 self-efficacy and adaptation intent. *Reg. Environ. Chang.*, **17**, 171–186, doi:10.1007/s10113-016-0975-6.
- 34 Burns, W. C. G., 2010: Climate geoengineering: Solar radiation management and its implications for intergenerational
35 equity. *Clim. Chang. Geoengin. Philos. Perspect. Leg. Issues, Gov. Fram.*, **98**, 200–220,
36 doi:10.1017/CBO9781139161824.012.
- 37 Burt, A., B. Hughes, and G. Milante, 2014: *Eradicating Poverty in Fragile States: Prospects of Reaching The “High-
38 Hanging” Fruit by 2030*. Washington D.C., 35 pp.
- 39 Busby, J., 2016: After Paris: Good enough climate governance. *Curr. Hist.*, **115**.
- 40 Bustamante, J. G., A. S. Rattner, and S. Garimella, 2016: Achieving near-water-cooled power plant performance with
41 air-cooled condensers. *Appl. Therm. Eng.*, **105**, 362–371, doi:10.1016/j.applthermaleng.2015.05.065.
- 42 Butler, C., K. a Parkhill, and N. Pidgeon, 2013: *Deliberating Energy System Transitions in the UK - Transforming the
43 UK Energy System: Public Values, Attitudes and Acceptability*. London, UK, 72 pp.
- 44 Butler, J. R. A., and Coauthors, 2015: Integrating Top-Down and Bottom-Up Adaptation Planning to Build Adaptive
45 Capacity: A Structured Learning Approach. *Coast. Manag.*, **43**, 346–364, doi:10.1080/08920753.2015.1046802.
- 46 Butler, J. R. A., and Coauthors, 2016: Scenario planning to leap-frog the Sustainable Development Goals: An
47 adaptation pathways approach. *Clim. Risk Manag.*, **12**, 83–99, doi:10.1016/j.crm.2015.11.003.
- 48 Caldecott, B.; Lomax, G.; Workman, M., 2015: *Stranded Carbon Assets and Negative Emissions Technologies*. Oxford,
49 UK, 37 pp.
- 50 Caldecott, B., 2017: Introduction to special issue: stranded assets and the environment. *J. Sustain. Financ. Invest.*, **7**, 1–
51 13, doi:10.1080/20430795.2016.1266748.
- 52 Caldeira, K., and G. Bala, 2017: Reflecting on 50 years of geoengineering research. *Earth’s Futur.*, **5**, 10–17,
53 doi:10.1002/2016EF000454.
- 54 Campbell-Lendrum, D., and C. Corvalán, 2007: Climate change and developing-country cities: implications for
55 environmental health and equity. *J. Urban Health*, **84**, 109–117, doi:10.1007/s11524-007-9170-x.
- 56 Campiglio, E., 2016: Beyond carbon pricing: The role of banking and monetary policy in financing the transition to a
57 low-carbon economy. *Ecol. Econ.*, **121**, 220–230, doi:10.1016/j.ecolecon.2015.03.020.
- 58 ———, W. P. No, and W. P. No, 2014: Beyond carbon pricing : The role of banking and monetary policy in financing the
59 transition to a low-carbon economy Centre for Climate Change Economics and Policy the Environment.
- 60 Canales, F. A., A. Beluco, and C. A. B. Mendes, 2015: A comparative study of a wind hydro hybrid system with water

- 1 storage capacity: Conventional reservoir or pumped storage plant? *J. Energy Storage*, **4**, 96–105,
2 doi:10.1016/j.est.2015.09.007.
- 3 Carney, S., and S. Shackley, 2009: The greenhouse gas regional inventory project (GRIP): Designing and employing a
4 regional greenhouse gas measurement tool for stakeholder use. *Energy Policy*, **37**, 4293–4302,
5 doi:10.1016/j.enpol.2009.05.028.
- 6 Cartwright, A., 2015: *Better growth, better cities: reimagining and rethinking urbanisation in Africa*. Rondebosch,
7 South Africa, 44 pp.
- 8 ———, J. Blijnaut, M. De Wit, K. Goldberg, M. Mander, S. O’Donoghue, and D. Roberts, 2013: Economics of climate
9 change adaptation at the local scale under conditions of uncertainty and resource constraints: the case of Durban,
10 South Africa. *Environ. Urban.*, **25**, 139–156, doi:10.1177/0956247813477814.
- 11 Cashman, A., and M. Nagdee, 2017: *Impacts of Climate Change on Settlements and Infrastructure in the Coastal and*
12 *Marine Environments of Caribbean Small Island Developing States (SIDS)*.
13 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/605066/11._Settlements_and_Infra
14 [structure_combined.docx.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/605066/11._Settlements_and_Infra) (Accessed July 23, 2017).
- 15 Castán Broto, V., and H. Bulkeley, 2013: A survey of urban climate change experiments in 100 cities. *Glob. Environ.*
16 *Chang.*, **23**, 92–102, doi:10.1016/j.gloenvcha.2012.07.005.
- 17 Chaffin, B. C., and L. H. Gunderson, 2016: Emergence, institutionalization and renewal: Rhythms of adaptive
18 governance in complex social-ecological systems. *J. Environ. Manage.*, **165**, 81–87,
19 doi:10.1016/j.jenvman.2015.09.003.
- 20 Chaffin, B. C., H. Gosnell, and B. A. Cosens, 2014: A Decade of Adaptive Governance Scholarship: Synthesis and
21 Future Directions. **19**, 56.
- 22 Challinor, A. J., J. Watson, D. B. Lobell, S. M. Howden, D. R. Smith, and N. Chhetri, 2014: A meta-analysis of crop
23 yield under climate change and adaptation. *Nat. Clim. Chang.*, **4**, 287–291, doi:10.1038/nclimate2153.
- 24 Chandel, M. K., L. F. Pratson, and R. B. Jackson, 2011: The potential impacts of climate-change policy on freshwater
25 use in thermoelectric power generation. *Energy Policy*, **39**, 6234–6242, doi:10.1016/j.enpol.2011.07.022.
- 26 Chandrasekharam, D., A. Lashin, N. Al Arafi, C. Varun, and A. Al Bassam, 2015: Climate Change Mitigation Strategy
27 through Utilization of Geothermal Energy Resources from Western Arabian Shield, Saudi Arabia. *J. Clim.*
28 *Chang.*, **1**, 129–134, doi:10.3233/JCC-150011.
- 29 Chang, N. Bin, M. V. Vasquez, C. F. Chen, S. Imen, and L. Mullon, 2015: Global nonlinear and nonstationary climate
30 change effects on regional precipitation and forest phenology in Panama, Central America. *Hydrol. Process.*, **29**,
31 339–355, doi:10.1002/hyp.10151.
- 32 Chapman, A., and S. Darby, 2016: Evaluating sustainable adaptation strategies for vulnerable mega-deltas using system
33 dynamics modelling: Rice agriculture in the Mekong Delta’s An Giang Province, Vietnam. *Sci. Total Environ.*,
34 **559**, 326–338, doi:10.1016/j.scitotenv.2016.02.162.
- 35 Chapman, A. D., S. E. Darby, H. M. H??ng, E. L. Tompkins, and T. P. D. Van, 2016: Adaptation and development
36 trade-offs: fluvial sediment deposition and the sustainability of rice-cropping in An Giang Province, Mekong
37 Delta. *Climatic Change*, August 30.
- 38 Chatrchyan, A. M., R. C. Erlebacher, N. T. Chaopricha, J. Chan, D. Tobin, and S. B. Allred, 2017: United States
39 agricultural stakeholder views and decisions on climate change. *Wiley Interdiscip. Rev. Clim. Chang.*, e467,
40 doi:10.1002/wcc.469.
- 41 Chaturvedi, V., and S. H. Kim, 2015: Long term energy and emission implications of a global shift to electricity-based
42 public rail transportation system. *Energy Policy*, **81**, 176–185, doi:10.1016/j.enpol.2014.11.013.
- 43 Chaudhari, V. R., and A. Mishra, 2015: Multilevel policy responses to mainstream climate adaptation through
44 watershed development in rainfed farming systems of India. *Clim. Dev.*, **5529**, 1–12,
45 doi:10.1080/17565529.2015.1064808.
- 46 Chen, C., and M. Tavoni, 2013: Direct air capture of CO₂ and climate stabilization: A model based assessment. *Clim.*
47 *Change*, **118**, 59–72, doi:10.1007/s10584-013-0714-7.
- 48 Chen, Y., and Y. Xin, 2017: Implications of geoengineering under the 1.5°C target: Analysis and policy suggestions.
49 *Adv. Clim. Chang. Res.*, **7**, 1–7, doi:10.1016/j.accre.2017.05.003.
- 50 Cheshmehzangi, A., 2016: China’s New-type Urbanisation Plan (NUP) and the Foreseeing Challenges for
51 Decarbonization of Cities: A Review. *Energy Procedia*, **104**, 146–152, doi:10.1016/j.egypro.2016.12.026.
- 52 Chomba, S., J. Kariuki, J. F. Lund, and F. Sinclair, 2016: Roots of inequity: How the implementation of REDD+
53 reinforces past injustices. *Land use policy*, **50**, 202–213, doi:10.1016/j.landusepol.2015.09.021.
54 <http://linkinghub.elsevier.com/retrieve/pii/S0264837715002926> (Accessed July 21, 2017).
- 55 Christensen, C., 1997: *The Innovator’s Dilemma: When New Technologies Cause Great Firms to Fail*. Harvard
56 Business School Press, Boston, Mass.,.
- 57 Christensen, C., M. Raynor, and R. McDonald, 2015: What is Disruptive Innovation? *Harv. Bus. Rev.*,,
58 <https://hbr.org/2015/12/what-is-disruptive-innovation>.
- 59 Christoforidis, G. C., K. C. Chatzisavvas, S. Lazarou, and C. Parisses, 2013: Covenant of Mayors initiative—Public
60 perception issues and barriers in Greece. *Energy Policy*, **60**, 643–655, doi:10.1016/j.enpol.2013.05.079.

- 1 Chu, E., 2016: The political economy of urban climate adaptation and development planning in Surat, India. *Environ.*
2 *Plan. C Gov. Policy*, **34**, 281–298.
- 3 ———, I. Anguelovski, and J. Carmin, 2016: Inclusive approaches to urban climate adaptation planning and
4 implementation in the Global South. *Clim. Policy*, **16**, 372–392.
- 5 Chu, S., 2015: Car restraint policies and mileage in Singapore. *Transp. Res. Part A Policy Pract.*, **77**, 404–412.
- 6 Clack, C. T. M., and Coauthors, 2017: Evaluation of a proposal for reliable low-cost grid power with 100% wind,
7 water, and solar. *Proc. Natl. Acad. Sci. U. S. A.*, **114**, 6722–6727, doi:10.1073/pnas.1610381114.
8 <http://www.ncbi.nlm.nih.gov/pubmed/28630353> (Accessed July 22, 2017).
- 9 Clark, D., 2016: Vulnerability to Injury: assessing biophysical and social determinants of land-user injuries in Nunavut,
10 Canada. McGill University Libraries, .
- 11 Clark, M., and D. Tilman, 2017: Comparative analysis of environmental impacts of agricultural production systems,
12 agricultural input efficiency, and food choice. *Environ. Res. Lett.*, **12**, 64016, doi:10.1088/1748-9326/aa6cd5.
- 13 Clarke, L., and Coauthors, 2014: Assessing transformation pathways. *Climate Change 2014: Mitigation of Climate*
14 *Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on*
15 *Climate Change*, T.Z. and J.C.M. (eds. . Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K.
16 Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von
17 Stechow, Ed., Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 413–510.
- 18 Clayton, S., P. Devine-Wright, P. C. Stern, L. Whitmarsh, A. Carrico, L. Steg, J. Swim, and M. Bonnes, 2015:
19 Psychological research and global climate change. *Nat. Clim. Chang.*, **5**, 640–646, doi:10.1038/nclimate2622.
- 20 Colman, A. M., T. W. Körner, O. Musy, and T. Tazdaït, 2011: Mutual support in games: Some properties of Berge
21 equilibria. *J. Math. Psychol.*, **55**, 166–175, doi:10.1016/j.jmp.2011.02.001.
- 22 Colville-Anderson, M., 2016: Meteoric Rise in Bicycle Traffic in Copenhagen.
23 <http://www.copenhagenize.com/2016/11/meteoric-rise-in-bicycle-traffic-in.html> (Accessed July 24, 2017).
- 24 Combet, E., F Ghersi, JC Hourcade, C Thubin - Revue française d'économie, 2010 La fiscalité carbone au risque des
25 enjeux d'équité
- 26 Combet, E., F Ghersi, JC Hourcade, D Théry, Carbon tax and equity: The importance of policy design Critical issues in
27 environmental taxation pp 277-295, Éditeur Oxford University Press 2015de
- 28 Coninck, H. C., and A. Sagar, Technology Development and Transfer (Article 10). *Paris Agreement*, Oxford
29 University Press, Oxford.
- 30 Coninck, H. De, and S. M. Benson, 2014: Carbon Dioxide Capture and Storage: Issues and Prospects. *Annu. Rev.*
31 *Environ. Resour.*, **39**, 243–70, doi:10.1146/annurev-environ-032112-095222.
- 32 Cook, G., and P. Zakkour, 2015: *CCS deployment in the context of regional developments in meeting long-term climate*
33 *change objectives 2015/TR3*. 133 pp.
- 34 Cortekar, J., and M. Groth, 2015: Adapting energy infrastructure to climate change - Is there a need for government
35 interventions and legal obligations within the German “energiewende”? *Energy Procedia*, Vol. 73 of, 12–17.
- 36 Cosbey, A., and R. Tarasofsky, 2007: *Climate Change, Competitiveness and Trade*. Chatham House, London, 41 pp.
- 37 Courtois, P., R. Nessah, and T. Tazdaït, 2015: How to play games? Nash versus Berge Behaviour Rules. *Econ. Philos.*,
38 **31**, 123–139, doi:DOI: 10.1017/S026626711400042X.
- 39 Covenant of Mayors, 2017: Covenant Coordinators. [http://www.covenantofmayors.eu/about/covenant-](http://www.covenantofmayors.eu/about/covenant-coordinators_en.html)
40 [coordinators_en.html](http://www.covenantofmayors.eu/about/covenant-coordinators_en.html) (Accessed July 22, 2017).
- 41 Cox, K., M. Renouf, A. Dargan, C. Turner, and D. Klein-Marcuschamer, 2014: Environmental life cycle assessment
42 (LCA) of aviation biofuel from microalgae, *Pongamia pinnata* , and sugarcane molasses. *Biofuels, Bioprod.*
43 *Biorefining*, **8**, 579–593, doi:10.1002/bbb.1488. <http://doi.wiley.com/10.1002/bbb.1488> (Accessed July 22, 2017).
- 44 Craig, R. K., and Coauthors, 2017: Balancing stability and flexibility in adaptive governance: an analysis of tools
45 available in U.S. environmental law. *Ecol. Soc.*, **22**, art3, doi:10.5751/ES-08983-220203.
- 46 Creutzig, F., G. Baiocchi, R. Bierkandt, P.-P. Pichler, and K. C. Seto, 2015: Global typology of urban energy use and
47 potentials for an urbanization mitigation wedge. *Proc. Natl. Acad. Sci.*, **112**, 6283–6288,
48 doi:10.1073/pnas.1315545112.
- 49 Croci, E., B. Lucchitta, G. Janssens-Maenhout, S. Martelli, and T. Molteni, 2017: Urban CO₂ mitigation strategies
50 under the Covenant of Mayors: An assessment of 124 European cities. *J. Clean. Prod.*,
51 doi:10.1016/j.jclepro.2017.05.165.
- 52 Crutzen, P. J., 2006: Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy
53 Dilemma? *Clim. Change*, **77**, 211–220, doi:10.1007/s10584-006-9101-y.
54 <http://link.springer.com/10.1007/s10584-006-9101-y> (Accessed April 8, 2017).
- 55 Cuéllar-Franca, R. M., and A. Azapagic, 2015: Carbon capture, storage and utilisation technologies: A critical analysis
56 and comparison of their life cycle environmental impacts. *J. CO₂ Util.*, **9**, 82–102,
57 doi:http://dx.doi.org/10.1016/j.jcou.2014.12.001.
- 58 Dahlmann, K., and Coauthors, 2016: Climate-Compatible Air Transport System—Climate Impact Mitigation Potential
59 for Actual and Future Aircraft. *Aerospace*, **3**, 38, doi:10.3390/aerospace3040038. [http://www.mdpi.com/2226-](http://www.mdpi.com/2226-4310/3/4/38)
60 [4310/3/4/38](http://www.mdpi.com/2226-4310/3/4/38) (Accessed July 22, 2017).

- 1 DaMatta, F. M., A. Grandis, B. C. Arenque, and M. S. Buckeridge, 2010: Impacts of climate changes on crop
2 physiology and food quality. *Food Res. Int.*, **43**, 1814–1823, doi:10.1016/j.foodres.2009.11.001.
- 3 Daron, J. D., and D. A. Stainforth, 2013: On predicting climate under climate change. *Environ. Res. Lett.*, **8**, 34021.
- 4 Daron, J. D., K. Sutherland, C. Jack, and B. C. Hewitson, 2015: The role of regional climate projections in managing
5 complex socio-ecological systems. *Reg. Environ. Chang.*, **15**, 1–12, doi:10.1007/s10113-014-0631-y.
- 6 Davidson, E. A., and Coauthors, 2006: Temperature sensitivity of soil carbon decomposition and feedbacks to climate
7 change. *Nature*, **440**, 165–173, doi:10.1038/nature04514.
- 8 Day, J., and R. Cervero, 2010: Effects of residential relocation on household and commuting expenditures in Shanghai,
9 China. *Int. J. Urban Reg. Res.*, **34**, 762–788.
- 10 Decanio, S. J., 1993: Barriers within firms to energy- efficient investments. *Energy Policy*, **21**, 906–914.
- 11 Deklu, N. K., 2015: Evaluating climate change adaptation readiness of Caribbean island nations in relation to
12 communities, fisheries and fishing communities. Halifax, N.S. : Saint Mary’s University, .
- 13 Deng, X., and C. Zhao, 2015: Identification of Water Scarcity and Providing Solutions for Adapting to Climate
14 Changes in the Heihe River Basin of China. *Adv. Meteorol.*, **2015**, 1–13, doi:10.1155/2015/279173.
- 15 Denton, F., and Coauthors, 2014: Climate-Resilient Pathways: Adaptation, Mitigation, and Sustainable Development.
16 *Climate Change 2014 Impacts, Adaptation, and Vulnerability*, C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach,
17 and M.D. Mastrandrea, Eds., Cambridge University Press, Cambridge, 1101–1131.
- 18 Devine-Wright, P., 2003: A cross-national, comparative analysis of public understanding of, and attitudes towards
19 nuclear, renewable and fossil-fuel energy sources. *Proceedings of the 3rd conference of the UK network*
20 *Environmental Psychology in the UK: Crossing boundaries: The value of interdisciplinary research*, Aberdeen,
21 UK, Robert Gordon University, 160–173.
- 22 Diaz-Rainey, I., B. Robertson, and C. Wilson, 2017: Stranded research? Leading finance journals are silent on climate
23 change. *Clim. Change*, **143**, 243–260, doi:10.1007/s10584-017-1985-1.
- 24 Dietz, T., G. T. Gardner, J. Gilligan, P. C. Stern, and M. P. Vandenbergh, 2009: Household actions can provide a
25 behavioral wedge to rapidly reduce US carbon emissions. *Proc. Natl. Acad. Sci.*, **106**, 18452–18456,
26 doi:10.1073/pnas.0908738106.
- 27 ———, P. C. Stern, and E. U. Weber, 2013: Reducing Carbon-Based Energy Consumption through Changes in
28 Household Behavior. *Daedalus*, **142**, 78–89, doi:10.1162/DAED_a_00186.
29 http://dx.doi.org/10.1162/DAED_a_00186.
- 30 ———, K. A. Frank, C. T. Whitley, J. Kelly, and R. Kelly, 2015: Political influences on greenhouse gas emissions from
31 US states. *Proceeding Natl. Acad. Sci. United States Am.*, **112**, 8254–8259, doi:10.1073/pnas.1417806112.
- 32 Dinner, I., E. J. Johnson, D. G. Goldstein, and K. Liu, 2011: “Partitioning default effects: Why people choose not to
33 choose”: Correction to Dinner et al. (2011). *J. Exp. Psychol. Appl.*, **17**, 432–432, doi:10.1037/a0026470.
- 34 Dóci, G., and E. Vasileiadou, 2015: “Let’s do it ourselves” Individual motivations for investing in renewables at
35 community level. *Renew. Sustain. Energy Rev.*, **49**, 41–50, doi:10.1016/j.rser.2015.04.051.
- 36 Dodman, D., S. Colenbrander, and D. Archer, 2016: Conclusion. *Responding to climate change in Asian cities :
37 governance for a more resilient urban future*, D. Archer, S. Colenbrander, and D. Dodman, Eds., Routledge
38 Earthscan, London.
- 39 Donovan, M. G., 2017: *A Blue Urban Agenda: Adapting to Climate Change in the Coastal Cities of Caribbean and
40 Pacific Small Island Developing States*. Washington, D.C., <https://publications.iadb.org/handle/11319/8264>
41 (Accessed July 9, 2017).
- 42 Dorward, P., G. Clarkson, and R. Stern, 2015: *Participatory integrated climate services for agriculture (PICSA): Field
43 manual*. Walker Institute, University of Reading, Reading, UK, 65 pp.
- 44 Mac Dowell, N., P. S. Fennell, N. Shah, and G. C. Maitland, 2017: The role of CO₂ capture and utilization in mitigating
45 climate change. *Nat. Clim. Chang.*, **7**, 243–249, doi:10.1038/nclimate3231.
46 <http://www.nature.com/doi/10.1038/nclimate3231>.
- 47 Droste, N., and Coauthors, 2016: Steering innovations towards a green economy: Understanding government
48 intervention. *J. Clean. Prod.*, **135**, 426–434, doi:10.1016/j.jclepro.2016.06.123.
- 49 Dunlop, T., and E. Corbera, 2016: Incentivizing REDD+: How developing countries are laying the groundwork for
50 benefit-sharing. *Environ. Sci. Policy*, **63**, 44–54, doi:10.1016/j.envsci.2016.04.018.
51 <http://linkinghub.elsevier.com/retrieve/pii/S1462901116301022> (Accessed July 21, 2017).
- 52 Eakin, H., and Coauthors, 2015: Information and communication technologies and climate change adaptation in Latin
53 America and the Caribbean: a framework for action. *Clim. Dev.*, **7**, 208–222,
54 doi:10.1080/17565529.2014.951021. <http://www.tandfonline.com/doi/full/10.1080/17565529.2014.951021>
55 (Accessed July 9, 2017).
- 56 Eastham, J., F. Mpelasoka, M. Mainuddin, C. Ticehurst, P. Dyce, G. Hodgson, R. Ali, and M. Kirby, 2008: *Mekong
57 river basin water resources assessment: Impacts of climate change*. CSIRO: water for a healthy country national
58 research flagship Canberra,.
- 59 Edenhofer, O., M. Jakob, F. Creutzig, C. Flachsland, S. Fuss, M. Kowarsch, K. Lessmann, L. Mattauach, J. Siegmeier,
60 and J.C.Steckel. 2015. Closing the Emission Price Gap. *Global Environmental Change* 31: 132–43. EIB, 2015:

- 1 ELENA Project Factsheet: U.E.F.A. - European Union ELENA Foggia Facility Assistance.
- 2 Eicken, H., M. Kaufman, I. Krupnik, P. Pulsifer, L. Apangalook, P. Apangalook, W. Weyapuk, and J. Leavitt, 2014: A
3 framework and database for community sea ice observations in a changing Arctic: an Alaskan prototype for
4 multiple users. *Polar Geogr.*, **37**, 5–27, doi:10.1080/1088937X.2013.873090.
- 5 Einarsson, N., 2014a: Arctic Human Development Report. *Encyclopedia of Quality of Life and Well-Being Research*,
6 A.C. Michalos, Ed., Vol. 777 of, Springer, Dordrecht, Netherlands, 213–214.
- 7 Einarsson, N., 2014b: *Arctic human development report (AHDR)*.
- 8 Eisenack, K., and R. Stecker, 2012: A framework for analyzing climate change adaptations as actions. *Mitig. Adapt.*
9 *Strateg. Glob. Chang.*, **17**, 243–260, doi:10.1007/s11027-011-9323-9.
- 10 Eizenberg, E., and Y. Jabareen, 2017: Social sustainability: A new conceptual framework. *Sustain.*, **9**,
11 doi:10.3390/su9010068.
- 12 Ek, K., and P. Söderholm, 2008: Households' switching behavior between electricity suppliers in Sweden. *Util. Policy*,
13 **16**, 254–261, doi:10.1016/j.jup.2008.04.005.
- 14 ———, and P. Söderholm Patrik, 2010: The devil is in the details: Household electricity saving behavior and the role of
15 information. *Energy Policy*, **38**, 1578–1587, doi:10.1016/j.enpol.2009.11.041.
- 16 Eliasson, J., 2014: The role of attitude structures, direct experience and reframing for the success of congestion pricing.
17 *Transp. Res. Part A Policy Pract.*, **67**, 81–95, doi:10.1016/j.tra.2014.06.007.
- 18 Elshout, P. M. F., R. van Zelm, R. Karuppiyah, I. J. Laurenzi, and M. A. J. Huijbregts, 2014: A spatially explicit data-
19 driven approach to assess the effect of agricultural land occupation on species groups. *Int. J. Life Cycle Assess.*,
20 **19**, 758–769, doi:10.1007/s11367-014-0701-x. <http://link.springer.com/10.1007/s11367-014-0701-x> (Accessed
21 July 22, 2017).
- 22 den Elzen, M., A. Admiraal, M. Roelfsema, H. van Soest, A. F. Hof, and N. Forsell, 2016: Contribution of the G20
23 economies to the global impact of the Paris agreement climate proposals. *Clim. Change*, **137**, 655–665,
24 doi:10.1007/s10584-016-1700-7. <http://link.springer.com/10.1007/s10584-016-1700-7> (Accessed July 24, 2017).
- 25 EMUDC, 2014: *National Report on Housing & Sustainable Urban Development*.
- 26 Esham, M., and C. Garforth, 2013: Agricultural adaptation to climate change: insights from a farming community in Sri
27 Lanka. *Mitig. Adapt. Strateg. Glob. Chang.*, **18**, 535–549, doi:10.1007/s11027-012-9374-6.
- 28 Ewing, R., S. Hamidi, and J. B. Grace, 2016: Compact development and VMT—Environmental determinism, self-
29 selection, or some of both? *Environ. Plan. B Plan. Des.*, **43**, 737–755, doi:10.1177/0265813515594811.
30 <http://journals.sagepub.com/doi/10.1177/0265813515594811> (Accessed July 25, 2017).
- 31 Farfan, J., and C. Breyer, 2017: Structural changes of global power generation capacity towards sustainability and the
32 risk of stranded investments supported by a sustainability indicator. *J. Clean. Prod.*, **141**, 370–384,
33 doi:10.1016/j.jclepro.2016.09.068. <http://dx.doi.org/10.1016/j.jclepro.2016.09.068>.
- 34 Fargione, J., J. Hill, D. Tilman, S. Polasky, and P. Hawthorne, 2008: Land Clearing and the Biofuel Carbon Debt.
35 *Science (80-.)*, **319**, 1235–1238, doi:10.1126/science.1152747.
- 36 Favretto, N., L. C. Stringer, M. S. Buckeridge, and S. Afionis, 2017: Policy and Diplomacy in the Production of Second
37 Generation Ethanol in Brazil: International Relations with the EU, the USA and Africa BT - Advances of Basic
38 Science for Second Generation Bioethanol from Sugarcane. *Advances of Basic Science for Second Generation*
39 *from Sugarcane*, M.S. Buckeridge and A.P. De Souza, Eds., Springer International Publishing, New York, 197–
40 212.
- 41 Fawcett, A. A., and Coauthors, 2015: Can Paris pledges avert severe climate change? *Science (80-.)*, **350**, 1168–1169,
42 doi:10.1126/science.aad5761.
- 43 Fazey, I., R. M. Wise, C. Lyon, C. Câmpeanu, P. Moug, and T. E. Davies, 2016: Past and future adaptation pathways.
44 *Clim. Dev.*, **8**, 26–44, doi:10.1080/17565529.2014.989192.
- 45 ———, and Coauthors, 2017: Transformation in a changing climate: a research agenda. *Clim. Dev.*, **0**, 1–21,
46 doi:10.1080/17565529.2017.1301864.
- 47 Fearnside, P. M., 1985: Brazil's Amazon Forest and the Global Carbon Problem. *Interciencia*, 179–186.
- 48 Fenton, A., D. Gallagher, H. Wright, S. Huq, and C. Nyandiga, 2014: Up-scaling finance for community-based
49 adaptation. *Clim. Dev.*, **6**, 388–397.
- 50 Feola, G., A. M. Lerner, M. Jain, M. J. F. Montefrío, and K. a. Nicholas, 2015: Researching farmer behaviour in climate
51 change adaptation and sustainable agriculture: Lessons learned from five case studies. *J. Rural Stud.*, **39**, 74–84,
52 doi:10.1016/j.jrurstud.2015.03.009.
- 53 Fernández-Giménez, M. E., B. Batkhisig, B. Batbuyan, and T. Ulambayar, 2015: Lessons from the Dzud: Community-
54 Based Rangeland Management Increases the Adaptive Capacity of Mongolian Herders to Winter Disasters. *World*
55 *Dev.*, **68**, 48–65, doi:10.1016/j.worlddev.2014.11.015.
- 56 Figueres, C., H. J. Schellnhuber, G. Whiteman, J. Rockström, A. Hopley, and S. Rahmstorf, 2017: Three years to
57 safeguard our climate. *Nature*, **546**, 593–595.
- 58 Finn, D., R. Dalal, and A. Klieve, 2015: Methane in Australian agriculture: Current emissions, sources and sinks, and
59 potential mitigation strategies. *Crop Pasture Sci.*, **66**, 1–22, doi:10.1071/CP14116.
- 60 Fleming, A., A. M. Dowd, E. Gaillard, S. Park, and M. Howden, 2015: “Climate change is the least of my worries”:

- 1 Stress limitations on adaptive capacity. *Rural Soc.*, **24**, 24–41, doi:10.1080/10371656.2014.1001481.
- 2 Fleurbaey, M., and Coauthors, 2014: Sustainable Development and Equity. *Climate Change 2014: Mitigation of*
- 3 *Climate Change*, P.E. Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A.
- 4 Adler, I. Baum, S. Brunner and T.Z. and J.C.M. B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, Eds.,
- 5 Cambridge University Press, Cambridge, UK and New York, NY, USA, 283–350.
- 6 Fook, T. C. T., 2015: Transformational processes for community-focused adaptation and social change: a synthesis.
- 7 *Clim. Dev.*, **5529**, 1–17, doi:10.1080/17565529.2015.1086294.
- 8 Ford, J. D., K. Bolton, J. Shirley, T. Pearce, M. Tremblay, and M. Westlake, 2012: Mapping human dimensions of
- 9 climate change research in the Canadian Arctic. *Ambio*, **41**, 808–822, doi:10.1007/s13280-012-0336-8.
- 10 ———, G. McDowell, and J. Jones, 2014a: The state of climate change adaptation in the Arctic. *Environ. Res. Lett.*, **9**,
- 11 104005, doi:10.1088/1748-9326/9/10/104005.
- 12 ———, A. C. Willox, S. Chatwood, C. Furgal, S. Harper, I. Mauro, and T. Pearce, 2014b: Adapting to the effects of
- 13 climate change on Inuit health. *Am. J. Public Health*, **104**, e9–e17, doi:10.2105/AJPH.2013.301724.
- 14 ———, G. McDowell, and T. Pearce, 2015: The adaptation challenge in the Arctic. *Nat. Clim. Chang.*, **5**, 1046–1053,
- 15 doi:10.1038/nclimate2723. <http://www.nature.com/doi/10.1038/nclimate2723>.
- 16 ———, T. Bell, and N. J. Couture, 2016: Perspectives on Canada’s North Coast Region. *Climate Change Impacts and*
- 17 *Adaptation Assessment of Canada’s Marine Coasts*, Government of Canada Ottawa, ON.
- 18 Fouquet, R., 2016: Lessons from energy history for climate policy: Technological change, demand and economic
- 19 development. *Energy Res. Soc. Sci.*, **22**, 79–93, doi:10.1016/j.erss.2016.09.001.
- 20 <http://www.sciencedirect.com/science/article/pii/S2214629616302080> (Accessed April 6, 2017).
- 21 Frank, S., H. Böttcher, P. Havlík, H. Valin, A. Mosnier, M. Obersteiner, E. Schmid, and B. Elbersen, 2013: How
- 22 effective are the sustainability criteria accompanying the European Union 2020 biofuel targets? *GCB Bioenergy*,
- 23 **5**, 306–314, doi:10.1111/j.1757-1707.2012.01188.x. <http://doi.wiley.com/10.1111/j.1757-1707.2012.01188.x>
- 24 (Accessed July 6, 2017).
- 25 Frederiks, E. R., K. Stenner, and E. V. Hobman, 2015: Household energy use: Applying behavioural economics to
- 26 understand consumer decision-making and behaviour. *Renew. Sustain. Energy Rev.*, **41**, 1385–1394,
- 27 doi:10.1016/j.rser.2014.09.026.
- 28 Freeman, C., and C. Perez, 2000: Structural crises of adjustment, business cycles and investment behaviour. *Technol.*
- 29 *Organ. Innov. Theor. Concepts Paradig.*, **871**.
- 30 Freire, M., S. Lall, and D. Leipziger, 2014: *Africa’s urbanization: challenges and opportunities*. Washington D.C.,
- 31 Fridahl, M., and L. Johansson, 2016: An assessment of the potential for spurring transformational change through
- 32 Nationally Appropriate Mitigation Actions (NAMAs). *Environ. Innov. Soc. Transitions*,
- 33 doi:10.1016/j.eist.2016.11.003.
- 34 Friend, R., J. Jarvie, S. O. Reed, R. Sutarto, P. Thinphanga, and V. C. Toan, 2014: Mainstreaming urban climate
- 35 resilience into policy and planning; reflections from Asia. *Urban Clim.*, **7**, 6–19.
- 36 Froud, J., C. Haslam, J. Sukhdev., K. Williams., Shareholder value and Financialization: consultancy promises,
- 37 management moves, *Economy and Society* Vol. 29 , Iss. 1,2000
- 38 Fudge, S., M. Peters, and B. Woodman, 2016: Local authorities as niche actors: the case of energy governance in the
- 39 UK. *Environ. Innov. Soc. Transitions*, **18**, 1–17, doi:10.1016/j.eist.2015.06.004.
- 40 Fujii, S., and R. Kitamura, 2003: What does a one-month free bus ticket do to habitual drivers? An experimental
- 41 analysis of habit and attitude change. *Transportation (Amst.)*, **30**, 81–95, doi:10.1023/A:1021234607980.
- 42 ———, T. Gärling, and R. Kitamura, 2001: Changes in Drivers’ Perceptions and Use of Public Transport during a
- 43 Freeway Closure: Effects of Temporary Structural Change on Cooperation in a Real-Life Social Dilemma.
- 44 *Environ. Behav.*, **33**, 796–808, doi:10.1177/00139160121973241.
- 45 Fujimori, S., X. Su, J.-Y. Liu, T. Hasegawa, K. Takahashi, T. Masui, and M. Takimi, 2016: Implication of Paris
- 46 Agreement in the context of long-term climate mitigation goals. *Springerplus*, **5**, 1620, doi:10.1186/s40064-016-
- 47 3235-9.
- 48 Fünfgeld, H., 2015: Facilitating local climate change adaptation through transnational municipal networks. *Curr. Opin.*
- 49 *Environ. Sustain.*, **12**, 67–73.
- 50 Fuss, S., 2017: Oxford Research Encyclopedia of Climate Science: The 1.5°C Target , Political Implications, and the
- 51 Role of BECCS. 1–29
- 52 [http://climatescience.oxfordre.com/view/10.1093/acrefore/9780190228620.001.0001/acrefore-9780190228620-e-](http://climatescience.oxfordre.com/view/10.1093/acrefore/9780190228620.001.0001/acrefore-9780190228620-e-585?print=pdf)
- 53 [585?print=pdf](http://climatescience.oxfordre.com/view/10.1093/acrefore/9780190228620.001.0001/acrefore-9780190228620-e-585?print=pdf).
- 54 Fuss, S., and Coauthors, 2016: Research priorities for negative emissions. *Environ. Res. Lett.*, **11**, 115007,
- 55 doi:10.1088/1748-9326/11/11/115007.
- 56 Gajjar, S., C. Singh, and T. Deshpande, (Under Review) Tracing back to move ahead: A review of development
- 57 pathways that shape adaptation futures. *Clim. Dev.*,..
- 58 Gao, Y., and J. Kenworthy, 2017: China. *The Urban Transport Crisis in Emerging Economies*, Springer International
- 59 Publishing, Switzerland, 33–58.
- 60 Gardiner, S., 2010: Is “Arming the Future” with Geoengineering Really the Lesser Evil? Some Doubts About the Ethics

- 1 of Intentionally Manipulating the Climate System. *Climate Ethics: Essential Readings*, S. Gardiner, S. Caney, D.
2 Jamieson, and H. Shue, Eds., Oxford University Press, Oxford.
- 3 Garsaball, E. C., and H. Markov, 2017: Climate change: are building codes keeping up? A case study on hurricanes in
4 the Caribbean. *Proc. Inst. Civ. Eng. - Forensic Eng.*, **170**, 67–71, doi:10.1680/jfoen.16.00034.
- 5 Gaunt, J. L., and J. Lehmann, 2008: Energy Balance and Emissions Associated with Biochar Sequestration and
6 Pyrolysis Bioenergy Production. *Environ. Sci. Technol.*, **42**, 4152–4158, doi:10.1021/es071361i.
7 <http://dx.doi.org/10.1021/es071361i>.
- 8 GCEC, 2014: *Better growth, better climate: The new climate economy report*.
- 9 Geels, F. W., 2014: Regime Resistance against Low-Carbon Transitions: Introducing Politics and Power into the Multi-
10 Level Perspective. *Theory, Cult. Soc.*, **31**, 21–40, doi:10.1177/0263276414531627.
- 11 Geels, F. W., and J. Schot, 2007: Typology of sociotechnical transition pathways. *Res. Policy*, **36**, 399–417,
12 doi:10.1016/j.respol.2007.01.003.
- 13 Geels, F. W., and J. W. Schot, 2010: Part 1: The Dynamics of Transitions: A Socio-Technical Perspective. *Transitions
14 to Sustainable Development: New Directions in the Study of Long Term Transformative Change*, D. Grin, J.,
15 Rotmans, J., Schot, J., Geels, F.W., Loorbach, Ed., Routledge, New York, 9–87.
- 16 Geels, F. W., F. Berkhout, and D. P. van Vuuren, 2016a: Bridging analytical approaches for low-carbon transitions.
17 *Nat. Clim. Chang.*, **6**, 576–583, doi:10.1038/nclimate2980.
- 18 —, F. Kern, G. Fuchs, N. Hinderer, G. Kungl, J. Mylan, M. Neukirch, and S. Wassermann, 2016b: The enactment of
19 socio-technical transition pathways: A reformulated typology and a comparative multi-level analysis of the
20 German and UK low-carbon electricity transitions (1990–2014). *Res. Policy*, **45**, 896–913,
21 doi:10.1016/j.respol.2016.01.015.
- 22 Gehl, J., 2010: *Cities for people*. Island Press, 269 pp.
- 23 Georgeson, L., M. Maslin, M. Poessinouw, and S. Howard, 2016: Adaptation responses to climate change differ
24 between global megacities. *Nat. Clim. Chang.*, **6**, 584–588.
- 25 Gerbens-Leenes, W., A. Y. Hoekstra, and T. H. van der Meer, 2009: The water footprint of bioenergy. *Proc. Natl.
26 Acad. Sci.*, **106**, 10219–10223, doi:10.1073/pnas.0812619106.
- 27 van der Giesen, C., C. J. Meinrenken, R. Kleijn, B. Sprecher, K. S. Lackner, and G. J. Kramer, 2017: A Life Cycle
28 Assessment Case Study of Coal-Fired Electricity Generation with Humidity Swing Direct Air Capture of CO₂
29 versus MEA-Based Postcombustion Capture. *Environ. Sci. Technol.*, **51**, 1024–1034,
30 doi:10.1021/acs.est.6b05028.
- 31 Gigerenzer, G., and D. Goldstein, 1996: Reasoning the fast and frugal way: Models of bounded rationality. *Psychol.
32 Rev.*, **103**, 650–669.
- 33 Gillingham, K., and K. Palmer, 2014: Bridging the Energy Efficiency Gap: Insights for Policy from Economic Theory
34 and Empirical Analysis. *Rev. Environ. Econ. Policy*, **8**, 18–38.
- 35 —, M. J. Kotchen, D. S. Rapson, and G. Wagner, 2013: Energy policy: The rebound effect is overplayed. *Nature*,
36 **493**, 475–476, doi:10.1038/493475a. <http://www.nature.com/doi/10.1038/493475a> (Accessed October 7,
37 2013).
- 38 Glaeser, E. L., 2012: The challenge of urban policy. *J. Policy Anal. Manag.*, **31**, 111–122, doi:10.1002/pam.20631.
- 39 Global CCS Institute, 2015: The global status of CCS: 2015. *Glob. CCS Inst.*, 18, doi:978-0-9944115-2-5.
- 40 Goepfert, A., M. Czaun, G. K. Surya Prakash, and G. A. Olah, 2012: Air as the renewable carbon source of the future:
41 an overview of CO₂ capture from the atmosphere. *Energy Environ. Sci.*, **5**, 7833, doi:10.1039/c2ee21586a.
- 42 Goldemberg, J., 2011: The role of biomass in the world's energy system. *Routes to Cellulosic Ethanol*, Springer, 3–14.
- 43 Gonzales, M. H., E. Aronson, and M. A. Costanzo, 1988: Using Social Cognition and Persuasion to Promote Energy
44 Conservation: A Quasi-Experiment. *J. Appl. Soc. Psychol.*, **18**, 1049–1066.
- 45 Goodwin, P., and K. Van Dender, 2013: “Peak Car” — Themes and Issues. *Transp. Rev.*, **33**, 243–254,
46 doi:10.1080/01441647.2013.804133. <http://dx.doi.org/10.1080/01441647.2013.804133> (Accessed July 22, 2017).
- 47 Government of Western Australia, 2016: *Statistics Digest 2015-16*. Perth,.
- 48 Gowdy, J., 2008: Behavioral economics and climate change policy. *J. Econ. Behav. Organ.*, **68**, 632–644,
49 doi:10.1016/j.jebo.2008.06.011.
- 50 Goytia, S., M. Pettersson, T. Schellenberger, W. J. van Doorn-Hoekveld, and S. Priest, 2016: Dealing with change and
51 uncertainty within the regulatory frameworks for flood defense infrastructure in selected European countries.
52 *Ecol. Soc.*, **21**, doi:10.5751/ES-08908-210423. <http://www.ecologyandsociety.org/vol21/iss4/art23/> (Accessed
53 July 17, 2017).
- 54 Gray, E., and A. Srinidhi, 2013: Watershed Development in India : Economic valuation and adaptation considerations.
- 55 Green, D., and G. Raygorodetsky, 2010: Indigenous knowledge of a changing climate. *Clim. Change*, **100**, 239–242,
56 doi:10.1007/s10584-010-9804-y.
- 57 Green, J., and P. Newman, 2017a: Citizen utilities: The emerging power paradigm. *Energy Policy*, **105**, 283–293,
58 doi:10.1016/j.enpol.2017.02.004.
- 59 —, and —, 2017b: Disruptive innovation, stranded assets and forecasting: the rise and rise of renewable energy. *J.
60 Sustain. Financ. Invest.*, **7**, 169–187, doi:10.1080/20430795.2016.1265410.

- 1 Green, K. E., 2016: A political ecology of scaling: Struggles over power, land and authority. *Geoforum*, **74**, 88–97,
2 doi:10.1016/j.geoforum.2016.05.007.
- 3 Greene, D. L., 2011: Uncertainty, loss aversion, and markets for energy efficiency. *Energy Econ.*, **33**, 608–616,
4 doi:10.1016/j.eneco.2010.08.009.
- 5 Greening, L. A., Greene, D. L., & Difiglio, C. (2000). Energy efficiency and consumption—the rebound effect—a
6 survey. *Energy policy*, 28(6), 389-401.
- 7 Grubb, M., 1990: The Greenhouse Effect: Negotiating Targets. *Int. Aff.*, **66**, 67–89.
- 8 Guerra, A., 2017: La Crisis como Oportunidad, Análisis de la sequía en la costa sur de Guatemala en 2016. *Red*
9 *Nacional de Formacion e Investigacion Ambiental*.
- 10 Gupta, J., 2014: *The History of Global Climate Governance*. Cambridge University Press, 1-244 pp.
- 11 Gwedla, N., and C. M. Shackleton, 2015: The development visions and attitudes towards urban forestry of officials
12 responsible for greening in South African towns. *Land use policy*, **42**, 17–26,
13 doi:10.1016/j.landusepol.2014.07.004.
- 14 Ha-Duong, M., A. Nadaï, and A. S. Campos, 2009: A survey on the public perception of CCS in France. *Int. J. Greenh.*
15 *Gas Control*, **3**, 633–640, doi:10.1016/j.ijggc.2009.05.003.
- 16 Haberl, H., 2015: Competition for land: A sociometabolic perspective. *Ecol. Econ.*, **119**, 424–431,
17 doi:http://doi.org/10.1016/j.ecolecon.2014.10.002.
- 18 Hackmann, H., S. C. Moser, and A. L. St. Clair, 2014a: The social heart of global environmental change. *Nat. Clim.*
19 *Chang.*, **4**, 653–655, doi:10.1038/nclimate2320.
- 20 —, —, and —, 2014b: The social heart of global environmental change. *Nat. Clim. Chang.*, **4**, 653–655.
21 http://dx.doi.org/10.1038/nclimate2320.
- 22 Haigh, M., 2011: Climate policy and financial institutions. *Clim. Policy*, **11**, 1367–1385,
23 doi:10.1080/14693062.2011.579265.
- 24 Hale, T., 2016: “ All Hands on Deck ” : The Paris Agreement and Nonstate Climate Action. *Glob. Environ. Polit.*, **16**,
25 12–22, doi:10.1162/GLEP.
- 26 Hallegatte, S., and K. J. Mach, 2016a: Make climate-change assessments more relevant. *Nature*, **534**, 613–615,
27 doi:10.1038/534613a.
- 28 —, and —, 2016b: Make climate-change assessments more relevant. *Nature*, **534**, 613–615.
- 29 Hallegatte, S., A. Shah, R. Lempert, C. Brown, and S. Gill, 2012: *Investment Decision Making Under Deep Uncertainty*
30 *Application to Climate Change*.
- 31 Hallegatte, S., C. Green, R. J. Nicholls, and J. Corfee-Morlot, 2013: Future flood losses in major coastal cities. *Nat.*
32 *Clim. Chang.*, **3**, 802–806, doi:10.1038/nclimate1979.
33 http://www.nature.com/nclimate/journal/v3/n9/full/nclimate1979.html%5Cnhttp://www.nature.com/nclimate/jour
34 nal/v3/n9/pdf/nclimate1979.pdf (Accessed July 20, 2017).
- 35 Hallegatte, S., A. Vogt-Schilb, M. Bangalore, and J. Rozenberg, 2017: *Unbreakable: Building the Resilience of the*
36 *Poor in the Face of Natural Disasters*. Washington, DC: World Bank,.
- 37 Hammill, A., R. Matthew, and E. McCarter, 2008: Microfinance and climate change adaptation. *IDS Bull.*, **39**, 113–122.
- 38 Hansen, A. M., and S. V. Larsen, 2014: Use of scenarios and strategic planning to explore an uncertain future in
39 Greenland. *Reg. Environ. Chang.*, **14**, 1575–1585, doi:10.1007/s10113-014-0593-0.
- 40 Harding, A., and J. B. Moreno-Cruz, 2016: Solar geoengineering economics: From incredible to inevitable and half-
41 way back. *Earth’s Futur.*, **4**, 569–577, doi:10.1002/2016EF000462.
- 42 Hardoy, J., and L. S. Velasquez Barrero, 2014: Re-thinking “Biomanzales”: addressing climate change adaptation in
43 Manzales, Colombia. *Environ. Urban.*, **26**, 53–68.
- 44 Hardoy, J., and L. S. Velasquez Barrero, 2016: Manzales, Colombia. *Cities on a finite planet: Towards transformative*
45 *responses to climate change*, S. Bartlett and D. Satterthwaite, Eds., Routledge.
- 46 Hargroves, K., and M. H. Smith, 2005: *The natural advantage of nations : business opportunities, innovation and*
47 *governance in the 21st century*. Earthscan, 527 pp.
- 48 Harnisch, S., S. Uther, and M. Boettcher, 2015: From “Go Slow” to “Gung Ho”? Climate Engineering Discourses in the
49 UK, the US, and Germany. *Glob. Environ. Polit.*, **15**, 57–78, doi:10.1162/GLEP_a_00298.
- 50 Harrison, D. P., 2013: A method for estimating the cost to sequester carbon dioxide by delivering iron to the ocean. *Int.*
51 *J. Glob. Warm.*, **5**, 231–254, doi:10.1504/IJGW.2013.055360.
52 http://www.inderscienceonline.com/doi/abs/10.1504/IJGW.2013.055360.
- 53 Hartley, P. R., and K. B. Medlock, 2013: The Valley of Death for New Energy Technologies. *Energy J.*, **38**, 1–61.
- 54 Hartmann, J., A. J. West, P. Renforth, P. Köhler, C. L. De La Rocha, D. A. Wolf-Gladrow, H. H. Dürr, and J.
55 Scheffran, 2013: Enhanced chemical weathering as a geoengineering strategy to reduce atmospheric carbon
56 dioxide, supply nutrients, and mitigate ocean acidification: Enhanced weathering. *Rev. Geophys.*, **51**, 113–149,
57 doi:10.1002/rog.20004.
- 58 Haslam, P. A., and N. Ary Tanimoune, 2016: The Determinants of Social Conflict in the Latin American Mining
59 Sector: New Evidence with Quantitative Data. *World Dev.*, **78**, 401–419, doi:10.1016/j.worlddev.2015.10.020.
- 60 Havlík, P., and Coauthors, 2011: Global land-use implications of first and second generation biofuel targets. *Energy*

- 1 *Policy*, **39**, 5690–5702, doi:10.1016/j.enpol.2010.03.030.
- 2 Heard, B. P., B. W. Brook, T. M. L. Wigley, and C. J. A. Bradshaw, 2017: Burden of proof: A comprehensive review of
3 the feasibility of 100% renewable-electricity systems. *Renew. Sustain. Energy Rev.*, **76**, 1122–1133,
4 doi:10.1016/j.rser.2017.03.114. <http://dx.doi.org/10.1016/j.rser.2017.03.114>.
- 5 Heidrich, O., and Coauthors, 2016: National climate policies across Europe and their impacts on cities strategies. *J.*
6 *Environ. Manage.*, **168**, 36–45.
- 7 Hekkert, M. P., R. A. A. Suurs, S. O. Negro, S. Kuhlmann, and R. E. H. M. Smits, 2007: Functions of innovation
8 systems: A new approach for analysing technological change. *Technol. Forecast. Soc. Change*, **74**, 413–432,
9 doi:10.1016/j.techfore.2006.03.002.
- 10 Heltberg, R., P. B. Siegel, and S. L. Jorgensen, 2009: Addressing human vulnerability to climate change: Toward a “no-
11 regrets” approach. *Glob. Environ. Chang.*, **19**, 89–99, doi:10.1016/j.gloenvcha.2008.11.003.
- 12 Henry, R. K., Z. Yongsheng, and D. Jun, 2006: Municipal solid waste management challenges in developing countries -
13 Kenyan case study. *Waste Manag.*, **26**, 92–100, doi:10.1016/j.wasman.2005.03.007.
- 14 Hermwille, L., W. Obergassel, H. E. Ott, and C. Beuermann, 2017: UNFCCC before and after Paris – what’s necessary
15 for an effective climate regime? *Clim. Policy*, **17**, 150–170, doi:10.1080/14693062.2015.1115231.
- 16 Heutel, G., J. Moreno-Cruz, and K. Ricke, 2016: Climate Engineering Economics. *Annu. Rev. Resour. Econ.*, **8**, 99–
17 118, doi:10.1146/annurev-resource-100815-095440.
- 18 Heyen, D., T. Wiertz, and P. J. Irvine, 2015: Regional disparities in SRM impacts: the challenge of diverging
19 preferences. *Clim. Change*, **133**, 557–563, doi:10.1007/s10584-015-1526-8.
- 20 Higham, J., S. A. Cohen, C. T. Cavaliere, A. Reis, and W. Finkler, 2016: Climate change, tourist air travel and radical
21 emissions reduction. *J. Clean. Prod.*, **111**, 336–347, doi:10.1016/j.jclepro.2014.10.100.
- 22 Hileman, J., P. Hicks, and R. Jones, 2015: An alternative framework for analysing and managing conflicts in integrated
23 water resources management (IWRM): linking theory and practice. *Int. J. Water Resour. Dev.*, **32**, 1–17,
24 doi:10.1080/07900627.2015.1076719.
- 25 Hill Clarvis, M., and N. L. Engle, 2015: Adaptive capacity of water governance arrangements: a comparative study of
26 barriers and opportunities in Swiss and US states. *Reg. Environ. Chang.*, **15**, 517–527, doi:10.1007/s10113-013-
27 0547-y.
- 28 Hinzman, L. D., and Coauthors, 2005: Evidence and implications of recent climate change in Northern Alaska and other
29 Arctic regions. *Clim. Change*, **72**, 251–298, doi:10.1007/s10584-005-5352-2.
- 30 Hoang, L. P., and Coauthors, 2016: Mekong River flow and hydrological extremes under climate change. *Hydrol. Earth*
31 *Syst. Sci.*, **20**, 3027–3041, doi:10.5194/hess-20-3027-2016.
- 32 Hoch, 2017: Underwriting 1.5°C: Competitive Approaches to Financing Accelerated Climate Mitigation. *Clim. Policy.*,
33 Hof, A., 2014: *Costs and benefits of climate change adaptation and mitigation: An assessment on different regional*
34 *scales*. The Hague,
35 [http://www.pbl.nl/sites/default/files/cms/publicaties/PBL_2014_Costs_and_benefits_of_climate_change_adaption](http://www.pbl.nl/sites/default/files/cms/publicaties/PBL_2014_Costs_and_benefits_of_climate_change_adaption_and_mitigation_1198.pdf)
36 [_and_mitigation_1198.pdf](http://www.pbl.nl/sites/default/files/cms/publicaties/PBL_2014_Costs_and_benefits_of_climate_change_adaption_and_mitigation_1198.pdf) (Accessed July 21, 2017).
- 37 Hof, A. F., M. G. J. den Elzen, A. Admiraal, M. Roelfsema, D. E. H. J. Gernaat, and D. P. van Vuuren, 2017: Global
38 and regional abatement costs of Nationally Determined Contributions (NDCs) and of enhanced action to levels
39 well below 2°C and 1.5°C. *Environ. Sci. Policy*, **71**, 30–40, doi:10.1016/j.envsci.2017.02.008.
- 40 Höglund-Isaksson, L., P. Purohit, M. Amann, I. Bertok, P. Rafaj, W. Schöpp, and J. Borken-Kleefeld, 2017: Cost
41 estimates of the Kigali Amendment to phase-down hydrofluorocarbons. *Environ. Sci. Policy*, **75**, 138–147,
42 doi:10.1016/j.envsci.2017.05.006.
- 43 Högy, P., H. Wieser, P. Köhler, K. Schwadorf, J. Breuer, J. Franzaring, R. Muntiferung, and A. Fangmeier, 2009:
44 Effects of elevated CO₂ on grain yield and quality of wheat: results from a 3-year free-air CO₂ enrichment
45 experiment. *Plant Biol.*, **11**, 60–69, doi:10.1111/j.1438-8677.2009.00230.x.
- 46 Höhne, N., H. Fekete, M. G. J. den Elzen, A. F. Hof, and T. Kuramochi, 2017: Assessing the ambition of post-2020
47 climate targets: a comprehensive framework. *Clim. Policy*, 1–16, doi:10.1080/14693062.2017.1294046.
- 48 Höök, M., J. Li, N. Oba, and S. Snowden, 2011: Descriptive and Predictive Growth Curves in Energy System Analysis.
49 *Nat. Resour. Res.*, **20**, 103–116, doi:10.1007/s11053-011-9139-z.
- 50 Hoppe, R., and A. Wesselink, 2014: Comparing the role of boundary organizations in the governance of climate change
51 in three EU member states. *Environ. Sci. Policy*, **44**, 73–85.
- 52 Hornsey, M. J., E. A. Harris, P. G. Bain, and K. S. Fielding, 2016: Meta-analyses of the determinants and outcomes of
53 belief in climate change. *Nat. Clim. Chang.*, **6**, 622–626, doi:10.1038/nclimate2943.
- 54 Hossain, T., and J. Morgan, 2006: ...Plus Shipping and Handling: Revenue (Non) Equivalence in Field Experiments on
55 eBay. *Adv. Econ. Anal. Policy*, **5**, 1–30, doi:10.2202/1538-0637.1429.
- 56 Houghton, R. A., B. Byers, and A. A. Nassikas, 2015: A role for tropical forests in stabilizing atmospheric CO₂. *Nat.*
57 *Clim. Chang.*, **5**, 1022–1023.
- 58 Hourcade, J.-C., P.-R. Shukla, and C. Cassen, 2015: Climate policy architecture for the Cancun paradigm shift: building
59 on the lessons from history. *Int. Environ. Agreements Polit. Law Econ.*, **15**, 353–367, doi:10.1007/s10784-015-
60 9301-x.

- 1 Hovi, J., D. F. Sprinz, H. Sælen, and A. Underdal, 2016: Climate change mitigation: a role for climate clubs? *Palgrave*
2 *Commun.*, **2**. <http://10.0.4.33/palcomms.2016.20>.
- 3 Hsu, A., A. J. Weinfurter, and K. Xu, 2017: Aligning subnational climate actions for the new post-Paris climate regime.
4 *Clim. Change*, 1–14.
- 5 Hubert, A.-M., and D. Reichwein, 2015: *An Exploration of a Code of Conduct for Responsible Scientific Research*
6 *involving Geoengineering*. Potsdam, 96 pp.
- 7 Huttunen, S., E. Skytén, and M. Hildén, 2015: Emerging policy perspectives on geoengineering: An international
8 comparison. *Anthr. Rev.*, **2**, 14–32, doi:10.1177/2053019614557958.
- 9 ICEM, 2013: *USAID Mekong ARCC Climate Change Impact and Adaptation: Summary. Prepared for the United States*
10 *Agency for International Development by ICEM - International Centre for Environmental Management*.
11 http://www.mekongarcc.net/sites/default/files/mekong_arcc_climate_study_summary-press.pdf.
- 12 IEA, 2017: *Energy Technology Perspectives 2017. Catalysing Energy Technology Transformations*. Paris, France, 443
13 pp.
- 14 Ingalls, M. L., and M. B. Dwyer, 2016: Missing the forest for the trees? Navigating the trade-offs between mitigation
15 and adaptation under REDD. *Clim. Change*, **136**, 353–366, doi:10.1007/s10584-016-1612-6.
- 16 Ingold, K., and M. Fischer, 2014: Drivers of collaboration to mitigate climate change: An illustration of Swiss climate
17 policy over 15 years. *Glob. Environ. Chang.*, **24**, 88–98, doi:10.1016/j.gloenvcha.2013.11.021.
- 18 International Energy Agency (IEA), 2016: *20 Years of Carbon Capture and Storage - Accelerating Future Deployment*.
19 Paris, France, 115 pp.
- 20 International Energy Agency and OECD, 2017: *World Energy Outlook 2017*. Paris,.
- 21 IPCC, 2012: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special*
22 *Report of Working Groups I and II of IPCC Intergovernmental Panel on Climate Change*. C.B. Field et al., Eds.
23 Cambridge University Press, Cambridge, UK and New York, USA, 594 pp.
- 24 —, 2014a: *Climate change 2014: impacts, adaptation, and vulnerability-Part B: regional aspects-Contribution of*
25 *Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. V.R.
26 Barros et al., Eds. Cambridge University Press,.
- 27 —, 2014b: *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on*
28 *Climate Change*. K. Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, T.Z. and J.C. Seyboth,
29 A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, and
30 Minx, Eds. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA,.
- 31 Irvine, P. J., B. Kravitz, M. G. Lawrence, and H. Muri, 2016: An overview of the Earth system science of solar
32 geoengineering. *Wiley Interdiscip. Rev. Clim. Chang.*, **7**, 815–833, doi:10.1002/wcc.423.
- 33 Ishimoto, Y., M. Sugiyama, E. Kato, R. Moriyama, K. Tsuzuki, and A. Kurosawa, 2017: *Putting Costs of Direct Air*
34 *Capture in Context*.
- 35 ISSC, and UNESCO, 2013: *World Social Science Report 2013: Changing Global Environments*. Paris,
36 <http://www.unesco.org/new/en/social-and-human-sciences/resources/reports/world-social-science-report-2013/>.
- 37 Iyer, G. C., and Coauthors, 2015: The contribution of Paris to limit global warming to 2°C. *Environ. Res. Lett.*, **10**,
38 125002, doi:10.1088/1748-9326/10/12/125002.
- 39 Izrael, Y. A., E. M. Volodin, S. V. Kostykin, A. P. Revokatova, and A. G. Ryaboshapko, 2014: The ability of
40 stratospheric climate engineering in stabilizing global mean temperatures and an assessment of possible side
41 effects. *Atmos. Sci. Lett.*, **15**, 140–148, doi:10.1002/asl2.481.
- 42 Jabeen, H., 2014: Adapting the built environment : the role of gender in shaping vulnerability and resilience to climate
43 extremes in Dhaka. *Environ. Urban.*, **26**, 147–165, doi:10.1177/0956247813517851.
- 44 Jackson, T., and P. Senker, 2011: Prosperity without growth: Economics for a finite planet. *Energy Environ.*, **22**, 1013–
45 1016.
- 46 Jacobson, M. Z., M. A. Delucchi, M. A. Cameron, B. A. Frew, and S. Polasky, 2015: Low-cost solution to the grid
47 reliability problem with 100% penetration of intermittent wind, water, and solar for all purposes. *Proceeding Natl.*
48 *Acad. Sci. United States Am.*, 15060–15065, doi:10.1073/pnas.1510028112.
- 49 Jaglin, S., 2014: Regulating service delivery in southern cities: rethinking urban heterogeneity. *The Routledge*
50 *handbook on cities of the global South*, S. Parnell and S. Oldfield, Eds., Routledge, London.
- 51 Jahandideh-Tehrani, M., O. Bozorg Haddad, and H. A. Lo??iciga, 2014: Hydropower Reservoir Management Under
52 Climate Change: The Karoon Reservoir System. *Water Resour. Manag.*, **29**, 749–770, doi:10.1007/s11269-014-
53 0840-7.
- 54 James, R., R. Washington, C.-F. Schleussner, J. Rogelj, and D. Conway, 2017: Characterizing half-a-degree difference:
55 a review of methods for identifying regional climate responses to global warming targets. *Wiley Interdiscip. Rev.*
56 *Clim. Chang.*, **8**, e457, doi:10.1002/wcc.457.
- 57 Jegou, I., 2015: Taking stock of evolutions in the trade and climate relationship. *Biores*, **9**.
- 58 Ji, Z., and F. Sha, 2015: The challenges of the post-COP21 regime: interpreting CBDR in the INDC context. *Int.*
59 *Environ. Agreements Polit. Law Econ.*, **15**, 421–430, doi:10.1007/s10784-015-9303-8.
- 60 Jiang, K.-J., K. Tamura, and T. Hanaoka, 2017: Can we go beyond INDCs: Analysis of a future mitigation possibility in

- 1 China, Japan, EU and the U.S. *Adv. Clim. Chang. Res.*, **8**, 117–122, doi:10.1016/j.accre.2017.05.005.
- 2 Johannessen, S. C., and R. W. Macdonald, 2016: Geoengineering with seagrasses: is credit due where credit is given?
- 3 *Environ. Res. Lett.*, **11**, 113001, doi:10.1088/1748-9326/11/11/113001. [http://stacks.iop.org/1748-](http://stacks.iop.org/1748-9326/11/i=11/a=113001?key=crossref.1db6e1f7810fa528a2d86b3f3b5281a0)
- 4 [9326/11/i=11/a=113001?key=crossref.1db6e1f7810fa528a2d86b3f3b5281a0](http://stacks.iop.org/1748-9326/11/i=11/a=113001?key=crossref.1db6e1f7810fa528a2d86b3f3b5281a0).
- 5 Johnson, N., and Coauthors, 2015: The contributions of Community-Based monitoring and traditional knowledge to
- 6 Arctic observing networks: Reflections on the state of the field. *Arctic*, **68**, 1–13, doi:10.14430/arctic4447.
- 7 Jones, A. D., K. V. Calvin, W. D. Collins, and J. Edmonds, 2015: Accounting for radiative forcing from albedo change
- 8 in future global land-use scenarios. *Clim. Change*, **131**, 691–703, doi:10.1007/s10584-015-1411-5.
- 9 Jones, C. D., and Coauthors, 2016a: Simulating the Earth system response to negative emissions. *Environ. Res. Lett.*,
- 10 **11**, 95012, doi:10.1088/1748-9326/11/9/095012. [http://stacks.iop.org/1748-](http://stacks.iop.org/1748-9326/11/i=9/a=095012?key=crossref.6b5747055a178d1c59ffa940adb33091)
- 11 [9326/11/i=9/a=095012?key=crossref.6b5747055a178d1c59ffa940adb33091](http://stacks.iop.org/1748-9326/11/i=9/a=095012?key=crossref.6b5747055a178d1c59ffa940adb33091).
- 12 Jones, L., B. Harvey, and R. Godfrey-Wood, 2016b: *The changing role of NGOs in supporting climate services*.
- 13 London,.
- 14 Jordan, A., and D. Huitema, 2014: Policy innovation in a changing climate: Sources, patterns and effects. *Glob.*
- 15 *Environ. Chang.*, **29**, 387–394, doi:10.1016/j.gloenvcha.2014.09.005.
- 16 Joseph, D. D., 2017: Social work models for climate adaptation: the case of small islands in the Caribbean. *Reg.*
- 17 *Environ. Chang.*, **17**, 1117–1126, doi:10.1007/s10113-017-1114-8.
- 18 Joyette, A. R. T., L. A. Nurse, and R. S. Pulwarty, 2015: Disaster risk insurance and catastrophe models in risk-prone
- 19 small Caribbean islands. *Disasters*, **39**, 467–492, doi:10.1111/disa.12118.
- 20 Juhola, S., E. Glaas, B. O. Linnér, and T. S. Neset, 2016: Redefining maladaptation. *Environ. Sci. Policy*, **55**, 135–140,
- 21 doi:10.1016/j.envsci.2015.09.014.
- 22 Kahneman, D., 2003: A perspective on judgment and choice: Mapping bounded rationality. *Am. Psychol.*, **58**, 697–720,
- 23 doi:10.1037/0003-066X.58.9.697.
- 24 ———, and R. H. Thaler, 2006: Anomalies: Utility Maximization and Experienced Utility. *J. Econ. Perspect.*, **20**, 221–
- 25 234, doi:10.1257/089533006776526076.
- 26 ———, J. L. Knetsch, and R. H. Thaler, 1991: Anomalies: The Endowment Effect, Loss Aversion, and Status Quo Bias.
- 27 *J. Econ. Perspect.*, **5**, 193–206, doi:10.1257/jep.5.1.193.
- 28 Kaika, M., 2017: New Urban Agenda as immunology ... or ... what happens when communities refuse to be vaccinated
- 29 with “ smart cities ” and indicators. *Environ. Urban.*, **29**, 89–102, doi:10.1177/0956247816684763.
- 30 Kale, E., 2015: Problematic Uses and Practices of Farm Ponds in Maharashtra. *Econ. Polit. Wkly.*, **52**, 7–8.
- 31 Kalra, N., S. Hallegatte, R. Lempert, C. Brown, and A. Fozzard, 2014: *Agreeing on Robust Decisions New Processes*
- 32 *for Decision Making Under Deep Uncertainty*.
- 33 <https://openknowledge.worldbank.org/bitstream/handle/10986/18772/WPS6906.pdf?sequence=1&isAllowed=yWorld>.
- 34
- 35 Kastner, I., and P. C. Stern, 2015: Examining the decision-making processes behind household energy investments: A
- 36 review. *Energy Res. Soc. Sci.*, **10**, 72–89, doi:10.1016/j.erss.2015.07.008.
- 37 Kates, R. W., W. R. Travis, and T. J. Wilbanks, 2012: Transformational adaptation when incremental adaptations to
- 38 climate change are insufficient. *Proc. Natl. Acad. Sci. U. S. A.*, **109**, 7156–7161, doi:10.1073/pnas.1115521109.
- 39 <http://www.ncbi.nlm.nih.gov/pubmed/22509036> (Accessed July 7, 2017).
- 40 Kato, T., and J. Ellis, 2016: *Communicating Progress in National and Global Adaptation to Climate Change*. 47 pp.
- 41 [http://www.oecd-ilibrary.org/environment/communicating-progress-in-national-and-global-adaptation-to-climate-](http://www.oecd-ilibrary.org/environment/communicating-progress-in-national-and-global-adaptation-to-climate-change_5j1ww009v1hj-en)
- 42 [change_5j1ww009v1hj-en](http://www.oecd-ilibrary.org/environment/communicating-progress-in-national-and-global-adaptation-to-climate-change_5j1ww009v1hj-en) (Accessed July 11, 2017).
- 43 Keith, D. W., and D. G. MacMartin, 2015: A temporary, moderate and responsive scenario for solar geoengineering.
- 44 *Nat. Clim. Chang.*, **5**, 201–206, doi:10.1038/nclimate2493.
- 45 Keith, D. W., and P. J. Irvine, 2016: Solar geoengineering could substantially reduce climate risks - a research
- 46 hypothesis for the next decade. *Earth's Futur.*, **4**, 2016EF000465, doi:10.1002/2016EF000465.
- 47 Keith, D. W., D. K. Weisenstein, J. A. Dykema, and F. N. Keutsch, 2016: Stratospheric solar geoengineering without
- 48 ozone loss. *Proc. Natl. Acad. Sci. U. S. A.*, **113**, 14910–14914, doi:10.1073/pnas.1615572113.
- 49 Kemp, R., J. Schot, and R. Hoogma, 1998: Regime shifts to sustainability through processes of niche formation: The
- 50 approach of strategic niche management. *Technol. Anal. Strateg. Manag.*, **10**, 175–198,
- 51 doi:10.1080/09537329808524310.
- 52 Kemp, R., S. Parto, and R. B. Gibson, 2005: Governance for sustainable development: moving from theory to practice.
- 53 *Int. J. Sustain. Dev.*, **8**, 12, doi:10.1504/IJSD.2005.007372.
- 54 Kemper, J., 2015: Biomass and carbon dioxide capture and storage: A review. *Int. J. Greenh. Gas Control*, **40**, 401–
- 55 430, doi:10.1016/j.ijggc.2015.06.012.
- 56 Keohane, R. O., and D. G. Victor, 2011: The Regime Complex for Climate Change. *Perspect. Polit.*, **9**, 7–23,
- 57 doi:10.1017/S1537592710004068.
- 58 Kern, F., and K. S. Rogge, 2016: The pace of governed energy transitions: Agency, international dynamics and the
- 59 global Paris agreement accelerating decarbonisation processes? *Energy Res. Soc. Sci.*, **22**, 13–17,
- 60 doi:10.1016/j.erss.2016.08.016. <http://dx.doi.org/10.1016/j.erss.2016.08.016>.

- 1 Kern, K., and G. Alber, 2009: Governing Climate Change in Cities: Modes of Urban Climate Governance in Multi-
2 level Systems. *The international conference on Competitive Cities and Climate Change, Milan, Italy*, OECD,
3 Paris, 171–196.
- 4 Kholod, N., and M. Evans, 2016: Reducing black carbon emissions from diesel vehicles in Russia: An assessment and
5 policy recommendations. *Environ. Sci. Policy*, **56**, 1–8, doi:10.1016/j.envsci.2015.10.017.
- 6 Kirtman, B., and Coauthors, 2013: Near-term Climate Change: Projections and Predictability. *Climate Change 2013:
7 The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the
8 Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, 953–1028.
- 9 Kivimaa, P., M. Hildén, D. Huitema, A. Jordan, and J. Newig, 2017: Experiments in climate governance – A systematic
10 review of research on energy and built environment transitions. *J. Clean. Prod.*, 1–13,
11 doi:10.1016/j.jclepro.2017.01.027.
- 12 Klein, D., F. Humpenöder, N. Bauer, J. P. Dietrich, A. Popp, B. Leon Bodirsky, M. Bonsch, and H. Lotze-Campen,
13 2014: The global economic long-term potential of modern biomass in a climate-constrained world. *Environ. Res.
14 Lett.*, **9**, 74017, doi:10.1088/1748-9326/9/7/074017.
- 15 Klepper, G., and W. Rickels, 2014: Climate Engineering: Economic Considerations and Research Challenges. *Rev.
16 Environ. Econ. Policy*, **8**, 270–289, doi:10.1093/leep/reu010.
- 17 Klimont, Z., K. Kupiainen, C. Heyes, P. Purohit, J. Cofala, P. Rafaj, J. Borken-Kleefeld, and W. Schöpp, 2017: Global
18 anthropogenic emissions of particulate matter including black carbon. *Atmos. Chem. Phys.*, **17**, 8681–8723,
19 doi:10.5194/acp-17-8681-2017.
- 20 Klotz, L., 2011: Cognitive biases in energy decisions during the planning, design, and construction of commercial
21 buildings in the United States: An analytical framework and research needs. *Energy Effic.*, **4**, 271–284,
22 doi:10.1007/s12053-010-9089-z.
- 23 Knutti, R., J. Rogelj, J. Sedláček, and E. M. Fischer, 2015: A scientific critique of the two-degree climate change target.
24 *Nat. Geosci.*, **9**, 13–18, doi:10.1038/ngeo2595. <http://www.nature.com/doi/10.1038/ngeo2595>.
- 25 Koelbl, B. S., M. A. van den Broek, B. J. van Ruijven, A. P. C. Faaij, and D. P. van Vuuren, 2014: Uncertainty in the
26 deployment of Carbon Capture and Storage (CCS): A sensitivity analysis to techno-economic parameter
27 uncertainty. *Int. J. Greenh. Gas Control*, **27**, 81–102, doi:10.1016/j.ijggc.2014.04.024.
- 28 Kolstad, C., and Coauthors, 2014: *Social, Economic and Ethical Concepts and Methods*. Cambridge University Press,
29 207–282 pp.
- 30 Kona, A., P. Bertoldi, G. Melica, and S. Rivas, 2017: (Submitted) Covenant of Mayors signatories leading the way
31 toward 1.5 degree future. *Curr. Opin. Environ. Sustain.*..
- 32 Kontgis, C., A. Schneider, and M. Ozdogan, 2015: Mapping rice paddy extent and intensification in the Vietnamese
33 Mekong River Delta with dense time stacks of Landsat data. *Remote Sens. Environ.*, **169**, 255–269,
34 doi:10.1016/j.rse.2015.08.004.
- 35 Kossoy, A., G. Peszko, K. Oppermann, N. Prytz, N. Klein, and K. Blok, 2015: *State and Trends of Carbon Pricing
36 October 2015*. The World Bank, 140 pp.
- 37 Kosugi, T., 2013: Fail-safe solar radiation management geoengineering. *Mitig. Adapt. Strateg. Glob. Chang.*, **18**, 1141–
38 1166, doi:10.1007/s11027-012-9414-2.
- 39 Kowarsch, M., and Coauthors, 2017: A road map for global environmental assessments. *Nat. Clim. Chang.*, **7**, 379–382,
40 doi:10.1038/nclimate3307.
- 41 Kraucunas, I., and Coauthors, 2015: Investigating the nexus of climate, energy, water, and land at decision-relevant
42 scales: the Platform for Regional Integrated Modeling and Analysis (PRIMA). *Clim. Change*, **129**, 573–588,
43 doi:10.1007/s10584-014-1064-9.
- 44 Krugman, P., 2008: *The Return of Depression Economics and the Crisis of 2008*. W. W. Norton & Company, New
45 York, 207 pp.
- 46 Kura, Y., O. Joffre, B. Laplante, and B. Sengvilaykham, 2017: Coping with resettlement: A livelihood adaptation
47 analysis in the Mekong River basin. *Land use policy*, **60**, 139–149, doi:10.1016/j.landusepol.2016.10.017.
- 48 La Rovere, E. L., C. Gesteira, C. Grottera, and W. William. 2017. “Pathways to a Low Carbon Economy in Brazil.” In:
49 ISSBERNER, Liz-Rejane; LÉNA, Philippe (Edit). *Brazil in the Anthropocene: Conflicts between predatory
50 development and environmental policies*. Routledge, 2017, p. 243–266.
51 <http://www.centroclima.coppe.ufrj.br/index.php/destaque/>
- 52 La Rovere, E., Hourcade J.C., Priyadarshi S., Espagne E., Perrissin-Fabert B., Social Value of Mitigation Activities and
53 forms of Carbon Pricing, Working Paper CIRED n°2017-60 Paris, March 2017
- 54 Labanca, N., 2017: *Complex Systems and Social Practices in Energy Transitions: Framing Energy Sustainability in the
55 Time of Renewables*. Springer,.
- 56 Labbe, J., J. D. Ford, M. Araos, and M. Flynn, 2016: The government-led climate change adaptation landscape in
57 Nunavut, Canada. *Environ. Rev.*, 1–14, doi:10.1139/er-2016-0032.
- 58 Lackner, K. S., C. H. Wendt, D. P. Butt, E. L. Joyce, and D. H. Sharp, 1995: Carbon dioxide disposal in carbonate
59 minerals. *Energy*, **20**, 1153–1170, doi:http://dx.doi.org/10.1016/0360-5442(95)00071-N.
- 60 —, S. Brennan, J. M. Matter, A.-H. A. Park, A. Wright, and B. van der Zwaan, 2012: The urgency of the

- 1 development of CO₂ capture from ambient air. *Proc. Natl. Acad. Sci.*, **109**, 13156–13162,
2 doi:10.1073/pnas.1108765109.
- 3 Laloë, J.-O., N. Esteban, J. Berkel, and G. C. Hays, 2016: Sand temperatures for nesting sea turtles in the Caribbean:
4 Implications for hatchling sex ratios in the face of climate change. *J. Exp. Mar. Bio. Ecol.*, **474**, 92–99,
5 doi:10.1016/j.jembe.2015.09.015.
- 6 Lamb, W. F., and N. D. Rao, 2015: Human development in a climate-constrained world: What the past says about the
7 future. *Glob. Environ. Chang.*, **33**, 14–22, doi:10.1016/j.gloenvcha.2015.03.010.
- 8 Lamb, W. F., J. K. Steinberger, A. Bows-Larkin, G. P. Peters, J. T. Roberts, and F. R. Wood, 2014: Transitions in
9 pathways of human development and carbon emissions. *Environ. Res. Lett.*, **9**, 14011, doi:10.1088/1748-
10 9326/9/1/014011.
- 11 Lambini, C. K., 2016: Internalising solar radiation management technological externalities: An ethical review on the
12 design of economic instruments. *Adv. Clim. Chang. Res.*, **7**, 109–112, doi:10.1016/j.accre.2016.04.003.
- 13 Lampin, L. B. A., Nadaud, F., Grazi, F., & Hourcade, J.-C. (2013). Long-term fuel demand: Not only a matter of fuel
14 price, long-term fuel demand: Not only a matter of fuel price, energy policy (Vol. 62, pp. 780–787). Amsterdam:
15 Elsevier. doi:10.1016/j.enpol.2013.05.021.
- 16 Larsen, K., and U. Gunnarsson-Östling, 2009: Climate change scenarios and citizen-participation: Mitigation and
17 adaptation perspectives in constructing sustainable futures. *Habitat Int.*, **33**, 260–266,
18 doi:10.1016/j.habitatint.2008.10.007.
- 19 Larsen, P., S. Goldsmith, O. Smith, M. Wilson, K. Strzepek, P. Chinowsky, and B. Saylor, 2008: Estimating future
20 costs for Alaska public infrastructure at risk from climate change. *Glob. Environ. Chang.*, **18**, 442–457,
21 doi:10.1016/j.gloenvcha.2008.03.005.
- 22 Larsson, L., E. C. H. Keskitalo, and J. Åkermark, 2016: Climate Change Adaptation and Vulnerability Planning within
23 the Municipal and Regional System: Examples from Northern Sweden. *J. North. Stud.*, **10**, 61–90.
- 24 Lashley, J. G., and K. Warner, 2015: Evidence of demand for microinsurance for coping and adaptation to weather
25 extremes in the Caribbean. *Clim. Change*, **133**, 101–112, doi:10.1007/s10584-013-0922-1.
- 26 Laurance, W. F., and G. B. Williamson, 2001: Positive Feedbacks among Forest Fragmentation, Drought, and Climate
27 Change in the Amazon. *Conserv. Biol.*, **15**, 1529–1535, doi:10.1046/j.1523-1739.2001.01093.x.
- 28 Lauren, N., K. S. Fielding, L. Smith, and W. R. Louis, 2016: You did, so you can and you will: Self-efficacy as a
29 mediator of spillover from easy to more difficult pro-environmental behaviour. *J. Environ. Psychol.*, **48**, 191–199,
30 doi:10.1016/j.jenvp.2016.10.004. <http://dx.doi.org/10.1016/j.jenvp.2016.10.004>.
- 31 Lawrence, M. G., and P. J. Crutzen, 2017: Was breaking the taboo on research on climate engineering via albedo
32 modification a moral hazard, or a moral imperative? *Earth's Futur.*, **5**, 136–143, doi:10.1002/2016EF000463.
- 33 Lebel, L., C. T. Hoanh, C. Krittasudhacheewa, and R. Daniel, 2014: *Climate risks, regional integration and*
34 *sustainability in the Mekong region*. Strategic Information and Research Development Centre (SIRDC) and
35 SUMERNET Stockholm Environment Institute (SEI),.
- 36 Leck, H., and D. Roberts, 2015: What lies beneath: understanding the invisible aspects of municipal climate change
37 governance. *Curr. Opin. Environ. Sustain.*, **13**, 61–67, doi:10.1016/j.cosust.2015.02.004.
- 38 Lee, T., and M. Painter, 2015: Comprehensive local climate policy: The role of urban governance. *Urban Clim.*, **14**,
39 566–577, doi:10.1016/j.uclim.2015.09.003.
- 40 Lehmann, P., M. Brenck, O. Gebhardt, S. Schaller, and E. Süßbauer, 2015: Barriers and opportunities for urban
41 adaptation planning: analytical framework and evidence from cities in Latin America and Germany. *Mitig. Adapt.*
42 *Strateg. Glob. Chang.*, **20**, 75–97.
- 43 Lemos, M. C., 2015: Usable climate knowledge for adaptive and co-managed water governance. *Curr. Opin. Environ.*
44 *Sustain.*, **12**, 48–52, doi:10.1016/j.cosust.2014.09.005.
- 45 Lenton, T. M., 2010: The potential for land-based biological CO₂ removal to lower future atmospheric CO₂
46 concentration. *Carbon Manag.*, **1**, 145–160, doi:10.4155/cmt.10.12.
- 47 de Leon, E. G., and J. Pittock, 2016: Integrating climate change adaptation and climate-related disaster risk-reduction
48 policy in developing countries: A case study in the Philippines. *Clim. Dev.*, **5529**, 1–8,
49 doi:10.1080/17565529.2016.1174659.
- 50 Lewandowski, M., 2016: Designing the Business Models for Circular Economy—Towards the Conceptual Framework.
51 *Sustainability*, **8**, 43, doi:10.3390/su8010043.
- 52 Ley, D., 2017: Sustainable Development, Climate Change, and Renewable Energy in Rural Central America.
53 *Evaluating Climate Change Action for Sustainable Development*, Springer International Publishing, Cham, 187–
54 212.
- 55 Li, L., and B. P. Y. Loo, 2017: Railway Development and Air Patronage in China, 1993–2012: Implications for Low-
56 Carbon Transport. *J. Reg. Sci.*, **57**, 507–522, doi:10.1111/jors.12276.
- 57 Lillemo, S., 2014: Measuring the effect of procrastination and environmental awareness on households' energy-saving
58 behaviours: An empirical approach. *Energy Policy*, **66**, 249–256, doi:https://doi.org/10.1016/j.enpol.2013.10.077.
- 59 Lin, A. C., 2013: Does Geoengineering Present a Moral Hazard? *Ecol. Law Q.*, **40**, 673–712, doi:10.2307/24113611.
- 60 Linder, M., and M. Williander, 2017: Circular Business Model Innovation: Inherent Uncertainties. *Bus. Strateg.*

- 1 *Environ.*, **26**, 182–196, doi:10.1002/bse.1906.
- 2 Ling, F. H., M. Tamura, K. Yasuhara, K. Ajima, and C. Van Trinh, 2015: Reducing flood risks in rural households:
3 survey of perception and adaptation in the Mekong delta. *Clim. Change*, **132**, 209–222.
- 4 Linnér, B.-O., and V. Wibeck, 2015: Dual high-stake emerging technologies: a review of the climate engineering
5 research literature. *Wiley Interdiscip. Rev. Clim. Chang.*, **6**, 255–268, doi:10.1002/wcc.333.
6 <http://doi.wiley.com/10.1002/wcc.333> (Accessed July 23, 2017).
- 7 Linnerooth-Bayer, J., and S. Hochrainer-Stigler, 2015: Financial instruments for disaster risk management and climate
8 change adaptation. *Clim. Change*, **133**, 85–100, doi:10.1007/s10584-013-1035-6.
9 <http://dx.doi.org/10.1007/s10584-013-1035-6>.
- 10 Lloyd, I. D., and M. Oppenheimer, 2014: On the Design of an International Governance Framework for
11 Geoengineering. *Glob. Environ. Polit.*, **14**, 45–63, doi:10.1162/GLEP_a_00228.
12 http://www.mitpressjournals.org/doi/10.1162/GLEP_a_00228 (Accessed July 23, 2017).
- 13 Lobo, C., N. Chattopadhyay, and K. Rao, 2017: Making smallholder farming climate-smart. *Econ. Polit. Weekly*, **LII**,
14 **52**, 53–58.
- 15 Loboda, T. V, 2014: Adaptation strategies to climate change in the Arctic: a global patchwork of reactive community-
16 scale initiatives. *Environ. Res. Lett.*, **9**, 7–10, doi:10.1088/1748-9326/9/11/111006.
- 17 Locatelli, B., C. Pavageau, E. Pramova, and M. Di Gregorio, 2015: Integrating climate change mitigation and
18 adaptation in agriculture and forestry: opportunities and trade-offs. *Wiley Interdiscip. Rev. Clim. Chang.*, **6**, 585–
19 598, doi:10.1002/wcc.357.
- 20 Lombardi, M., P. Paziienza, and R. Rana, 2016: The EU environmental-energy policy for urban areas: The Covenant of
21 Mayors, the ELENA program and the role of ESCos. *Energy Policy*, **93**, 33–40, doi:10.1016/j.enpol.2016.02.040.
- 22 Long, J., and J. Shepherd, 2014: Strategic value of geoengineering research. *Global Environmental Change*, B.
23 Freedman, Ed., Springer, p. 757.
- 24 Lopes, M. a. R., C. H. Antunes, and N. Martins, 2012: Energy behaviours as promoters of energy efficiency: A 21st
25 century review. *Renew. Sustain. Energy Rev.*, **16**, 4095–4104, doi:https://doi.org/10.1016/j.rser.2012.03.034.
- 26 Lourenço, T. C., R. Swart, H. Goosen, and R. Street, 2015: The rise of demand-driven climate services. *Nat. Clim.*
27 *Chang.*, **6**, 1–2, doi:10.1038/nclimate2836.
- 28 Loutatidou, S., and H. A. Arafat, 2015: Techno-economic analysis of MED and RO desalination powered by low-
29 enthalpy geothermal energy. *Desalination*, **365**, 277–292, doi:10.1016/j.desal.2015.03.010.
- 30 Lövbrand, E., M. Hjerpe, and B.-O. Linnér, 2017: Making climate governance global: how UN climate summitry comes
31 to matter in a complex climate regime. *Env. Polit.*, **26**, 1–20, doi:10.1080/09644016.2017.1319019.
32 <https://www.tandfonline.com/doi/full/10.1080/09644016.2017.1319019>.
- 33 LTA, 2013: *Land Transport Master Plan*. 1-58 pp.
- 34 ———, 2015: *Singapore land transport statistics in brief 2014*.
- 35 ———, 2017: *Annual Vehicle Statistics 2016: Motor vehicle population by vehicle type*.
- 36 Luderer, G., and Coauthors, 2016: *DEEP DECARBONISATION TOWARDS 1.5°C – 2°C STABILISATION. Policy*
37 *findings from the ADVANCE project (first edition)*. 23 pp.
- 38 Lustick, I. S., D. Nettle, D. S. Wilson, H. Kokko, and B. A. Thayer, 2011: Institutional rigidity and evolutionary theory:
39 Trapped on a local maximum. *Cliodynamics J. Theor. Math. Hist.*, **2**.
- 40 Lwasa, S., F. Mugagga, B. Wahab, D. Simon, J. P. Connors, and C. Griffith, 2015: A meta-analysis of urban and peri-
41 urban agriculture and forestry in mediating climate change. *Curr. Opin. Environ. Sustain.*, **13**, 68–73,
42 doi:10.1016/j.cosust.2015.02.003.
- 43 Ma, K.-R., and D. Banister, 2006: Extended Excess Commuting: A Measure of the Jobs-Housing Imbalance in Seoul.
44 *Urban Stud.*, **43**, 2099–2113, doi:10.1080/00420980600945245.
- 45 Ma, Y., 2014: A Study on Carbon Financing Innovation of Financial Institutions in China. *Int. J. Bus. Adm.*, **5**, 1923–
46 4007, doi:10.5430/ijba.v5n4p103. www.sciedu.ca/ijba%5Cnhttp://dx.doi.org/10.5430/ijba.v5n4p103 (Accessed
47 July 23, 2017).
- 48 Macedo, I. C., J. E. A. Seabra, and J. E. A. R. Silva, 2008: Green house gases emissions in the production and use of
49 ethanol from sugarcane in Brazil: The 2005/2006 averages and a prediction for 2020. *Biomass and Bioenergy*, **32**,
50 582–595, doi:10.1016/j.biombioe.2007.12.006.
- 51 MacGillivray, B. H., 2015: The position of place in governing global problems: A mechanistic account of place-as-
52 context, and analysis of transitions towards spatially explicit approaches to climate science and policy. *Environ.*
53 *Sci. Policy*, **53**, 8–17, doi:10.1016/j.envsci.2015.05.015.
- 54 Mackerron, G., 2014: *Costs and economics of geoengineering*. 28 pp. [http://www.geoengineering-governance-
55 research.org/perch/resources/workingpaper13mackerroncostsandeconomicsofgeoengineering.pdf](http://www.geoengineering-governance-research.org/perch/resources/workingpaper13mackerroncostsandeconomicsofgeoengineering.pdf) (Accessed July
56 22, 2017).
- 57 Macreadie, P. I., and Coauthors, 2017: Can we manage coastal ecosystems to sequester more blue carbon? *Front. Ecol.*
58 *Environ.*, **15**, 206–213, doi:10.1002/fee.1484. <http://dx.doi.org/10.1002/fee.1484>.
- 59 Maggioni, V., P. C. Meyers, M. D. Robinson, V. Maggioni, P. C. Meyers, and M. D. Robinson, 2016: A Review of
60 Merged High-Resolution Satellite Precipitation Product Accuracy during the Tropical Rainfall Measuring

- 1 Mission (TRMM) Era. *J. Hydrometeorol.*, **17**, 1101–1117, doi:10.1175/JHM-D-15-0190.1.
 2 <http://journals.ametsoc.org/doi/10.1175/JHM-D-15-0190.1> (Accessed July 20, 2017).
- 3 Maghari, B. M., and A. M. Ardekani, 2011: Genetically modified foods and social concerns. *Avicenna J. Med.*
 4 *Biotechnol.*, **3**, 109–117.
- 5 Magnan, A., Ribera, T., Treyer, S., A. K. Magnan, T. Ribera, and S. Treyer, 2015: *National adaptation is also a global*
 6 *concern*. Paris, France, 16 pp. <http://www.iddri.org/Publications/National-adaptation-is-also-a-global-concern>.
- 7 Magnan, A. K., and Coauthors, 2016: Addressing the risk of maladaptation to climate change. *Wiley Interdiscip. Rev.*
 8 *Clim. Chang.*, **7**, 646–665, doi:10.1002/wcc.409.
- 9 Magrin, G. O., J. A. Marengo, J.-P. Boulanger, M. S. Buckeridge, E. Castellanos, G. Poveda, F. R. Scarano, and S.
 10 Vicuña, 2014: Central and South America. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part*
 11 *B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental*
 12 *Panel of Climate Change*, V.R. Barros et al., Eds., Cambridge University Press, Cambridge, United Kingdom and
 13 New York, NY, USA, 1499–1566.
- 14 Malhi, Y., J. T. Roberts, R. A. Betts, T. J. Killeen, W. Li, and C. A. Nobre, 2008: Climate Change, Deforestation, and
 15 the Fate of the Amazon. *Science (80-.)*, **319**, 169–172, doi:10.1126/science.1146961.
- 16 Manju, S., and N. Sagar, 2017: Renewable energy integrated desalination: A sustainable solution to overcome future
 17 fresh-water scarcity in India. *Renew. Sustain. Energy Rev.*, **73**, 594–609, doi:10.1016/j.rser.2017.01.164.
- 18 Manoussi, V., and A. Xepapadeas, 2015: Cooperation and Competition in Climate Change Policies : Mitigation and
 19 Climate Engineering when Countries are Asymmetric. *Environ. Resour. Econ.*, doi:10.1007/s10640-015-9956-3.
- 20 Maor, M., J. Tosun, and A. Jordan, 2017: Proportionate and disproportionate policy responses to climate change: core
 21 concepts and empirical applications. *J. Environ. Policy Plan.*, **0**, 1–13, doi:10.1080/1523908X.2017.1281730.
- 22 Margerum, R. D., and C. J. Robinson, 2015: Collaborative partnerships and the challenges for sustainable water
 23 management. *Curr. Opin. Environ. Sustain.*, **12**, 53–58, doi:10.1016/j.cosust.2014.09.003.
- 24 Markusson, N., and Coauthors, 2012: A socio-technical framework for assessing the viability of carbon capture and
 25 storage technology. *Technol. Forecast. Soc. Change*, **79**, 903–918, doi:10.1016/j.techfore.2011.12.001.
- 26 Massey, E., R. Biesbroek, D. Huitema, and A. Jordan, 2014: Climate policy innovation: The adoption and diffusion of
 27 adaptation policies across Europe. *Glob. Environ. Chang.*, **29**, 434–443, doi:10.1016/j.gloenvcha.2014.09.002.
- 28 Mazzucato, M., and G. Semieniuk, 2017: Public financing of innovation: new questions. *Oxford Rev. Econ. Policy*, **33**,
 29 24–48, doi:10.1093/oxrep/grw036.
- 30 McClellan, J., D. W. Keith, and J. Apt, 2012: Cost analysis of stratospheric albedo modification delivery systems.
 31 *Environ. Res. Lett.*, **7**, 34019, doi:10.1088/1748-9326/7/3/034019.
- 32 McClintock, N., H. Wooten, and A. Brown, 2012: Toward a Food Policy “First Step” in Oakland, California: A Food
 33 Policy Council’s Efforts To Promote Urban Agriculture Zoning. *J. Agric. Food Syst. Community Dev.*, 15–42,
 34 doi:10.5304/jafscd.2012.024.009.
- 35 McCormick, K., and T. Käberger, 2007: Key barriers for bioenergy in Europe: Economic conditions, know-how and
 36 institutional capacity, and supply chain co-ordination. *Biomass and Bioenergy*, **31**, 443–452,
 37 doi:10.1016/j.biombioe.2007.01.008.
- 38 McGlade, C., and P. Ekins, 2015: The geographical distribution of fossil fuels unused when limiting global warming to
 39 2 [deg] C. *Nature*, **517**, 187–190.
- 40 McGlashan, N., N. Shah, B. Caldecott, and M. Workman, 2012: High-level techno-economic assessment of negative
 41 emissions technologies. *Process Saf. Environ. Prot.*, **90**, 501–510, doi:10.1016/j.psep.2012.10.004.
- 42 McGranahan, G., D. Schensul, and G. Singh, 2016: Inclusive urbanization: Can the 2030 Agenda be delivered without
 43 it? *Environ. Urban.*, **28**, 13–34, doi:10.1177/0956247815627522.
 44 <http://eau.sagepub.com/cgi/content/long/28/1/13>.
- 45 McKay, B., S. Sauer, B. Richardson, and R. Herre, 2016: The political economy of sugarcane flexing: initial insights
 46 from Brazil, Southern Africa and Cambodia. *J. Peasant Stud.*, **43**, 195–223, doi:10.1080/03066150.2014.992016.
- 47 McLaren, D., 2012: A comparative global assessment of potential negative emissions technologies. *Spec. Issue Negat.*
 48 *Emiss. Technol.*, **90**, 489–500, doi:10.1016/j.psep.2012.10.005.
- 49 —, 2016: Mitigation deterrence and the “moral hazard” of solar radiation management. *Earth’s Futur.*, **4**, 596–602,
 50 doi:10.1002/2016EF000445.
- 51 McPhearson, T., S. Parnell, D. Simon, O. Gaffney, T. Elmqvist, X. Bai, D. Roberts, and A. Revi, 2016: Scientists must
 52 have a say in the future of cities. *Nature*, **538**, 165–166, doi:10.1038/538165a.
- 53 Méjean, A., F. Lecocq, and Y. Mulugetta, 2015: Equity, burden sharing and development pathways: reframing
 54 international climate negotiations. *Int. Environ. Agreements Polit. Law Econ.*, **15**, 387–402, doi:10.1007/s10784-
 55 015-9302-9.
- 56 Mekonnen, M. M., M. Pahlow, M. M. Aldaya, E. Zarate, and A. Y. Hoekstra, 2015: Sustainability, efficiency and
 57 equitability of water consumption and pollution in latin America and the Caribbean. *Sustainability*, **7**, 2086–2112,
 58 doi:10.3390/su7022086. <http://www.mdpi.com/2071-1050/7/2/2086/> (Accessed July 20, 2017).
- 59 Melica, G., P. Bertoldi, A. Iancu, A. Kona, S. Rivas, and P. Zancanella, 2017: How is energy efficiency governed in the
 60 EU? Multilevel Governance of Energy Efficiency polices, strategies and targets at EU, National, Regional, and

- 1 local level. *Eur. Urban Reg. Stud.*,
- 2 Melvin, A. M., and Coauthors, 2016: Climate change damages to Alaska public infrastructure and the economics of
3 proactive adaptation. *Proc. Natl. Acad. Sci.*, **114**, 201611056, doi:10.1073/pnas.1611056113.
- 4 Menezes, E., A. G. Maia, and C. S. de Carvalho, 2017: Effectiveness of low-carbon development strategies: Evaluation
5 of policy scenarios for the urban transport sector in a Brazilian megacity. *Technol. Forecast. Soc. Change*, **114**,
6 226–241, doi:10.1016/j.techfore.2016.08.016.
- 7 Metcalf, G., and J. Stock, 2015: *The Role of Integrated Assessment Models in Climate Policy: A User's Guide and*
8 *Assessment*. Cambridge,.
- 9 Metcalf, G. E., and D. Weisbach, 2012: Linking Policies When Tastes Differ: Global Climate Policy in a
10 Heterogeneous World. *Rev. Environ. Econ. Policy*, **6**, 110–129, doi:10.1093/reep/rer021.
- 11 Metz, B., O. Davidson, H. de Coninck, M. Loos, L. Meyer, and IPCC, 2005: *IPCC special report on carbon dioxide*
12 *capture and storage*. Cambridge, UK,.
- 13 Millard-Ball, A., and L. Schipper, 2011: Are We Reaching Peak Travel? Trends in Passenger Transport in Eight
14 Industrialized Countries. *Transp. Rev.*, **31**, 357–378, doi:10.1080/01441647.2010.518291.
- 15 Miller, A. S., 2008: Financing the integration of climate change mitigation into development. *Clim. Policy*, **8**, 152–169,
16 doi:10.3763/cpol.2007.0432.
17 <http://www.ingentaconnect.com/content/earthscan/cpol/2008/00000008/00000002/art00005>.
- 18 Milner, J., M. Davies, and P. Wilkinson, 2012: Urban energy, carbon management (low carbon cities) and co-benefits
19 for human health. *Curr. Opin. Environ. Sustain.*, **4**, 398–404, doi:10.1016/j.cosust.2012.09.011.
- 20 Mingorría, S., 2017: Violence and visibility in oil palm and sugarcane conflicts: the case of Polochic Valley,
21 Guatemala. *J. Peasant Stud.*, **6150**, 1–26, doi:10.1080/03066150.2017.1293046.
22 <https://www.tandfonline.com/doi/full/10.1080/03066150.2017.1293046> (Accessed July 20, 2017).
- 23 Minville, M., F. Brissette, S. Krau, and R. Leconte, 2009: Adaptation to Climate Change in the Management of a
24 Canadian Water-Resources System Exploited for Hydropower. *Water Resour. Manag.*, **23**, 2965–2986,
25 doi:10.1007/s11269-009-9418-1.
- 26 Minx, J., W. F. Lamb, M. W. Callaghan, L. Bornmann, and S. Fuss, 2017: Fast growing research on negative emissions.
27 *Environ. Res. Lett.*, **12**. <http://iopscience.iop.org/1748-9326/12/3/035007>.
- 28 Mistry, J., and A. Berardi, 2016: Bridging indigenous and scientific knowledge. *Science (80-.)*, **352**, 1274–1275,
29 doi:10.1126/science.aaf1160. <http://science.sciencemag.org/content/352/6291/1274> (Accessed July 20, 2017).
- 30 Mitchell, D., and Coauthors, 2017: Half a degree additional warming, prognosis and projected impacts (HAPPI):
31 background and experimental design. *Geosci. Model Dev.*, **10**, 571–583, doi:10.5194/gmd-10-571-2017.
- 32 Mitchell, P., and C. Borchard, 2014: Mainstreaming children's vulnerabilities and capacities into community-based
33 adaptation to enhance impact. *Clim. Dev.*, **6**, 372–381.
- 34 Mitlin, D., and D. Satterthwaite, 2013: *Urban poverty in the global South : scale and nature*. Routledge, Abingdon,
35 Oxon, UK and New York, NY, USA, 354 pp.
- 36 Mittal, S., H. Dai, and P. R. Shukla, 2016: Low carbon urban transport scenarios for China and India: A comparative
37 assessment. *Transp. Res. Part D Transp. Environ.*, **44**, 266–276, doi:10.1016/j.trd.2015.04.002.
- 38 Moffatt, S., 2014: Resilience and competing temporalities in cities. *Build. Res. Inf.*, **42**, 202–220,
39 doi:10.1080/09613218.2014.869894.
- 40 Mohan, P., 2017: Impact of Hurricanes on Agriculture: Evidence from the Caribbean. *Nat. Hazards Rev.*, **18**, 4016012,
41 doi:10.1061/(ASCE)NH.1527-6996.0000235.
- 42 Moloney, S., R. E. Horne, and J. Fien, 2010: Transitioning to low carbon communities—from behaviour change to
43 systemic change: Lessons from Australia. *Energy Policy*, **38**, 7614–7623, doi:10.1016/j.enpol.2009.06.058.
- 44 Monfreda, C., N. Ramankutty, and J. A. Foley, 2008: Farming the planet: 2. Geographic distribution of crop areas,
45 yields, physiological types, and net primary production in the year 2000. *Global Biogeochem. Cycles*, **22**,
46 doi:10.1029/2007GB002947.
- 47 Montzka, S. A., E. J. Dlugokencky, and J. H. Butler, 2011: Non-CO₂ Greenhouse Gases and Climate Change. *Nature*,
48 **476**, 43–50, doi:10.1038/nature10322.
- 49 Moreno-Cruz, J. B., 2015: Mitigation and the geoengineering threat. *Resour. Energy Econ.*, **41**, 248–263,
50 doi:10.1016/j.reseneeco.2015.06.001.
- 51 ———, and D. W. Keith, 2013: Climate policy under uncertainty: a case for solar geoengineering. *Clim. Change*, **121**,
52 431–444, doi:10.1007/s10584-012-0487-4.
- 53 ———, and S. Smulders, 2017: Revisiting the economics of climate change: the role of geoengineering. *Res. Econ.*, **71**,
54 212–224, doi:10.1016/j.rie.2016.12.001.
- 55 Moriyama, R., M. Sugiyama, A. Kurosawa, K. Masuda, K. Tsuzuki, and Y. Ishimoto, 2016: The cost of stratospheric
56 climate engineering revisited. *Mitig. Adapt. Strateg. Glob. Chang.*, 1–22, doi:10.1007/s11027-016-9723-y.
- 57 Morrow, D., and T. Svoboda, 2016: Geoengineering and Non-Ideal Theory. *Public Aff. Q.*, **30**, 85–104.
- 58 Morrow, D. R., 2014a: Starting a flood to stop a fire? Some moral constraints on solar radiation management. *Ethics*,
59 *Policy Environ.*, **17**, 123–138, doi:10.1080/21550085.2014.926056.
- 60 Morrow, D. R., 2014b: Ethical aspects of the mitigation obstruction argument against climate engineering research.

- 1 *Philos. Trans. R. Soc. A Math. Phys. Eng. Sci.*, **372**, 20140062, doi:10.1098/rsta.2014.0062.
- 2 Mortreux, C., and J. Barnett, 2017: Adaptive capacity: exploring the research frontier. *WIREs Clim Chang.*, 1–12,
3 doi:10.1002/wcc.467.
- 4 Muis, S., M. Verlaan, H. C. Winsemius, J. C. J. H. Aerts, and P. J. Ward, 2016: A global reanalysis of storm surges and
5 extreme sea levels. *Nat. Commun.*, **7**, 11969, doi:10.1038/ncomms11969.
- 6 Murrant, D., A. Quinn, and L. Chapman, 2015: The water-energy nexus: Future water resource availability and its
7 implications on UK thermal power generation. *Water Environ. J.*, **29**, 307–319, doi:10.1111/wej.12126.
- 8 Musall, F. D., and O. Kuik, 2011: Local acceptance of renewable energy—A case study from southeast Germany.
9 *Energy Policy*, **39**, 3252–3260, doi:10.1016/j.enpol.2011.03.017.
- 10 Myhre, G., and Coauthors, 2013: Anthropogenic and Natural Radiative Forcing. *Climate Change 2013: The Physical
11 Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel
12 on Climate Change*, T. Stocker et al., Eds., Cambridge University Press, Cambridge, United Kingdom and New
13 York, NY, USA.
- 14 Nakicenovic, N., J. Alcamo, A. Grubler, K. Riahi, R. A. Roehrl, H.-H. Rogner, and N. Victor, 2000: *Special Report on
15 Emissions Scenarios (SRES), A Special Report of Working Group III of the Intergovernmental Panel on Climate
16 Change*. Cambridge University Press,.
- 17 Nanaki, E. A., and C. J. Koroneos, 2016: Climate change mitigation and deployment of electric vehicles in urban areas.
18 *Renew. Energy*, **99**, 1153–1160, doi:10.1016/j.renene.2016.08.006.
- 19 National Academy of Sciences, 2015: *Climate Intervention*. National Academies Press, Washington, D.C., 154 pp.
- 20 Nature, 2004: Leapfrogging the power grid. *Nature*, **427**, 661–661, doi:10.1038/427661a.
- 21 NEC, 2011: *Second National Communication to the UNFCCC*. Thimphu, Bhutan.,
22 —, 2015: *Communication of INDC of the Kingdom of Bhutan*.
- 23 De Nederlandsche Bank, 2016: *Time for Transition: an exploratory study of the transition to a carbon-neutral
24 economy*. 92 pp.
- 25 Nemet, G. F., M. Jakob, J. C. Steckel, and O. Edenhofer, 2017: Addressing policy credibility problems for low-carbon
26 investment. *Glob. Environ. Chang.*, **42**, 47–57, doi:10.1016/j.gloenvcha.2016.12.004.
- 27 Newell, R. G., and W. A. Pizer, 2003: Regulating stock externalities under uncertainty. *J. Environ. Econ. Manage.*, **45**,
28 416–432, doi:10.1016/S0095-0696(02)00016-5.
- 29 Newman, P., 2017: Decoupling Economic Growth from Fossil Fuels. *Mod. Econ.*,
30 —, and J. Kenworthy, 2011: “Peak Car Use”: Understanding the Demise of Automobile Dependence. *J. World
31 Transp. Policy Pract.*, **17**, 31–42. <http://www.eco-logica.co.uk/pdf/wtp17.2.pdf> (Accessed July 22, 2017).
- 32 —, and J. Kenworthy, 2015: The End of Automobile Dependence. *The End of Automobile Dependence*, Island
33 Press/Center for Resource Economics, Washington, DC, 201–226.
- 34 —, L. Kosonen, and J. Kenworthy, 2016: Theory of urban fabrics: planning the walking, transit/public transport and
35 automobile/motor car cities for reduced car dependency. *Town Plan. Rev.*, **87**, 429–458, doi:10.3828/tpr.2016.28.
- 36 —, T. Beatley, and H. Boyer, 2017: *Resilient Cities: Overcoming Fossil Fuel Dependence*. Island Press,.
- 37 Ngendakumana, S., M. P. Feudjio, S. Speelman, A. P. Minang, S. Namirembe, and P. V. A. N. Damme, 2017:
38 Implementing REDD + : learning from forest conservation policy and social safeguards frameworks in Cameroon.
39 *Int. For. Rev.*, **XX**, 1–15, doi:10.1505/146554817821255187.
- 40 Nicolson, M., G. Huebner, and D. Shipworth, 2017: Are consumers willing to switch to smart time of use electricity
41 tariffs? The importance of loss-aversion and electric vehicle ownership. *Energy Res. Soc. Sci.*, **23**, 82–96,
42 doi:10.1016/j.erss.2016.12.001.
- 43 Nightingale, A. J., 2017: Power and politics in climate change adaptation efforts: Struggles over authority and
44 recognition in the context of political instability. *Geoforum*, **84**, 11–20, doi:10.1016/j.geoforum.2017.05.011.
- 45 Nobre, C. A., G. Sampaio, L. S. Borma, J. C. Castilla-Rubio, J. S. Silva, and M. Cardoso, 2016: Land-use and climate
46 change risks in the Amazon and the need of a novel sustainable development paradigm. *Proc. Natl. Acad. Sci. U.
47 S. A.*, **113**, 10759–10768, doi:10.1073/pnas.1605516113.
- 48 Nordhaus, W., 2015: Climate clubs: Overcoming free-riding in international climate policy. *Am. Econ. Rev.*, **105**, 1339–
49 1370, doi:10.1257/aer.15000001.
- 50 North, D. C., 1990: *Institutions, institutional change and economic performance*. Cambridge university press,.
- 51 Numata, I., S. S. Silva, M. A. Cochrane, and M. V D’Oliveira, 2017: Fire and edge effects in a fragmented tropical
52 forest landscape in the southwestern Amazon. *For. Ecol. Manage.*, **401**, 135–146.
- 53 Nyong, A., F. Adesina, and B. Osman Elasha, 2007: The value of indigenous knowledge in climate change mitigation
54 and adaptation strategies in the African Sahel. *Mitig. Adapt. Strateg. Glob. Chang.*, **12**, 787–797,
55 doi:10.1007/s11027-007-9099-0. <http://link.springer.com/10.1007/s11027-007-9099-0> (Accessed July 20, 2017).
- 56 O’Neill, B. C., and Coauthors, 2015: The roads ahead: Narratives for shared socioeconomic pathways describing world
57 futures in the 21st century. *Glob. Environ. Chang.*, **42**, 169–180, doi:10.1016/j.gloenvcha.2015.01.004.
- 58 Oberthür, S., and L. Groen, 2017: Explaining goal achievement in international negotiations: the EU and the Paris
59 Agreement on climate change. *J. Eur. Public Policy*, **0**, 1–20, doi:10.1080/13501763.2017.1291708.
60 <https://www.tandfonline.com/doi/full/10.1080/13501763.2017.1291708>.

- 1 OECD, 2011: *Invention and Transfer of Environmental Technologies*, *OECD Studies on Environmental Innovation*.
2 237 pp.
- 3 Ölander, F., and J. Thøgersen, 2014: Informing Versus Nudging in Environmental Policy. *J. Consum. Policy*, **37**, 341–
4 356, doi:10.1007/s10603-014-9256-2.
- 5 Oliver, T. H., and M. D. Morecroft, 2014: Interactions between climate change and land use change on biodiversity:
6 attribution problems, risks, and opportunities. *Wiley Interdiscip. Rev. Clim. Chang.*, **5**, 317–335,
7 doi:10.1002/wcc.271.
- 8 Ostrom, E., 2009: A general framework for analyzing sustainability of social-ecological systems. *Science (80-.)*, **325**,
9 419–422, doi:10.1126/science.1172133. <https://www.ncbi.nlm.nih.gov/pubmed/19628857>.
- 10 Ostrom, E., and J. Walker, 2005: *Trust and Reciprocity: Interdisciplinary Lessons for Experimental Research*. Russell
11 Sage Foundation, 424 pp.
- 12 Ostrom, E., J. Burger, C. B. Field, R. B. Norgaard, and D. Policansky, 1999: Revisiting the Commons: Local Lessons,
13 Global Challenges. *Science (80-.)*, **284**. <http://science.sciencemag.org/content/284/5412/278> (Accessed April 9,
14 2017).
- 15 Pan, X., M. den Elzen, N. Höhne, F. Teng, and L. Wang, 2017: Exploring fair and ambitious mitigation contributions
16 under the Paris Agreement goals. *Environ. Sci. Policy*, **74**, 49–56, doi:10.1016/j.envsci.2017.04.020.
- 17 Panagopoulos, T., J. A. González Duque, and M. Bostenaru Dan, 2016: Urban planning with respect to environmental
18 quality and human well-being. *Environ. Pollut.*, **208**, 137–144, doi:10.1016/j.envpol.2015.07.038.
- 19 Panteli, M., and P. Mancarella, 2015: Influence of extreme weather and climate change on the resilience of power
20 systems: Impacts and possible mitigation strategies. *Electr. Power Syst. Res.*, **127**, 259–270,
21 doi:10.1016/j.epsr.2015.06.012.
- 22 Parkinson, S. C., and N. Djilali, 2015: Robust response to hydro-climatic change in electricity generation planning.
23 *Clim. Change*, **130**, 475–489, doi:10.1007/s10584-015-1359-5.
- 24 Pasgaard, M., Z. Sun, D. Müller, and O. Mertz, 2016: Challenges and opportunities for REDD+: A reality check from
25 perspectives of effectiveness, efficiency and equity. *Environ. Sci. Policy*, **63**, 161–169,
26 doi:10.1016/j.envsci.2016.05.021. <http://linkinghub.elsevier.com/retrieve/pii/S1462901116302428> (Accessed July
27 22, 2017).
- 28 Pasimeni, M. R., I. Petrosillo, R. Aretano, T. Semeraro, A. De Marco, N. Zaccarelli, and G. Zurlini, 2014: Scales,
29 strategies and actions for effective energy planning: A review. *Energy Policy*, **65**, 165–174,
30 doi:10.1016/j.enpol.2013.10.027.
- 31 Pasquini, L., G. Ziervogel, R. M. Cowling, and C. Shearing, 2015: What enables local governments to mainstream
32 climate change adaptation? Lessons learned from two municipal case studies in the Western Cape, South Africa.
33 *Clim. Dev.*, **7**, 60–70, doi:<http://dx.doi.org/10.1080/17565529.2014.886994>.
- 34 Patt, A., 2017: Beyond the tragedy of the commons: Reframing effective climate change governance. *Energy Res. Soc.*
35 *Sci.*, **34**, 1–3, doi:10.1016/j.erss.2017.05.023.
- 36 Patt, A. G., and D. Schröter, 2008: Perceptions of climate risk in Mozambique: Implications for the success of
37 adaptation strategies. *Glob. Environ. Chang.*, **18**, 458–467, doi:10.1016/j.gloenvcha.2008.04.002.
- 38 Pauw, W. P., 2017: Mobilising private adaptation finance: developed country perspectives. *Int. Environ. Agreements*
39 *Polit. Law Econ.*, **17**, 55–71, doi:10.1007/s10784-016-9342-9.
- 40 Pelletier, L. G., K. M. Tuson, I. Green-Demers, K. Noels, and A. M. Beaton, 1998: Why Are You Doing Things for the
41 Environment? The Motivation Toward the Environment Scale (MTES)1. *J. Appl. Soc. Psychol.*, **28**, 437–468,
42 doi:10.1111/j.1559-1816.1998.tb01714.x.
- 43 Pelling, M., H. Leck, L. Pasquini, I. Ajibade, E. Osuteye, S. Parbnell, and S. Lwasa, (under review) Africa’s Urban
44 Adaptation Transition Under a 1.5 Degree. *Curr. Opin. Environ. Sustain.*,.
- 45 Pelling, M., K. O’Brien, and D. Matyas, 2015: Adaptation and transformation. *Clim. Change*, **133**, 113–127,
46 doi:10.1007/s10584-014-1303-0.
- 47 Pemberton, C., and H. Patterson-Andrews, 2016: Relative Vulnerability of Selected Caribbean States to Changes in
48 Food Security Due to Tropical Storms and Hurricanes. *Int. J. Food Agric. Econ.*, **4**, 125–136.
- 49 Peng, J., and Coauthors, 2016: Markedly enhanced absorption and direct radiative forcing of black carbon under
50 polluted urban environments. *Proc. Natl. Acad. Sci. U. S. A.*, 1602310113-, doi:10.1073/pnas.1602310113.
- 51 Perez, C., 2002: *Technological revolutions and financial capital: The Dynamics of Bubbles and Golden Ages*. Edward
52 Elgar Publishing, Northampton.
- 53 ———, 2009a: Technological revolutions and techno-economic paradigms. *Cambridge J. Econ.*, **34**, 185–202.
- 54 ———, 2009b: The double bubble at the turn of the century: technological roots and structural implications. *Cambridge*
55 *J. Econ.*, **33**, 779–805.
- 56 Peters, G. P., R. M. Andrew, J. G. Canadell, S. Fuss, R. B. Jackson, J. I. I. Korsbakken, C. Le Quéré, and N.
57 Nakicenovic, 2017: Key indicators to track current progress and future ambition of the Paris Agreement. *Nat.*
58 *Clim. Chang.*, **7**, 118–122, doi:10.1038/nclimate3202.
- 59 Pfeiffer, A., R. Millar, C. Hepburn, and E. Beinhocker. 2016. “The ‘2°C Capital Stock’ for Electricity Generation:
60 Committed Cumulative Carbon Emissions from the Electricity Generation Sector and the Transition to a Green

- 1 Economy.” *Applied Energy* 179 (October): 1395–1408. doi:10.1016/j.apenergy.2016.02.093.
- 2 Phelps, J., E. L. Webb, and W. M. Adams, 2012: Biodiversity co-benefits of policies to reduce forest-carbon emissions.
3 *Nat. Clim. Chang.*, **2**, 497–503.
- 4 Pichert, D., and K. V. Katsikopoulos, 2008: Green defaults: Information presentation and pro-environmental behaviour.
5 *J. Environ. Psychol.*, **28**, 63–73, doi:10.1016/j.jenvp.2007.09.004.
- 6 Pichler, M., A. Schaffartzik, H. Haberl, and C. Görg, 2017: Drivers of society-nature relations in the Anthropocene and
7 their implications for sustainability transformations. *Curr. Opin. Environ. Sustain.*, **26–27**, 32–36,
8 doi:10.1016/j.cosust.2017.01.017.
- 9 Pielke, R. A., J. Rubiera, C. Landsea, M. L. Fernández, and R. Klein, 2003: Hurricane Vulnerability in Latin America
10 and The Caribbean: Normalized Damage and Loss Potentials. *Nat. Hazards Rev.*, **4**, 101–114,
11 doi:10.1061/(ASCE)1527-6988(2003)4:3(101).
- 12 Pierrehumbert, R. T., 2014: Short-Lived Climate Pollution. *Annu. Rev. Earth Planet. Sci.*, **42**, 341–79,
13 doi:10.1146/annurev-earth-060313-054843.
- 14 Piketty, T., 2014: *Capital in the Twenty-first Century*. The Belknap Press of Harvard University Press, Cambridge
15 Massachusetts,.
- 16 Pitari, G., and Coauthors, 2014: Stratospheric ozone response to sulfate geoengineering: Results from the
17 Geoengineering Model Intercomparison Project (GeoMIP). *J. Geophys. Res. Atmos.*, **119**, 2629–2653,
18 doi:10.1002/2013JD020566.
- 19 Pittelkow, C. M., and Coauthors, 2014: Productivity limits and potentials of the principles of conservation agriculture.
20 *Nature*, **517**, 365–368, doi:10.1038/nature13809.
- 21 Pittman, J., D. Armitage, S. Alexander, D. Campbell, and M. Alleyne, 2015: Governance fit for climate change in a
22 Caribbean coastal-marine context. *Mar. Policy*, **51**, 486–498, doi:10.1016/j.marpol.2014.08.009.
- 23 Pizer, W. A., 2002: Combining price and quantity controls to mitigate global climate change. *J. Public Econ.*, **85**, 409–
24 434, doi:10.1016/S0047-2727(01)00118-9.
- 25 Plevin, R. J., M. O’Hare, A. D. Jones, M. S. Torn, and H. K. Gibbs, 2010: Greenhouse Gas Emissions from Biofuels’
26 Indirect Land Use Change Are Uncertain but May Be Much Greater than Previously Estimated. *Environ. Sci.*
27 *Technol.*, **44**, 8015–8021, doi:10.1021/es101946t.
28 <http://pubs.acs.org/globalproxy.cvt.dk/doi/full/10.1021/es101946t>.
- 29 Poff, N. L., and Coauthors, 2015: Sustainable water management under future uncertainty with eco-engineering
30 decision scaling. *Nat. Clim. Chang.*, **6**, 25–34, doi:10.1038/nclimate2765.
- 31 Pollak, M., B. Meyer, and E. Wilson, 2011: Reducing greenhouse gas emissions: Lessons from state climate action
32 plans. *Energy Policy*, **39**, 5429–5439, doi:10.1016/j.enpol.2011.05.020.
- 33 Popp, A., and Coauthors, 2014: Land-use transition for bioenergy and climate stabilization: model comparison of
34 drivers, impacts and interactions with other land use based mitigation options. *Clim. Change*, **123**, 495–509,
35 doi:10.1007/s10584-013-0926-x. <http://dx.doi.org/10.1007/s10584-013-0926-x>.
- 36 Postic, S., S. Selosse, and N. Maïzi, 2017: Energy contribution to Latin American INDCs: Analyzing sub-regional
37 trends with a TIMES model. *Energy Policy*, **101**, 170–184, doi:10.1016/j.enpol.2016.11.023.
- 38 Pradhan, A., C. Chan, P. K. Roul, J. Halbrendt, and B. Sipes, 2017: Potential of conservation agriculture (CA) for
39 climate change adaptation and food security under rainfed uplands of India: A transdisciplinary approach. *Agric.*
40 *Syst.*, doi:10.1016/j.agsy.2017.01.002.
- 41 Pratomo, R. A., V. Jetten, and D. Alkema, 2016: A comparison of flash flood response at two different watersheds in
42 Grenada, Caribbean Islands. *IOP Conf. Ser. Earth Environ. Sci.*, **29**, 12004, doi:10.1088/1755-1315/29/1/012004.
- 43 Preston, B. L., J. Mustelin, and M. C. Maloney, 2013: Climate adaptation heuristics and the science/policy divide.
44 *Mitig. Adapt. Strateg. Glob. Chang.*, **20**, 467–497, doi:10.1007/s11027-013-9503-x.
- 45 Preston, C. J., 2013: Ethics and geoengineering: reviewing the moral issues raised by solar radiation management and
46 carbon dioxide removal. *Wiley Interdiscip. Rev. Clim. Chang.*, **4**, 23–37, doi:10.1002/wcc.198.
47 <http://onlinelibrary.wiley.com/doi/10.1002/wcc.198/abstract> (Accessed July 23, 2017).
- 48 Prevatt, D. O., L. Dupigny-Giroux, and F. J. Masters, 2010: Twenty-Five Years of Caribbean Hurricane Disaster
49 Mitigation. *Wind Storm and Storm Surge Mitigation*, American Society of Civil Engineers, Reston, VA, 153–161
50 <http://ascelibrary.org/doi/10.1061/9780784410813.ch13> (Accessed July 9, 2017).
- 51 Pritchard, C., A. Yang, P. Holmes, and M. Wilkinson, 2015: Thermodynamics, economics and systems thinking: What
52 role for air capture of CO₂? *Process Saf. Environ. Prot.*, **94**, 188–195,
53 doi:10.1016/j.psep.2014.06.011.
- 54 Proost, S., Regemorter, D., 1995. The double dividend and the role of inequality aversion and macroeconomic regimes.
55 *International Tax Public Finance*, **2**, 207–219.
- 56 Pucher, J., and R. Buehler, 2016: Safer Cycling Through Improved Infrastructure. *Am. J. Public Heal.*, **106**, 2089–
57 2091, doi:10.2105/AJPH.2016.303507.
- 58 Puentes, R., and A. Tomer, 2008: The Road...Less Traveled: An Analysis of Vehicle Miles Traveled Trends in the U.S.
59 <https://www.brookings.edu/research/the-roadless-traveled-an-analysis-of-vehicle-miles-traveled-trends-in-the-u-s/>
60 (Accessed July 24, 2017).

- 1 Puppim de Oliveira, J. A., C. N. H. Doll, T. A. Kurniawan, Y. Geng, M. Kapshe, and D. Huisingsh, 2013: Promoting
2 win-win situations in climate change mitigation, local environmental quality and development in Asian cities
3 through co-benefits. *J. Clean. Prod.*, **58**, 1–6, doi:10.1016/j.jclepro.2013.08.011.
- 4 Qin, Y., X. Sheng, S. Liu, G. Ren, X. Wang, and F. Wang, 2015: Recent advances in carbon dioxide based copolymers.
5 *J. CO₂ Util.*, **11**, 3–9, doi:http://dx.doi.org/10.1016/j.jcou.2014.10.003.
- 6 Quaas, J., M. F. Quaas, O. Boucher, and W. Rickels, 2016: Regional climate engineering by radiation management:
7 Prerequisites and prospects. *Earth's Futur.*, **4**, 618–625, doi:10.1002/2016EF000440.
- 8 Rabitz, F., 2016: Going rogue? Scenarios for unilateral geoengineering. *Futures*, **84**, 98–107,
9 doi:10.1016/j.futures.2016.11.001.
- 10 Rajan, R. G., 2010: *Fault Lines: How Hidden Fractures Still Threaten the World Economy*. Princeton University Press,
11 Princeton, N.J., 272 pp.
- 12 Rasul, G., and B. Sharma, 2016: The nexus approach to water-energy-food security: an option for adaptation to climate
13 change. *Clim. Policy*, **16**, 682–702, doi:10.1080/14693062.2015.1029865.
- 14 Rathore, D., A.-S. Nizami, A. Singh, and D. Pant, 2016: Key issues in estimating energy and greenhouse gas savings of
15 biofuels: challenges and perspectives. *Biofuel Res. J.*, **3**, 380–393, doi:10.18331/BRJ2016.3.2.3.
- 16 Ray, D., S. Bathgate, D. Moseley, P. Taylor, B. Nicoll, S. Pizzirani, and B. Gardiner, 2015: Comparing the provision of
17 ecosystem services in plantation forests under alternative climate change adaptation management options in
18 Wales. *Reg. Environ. Chang.*, **15**, 1501–1513.
- 19 Rayner, S., C. Heyward, T. Kruger, N. Pidgeon, C. Redgwell, and J. Savulescu, 2013: The Oxford Principles. *Clim.*
20 *Change*, **121**, 499–512, doi:10.1007/s10584-012-0675-2.
- 21 Reckien, D., and Coauthors, 2014: Climate change response in Europe: what's the reality? Analysis of adaptation and
22 mitigation plans from 200 urban areas in 11 countries. *Clim. Change*, **122**, 331–340, doi:10.1007/s10584-013-
23 0989-8. http://dx.doi.org/10.1007/s10584-013-0989-8.
- 24 Reckien, D., J. Flacke, M. Olazabal, and O. Heidrich, 2015: The Influence of drivers and barriers on urban adaptation
25 and mitigation plans—An empirical analysis of european cities. *PLoS One*, **10**, e0135597.
- 26 ———, F. Creutzig, B. Fernandez, S. Lwasa, M. Tovar-restrepo, and D. Satterthwaite, 2017: Climate change , equity and
27 the Sustainable Development Goals : an urban perspective. *Environ. Urban.*, **29**, 159–182,
28 doi:10.1177/0956247816677778.
- 29 Reed, S. O., R. Friend, J. Jarvie, J. Henceroth, P. Thinphanga, D. Singh, P. Tran, and R. Sutarto, 2015: Resilience
30 projects as experiments: implementing climate change resilience in Asian cities. *Clim. Dev.*, **7**, 469–480,
31 doi:10.1080/17565529.2014.989190.
- 32 Regmi, M. B., and S. Hanaoka, 2011: A survey on impacts of climate change on road transport infrastructure and
33 adaptation strategies in Asia. *Environ. Econ. Policy Stud.*, **13**, 21–41, doi:10.1007/s10018-010-0002-y.
- 34 Reid, H., 2016: Ecosystem- and community-based adaptation: learning from community-based natural resource
35 management. *Clim. Dev.*, **8**, 4–9, doi:10.1080/17565529.2015.1034233.
- 36 ———, and S. Huq, 2014: *Mainstreaming community-based adaptation into national and local planning*. Taylor &
37 Francis,.
- 38 Reid, H., M. Alam, R. Berger, T. Cannon, M. Huq, S., and A. Milligan, 2009: Community-based adaptation to climate
39 change: An overview. *Participatory learning 60: Community-based adaptation to climate change*, H. Ashley and
40 A. Milligan, Eds., International Institute for Environment and Development, 11–38.
- 41 Reiner, D. M., T. E. Curry, M. A. de Figueiredo, H. J. Herzog, S. D. Ansolabehere, K. Itaoka, F. Johnsson, and M.
42 Odenberger, 2006: American Exceptionalism? Similarities and Differences in National Attitudes Toward Energy
43 Policy and Global Warming. *Environ. Sci. Technol.*, **40**, 2093–2098, doi:10.1021/es052010b.
- 44 REN21, 2017: *Global Renewables Status Report 2016*. Paris, France, 302 pp. http://www.ren21.net/wp-
45 content/uploads/2017/06/17-8399_GSR_2017_Full_Report_0621_Opt.pdf.
- 46 Renaud, F. G., T. T. H. Le, C. Lindener, V. T. Guong, and Z. Sebesvari, 2015: Resilience and shifts in agro-ecosystems
47 facing increasing sea-level rise and salinity intrusion in Ben Tre Province, Mekong Delta. *Clim. Change*, **133**, 69–
48 84, doi:10.1007/s10584-014-1113-4.
- 49 Renforth, P., and G. Henderson, 2017: Assessing ocean alkalinity for carbon sequestration. *Rev. Geophys.*,
50 doi:10.1002/2016RG000533.
- 51 Resnick, D., F. Tarp, and J. Thurlow, 2012: The political economy of green growth: Cases from Southern Africa. *Adm.*
52 *Dev.*, **32**, 215–228, doi:10.1002/pad.1619.
- 53 Revi, A., 2016: Afterwards: Habitat III and the Sustainable Development Goals. *Urbanisation*, **1**, x–xiv,
54 doi:10.1177/2455747116682899.
- 55 Revi, A., D. E. Satterthwaite, F. Aragón-Durand, J. Corfee-Morlot, R. B. R. Kiunsi, M. Pelling, D. C. Roberts, and W.
56 Solecki, 2014: Urban Areas. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and*
57 *Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental*
58 *Panel of Climate Change*, C.B. Field et al., Eds., Cambridge University Press, Cambridge, United Kingdom and
59 New York, NY, USA, 535–612.
- 60 Reyers, B., M. Stafford-Smith, K.-H. Erb, R. J. Scholes, and O. Selomane, 2017: Essential Variables help to focus

- 1 Sustainable Development Goals monitoring. *Curr. Opin. Environ. Sustain.*, **26**, 97–105,
2 doi:10.1016/j.cosust.2017.05.003.
- 3 Reyes-Garcia, V., A. Fernández-Llamazares, M. Guèze, A. Garcés, M. Mallo, M. Vila-Gomez, and M. Vilaseca, 2016:
4 Local indicators of climate change: The potential contribution of local knowledge to climate research. *Wiley*
5 *Interdiscip. Rev. Clim. Chang.*, **7**, 109–124, doi:10.1002/wcc.374. <http://doi.wiley.com/10.1002/wcc.374>
6 (Accessed July 20, 2017).
- 7 Reynolds, J., 2015: A critical examination of the climate engineering moral hazard and risk compensation concern.
8 *Anthr. Rev.*, **2**, 174–191, doi:10.1177/2053019614554304.
- 9 RGoB, 2012: *The Report of the High-Level Meeting on Wellbeing and Happiness: Defining a New Economic*
10 *Paradigm*. New York,.
- 11 ———, 2013: *Eleventh five year plan. Volume I: Main Document*. Thimphu, Bhutan,.
- 12 ———, 2016: *Economic Development Policy*. Thimphu, Bhutan, 52 pp.
- 13 Rhiney, K., 2015: Geographies of Caribbean Vulnerability in a Changing Climate: Issues and Trends. *Geogr. Compass*,
14 **9**, 97–114, doi:10.1111/gec3.12199.
- 15 Riahi, K., and Coauthors, 2015a: The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas
16 emissions implications: An overview. *Glob. Environ. Chang.*, **42**, 153–168, doi:10.1016/j.gloenvcha.2016.05.009.
- 17 ———, and Coauthors, 2015b: Locked into Copenhagen pledges - Implications of short-term emission targets for the cost
18 and feasibility of long-term climate goals. *Technol. Forecast. Soc. Change*, **90**, 8–23,
19 doi:10.1016/j.techfore.2013.09.016. <http://dx.doi.org/10.1016/j.techfore.2013.09.016>.
- 20 Ribot, J., 2011: Vulnerability before Adaptation: Toward Transformative Climate Action Posted in this format with
21 permission of Global Environmental Change. *Glob. Environ. Chang.*, **21**.
- 22 de Richter, R., T. Ming, P. Davies, W. Liu, and S. Caillol, 2017: Removal of non-CO₂ greenhouse gases by large-scale
23 atmospheric solar photocatalysis. *Prog. Energy Combust. Sci.*, **60**, 68–96,
24 doi:<https://doi.org/10.1016/j.pecs.2017.01.001>.
25 <http://www.sciencedirect.com/science/article/pii/S0360128516300569>.
- 26 Ricke, K. L., J. B. Moreno-Cruz, and K. Caldeira, 2013: Strategic incentives for climate geoengineering coalitions to
27 exclude broad participation. *Environ. Res. Lett.*, **8**, 14021, doi:10.1088/1748-9326/8/1/014021.
28 <http://iopscience.iop.org/article/10.1088/1748-9326/8/1/014021/pdf> (Accessed July 23, 2017).
- 29 Ringel, M., 2017: Energy efficiency policy governance in a multi-level administration structure — evidence from
30 Germany. *Energy Effic.*, **10**, 753–776, doi:10.1007/s12053-016-9484-1.
- 31 Rivas, S., and Coauthors, 2015: *The Covenant of Mayors: In-depth Analysis of Sustainable Energy Actions Plans*.
32 Rivera-Collazo, I., A. Winter, D. Scholz, A. Mangini, T. Miller, Y. Kushnir, and D. Black, 2015: Human adaptation
33 strategies to abrupt climate change in Puerto Rico ca. 3.5 ka. *The Holocene*, **25**, 627–640,
34 doi:10.1177/0959683614565951.
- 35 Rivera, C., and C. Wamsler, 2014: Integrating climate change adaptation, disaster risk reduction and urban planning: A
36 review of Nicaraguan policies and regulations. *Int. J. Disaster Risk Reduct.*, **7**, 78–90,
37 doi:<https://doi.org/10.1016/j.ijdrr.2013.12.008>.
38 <http://www.sciencedirect.com/science/article/pii/S2212420913000708>.
- 39 Roberts, D., 2008: Thinking globally, acting locally—institutionalizing climate change at the local government level in
40 Durban, South Africa. *Environ. Urban.*, **20**, 521–537, doi:10.1177/0956247808096126.
- 41 ———, 2016a: The New Climate Calculus: 1.5°C = Paris Agreement, Cities, Local Government, Science and Champions
42 (PLSC2). *Urbanisation*, **1**, 71–78, doi:10.1177/2455747116672474.
- 43 ———, 2016b: The New Climate Calculus: 1.5°C = Paris Agreement, Cities, Local Government, Science and Champions
44 (PLSC 2). *Urbanisation*, **1**, 71–78, doi:10.1177/2455747116672474.
- 45 Robiou du Pont, Y., M. L. Jeffery, J. Gütschow, J. Rogelj, P. Christoff, and M. Meinshausen, 2016: Equitable
46 mitigation to achieve the Paris Agreement goals. *Nat. Clim. Chang.*, **7**, 38–43, doi:10.1038/nclimate3186.
47 <http://www.nature.com/doi/10.1038/nclimate3186>.
- 48 Robock, A., 2016: Albedo enhancement by stratospheric sulfur injections: More research needed. *Earth's Futur.*, **4**,
49 644–648, doi:10.1002/2016EF000407.
- 50 Robock, A., A. Marquardt, B. Kravitz, and G. Stenchikov, 2009: Benefits, risks, and costs of stratospheric
51 geoengineering. *Geophys. Res. Lett.*, **36**.
- 52 Rockström, J., O. Gaffney, J. Rogelj, M. Meinshausen, N. Nakicenovic, and H. J. Schellnhuber, 2017: A roadmap for
53 rapid decarbonization. *Science (80-.)*, **355**, 1269–1271, doi:10.1126/science.aah3443.
- 54 Rode, P., G. Floater, and P. Floater, G; Rode, 2014: *Steering Urban Growth: Governance, Policy and Finance*. London,
55 1-49 pp.
- 56 Rodrigues, R. R., R. A. F. Lima, S. Gandolfi, and A. G. Nave, 2009: On the restoration of high diversity forests: 30
57 years of experience in the Brazilian Atlantic Forest. *Biol. Conserv.*, **142**, 1242–1251,
58 doi:10.1016/j.biocon.2008.12.008.
- 59 Rodríguez, M., and Y. Pena-Boquete, 2017: Carbon Intensity Changes in the Asian Dragons. Lessons for climate policy
60 design. *Energy Econ.*, doi:10.1016/j.eneco.2017.05.028.

- 1 Rogelj, J., M. Schaeffer, M. Meinshausen, R. Knutti, J. Alcamo, K. Riahi, and W. Hare, 2015: Zero emission targets as
2 long-term global goals for climate protection. *Environ. Res. Lett.*, **10**, 105007, doi:10.1088/1748-
3 9326/10/10/105007.
- 4 ———, and Coauthors, 2016: Perspective : Paris Agreement climate proposals need boost to keep warming well below 2
5 °C. *Nat. Clim. Chang.*, **534**, 631–639, doi:10.1038/nature18307.
- 6 ———, O. Fricko, M. Meinshausen, V. Krey, J. J. J. Zilliacus, and K. Riahi, 2017: Understanding the origin of Paris
7 Agreement emission uncertainties. *Nat. Commun.*, **8**, 15748, doi:10.1038/ncomms15748.
- 8 Romero-Lankao, P., S. Hughes, A. Rosas-Huerta, R. Borquez, and D. M. Gnatz, 2013: Institutional capacity for climate
9 change responses: An examination of construction and pathways in Mexico City and Santiago. *Environ. Plan. C*
10 *Gov. Policy*, **31**, 785–805, doi:10.1068/c12173.
- 11 Rööß, E., B. Bajželj, P. Smith, M. Patel, D. Little, and T. Garnett, 2017: Protein futures for Western Europe: potential
12 land use and climate impacts in 2050. *Reg. Environ. Chang.*, **17**, 367–377, doi:10.1007/s10113-016-1013-4.
- 13 Rosales, J., and J. Chapman, 2015: Perceptions of obvious and disruptive climate change: community-based risk
14 assessment for two native villages in Alaska. *Climate*, **3**, 812–832, doi:10.3390/cli3040812.
15 <http://www.mdpi.com/2225-1154/3/4/812/>.
- 16 Rose, S. K., R. Richels, G. Blanford, and T. Rutherford, 2017: The Paris Agreement and next steps in limiting global
17 warming. *Clim. Change*, **142**, 255–270, doi:10.1007/s10584-017-1935-y.
- 18 Rosenbloom, D., 2017: Pathways: An emerging concept for the theory and governance of low-carbon transitions. *Glob.*
19 *Environ. Chang.*, **43**, 37–50, doi:10.1016/j.gloenvcha.2016.12.011.
- 20 Rubin, E. S., J. E. Davison, and H. J. Herzog, 2015: The cost of CO₂ capture and storage. *Int. J. Greenh. Gas Control*,
21 **40**, 378–400, doi:10.1016/j.ijggc.2015.05.018. <http://dx.doi.org/10.1016/j.ijggc.2015.05.018>.
- 22 Rutherford, J., and S. Jaglin, 2015: Introduction to the special issue – Urban energy governance: Local actions,
23 capacities and politics. *Energy Policy*, **78**, 173–178, doi:10.1016/j.enpol.2014.11.033.
- 24 Ryaboshapko, A. G., and A. P. Revokatova, 2015: Technical Capabilities for Creating an Aerosol Layer In the
25 Stratosphere for Climate Stabilization Purpose. *Probl. Environ. Monit. Ecosyst. Model.*, **T 26**, 115–127.
- 26 Sain, G., A. María, C. Corner-dolloff, M. Lizarazo, A. Nowak, D. Martínez-barón, and N. Andrieu, 2017: Costs and
27 benefits of climate-smart agriculture: The case of the Dry Corridor in Guatemala. *Agric. Syst.*, **151**, 163–173,
28 doi:10.1016/j.agry.2016.05.004.
- 29 Salter, S., G. Sortino, and J. Latham, 2008: Sea-going hardware for the cloud albedo method of reversing global
30 warming. *Philos. Trans. A. Math. Phys. Eng. Sci.*, **366**, 3989–4006, doi:10.1098/rsta.2008.0136.
- 31 Salvo, A., J. Brito, P. Artaxo, and F. M. Geiger, 2017: Reduced ultrafine particle levels in São Paulo’s atmosphere
32 during shifts from gasoline to ethanol use. *Nat. Commun.*, **8**.
- 33 Sammy, G., S. Sammy, and R. Boodoo, 2016: Incorporating Climate Change Issues into Project Planning in Trinidad
34 and Tobago. *J. Assoc. Prof. Eng. Trinidad Tobago*, **44**, 33–41.
- 35 Sampire, J., 2016: Why platform disruption is so much bigger than product disruption. *Harv. Bus. Rev.*,
36 <https://hbr.org/2016/04/why-platform-disruption-is-so-much-bigger-than-product-disruption> (Accessed July 11,
37 2016).
- 38 Samuelson, W., and R. Zeckhauser, 1988: Status quo bias in decision making. *J. Risk Uncertain.*, **1**, 7–59,
39 doi:10.1007/BF00055564.
- 40 Sanchez-Ibrahim, N., J. Olivier, C. Graucob, and S. Taheri, 2017: *Tool for Assessing Adaptation in the NDCs*.
- 41 Sanderson, B. M., B. C. O’Neill, and C. Tebaldi, 2016: What would it take to achieve the Paris temperature targets?
42 *Geophys. Res. Lett.*, **43**, 7133–7142, doi:10.1002/2016GL069563.
- 43 Sandler, T., 2017: Collective action and geoengineering. *Rev. Int. Organ.*, doi:10.1007/s11558-017-9282-3.
- 44 Sanesi, G., G. Colangelo, R. Laforteza, E. Calvo, and C. Davies, 2017: Urban green infrastructure and urban forests: a
45 case study of the Metropolitan Area of Milan. *Landsc. Res.*, **42**, 164–175, doi:10.1080/01426397.2016.1173658.
- 46 Santos, G., 2008: The London experience. *Pricing in road transport: A multi-disciplinary perspective*, Edgar Elgar,
47 Cheltenham, 273–292.
- 48 Sanz-Pérez, E. S., C. R. Murdock, S. A. Didas, and C. W. Jones, 2016: Direct Capture of CO₂ from Ambient Air. *Chem.*
49 *Rev.*, **116**, 11840–11876, doi:10.1021/acs.chemrev.6b00173. <http://dx.doi.org/10.1021/acs.chemrev.6b00173>.
- 50 Satterthwaite, D., 2016: Missing the Millennium Development Goal targets for water and sanitation in urban areas.
51 *Environ. Urban.*, **28**, 99–118, doi:10.1177/0956247816628435.
- 52 ———, and S. Bartlett, 2016: Urbanization, development and the Sustainable Development Goals. *Cities on a finite*
53 *planet: Towards transformative responses to climate change*, S. Bartlett and D. Satterthwaite, Eds., Routledge,
54 Abingdon, Oxon, p. 274.
- 55 Schaeffer, M., and Coauthors, 2015a: *Feasibility of limiting warming to 1.5 and 2 C*.
- 56 ———, J. Rogelj, N. Roming, F. Sferra, B. Hare, and O. Serdeczny, 2015b: *Feasibility of limiting warming to 1.5 and 2*
57 *C*.
- 58 Schaeffer, R., and Coauthors, 2012: Energy sector vulnerability to climate change: A review. *Energy*, **38**, 1–12,
59 doi:10.1016/j.energy.2011.11.056. <http://linkinghub.elsevier.com/retrieve/pii/S0360544211007870> (Accessed
60 July 16, 2017).

- 1 Scheben, A., Y. Yuan, and D. Edwards, 2016: Advances in genomics for adapting crops to climate change. *Curr. Plant*
2 *Biol.*, **6**, 2–10, doi:10.1016/j.cpb.2016.09.001.
- 3 Schelling, T. C., 1991: Cooperative Approaches to Global Warming. *Global Warming, Economic Policy Responses*, R.
4 Dornbusch and J.M. Poterba, Eds., MIT Press, p. 389.
- 5 Schipper, L., W. Liu, D. Krawanchid, and C. S., 2010: *Review of climate change adaptation methods and tools*. MRC
6 *Technical Paper No. 34*. Vientiane,.
- 7 Schleussner, C.-F. C.-F., and Coauthors, 2016: Differential climate impacts for policy-relevant limits to global
8 warming: the case of 1.5°C and 2°C. *Earth Syst. Dyn.*, **7**, 327–351, doi:10.5194/esd-7-327-2016.
- 9 Schmale, J., D. Shindell, E. von Schneidemesser, I. Chabay, and M. Lawrence, 2014: Clean up our skies. *Nature*, **515**,
10 335–337, doi:10.1038/515335a.
- 11 Schoenefeld, J. J., M. Hildén, and A. J. Jordan, 2016: The challenges of monitoring national climate policy: learning
12 lessons from the EU. *Clim. Policy*, 1–11, doi:10.1080/14693062.2016.1248887.
- 13 Schroeder, R., and K. Schroeder, 2014: Happy Environments: Bhutan, Interdependence and the West. *Sustainability*, **6**,
14 doi:10.3390/su6063521.
- 15 Schueler, V., S. Fuss, J. C. Steckel, U. Weddige, and T. Beringer, 2016: Productivity ranges of sustainable biomass
16 potentials from non-agricultural land. *Environ. Res. Lett.*, **11**, 74026, doi:10.1088/1748-9326/11/7/074026.
- 17 Schuitema, G., L. Steg, and S. Forward, 2010: Explaining differences in acceptability before and acceptance after the
18 implementation of a congestion charge in Stockholm. *Transp. Res. Part A Policy Pract.*, **44**, 99–109,
19 doi:10.1016/j.tra.2009.11.005.
- 20 Scott, V., R. S. Haszeldine, S. F. B. Tett, and A. Oschlies, 2015: Fossil fuels in a trillion tonne world. *Nat. Clim.*
21 *Chang.*, **5**, 419–423.
- 22 Scovronick, N., C. Dora, E. Fletcher, A. Haines, and D. Shindell, 2015: Reduce short-lived climate pollutants for
23 multiple benefits. *Lancet*, **386**, e28–e31, doi:10.1016/S0140-6736(15)61043-1.
- 24 Screen, J. A., and D. Williamson, 2017: Ice-free Arctic at 1.5° C? *Nat. Clim. Chang.*, **7**, nclimate3248.
- 25 Searchinger, T., and R. Heimlich, 2015: *Avoiding Bioenergy Competition for Food Crops and Land*. Washington, DC,.
- 26 Searchinger, T., and Coauthors, 2008: Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through
27 Emissions from Land-Use Change. *Science (80-)*, **319**, 1238–1240, doi:10.1126/science.1151861.
- 28 Searchinger, T. D., and Coauthors, 2009: Fixing a Critical Climate Accounting Error. *Science (80-)*, **326**, 527–528,
29 doi:10.1126/science.1178797.
- 30 Seba, T., 2014: *Clean Disruption of Energy and Transportation: How Silicon Valley Will Make Oil, Nuclear, Natural*
31 *Gas, Coal, Electric Utilities and Conventional Cars Obsolete by 2030*. Clean Planet Ventures, California,.
- 32 Sebesvari, Z., S. Rodrigues, and F. Renaud, 2017: Mainstreaming ecosystem-based climate change adaptation into
33 integrated water resources management in the Mekong region. *Regional Environmental Change*, May 17.
- 34 Shackley, S., D. Reiner, P. Upham, H. de Coninck, G. Sigurthorsson, and J. Anderson, 2009: The acceptability of CO₂
35 capture and storage (CCS) in Europe: An assessment of the key determining factors. Part 2. The social
36 acceptability of CCS and the wider impacts and repercussions of its implementation. *Int. J. Greenh. Gas Control*,
37 **3**, 344–356, doi:10.1016/j.ijggc.2008.09.004.
- 38 Shah, N., M. Wei, V. Letschert, A. Phadke, and E. O. Lawrence, 2015: *Benefits of Leapfrogging to Superefficiency and*
39 *Low Global Warming Potential Refrigerants in Room Air Conditioning*. Berkeley,.
- 40 Shannon, H. D., and R. P. Motha, 2015: Managing weather and climate risks to agriculture in North America, Central
41 America and the Caribbean. *Weather Clim. Extrem.*, **10**, 50–56, doi:10.1016/j.wace.2015.10.006.
42 <http://linkinghub.elsevier.com/retrieve/pii/S2212094715300384> (Accessed July 20, 2017).
- 43 Shaw, C., S. Hales, P. Howden-Chapman, and R. Edwards, 2014: Health co-benefits of climate change mitigation
44 policies in the transport sector. *Nat. Clim. Chang.*, **4**, 427–433, doi:10.1038/nclimate2247.
45 <http://www.nature.com/doi/10.1038/nclimate2247>.
- 46 de Sherbinin, A., 2014: Climate change hotspots mapping: what have we learned? *Clim. Change*, **123**, 23–37,
47 doi:10.1007/s10584-013-0900-7.
- 48 Shi, B., and J. Yang, 2015: Scale, distribution, and pattern of mixed land use in central districts: A case study of
49 Nanjing, China. *Habitat Int.*, **46**, 166–177, doi:10.1016/j.habitatint.2014.11.008.
- 50 Shi, L., and Coauthors, 2016: Roadmap towards justice in urban climate adaptation research. *Nat. Clim. Chang.*, **6**,
51 131–137, doi:10.1038/nclimate2841.
- 52 Shindell, D., and Coauthors, 2012: Simultaneously Mitigating Near-Term Climate Change and Improving Human
53 Health and Food Security. *Science (80-)*, **335**.
- 54 Shindell, D., and Coauthors, 2017: A climate policy pathway for near- and long-term benefits. *Science (80-)*, **356**, 493
55 LP-494.
- 56 Shogren, J. F., and L. O. Taylor, 2008: On Behavioral-Environmental Economics. *Rev. Environ. Econ. Policy*, **2**, 26–
57 44, doi:10.1093/reep/rem027.
- 58 Shove, E., 2010: Beyond the ABC: Climate change policy and theories of social change. *Environ. Plan. A*, **42**, 1273–
59 1285, doi:10.1068/a42282.
- 60 Shukla, J., C. Nobre, and P. Sellers, 1990: Amazon Deforestation and Climate Change. *Science (80-)*, **247**.

- 1 Shukla, P. R., 2005: Aligning justice and efficiency in the global climate change regime: A developing country
2 perspective. *Adv. Econ. Environ. Resour.*, **5**, 121–144.
- 3 Sievänen, R., 2013: The non-response of pension funds to climate change and human rights. *J. Sustain. Financ. Invest.*,
4 **3**, 204–222, doi:10.1080/20430795.2013.791141. <http://dx.doi.org/10.1080/20430795.2013.791141> (Accessed
5 July 22, 2017).
- 6 Simon, H., 1979: *Models of Thought*. Yale University Press, New Haven, CT, 542 pp.
- 7 Simone, A. M. (Abdou M., and E. A. (Edgar A. . Pieterse, *New urban worlds : inhabiting dissonant times*. 248 pp.
- 8 Sims, R., and Coauthors, 2014: Transport. *Climate Change 2014: Mitigation of Climate Change. Contribution of*
9 *Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, 599–670.
- 10 Singh, C., 2017: (under review) Is Participatory Watershed Development Building Local Adaptive Capacity? Findings
11 from a case study in Rajasthan, India. *Environ. Dev.*, ..
- 12 Singh, C., P. Dorward, and H. Osbahr, 2016a: Developing a holistic approach to the analysis of farmer decision-
13 making: Implications for adaptation policy and practice in developing countries. *Land use policy*, **59**, 329–343,
14 doi:10.1016/j.landusepol.2016.06.041.
- 15 —, P. Urquhart, and E. Kituyi, 2016b: From pilots to systems: Barriers and enablers to scaling up the use of climate
16 information services in smallholder farming communities. *ransitioning from climate information services (CIS)*
17 *pilot programmes to scaled up systems is possible when scaling up is mainstreamed in the project design stage,*
18 *along with a clear financial model for sustainability, and includes multiple stakeholders w*
19 <http://hdl.handle.net/10625/55485>.
- 20 —, J. Daron, A. Bazaz, G. Ziervogel, D. Spear, J. Krishnaswamy, M. Zaroug, and E. Kituyi, 2017: The utility of
21 weather and climate information for adaptation decision-making: current uses and future prospects in Africa and
22 India. *Clim. Dev.*, 1–17.
- 23 Sivak, M., and B. Schoettle, 2016: RECENT DECREASES IN THE PROPORTION OF PERSONS WITH A
24 DRIVER'S LICENSE ACROSS ALL AGE GROUPS.
- 25 Skutsch, M., A. Balderas Torres, and J. C. Carrillo Fuentes, 2017: Policy for pro-poor distribution of REDD+ benefits
26 in Mexico: How the legal and technical challenges are being addressed. *For. Policy Econ.*, **75**, 58–66,
27 doi:10.1016/j.forpol.2016.11.014.
- 28 Slade, R., A. Bauen, and R. Gross, 2014: Global bioenergy resources. *Nat. Clim. Chang.*, **4**, 99–105.
- 29 van Sluisveld, M. A. E. M. A. E., and Coauthors, 2015: Comparing future patterns of energy system change in 2°C
30 scenarios with historically observed rates of change. *Glob. Environ. Chang.*, **35**, 436–449,
31 doi:10.1016/j.gloenvcha.2015.09.019.
- 32 Smajgl, A., T. Q. Toan, D. K. Nhan, J. Ward, N. H. Trung, L. Q. Tri, V. P. D. Tri, and P. T. Vu, 2015: Responding to
33 rising sea levels in the Mekong Delta. *Nat. Clim. Chang.*, **5**, 167.
- 34 Smeets, E., M. Junginger, A. Faaij, A. Walter, P. Dolzan, and W. Turkenburg, 2008: The sustainability of Brazilian
35 ethanol-An assessment of the possibilities of certified production. *Biomass and Bioenergy*, **32**, 781–813,
36 doi:10.1016/j.biombioe.2008.01.005.
- 37 Šmihula, D., 2009: The Waves of the Technological Innovations of the Modern Age and the Present Crisis as the End
38 of the Wave of the Informational Technological Revolution. *Stud. Polit. Slovaca*, **II**, 32–47.
- 39 Smith, C. J., and Coauthors, 2017: Impacts of stratospheric sulfate geoengineering on global solar photovoltaic and
40 concentrating solar power resource. *J. Appl. Meteorol. Climatol.*, JAMC-D-16-0298.1, doi:10.1175/JAMC-D-16-
41 0298.1. <http://journals.ametsoc.org/doi/10.1175/JAMC-D-16-0298.1> (Accessed April 8, 2017).
- 42 Smith, H., and P. Jenkins, 2015: Trans-disciplinary research and strategic urban expansion planning in a context of
43 weak institutional capacity: Case study of Huambo, Angola. *Habitat Int.*, **46**, 244–251,
44 doi:10.1016/j.habitatint.2014.10.006.
- 45 Smith, J. B., J. M. Vogel, and J. E. Cromwell III, 2009: An architecture for government action on adaptation to climate
46 change. An editorial comment. *Clim. Change*, **95**, 53–61.
- 47 Smith, P., 2016: Soil carbon sequestration and biochar as negative emission technologies. *Glob. Chang. Biol.*, **22**,
48 1315–1324, doi:10.1111/gcb.13178.
- 49 Smith, P., and Coauthors, 2014a: Agriculture, forestry and other land use (AFOLU). *Climate Change 2014: Mitigation*
50 *of Climate Change. IPCC Working Group III Contribution to AR5*, Cambridge University Press, 811–922
51 <http://pure.iiasa.ac.at/11115/#.WV-m0ELRNCE.mendeley> (Accessed July 7, 2017).
- 52 Smith, P., M. Bustamante, P. S. Uk, and M. B. Brazil, 2014b: *AR5 WGIII Chapter 11 - Agriculture, Forestry and Other*
53 *Land Use (AFOLU)*. 811-922 pp.
- 54 —, and Coauthors, 2015: Biophysical and economic limits to negative CO₂ emissions. *Nat. Clim. Chang.*, **6**, 42–50,
55 doi:10.1038/nclimate2870.
- 56 —, R. S. Haszeldine, and S. M. Smith, 2016: Preliminary assessment of the potential for, and limitations to,
57 terrestrial negative emission technologies in the UK. *Environ. Sci. Process. Impacts*, **18**, 1400–1405,
58 doi:10.1039/C6EM00386A.
- 59 Smith, T., D. Thomsen, S. Gould, K. Schmitt, and B. Schlegel, 2013: Cumulative Pressures on Sustainable Livelihoods:
60 Coastal Adaptation in the Mekong Delta. *Sustainability*, **5**, 228–241, doi:10.3390/su5010228.

- 1 Smithers, R., Holdaway, E., Rass, N., and Sanchez Ibrahim, N., 2017: *Linking National Adaptation Plan Processes and*
2 *Nationally Determined Contributions*. Bonn, 8 pp.
- 3 Socolow, R., and Coauthors, 2011: *Direct air capture of CO₂ with chemicals: A technology assessment for the APS*
4 *Panel on Public Affairs*. American Physical Society, 100 pp.
- 5 van Soest, D. P., and E. H. Bulte, 2001: Does the Energy-Efficiency Paradox Exist? Technological Progress and
6 Uncertainty. *Environ. Resour. Econ.*, **18**, 101–112, doi:10.1023/A:1011112406964.
- 7 Solecki, W., K. C. Seto, and P. J. Marcotullio, 2013: It's Time for an Urbanization Science. *Environ. Sci. Policy*
8 *Sustain. Dev.*, **55**, 12–17, doi:10.1080/00139157.2013.748387.
- 9 Sorrell, S., Dimitropoulos, J., & Sommerville, M. (2009). Empirical estimates of the direct rebound effect: A review.
10 *Energy policy*, 37(4), 1356-1371
- 11 de Souza, A. P., A. Grandis, D. C. C. Leite, and M. S. Buckeridge, 2014: Sugarcane as a Bioenergy Source: History,
12 Performance, and Perspectives for Second-Generation Bioethanol. *Bioenergy Res.*, **7**, 24–35, doi:10.1007/s12155-
13 013-9366-8.
- 14 De Souza, A. P., J.-C. Cocuron, A. C. Garcia, A. P. Alonso, and M. S. Buckeridge, 2015: Changes in Whole-Plant
15 Metabolism during the Grain-Filling Stage in Sorghum Grown under Elevated CO₂ and Drought. *Plant Physiol.*,
16 **169**, 1755–1765, doi:10.1104/pp.15.01054.
- 17 De Souza, A. P., B. C. Arenque, E. Q. P. Tavares, and M. S. Buckeridge, 2016: Transcriptomics and Genetics
18 Associated with Plant Responses to Elevated CO₂ Atmospheric Concentrations. *Plant Genomics and Climate*
19 *Change*, Springer New York, New York, NY, 67–83.
- 20 Sovacool, B. K., 2014: Energy studies need social science. *Nature*, **511**, 529–530, doi:10.1016/j.jeem.2008.02.004.
21 ———, 2016: How long will it take? Conceptualizing the temporal dynamics of energy transitions. *Energy Res. Soc. Sci.*,
22 **13**, 202–215, doi:10.1016/j.erss.2015.12.020. <http://dx.doi.org/10.1016/j.erss.2015.12.020>.
- 23 Spaans, M., and B. Waterhout, 2017: Building up resilience in cities worldwide—Rotterdam as participant in the 100
24 Resilient Cities Programme. *Cities*, **61**, 109–116.
- 25 Spencer, T., R. Pierfederici, and others, 2015: *Beyond the numbers: understanding the transformation induced by*
26 *INDCs*. Paris,.
- 27 Stavins, R. N., 1988: *Project 88 - Harnessing Market Forces to Protect Our Environment: Initiatives for the New*
28 *President. A Public Policy Study sponsored by Senator Timothy E. Wirth, Colorado, and Senator John Heinz,*
29 *Pennsylvania*. Washington, D.C.,.
- 30 Steg, L., 2016: Values, Norms, and Intrinsic Motivation to Act Proenvironmentally. *Annu. Rev. Environ. Resour.*, **41**,
31 277–292, doi:10.1146/annurev-environ-110615-085947.
- 32 Steg, L., and C. Vlek, 2009: Encouraging pro-environmental behaviour: An integrative review and research agenda. *J.*
33 *Environ. Psychol.*, **29**, doi:10.1016/j.jenvp.2008.10.004.
- 34 Steg, L., G. Perlaviciute, and E. van der Werff, 2015a: Understanding the human dimensions of a sustainable energy
35 transition. *Front. Psychol.*, **6**, 1–17, doi:10.3389/fpsyg.2015.00805.
- 36 Steg, L., G. Perlaviciute, and E. van der Werff, 2015b: Understanding the human dimensions of a sustainable energy
37 transition. *Front. Psychol.*, **6**, 1–17.
- 38 ———, R. Shwom, and T. Dietz, 2017: What drives energy consumers? *IEEE Power Energy*,.
- 39 Steinhoff, D. F., A. J. Monaghan, and M. P. Clark, 2014: Projected impact of twenty-first century ENSO changes on
40 rainfall over Central America and northwest South America from CMIP5 AOGCMs. *Clim. Dyn.*, **44**, 1329–1349,
41 doi:10.1007/s00382-014-2196-3.
- 42 Stern, P. C., 2000: Toward a Coherent Theory of Environmentally Significant Behavior. *J. Soc. Issues*, **56**, 407–424.
- 43 Stern, P. C., 2014: Individual and household interactions with energy systems: Toward integrated understanding.
44 *Energy Res. Soc. Sci.*, **1**, 41–48, doi:10.1016/j.erss.2014.03.003.
- 45 ———, and G. T. Gardner, 1981: Psychological research and energy policy. *Am. Psychol.*, **36**, 329–342,
46 doi:10.1037/0003-066X.36.4.329.
- 47 Stern, P. C., K. B. Janda, M. A. Brown, L. Steg, E. L. Vine, and L. Lutzenhiser, 2016: consumption by households and
48 organizations. *Nat. Energy*, **1**, 16043, doi:10.1038/NENERGY.2016.43.
- 49 Stevenson, H., and J. S. Dryzek, 2014: *Democratizing Global Climate Governance*. Cambridge University Press,.
- 50 Stern N, Stiglitz (2017): report of the High Level Commission on carbon pricing; Carbon Pricing Leadership Coalition,
51 <https://www.carbonpricingleadership.org/report-of-the-highlevel-commission-on-carbon-prices/>
- 52 Stevenson, M., and Coauthors, 2016: Land use, transport, and population health: estimating the health benefits of
53 compact cities. *Lancet*, **388**, 2925–2935, doi:10.1016/S0140-6736(16)30067-8.
- 54 Stiglitz, J. E., 2002: *Globalization and its Discontents*. W. W. Norton & Company, New York, 304 pp.
- 55 Stolaroff, J. K., S. Bhattacharyya, C. A. Smith, W. L. Bourcier, P. J. Cameron-smith, and R. D. Aines, 2012: Review of
56 methane mitigation technologies with application to rapid release of methane from the Arctic. *Environ. Sci.*
57 *Technol.*, **46**, 6455–6469, doi:10.1021/es204686w.
- 58 Su, S., Q. Zhang, J. Pi, C. Wan, and M. Weng, 2016: Public health in linkage to land use: Theoretical framework,
59 empirical evidence, and critical implications for reconnecting health promotion to land use policy. *Land use*
60 *policy*, **57**, 605–618, doi:10.1016/j.landusepol.2016.06.030.

- 1 Su, X., and Coauthors, 2017: Emission pathways to achieve 2.0°C and 1.5°C climate targets. *Earth's Futur.*, 1–13,
2 doi:10.1002/2016EF000492.
- 3 Suarez, P., and M. van Aalst, 2017: Geoengineering: a humanitarian concern. *Earth's Futur.*, **5**, 183–195,
4 doi:10.1002/ef2.181.
- 5 Sugiyama, M., Y. Arino, T. Kosugi, A. Kurosawa, and S. Watanabe, 2017: Next steps in geoengineering scenario
6 research: limited deployment scenarios and beyond. *Clim. Policy*, 1–9, doi:10.1080/14693062.2017.1323721.
- 7 Summers, L. H., 2016: The Age of Secular Stagnation. *Foreign Aff.*, **March/Apri**.
8 <https://www.foreignaffairs.com/articles/united-states/2016-02-15/age-secular-stagnation> (Accessed July 21,
9 2017).
- 10 Sundqvist, E., P. Crill, M. Mölder, P. Vestin, and A. Lindroth, 2012: Atmospheric methane removal by boreal plants.
11 *Geophys. Res. Lett.*, **39**, n/a-n/a, doi:10.1029/2012GL053592. <http://dx.doi.org/10.1029/2012GL053592>.
- 12 Sutherland, R. J., 1991: Market barriers to energy-efficiency investments. *Energy J.*, **12**, 15–34.
- 13 Svoboda, T., 2017: *The Ethics of Climate Engineering: Solar Radiation Management and Non-Ideal Justice*. Taylor &
14 Francis, 232 pp.
- 15 Svoboda, T., and P. Irvine, 2014: Ethical and Technical Challenges in Compensating for Harm Due to Solar Radiation
16 Management Geoengineering. *Ethics, Policy Environ.*, **17**, 157–174.
- 17 Swilling, M., and Coauthors, 2013: *City-Level Decoupling Urban resource flows and the governance of infrastucture*
18 *transitions*. 99 pp.
- 19 Tacoli, C., 2009: Crisis or adaptation? Migration and climate change in a context of high mobility. *Environ. Urban.*, **21**,
20 513–525, doi:10.1177/0956247809342182.
- 21 Takahashi, B., M. Burnham, C. Terracina-Hartman, A. R. Sopchak, and T. Selfa, 2016: Climate Change Perceptions of
22 NY State Farmers : The Role of Risk Perceptions and Adaptive Capacity. *Environ. Manage.*, **58**, 946–957,
23 doi:10.1007/s00267-016-0742-y.
- 24 Tasker, K. A., and E. Y. Arima, 2016: Fire regimes in Amazonia: The relative roles of policy and precipitation.
25 *Anthropocene*, **14**, 46–57, doi:10.1016/j.ancene.2016.06.001.
- 26 Taufik, D., J. W. Bolderdijk, and L. Steg, 2015: Acting green elicits a literal warm glow. *Nat. Clim. Chang.*, **5**, 37–40,
27 doi:10.1038/nclimate2449.
- 28 —, —, and —, 2016: Going green? The relative importance of feelings over calculation in driving
29 environmental intent in the Netherlands and the United States. *Energy Res. Soc. Sci.*, **22**, 52–62,
30 doi:10.1016/j.erss.2016.08.012.
- 31 Taylor, A. L., S. Dessai, and W. Bruin de Bruin, 2014: Public perception of climate risk and adaptation in the UK: A
32 review of the literature. *Clim. Risk Manag.*, doi:10.1016/j.crm.2014.09.001.
- 33 Taylor, L. L., and Coauthors, 2016: Enhanced weathering strategies for stabilizing climate and averting ocean
34 acidification. *Nat. Clim. Chang.*, **6**, 402–406.
- 35 Teferi, Z., (submitted) Improvement of Slums in Addis Ababa: Moving Towards Community-Sensitive Distributed
36 Infrastructure? *Environ. Urban.*,.
- 37 Termeer, C. J. A. M. A. M., A. Dewulf, and G. R. Biesbroek, 2017: Transformational change: governance interventions
38 for climate change adaptation from a continuous change perspective. *J. Environ. Plan. Manag.*, **60**, 558–576,
39 doi:http://dx.doi.org/10.1080/09640568.2016.1168288.
- 40 Thaler, R., 1980: Toward a positive theory of consumer choice. *J. Econ. Behav. Organ.*, **1**, 39–60, doi:10.1016/0167-
41 2681(80)90051-7.
- 42 The Royal Society, 2009: *Geoengineering the climate: science, governance and uncertainty: RS Policy document*
43 *10/09*. London, 98 pp.
- 44 Thi Hong Phuong, L., G. R. Biesbroek, and A. E. J. Wals, 2017: The interplay between social learning and adaptive
45 capacity in climate change adaptation: A systematic review. *NJAS - Wageningen J. Life Sci.*, **82**, 1–9,
46 doi:10.1016/j.njas.2017.05.001.
- 47 Thieme, T. A., 2017: The hustle economy. *Prog. Hum. Geogr.*, 30913251769003, doi:10.1177/0309132517690039.
- 48 Thierfelder, C., P. Chivenge, W. Mupangwa, T. S. Rosenstock, C. Lamanna, and J. X. Eyre, 2017: How climate-smart
49 is conservation agriculture (CA)? – its potential to deliver on adaptation, mitigation and productivity on
50 smallholder farms in southern Africa. *Food Secur.*, **9**, 537–560, doi:10.1007/s12571-017-0665-3.
- 51 Tietenberg, T., 2009: Reflections - Energy efficiency policy: Pipe dream or pipeline to the future? *Review of*
52 *Environmental Economics and Policy*, Vol. 3 of, 304–320.
- 53 Tilmes, S., B. M. Sanderson, and B. C. O'Neill, 2016: Climate impacts of geoengineering in a delayed mitigation
54 scenario. *Geophys. Res. Lett.*, **43**, 8222–8229, doi:10.1002/2016GL070122.
- 55 Tobler, C., V. H. M. Visschers, and M. Siegrist, 2011: Organic Tomatoes Versus Canned Beans: How Do Consumers
56 Assess the Environmental Friendliness of Vegetables? *Proc. 3rd Conf. UK Netw. Environ. Psychol. UK -*
57 *Crossing boundaries value Interdiscip. Res.*, **43**, 591–611, doi:10.1177/0013916510372865.
- 58 Tobler, C., V. H. M. Visschers, and M. Siegrist, 2012: Consumers' knowledge about climate change. *Clim. Change*,
59 **114**, 189–209, doi:10.1007/s10584-011-0393-1.
- 60 Torvanger, A., and J. Meadowcroft, 2011: The political economy of technology support: Making decisions about

- 1 carbon capture and storage and low carbon energy technologies. *Glob. Environ. Chang.*, **21**, 303–312,
2 doi:<https://doi.org/10.1016/j.gloenvcha.2011.01.017>.
- 3 Tran, K., 2014: Community based adaptation strategy for the urban poor under a changing climate.
- 4 Trenberth, K. E., M. Marquis, and S. Zebiak, 2016: The vital need for a climate information system. *Nat. Clim. Chang.*,
5 **6**, 1057–1059, doi:10.1038/nclimate3170.
- 6 Turnhout, E., A. Gupta, J. Weatherley-Singh, M. J. Vijge, J. de Koning, I. J. Visseren-Hamakers, M. Herold, and M.
7 Lederer, 2017: Envisioning REDD+ in a post-Paris era: between evolving expectations and current practice.
8 *Wiley Interdiscip. Rev. Clim. Chang.*, **8**, e425, doi:10.1002/wcc.425.
- 9 UN-HABITAT, 2011: *Cities and Climate Change: Global Report on Human Settlements 2011*. Earthscan, London, UK
10 and Washington, DC, USA, 279 pp.
- 11 Ünal, A. B., L. Steg, and M. Gorsira, (in press) Values versus environmental knowledge as triggers of a process of
12 activation of personal norms for eco-driving. *Environ. Behav.*,.
- 13 UNEP, 2005: *Enhancing Capacity Building for Integrated Policy Design and Implementation for Sustainable*
14 *Development*. Geneva, [https://www.unpei.org/sites/default/files/PDF/institutioncapacity/Enhancing-Capacity-](https://www.unpei.org/sites/default/files/PDF/institutioncapacity/Enhancing-Capacity-Building-policy-Design.pdf)
15 [Building-policy-Design.pdf](https://www.unpei.org/sites/default/files/PDF/institutioncapacity/Enhancing-Capacity-Building-policy-Design.pdf).
- 16 —, 2016: *The Emissions Gap Report 2016*. Nairobi, Kenya, 1-85 pp.
- 17 UNFCCC, 2015: Adoption of the Paris Agreement. *Paris Clim. Chang. Conf. - Novemb. 2015, COP 21*,.
18 <http://unfccc.int/resource/docs/2015/cop21/eng/109r01.pdf> (Accessed March 10, 2016).
- 19 —, 2016: *Aggregate effect of the intended nationally determined contributions: an update*. Marrakech, 75 pp.
20 <http://unfccc.int/resource/docs/2016/cop22/eng/02.pdf>.
- 21 UNISDR, 2009: *Global Assessment Report on Disaster Risk Reduction 2009 – Risk and Poverty in a Changing*
22 *Climate: Invest Today for a Safer Tomorrow*. United Nations International Strategy for Disaster Reduction
23 (UNISDR), Geneva, Switzerland,.
- 24 —, 2011: *Global Assessment Report on Disaster Risk Reduction 2011 – Revealing Risk, Redefining Development*.
25 United Nations International Strategy for Disaster Reduction (UNISDR), Geneva, Switzerland,.
- 26 —, 2015: *Global Assessment Report on Disaster Risk Reduction 2015 – Making Development Sustainable: The*
27 *Future of Disaster Risk Management*. United Nations International Strategy for Disaster Reduction (UNISDR),
28 Geneva, Switzerland,.
- 29 United Nations, 2015: World Population Prospects - 2015 Revision. *World Popul. Prospect. Div. Nations*,.
30 —, 2016a: *Transforming our World: the 2030 Agenda for Sustainable Development*. New York,
31 [https://sustainabledevelopment.un.org/content/documents/21252030 Agenda for Sustainable Development](https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf)
32 [web.pdf](https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf).
- 33 —, 2016b: *The Sustainable Development Goals Report*. New York, USA,.
- 34 Upham, P., and T. Roberts, 2011: Public perceptions of CCS: Emergent themes in pan-European focus groups and
35 implications for communications. *Int. J. Greenh. Gas Control*, **5**, 1359–1367, doi:10.1016/j.ijggc.2011.06.005.
- 36 Ura, K., 2015: *The Experience of Gross National Happiness as Development Framework*.
- 37 —, S. Alkire, T. Zangmo, and K. Wangdi, 2015: *Provisional Findings of 2015 Gross National Happiness Survey*.
38 Thimphu, Bhutan,.
- 39 Ürge-Vorsatz, D., S. T. Herrero, N. K. Dubash, and F. Lecocq, 2014: Measuring the Co-Benefits of Climate Change
40 Mitigation. *Annu. Rev. Environ. Resour.*, **39**, 549–582, doi:10.1146/annurev-environ-031312-125456.
41 <http://www.annualreviews.org/doi/10.1146/annurev-environ-031312-125456>.
- 42 US National Academy of Sciences, 2015: Governance of research and other sociopolitical considerations. *Climate*
43 *Intervention: Reflectign Sunlight to Cool Earth*, National Research Council.
- 44 Valdivia, C., A. Seth, J. L. Gilles, M. García, E. Jiménez, J. Cusicanqui, F. Navia, and E. Yucra, 2010: Adapting to
45 Climate Change in Andean Ecosystems: Landscapes, Capitals, and Perceptions Shaping Rural Livelihood
46 Strategies and Linking Knowledge Systems. *Ann. Assoc. Am. Geogr.*, **100**, 818–834,
47 doi:10.1080/00045608.2010.500198.
- 48 Vandyck, T., K. Keramidas, B. Saveyn, A. Kitous, and Z. Vrontisi, 2016: A global stocktake of the Paris pledges:
49 Implications for energy systems and economy. *Glob. Environ. Chang.*, **41**, 46–63,
50 doi:10.1016/j.gloenvcha.2016.08.006.
- 51 Varela-Ortega, C., I. Blanco-Gutiérrez, P. Esteve, S. Bharwani, S. Fronzek, and T. E. Downing, 2016: How can
52 irrigated agriculture adapt to climate change? Insights from the Guadiana Basin in Spain. *Reg. Environ. Chang.*,
53 **16**, 59.
- 54 Vargas, R., P. Escobar, M. Cabrera, J. Cabrera, V. Hernández, V. Guzmán, and M. Cicowicz, 2017: *Climate risk and*
55 *food security in Guatemala*. PEP-MPIA, <https://ideas.repec.org/p/ivl/mpiacr/2017-01.html> (Accessed July 20,
56 2017).
- 57 Vásquez, W. F., and R. Espallat, 2014: Willingness to pay for reliable supplies of safe drinking water in Guatemala: A
58 referendum contingent valuation study. *Urban Water J.*, **9**, 1–9, doi:10.1080/1573062X.2014.991741.
- 59 —, and A. M. Aksan, 2015: Water, sanitation, and diarrhea incidence among children: Evidence from Guatemala.
60 *Water Policy*, **17**, 932–945, doi:10.2166/wp.2015.211.

- 1 Velasquez, B., and L. Stella, 1998: Agenda 21: a form of joint environmental management in Manizales, Colombia.
2 *Environ. Urban.*, **10**, 9–36.
- 3 Velders, G. J. M., D. W. Fahey, J. S. Daniel, S. O. Andersen, and M. McFarland, 2015: Future atmospheric abundances
4 and climate forcings from scenarios of global and regional hydrofluorocarbon (HFC) emissions. *Atmos. Environ.*,
5 **123**, 200–209, doi:10.1016/j.atmosenv.2015.10.071.
- 6 Venhoeven, L. A., J. W. Bolderdijk, and L. Steg, 2013: Explaining the paradox: How pro-environmental behaviour can
7 both thwart and foster well-being. *Sustain.*, **5**, 1372–1386, doi:10.3390/su5041372.
- 8 Venhoeven, L. A. L. A., J. W. J. W. Bolderdijk, and L. Steg, 2016: Why acting environmentally-friendly feels good:
9 Exploring the role of self-image. *Front. Psychol.*, **7**, 1990–1991, doi:10.3389/fpsyg.2016.01846.
- 10 Venkataraman, C., S. Ghosh, and M. Kandlikar, 2016: Breaking out of the Box: India and Climate Action on Short-
11 Lived Climate Pollutants. *Environ. Sci. Technol.*, **50**, 12527–12529, doi:10.1021/acs.est.6b05246.
- 12 Venter, Z., and Coauthors, 2017: Implications of historical interactions between herbivory and fire for rangeland
13 management in African savannas adaptively manipulating herbivore densities over time and space and
14 diversifying herbivore functional guilds. *submitted.*
- 15 Vergara, W., A. R. Rios, L. M. Galindo, and J. Samaniego, 2015: Physical Damages Associated with Climate Change
16 Impacts and the Need for Adaptation Actions in Latin America and the Caribbean. *Handbook of Climate Change
17 Adaptation*, Springer Berlin Heidelberg, Berlin, Heidelberg, 479–491.
- 18 Visoni, D., G. Pitari, and V. Aquila, 2016: Sulfate geoengineering: a review of the factors controlling the needed
19 injection of sulfur dioxide. *Atmos. Chem. Phys. Discuss*, 3879–3889, doi:doi:10.5194/acp-2016-985, 2016.
- 20 Vlek, C. A. J., and L. Steg, 2007: Human behavior and environmental sustainability: Problems, driving forces, and
21 research topics. *Journal of Social Issues*, March.
- 22 van Vliet, M. T. H., D. Wiberg, S. Leduc, and K. Riahi, 2016: Power-generation system vulnerability and adaptation to
23 changes in climate and water resources. *Nat. Clim. Chang.*, **6**, 375–380, doi:10.1038/nclimate2903.
- 24 Vringer, K., and K. Blok, 1995: The direct and indirect energy requirements of households in the Netherlands. *Energy
25 Policy*, **23**, 893–910, doi:10.1016/0301-4215(95)00072-Q.
26 <http://www.sciencedirect.com/science/article/pii/030142159500072Q> (Accessed July 30, 2013).
- 27 van Vuuren, D. P., O. Y. Edelenbosch, D. L. McCollum, and K. Riahi, 2017: A special issue on model-based long-term
28 transport scenarios: Model comparison and new methodological developments to improve energy and climate
29 policy analysis. *Transp. Res. Part D Transp. Environ.*, doi:10.1016/j.trd.2017.05.003.
- 30 Wakiyama, T., and T. Kuramochi, 2017: Scenario analysis of energy saving and CO₂ emissions reduction potentials to
31 ratchet up Japanese mitigation target in 2030 in the residential sector. *Energy Policy*, **103**, 1–15,
32 doi:10.1016/j.enpol.2016.12.059.
- 33 Wallquist, L., S. L. O. Seigo, V. H. M. Visschers, and M. Siegrist, 2012: Public acceptance of CCS system elements: A
34 conjoint measurement. *Int. J. Greenh. Gas Control*, **6**, 77–83, doi:10.1016/j.ijggc.2011.11.008.
- 35 Wamsler, C., 2009: *Urban risk reduction and adaptation: How to promote resilient communities and adapt to
36 increasing disasters and changing climatic conditions?* VDM Verlag Dr. Muller, Saarbrücken, 187 pp.
- 37 Wamsler, C., 2015: Mainstreaming ecosystem-based adaptation: transformation toward sustainability in urban
38 governance and planning. *Ecol. Soc.*, **20**.
- 39 ———, 2017: Stakeholder involvement in strategic adaptation planning: Transdisciplinarity and co-production at stake?
40 *Environ. Sci. Policy*, **75**, 148–157, doi:10.1016/j.envsci.2017.03.016.
41 <http://linkinghub.elsevier.com/retrieve/pii/S1462901117301296>.
- 42 ———, E. Brink, and O. Rantala, 2012: Climate Change, Adaptation, and Formal Education: the Role of Schooling for
43 Increasing Societies' Adaptive Capacities in El Salvador and Brazil. *Ecol. Soc.*, **17**, doi:10.5751/ES-04645-
44 170202.
- 45 ———, C. Luederitz, and E. Brink, 2014: Local levers for change: Mainstreaming ecosystem-based adaptation into
46 municipal planning to foster sustainability transitions. *Glob. Environ. Chang.*, **29**, 189–201,
47 doi:https://doi.org/10.1016/j.gloenvcha.2014.09.008.
- 48 Wang, Q., F. Xiao, F. Zhang, and S. Wang, 2013: Labile soil organic carbon and microbial activity in three subtropical
49 plantations. *Forestry*, **86**, 569–574, doi:10.1093/forestry/cpt024.
- 50 Wang, Q., P. Liu, X. Yuan, X. Cheng, R. Ma, R. Mu, and J. Zuo, 2015: Structural Evolution of Household Energy
51 Consumption: A China Study. *Sustainability*, **7**, 3919–3932, doi:10.3390/su7043919.
- 52 Weaver, C. P., and Coauthors, 2014: From global change science to action with social sciences. *Nat. Clim. Chang.*, **4**,
53 656–659.
- 54 Webber, M., and J. Barnett, 2010: *Accommodating Migration To Promote Adaptation To Climate Change*. The World
55 Bank.
- 56 Wee, B. van, 2015: Peak car: The first signs of a shift towards ICT-based activities replacing travel? A discussion
57 paper. *Transp. Policy*, **42**, 1–3, doi:10.1016/j.tranpol.2015.04.002.
58 <http://linkinghub.elsevier.com/retrieve/pii/S0967070X15300020> (Accessed July 24, 2017).
- 59 Wehkamp, J., A. Aquino, S. Fuss, and E. W. Reed, 2015: Analyzing the perception of deforestation drivers by African
60 policy makers in light of possible REDD+ policy responses. *For. Policy Econ.*, **59**, 7–18,

- 1 doi:10.1016/j.forpol.2015.05.005.
- 2 Weitzman, M. L., 2015: A Voting Architecture for the Governance of Free-Driver Externalities, with Application to
3 Geoengineering. *Scand. J. Econ.*, **117**, 1049–1068, doi:10.1111/sjoe.12120.
- 4 von Weizsäcker, E. U., and Coauthors, 2014: *Decoupling 2: technologies, opportunities and policy options*. United
5 Nations Environment Programme, <http://wedocs.unep.org/handle/20.500.11822/8892>.
- 6 Wejs, A., K. Harvold, S. V. Larsen, and I.-L. Saglie, 2014: Legitimacy building in weak institutional settings: *climate
7 change adaptation at local level in Denmark and Norway*. *Env. Polit.*, **23**, 490–508,
8 doi:10.1080/09644016.2013.854967.
- 9 Well, M., and A. Carrapatoso, 2016: REDD+ finance: policy making in the context of fragmented institutions. *Clim.
10 Policy*, **3062**, 1–21, doi:10.1080/14693062.2016.1202096.
- 11 Wenzel, G. W., 2009: Canadian Inuit subsistence and ecological instability - If the climate changes, must the Inuit?
12 *Polar Res.*, **28**, 89–99, doi:10.1111/j.1751-8369.2009.00098.x.
- 13 van der Werff, E., L. Steg, E. Van Der Werff, and L. Steg, 2016: The psychology of participation and interest in smart
14 energy systems: Comparing the value-belief-norm theory and the value-identity-personal norm model. *Energy
15 Res. Soc. Sci.*, **22**, 107–114, doi:10.1016/j.erss.2016.08.022.
- 16 Van Der Werff, E., and L. Steg, 2015: One model to predict them all: Predicting energy behaviours with the norm
17 activation model. *Energy Res. Soc. Sci.*, **6**, 8–14, doi:10.1016/j.erss.2014.11.002.
- 18 White, C. J., and Coauthors, 2017: Potential applications of subseasonal-to-seasonal (S2S) predictions. *Meteorol. Appl.*,
19 doi:10.1002/met.1654.
- 20 Whitmarsh, L., G. Seyfang, and S. O. Workspace., 2011: Public engagement with carbon and climate change: To what
21 extent is the public “carbon capable”? *Glob. Environ. Chang.*, **21**, 56–65, doi:10.1016/j.gloenvcha.2010.07.011.
- 22 Whyte, K. P., 2012: Now This! Indigenous Sovereignty, Political Obliviousness and Governance Models for SRM
23 Research. *Ethics, Policy Environ.*, **15**, 172–187, doi:10.1080/21550085.2012.685570.
- 24 Williamson, P., 2016: Emissions reduction: Scrutinize CO₂ removal methods. *Nature*, **530**, 5–7, doi:10.1038/530153a.
- 25 Wilson, C., and H. Dowlatabadi, 2007: Models of Decision Making and Residential Energy Use. *Annu. Rev. Environ.
26 Resour.*, **32**, 169–203, doi:10.1146/annurev.energy.32.053006.141137.
- 27 —, A. Grubler, N. Bauer, V. Krey, and K. Riahi, 2013: Future capacity growth of energy technologies: Are scenarios
28 consistent with historical evidence? *Clim. Change*, **118**, 381–395, doi:10.1007/s10584-012-0618-y.
- 29 Winkler, H., and Coauthors, 2011: *Equitable access to sustainable development*. Beijing, Brasilia, Cape Town and
30 Mumbai.,
- 31 Wise, M., M. Muratori, and P. Kyle, 2017: Biojet fuels and emissions mitigation in aviation: An integrated assessment
32 modeling analysis. *Transp. Res. Part D Transp. Environ.*, **52**, 244–253, doi:10.1016/j.trd.2017.03.006.
33 <http://linkinghub.elsevier.com/retrieve/pii/S1361920916308999> (Accessed July 22, 2017).
- 34 Wolak, F. A., 2011: Do residential customers respond to hourly prices? Evidence from a dynamic pricing experiment.
35 *American Economic Review*, Vol. 101 of, 83–87.
- 36 Wong, P.-H., 2014: Maintenance Required: The Ethics of Geoengineering and Post-Implementation Scenarios. *Ethics,
37 Policy Environ.*, **17**, 186–191, doi:10.1080/21550085.2014.926090.
- 38 Wood, B. T., A. J. Dougill, C. H. Quinn, and L. C. Stringer, 2016: Exploring Power and Procedural Justice Within
39 Climate Compatible Development Project Design: Whose Priorities Are Being Considered? *J. Environ. Dev.*, **25**,
40 363–395, doi:10.1177/1070496516664179.
- 41 —, C. H. Quinn, L. C. Stringer, and A. J. Dougill, 2017: Investigating Climate Compatible Development Outcomes
42 and their Implications for Distributive Justice: Evidence from Malawi. *Environ. Manage.*, **1**, 1–18,
43 doi:10.1007/s00267-017-0890-8.
- 44 Wood, S. A., A. S. Jina, M. Jain, P. Kristjanson, and R. S. DeFries, 2014: Smallholder farmer cropping decisions
45 related to climate variability across multiple regions. *Glob. Environ. Chang.*, **25**, 163–172,
46 doi:10.1016/j.gloenvcha.2013.12.011.
- 47 Woolf, D., J. Amonette, A. Street-Perrott, J. Lehmann, and S. Joseph, 2010: Sustainable bio-char to mitigate global
48 climate change. *Nat. Commun.*, **1**, doi:doi:10.1038/ncomms1053.
- 49 Wu, D., Y. Zhao, Y. Pei, and J. Zhai, 2011: Variation trends of temperature and precipitation in Lancang-Mekong River
50 basin during 1980–2009. *J. China Inst. Water Resour. Hydropower Res.*, **9**, 304–312.
- 51 Xue, X., M. E. Schoen, X. (Cissy) Ma, T. R. Hawkins, N. J. Ashbolt, J. Cashdollar, and J. Garland, 2015: Critical
52 insights for a sustainability framework to address integrated community water services: Technical metrics and
53 approaches. *Water Res.*, **77**, 155–169, doi:10.1016/j.watres.2015.03.017.
- 54 Yang, W., T. Li, and X. Cao, 2015: Examining the impacts of socio-economic factors, urban form and transportation
55 development on CO₂ emissions from transportation in China: A panel data analysis of China’s provinces.
56 *Habitat Int.*, **49**, 212–220, doi:10.1016/j.habitatint.2015.05.030.
- 57 Yang, Y. C. E., S. Wi, P. A. Ray, C. M. Brown, and A. F. Khalil, 2016: The future nexus of the Brahmaputra River
58 Basin: Climate, water, energy and food trajectories. *Glob. Environ. Chang.*, **37**, 16–30,
59 doi:10.1016/j.gloenvcha.2016.01.002.
- 60 Yangka, D., and M. Diesendorf, 2016: Modeling the benefits of electric cooking in Bhutan: A long term perspective.

- 1 *Renew. Sustain. Energy Rev.*, **59**, 494–503, doi:10.1016/j.rser.2015.12.265.
- 2 Yax, P., 2016: Bioindicadores y conocimiento ancestral/tradicional para el pronóstico meteorológico en comunidades
3 indígenas Maya - K'iche' de Nahualá, Sololá. *II Congreso Nacional de Cambio Climático Xela*, Poster
4 Presentation.
- 5 Young, O. R., 2016a: *Governing Complex Systems: Social Capital for the Anthropocene*. MIT Press,.
6 —, 2016b: *Governing Complex Systems: Social Capital for the Anthropocene*. MIT Press, 296 pp.
- 7 Yu, W. J., Y. L. Huang, and M. Y. Shao, 2015: Research on characteristics of extreme weather disasters and
8 fluctuations trend on Lancang river basin. *Acta Ecol. Sin.*, **35**, 1378–1386.
- 9 Zanzanaini, C., B. T. Trần, C. Singh, A. Hart, J. Milder, and F. DeClerck, 2017: Integrated landscape initiatives for
10 agriculture, livelihoods and ecosystem conservation: An assessment of experiences from South and Southeast
11 Asia. *Landsc. Urban Plan.*, **165**, 11–21, doi:10.1016/j.landurbplan.2017.03.010.
- 12 Zelli, F., 2011: The fragmentation of the global climate governance architecture. *Wiley Interdiscip. Rev. Clim. Chang.*,
13 **2**, 255–270.
- 14 Zhang, F., J. Tong, B. Su, J. Huang, and X. Zhu, 2016a: Simulation and projection of climate change in the south Asian
15 River basin by CMIP5 multi-model ensembles. *J. Trop. Meteorol.*, **32**, 734–742.
- 16 Zhang, H., W. Chen, and W. Huang, 2016b: TIMES modelling of transport sector in China and USA: Comparisons
17 from a decarbonization perspective. *Appl. Energy*, **162**, 1505–1514, doi:10.1016/j.apenergy.2015.08.124.
- 18 Zhang, Z., 2010: China in the transition to a low-carbon economy. *Energy Policy*, **38**, 6638–6653,
19 doi:10.1016/j.enpol.2010.06.034.
- 20 Zhuang, W., 2017: *Intellectual Property Rights and Climate Change: Interpreting the TRIPS Agreement for*
21 *Environmentally Sound Technologies*. Cambridge University Press, Cambridge,.
- 22 Ziervogel, G., A. Cowen, and J. Ziniades, 2016: Moving from Adaptive to Transformative Capacity: Building
23 Foundations for Inclusive, Thriving, and Regenerative Urban Settlements. *Sustainability*, **8**, 955.
- 24 Zusman, E., A. Miyatsuka, J. Romero, and M. Arif, 2015: *Aligning Interests around Mitigating Short Lived Climate*
25 *Pollutants (SLCP) in Asia: A Stepwise Approach*. 14 pp.
26 https://pub.iges.or.jp/system/files/publication_documents/pub/discussionpaper/5052/SLCP_Discussion_paper.pdf
27 (Accessed July 21, 2017).
28
29