,

Horizon 2020 Societal challenge 5: Climate action, environment, resource efficiency and raw materials

COP21 RIPPLES

COP21: Results and Implications for Pathways and Policies for Low Emissions European Societies

GA number: 730427, Funding type: RIA

Deliverable number (relative in WP)	**D4.1**
Deliverable name:	Key concepts, core challenges and governance functions of international climate governance
WP / WP number:	WP4: Assessment of the adequacy of COP21 outcomes for effective international climate governance and the EU's role
Delivery due date:	Project month 10 (30/09/2017)
Actual date of submission:	29/09/2017
Dissemination level:	public
Lead beneficiary:	IES-VUB
Responsible scientist/administrator:	Sebastian Oberthür
Estimated effort (PM):	3
Contributor(s):	Lukas Hermwille (WI), Gauri Khandekar (IES-VUB), Wolfgang Obergassel (WI), Tim Rayner (UEA), Tomas Wyns (IES-VUB), Florian Mersmann (WI), Damon Jones (CA), Bianca Kretschmer (CA), Mahlet Melkie (CA)
Estimated effort contributor(s) (PM):	16.5
Internal reviewer:	Tim Rayner (UEA)

1. Changes with respect to the DoA

No changes were made.

2. Dissemination and uptake

This deliverable will provide the basis for the further work under Work Package 4 of the project. In particular, Task 4.2 will use the framework developed to identify gaps and opportunities with respect to international climate governance in a sectoral perspective. The deliverable also provides useful background for the work under Work Packages 2 and 3 of the project.

Outside the project, the deliverable could be used and consulted by the broad community of experts and policymakers interested in the international governance of climate change. It provides a basis for identifying the challenges, barriers and opportunities that international climate governance faces and presents by taking a sectoral perspective and thereby enabling a more targeted approach to addressing the climate change challenge internationally.

3. Short Summary of results (<250 words)

Taking a sectoral perspective, this report (1) identifies the key governance challenges that exist internationally towards the deep transformations required for low-carbon societies and (2) specifies the resulting key governance functions to be fulfilled by means of international cooperation (international institutions). To this end, the report first clarifies a number of key concepts, including international (climate) governance, international and transnational institutions, institutional complexes and polycentricity, and presents our sectoral perspective. It then derives a number of functions that international institutions can fulfil from the relevant theoretical and conceptual literature. This provides the basis for an investigation into the key governance challenges and the potential of international governance in 14 key sectoral systems.

Our sectoral approach enables a sectorally differentiated and detailed analysis of the varying demand for international institutions' performance of governance functions. The demand for the performance of most governance functions varies significantly in accordance with the specific conditions and circumstances prevailing in each system. In contrast to an overall aggregate perspective on international climate governance that treats it as one integrated problem, our analysis advances towards taking into account the multifaceted nature of this challenge in various relevant sectors and contexts. It also leads us to realise that various sectoral systems need to be further disaggregated to get a grip on the underlying problem structures and related demands for international governance; different sectoral systems and different parts of sectoral systems require appropriately adapted responses and create varying demands for international governance.

4. Evidence of accomplishment

The results of the work are evident from the report enclosed.

Table of Contents

Abbreviations

AC	Alternating Current
APEC	Asia Pacific Economic Cooperation
ATAG	Air Transport Action Group
BECCS	Bio-energy carbon capture and storage
CFCs	Chlorofluorocarbons
CO_2	Carbon dioxide
CH_4	Methane
CAP	Common Agricultural Policy
CAPEX	Capital Expenditure
CCS	Carbon Capture and Storage
COP	Conference of the Parties
DC	Direct Current
EU	European Union
F-gases	Fluorinated GHGs
FAO	Food and Agriculture Organization
FFS	Fossil Fuel Subsidies
FSB	Financial Stability Board
G7	Group of Seven
G20	Group of Twenty
GDP	Gross Domestic Product
GHG	Greenhouse Gas
$GtCO_2eq$	Gigatonnes of CO_2 equivalent
HCFCs	Hydrochlorofluorocarbons
HFCs	Hydrofluorocarbons
HFOs	Hydrofluoroolefins
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
ICLEI	Local Governments for Sustainability
ICT	Information and Communication Technology
IEA	International Energy Agency
IMF	International Monetary Fund
IMO	International Maritime Organization

IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
ISWA	International Solid Waste Association
LED	Light Emitting Diode
LNG	Liquefied Natural Gas
LULUCF	Land use, land-use change and forestry
MDBs	Multilateral Development Banks
MENA	Middle East and North Africa
MEPS	Minimum Energy Performance Standards
MRV	Measuring, reporting and verification
MSW	Municipal solid waste
N_2O	Nitrous oxide
NF_3	Nitrogen Trifluoride
NZEBs	Net-Zero Energy Buildings
OECD	Organization for Economic Cooperation and Development
OPEC	Organization of Petroleum Exporting Countries
PFCs	Perfluorocarbons
PV	Photovoltaics
R&D	Research and Development
SF_6	Sulphur Hexafluoride
SO_2	Sulphur dioxide
SWM	Solid waste management
TVs	Televisions
TWh	Terawatt Hours
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WtE	Waste to Energy
WTO	World Trade Organization

Figures and Tables

1. Introduction

Climate change constitutes a long-term, transformational challenge. Phasing out greenhouse gas (GHG) emissions and adapting to the evolving impacts of climate change require a fundamental transformation of our economies and societies at a global scale. This global transformation entails a simultaneous conversion and deep change of various sectoral systems,[1] including energy, industry, transport, housing, and agriculture, that are key to the functioning of our economies and societies. Due to the inertia of the socio-technical sectoral systems involved, the necessary transformation implies a long-term transition[2] over a period of several decades. The individual steps taken in this process hence need to be aligned with the long-term target and vision. The Paris Agreement establishes such a long-term vision of achieving climate resilience, holding global temperature increase to below 2/1.5° C above preindustrial levels and phasing out GHG emission (Arts. 2 and 4) (e.g. Scoones et al. 2015; Incropera 2015; Bulkeley & Newell 2015; Levin et al. 2012).

This report investigates the core challenges and functions of the international governance of climate mitigation to this end. While acknowledging the crucial importance of the challenge of adaptation to build climate resilience, we focus – in line with the overall project – on the challenge of phasing out GHG emissions in the second half of this century (hereafter also referred to as "decarbonisation"). In doing so, we zoom in on international climate governance. While much, if not most, action to mitigate climate change is and needs to be taken at national and local levels, such action may require, or at least benefit from, international cooperation – be it to address barriers to action rooted in international *interdependence* or to enable, facilitate and promote action at other levels (e.g. Luterbacher & Sprinz, 2001; Stavins et al., 2014).

We go beyond existing analyses by disentangling the overall issue into several constituent parts. Traditional textbook analyses of international climate governance that present climate change as a collective-action problem prone to free-riding at the level of states (Barrett, 2011; Keohane & Victor, 2016; Luterbacher & Sprinz, 2001) do not commonly reflect that conditions in different sectors and societal sub-systems differ considerably. As will be further substantiated below, energy-intensive industries differ starkly from international finance and investment or the buildings sector when it comes to barriers to decarbonisation and related opportunities. Such differences should be taken into account when thinking about the need for and potential of international cooperation. And such a more differentiated analysis promises considerable insights into how the "complex" of international institutions relevant for the fight against climate change could and should be further developed.

In undertaking our analysis, we wish to acknowledge upfront that the (international and national) governance of transformative and long-term transitions is not a straight-forward endeavour. In line with the literature on transition management (e.g. Grin et al. 2010), the governance of long-term transitions requires regular review, adjustment and adaptation in line with evolving conditions. Thus, rather than simply "steering" the transformation process, the governance of the transition is about experimenting, searching and learning (Rotmans, Kemp, & Van Asselt, 2001).

Against this backdrop, this report – taking a sectoral perspective – has a twofold focus and purpose. First, we aim to identify the key governance challenges that exist internationally towards the deep transformations required for low-carbon societies in different sectoral systems. Second, we wish to distill and specify resulting key governance functions to be fulfilled in and for these sectoral systems by means of international cooperation (international institutions).

---

[1] In the following, we use the terms "sector" and "sectoral system" interchangeably; see also discussion in section 2.4.

[2] In the following, the term "transition" is used in this transformative sense.

To this end, this report proceeds along the following main steps. In section 2, we first introduce and clarify a number of key concepts, including international (climate) governance, international and transnational institutions, institutional complexes and polycentricity, and present our sectoral perspective. In the subsequent section 3, we derive a number of functions that international institutions can fulfil from the relevant theoretical and conceptual literature. Section 4 then introduces the sectoral systems we distinguish and include in our analysis, before investigating the key governance challenges and the potential of international governance for each of them. Finally, section 5 synthesises the results, including a comparison of the key functions and potentials of international governance of the different sectoral systems.

The application of our framing of the governance functions of international institutions in the sectoral analysis enables a more targeted, differentiated and detailed analysis of the varying demand for the performance of certain governance functions by international institutions in specific sectoral systems. Whereas demand for guidance and signal seems to be generally high across sectoral systems, the score of other functions varies significantly in accordance with the specific conditions and circumstances prevailing in each system. Our analysis therefore advances from an overall aggregate perspective on international climate governance that treats it as one integrated problem, towards taking into account the multifaceted nature of this challenge in various relevant sectors and contexts. It also leads us to realise that various sectoral systems need to be further disaggregated to get a grip on the underlying problem structures and related demands for international governance; different parts of the sectoral systems require appropriately adapted responses and create varying demands for international governance.

This report lays the basis for Work Package 4 of the COP 21 RIPPLES project as a whole, in particular for Task 4.2. The sectoral differentiation will structure and guide the mapping of international and transnational institutions in Task 4.2. Also, the sectoral analysis of the promise of international cooperation will provide the point of reference for the assessment of related international cooperation, including the identification of scope for its further development. As is usual in such research, the usefulness of the analytical framework developed here will have to be proven in its application in later parts of the project, especially in Task 4.2, and such application may well lead to the identification of scope for further improvement of the framework.

2. Key Concepts

2.1 International Governance and the Climate Challenge

Governance can be understood as the steering of actions/behaviour through the setting of rules, standards, or other kinds of guidelines, or through targeted support (capacity-building, technical assistance or finance) towards an explicitly "public" goal (Roger, Hale, & Andonova, 2017, pp. 5–6). Such an understanding of governance is generic in that it is not linked to any particular types of actors. It does not constitute an opposite to "government", as governance may emanate from governments as well as other forms of rule-setting, etc. We will use the term "governance" in this generic sense in this report.

International governance consequently entails the setting of rules and standards and the provision of support at the international level. It can be pursued by various actors, including state governments, (associations of) non-state actors (both business/firms and civil society actors), local authorities (cities, municipalities and regions) and others. It is not the actors that make governance international, but the fact that the setting of rules and standards or the provision of support transcend national boundaries. International institutions are probably the main platforms of international governance (as further discussed in section 2.2).

Governing the climate transition poses far-reaching challenges. It would go beyond the scope of this section to aspire to characterise these challenges to an exhaustive extent (see e.g. Bulkeley & Newell, 2015; Incropera, 2015; Levin et al., 2012; Scoones et al., 2015). Instead, we highlight a few central features of the overall challenge of governing the climate transition. Not least, the climate transition requires a wide array of sectoral systems to fundamentally shift towards low/zero-emission technologies and practices (see below). Most models even require negative emissions, usually generated by means of net afforestation and carbon capture and storage (CCS) from the burning of biomass for electricity generation (see sections 4.2 and 4.5). In line with the overall project, we focus here on the challenge of decarbonisation (rather than the challenge of moving toward negative emissions).

This shift itself frequently entails finding and introducing new technologies and innovative ways of satisfying needs. More often than not, these innovations also imply breaking with existing paradigms and replacing long-established and engrained structures, including large-scale and long-term infrastructures (e.g. transport, energy/power, etc.) and routines. Hence, the climate transition requires a wide spectrum of policies to be adapted in far-reaching ways ("policy integration") to, *inter alia*, decarbonise the buildings, transport, industry and power sectors and to green finance and investment (Dupont, 2016; A. Jordan & Lenschow, 2010).

We in this Work Package aim to assess the adequacy of international governance arrangements for addressing this governance challenge. Our focus on international governance implies that we cannot aspire to bring the central solution to the climate challenge. While international governance has important contributions to make to this end, it remains one level in the multi-level governance system, which cannot be expected to bring the solution on its own. Rather, we aim to identify the contribution international governance can make by elaborating on the potential of international governance institutions in general and with respect to the sectoral systems in focus. As international governance interacts with other governance levels, deficiencies of international governance do not necessarily spell doom for the climate transition, and effective/adequate international governance does not necessarily ensure that the 2/1.5°C goal will be achieved. But international governance can at times be necessary or at least create significant added value. International governance of the climate transition can be considered adequate to the extent that it exploits the potential of this governance level.

The benchmark of "adequacy" as such encompasses two interlinked criteria. First of all, international governance of the climate transition can be considered adequate if it as fully as possible exploits the potential of this governance level to contribute to climate mitigation, in line with literature on the "problem-solving effectiveness" of international institutions (e.g. Young 1999; Stokke 2012; Miles et al. 2002). This requires a more detailed analysis of the potential contribution of international governance in individual cases and for particular sub-problems, as appropriate. It is worth noting that in the context of the objectives of the Paris Agreement, problem-solving effectiveness should not only cover the mitigation perspective (1.5/2°C goal), which is our focus here, but also adaptation (Art. 2.1(b)) and financial flows consistent with low-GHG and climate-resilient development (Art. 2.1(c)). The achievement of the 2/1.5°C goal is not selected as an appropriate benchmark, since this would be the result of the interaction and combined contributions of different levels of governance (and various elements operating at these levels).

Moreover, Article 2.1 of the Paris Agreement posits that the global response to climate change has to be strengthened "in the context of sustainable development and efforts to eradicate poverty". It thereby highlights the second aspect of the adequacy of international governance, namely that it be considered fair and socially acceptable. This requirement can partially be justified on normative grounds, based on criteria of good governance. It can also be derived from the effectiveness objective since governance arrangements that are not considered fair and acceptable may not be stable and effective. Moreover, international governance may establish or enshrine related normative principles as is, for example, the case for the principle of equity and "common but differentiated responsibilities and respective capabilities (in the light of different national circumstances)" (Art. 3 UNFCCC and Art. 2 Paris Agreement) in the climate regime (cf. Lukas Hermwille, Obergassel, Ott, & Beuermann, 2017). The two interlinked adequacy criteria will especially come into play in the assessment of existing governance structures in Task 4.2.

2.2 International and Transnational Institutions

International institutions can be understood as negotiated, dynamic, sectoral normative systems consisting of rules and practices, including decision-making procedures, that prescribe behavioural roles, constrain activity and shape actor expectations (Young 1982; Young 1989; Keohane 1989; North 1991; Simmons & Martin 2002). We focus on negotiated, purposefully created international institutions because we are interested in them as governance instruments. We hence explicitly do not include what has been called "spontaneous institutions" that emerge from the uncoordinated behaviour of actors in the international system (Young, 1982). Such negotiated institutions usually have two principal components, namely (1) substantive rules addressing the issue at stake (climate change, world trade, etc.) and (2) procedural rules for making and implementing decisions, which may include development/change of the substantive rules (Gehring, 1994; Young, 1980). As mentioned, they can be considered main platforms of international governance.

The relevant literature in particular distinguishes three types of negotiated international institutions. First among these are formal international organisations (such as the World Trade Organization – WTO, the Food and Agriculture Organization – FAO, or the International Monetary Fund – IMF). International organisations are usually established by states through intergovernmental agreements containing the statutes of the organisation. International organisations possess themselves actor qualities, including a physical location ("a seat"), a staff of employees and usually legal personality (Young, 1986).

Second, international regimes serve to govern specific issue areas usually on the basis of intergovernmental treaties, as further developed through subsequent decision-making (frequently by the Conference of the Parties – COP). Hence, the climate change regime rests on the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol and the Paris Agreement – which have

been fleshed out by decisions of the COPs. International regimes are usually served by a secretariat, which may itself be provided by an international organisation (but can also be self-standing as is the case of the UNFCCC secretariat) (Levy, Young, & Zürn, 1995).

Third, we include in our analysis two types of transnational institutions/regimes that feature non-state actors as their members: private transnational institutions feature only non-state actors as their members and hybrid transnational institutions have both non-state and state actors/governments as their members. The emergence and rise of transnational institutions reflect the emergence and rise of non-state actors in international politics more generally, including firms, civil society organisations and local authorities (cities, municipalities, regions). In climate governance, transnational institutions include the growing number of "international cooperative initiatives" and transnational networks (such as various city networks, private certification initiatives, etc.) (Abbott, 2012; Bulkeley et al., 2014; Sanderink, Widerberg, Kristensen, & Pattberg, 2017; Widerberg & Stripple, 2016).

In view of the proliferation of international fora, coalitions and networks, it seems important to clarify which of these do or do not qualify as international institutions for the purposes of our research. As mentioned above, we are interested in international *governance* institutions. As such, the institutions should consist of identifiable rules and practices (aimed at affecting behaviour), be capable of collective decision-making and fulfil relevant functions such as rule-setting, provisions of means of implementation or generation of knowledge in pursuit of a public good (see also section 3 on governance functions). Soft-law institutions such as the Group of Seven (G7) or Group of Twenty (G20) would appear to be covered by such an understanding, whereas pure associations of firms (such as the International Chamber of Commerce) would rather constitute a lobby than an international governance institution. While borderline cases will certainly exist, this understanding should enable us to avoid confusing international coalitions and lobby groups with international governance institutions. While there is not necessarily a minimum requirement regarding the functions to be fulfilled, it should be useful to keep in mind the general requirement of a consequential normative core that forms part of the general definition of institutions introduced above.

We will in the following analysis use the term "international institutions" to refer to all three aforementioned categories, namely international organisations, international regimes (both constituting intergovernmental institutions) and transnational institutions/regimes.

2.3 Institutional Complexes and Polycentricity

Research over the past two decades or so has increasingly highlighted that international governance institutions do not operate in isolation but form so-called "institutional complexes" (Oberthür & Schram Stokke, 2011; Orsini, Morin, & Young, 2013; Raustiala & Victor, 2004). An institutional complex can in general be understood as a network of three or more international institutions that relate to a common subject matter; exhibit overlapping membership; and generate substantive, normative, or operative interactions (Orsini et al., 2013). For example, Keohane and Victor have identified a regime complex on climate change including a host of primarily intergovernmental fora (such as the Montreal Protocol addressing fluorinated GHGs, various minilateral fora and others) (Keohane & Victor, 2011). Such institutional complexes may also be subdivided in different ways, as various subgroups of institutions may address particular sectors or specific governance functions (Oberthür & Justyna, 2013; Orsini et al., 2013).

Although composed of formally unconnected, non-hierarchical and differentiated governance institutions, institutional complexes are not necessarily characterised by regime collisions and conflicts. Rather, a "patchwork" (Biermann, Pattberg, Van Asselt, & Zelli, 2009), of institutions can complement each other rather than collide and hence form an inter-institutional order. Such an inter-institutional order may be more or less effective and efficient and can be characterised by tensions between the

relevant institutions. Accordingly, existing research suggests that the relationship between different overlapping institutions may be best understood as an inter-institutional equilibrium that, over time, forms and deepens specific "divisions of labour" (Gehring & Faude, 2014; Oberthür & Schram Stokke, 2011). The emergence of such inter-institutional divisions of labour is not least driven by the desire of actors who are members of several institutions to prevent open conflict and to be able to sustain these institutions. As a result, enhancing and governing institutional complexes does usually not entail *creating* order, but *changing* or *deepening* it (Oberthür, 2016).

How could an existing order or division of labour in institutional complexes be steered or governed? The possibility of such governance is immanent in the concepts of "interplay management" (Oberthür, 2009) and "orchestration" (Abbott, Genschel, Snidal, & Zangl, 2015). Accordingly, it is important to realise that institutional complexes and their structures result from collective decision-making in the various component institutions in the first place. Hence, they can also be changed and shaped through the collective decision-making in the various institutions that form the complex. In addition, one could consider collective governance of institutional complexes through overarching institutions and/or coordination between the component institutions, which has, however, remained the exception to date. Action in the individual institutions that make up an institutional complex has remained the major form of their governance (Oberthür, 2016). In some cases, central institutions may specifically perform an orchestrating function in this respect.

The concept of "polycentricity" or "polycentric governance" to some extent overlaps with the notion of institutional complexes, but it also goes beyond it.[3] Both concepts are based on the notion that governance occurs through multiple units (institutions). While research on institutional complexes has traditionally focused on international regimes and organisations, polycentric governance casts the web even wider by including transnational arrangements (including private/sub-state actors) and institutional arrangements below the threshold of formal regimes/organisations (such as partnerships and international cooperative initiatives) (Bulkeley et al., 2014; A. J. Jordan et al., 2015; Ostrom, 2010). Polycentric governance even in principle incorporates a multi-level perspective and hence transcends a focus on cooperation across borders. While our focus is on international and transnational cooperation, we do include the wide range of institutional arrangements into our notion of institutional complexes, in line with research on polycentric governance.

Overall, there is a wide range of concepts and terms in use in relevant literature to refer to the reality that international governance in virtually all issue areas of international relations, including climate change, occurs through various fora and arrangements. Relevant catchwords include "institutional fragmentation", "governance architectures" and others. In this project, we interchangeably employ "institutional complexes" or "governance landscapes" as denoting this phenomenon.

In conclusion, we will analyse international governance as being advanced through various institutional arrangements, including international organisations, international regimes and transnational institutions and arrangements that interact with each other in specific ways. It follows that we (especially in Task 4.2) have to look at all institutions/institutional arrangements that are relevant for a specific challenge/function in order to assess achievements and shortcomings (and to identify possible venues for enhancing governance).

---

[3] It also has a strong normative component as polycentricity is considered as potentially superior in terms of effectiveness (and legitimacy), something that would need to be investigated empirically.

2.4 A Sectoral Perspective

In this report, we take a sectoral perspective. We thereby reflect that, over recent years, it has become increasingly acknowledged that conditions for decarbonisation vary considerably across different sectors which hence require specific targeted approaches and policies (e.g. Dupont & Oberthür 2015), as also immanent in the concept of climate stabilization wedges (Pacala & Socolow, 2004). Accordingly, the number of international institutions and initiatives that address particular sectors and sub-sectors – different aspects of the challenge of climate change – has thus been increasing. While climate change admittedly constitutes a challenge that cuts across different sectors and is thus overarching, there is therefore good reason to analyse the conditions for decarbonisation and the possible contribution of international governance to this end from a sectoral perspective.

This raises the question how "sectors" should be defined: how should we go about delimiting sectors for the purposes of our analysis? Various emission sectors as reflected in emission inventories and databases may not necessarily be suitable for our purposes if the delimitation does not correspond to useful units for governance efforts (e.g. where industrial emissions are separated into direct energy-related emissions and process emissions). Similarly, various economic sectors distinguished in the literature may not necessarily be suitable. Because of our governance perspective, we aim at identifying systems of related actors, technologies, infrastructures, institutions and ideas that fulfil specific identifiable societal functions and may hence provide for suitable units for political governance/steering (Schot & Laur 2016, p. 18; see also Borrás & Edler 2014). Because such "sectors" form socio-technical or social systems, we refer to them in the following as "sectoral systems".

We understand such complex "sectoral systems" as open systems. As such, they are not strictly separated from other sectoral systems, but may even overlap and be closely related to them. Defining the system boundaries for analytical purposes is therefore necessarily arbitrary to some extent and requires researchers to make informed choices. We therefore wish to acknowledge that a large number of overlapping "sectoral systems" could principally be identified, also because systems frequently can be subdivided into further sub-systems, depending on the preferences and choices of the analyst.

Under these circumstances, it seems particularly warranted to provide full transparency of the choices made and the guiding criteria. In identifying our sectoral systems, we pragmatically started from a number of established, widely recognised sector distinctions (as for example reflected in reporting to the UNFCCC, the European Commission, Eurostat, the US Environmental Protection Agency, and sector divisions of the IPCC). We then adapted and complemented these in accordance with our aforementioned conceptualisation of sectoral systems guided by the following considerations: (1) coverage of GHG emissions; (2) a pragmatic preference for larger systems (so as to keep the number of sectoral systems manageable); and (3) the inclusion of key emerging concepts and fields of action (see also below section 4).

3. Functions of International Governance Institutions

There is a rich literature elaborating on the functions and effects of international institutions and international governance/cooperation (Bulkeley et al., 2014; De Búrca, Keohane, & Sabel, 2014; Loorbach, 2010; Simmons & Martin, 2002; Stokke, 2012; Young, 1999). We take inspiration from this literature for distilling five key functions that international governance institutions can fulfil. The purpose is to specify how international institutions may help advance the climate transition. Identifying their core governance functions should allow us to pinpoint the potential of international institutions in this respect. While the aforementioned literature may cut the field in varying ways (e.g. Young & Marc A. Levy 1999), we believe that our categories cover the main functions of international institutions as discussed in the literature.

All the governance functions derive from the fact that dynamic international governance institutions constitute both normative systems and decision-making processes (Gehring, 1994). Hence, international institutions first of all entail rules and norms that can prescribe, proscribe, permit or direct relevant behaviour of states and other actors. But beyond such rules and norms, an international communication and decision-making process is also usually constitutive of international governance institutions. Such institutions provide fora for exchange, deliberation and decision-making that allow actors to interact and learn. They thereby help synchronise discourses across levels of governance, frame the issue at hand, shape parties' interests and enable the development of the institution. The functions distinguished in the following can to varying degrees be traced back to these constitutive characteristics of international governance institutions.

3.1 Guidance and Signal Function

The guidance and signal function of international institutions derives mainly from the principles and objectives on which they are commonly based (and hence from the normative dimension of international institutions). While not necessarily highlighted in institutional and regime theory, international institutions are regularly established for a specific purpose (advancing free trade, protecting human rights, limiting climate change, etc.). This purpose is commonly visible from principles and objectives enshrined in the underlying treaty or statutes and/or can be further developed and specified through subsequent institutional decision-making. Accordingly, especially the objectives contained in the Paris Agreement have been found to entail strong guidance as they signal the resolve of governments across the world to take far-reaching action on climate change (Bodansky, 2017; Falkner, 2016; Lukas Hermwille et al., 2017; Morseletto, Biermann, & Pattberg, 2016).

The potential, reach and significance of this signal function of contemporary international institutions goes much beyond the respective international institution per se and the international level in general. The principles and objectives enshrined in an international institution first of all reflect agreement among its members and establish collective expectations and a commitment to the development of the institution among these members cooperating at the international level. With increased transparency and means of communication as well a growing participation by various non-state actors in processes of international governance over the past decades, such agreement reached within international institutions can generate effects far beyond the process of international cooperation itself (even short of formal implementing activities). It signals the resolve of governments (or other members of international institutions) to pursue a certain course of action and hence indicates likely policy trajectories to business, investors and other actors operating at all levels of governance. As such, the signal and direction provided has the potential to help synchronise and align developments across levels of governance and across the boundaries of different countries (Kanie & Biermann, 2017). Accordingly, it

can be argued that the Paris Agreement generally provides an important (though imperfect) signal to business to invest in low- or zero-carbon development (Falkner, 2016).

3.2 Setting Rules to Facilitate Collective Action

One of the best-known functions of international governance institutions is setting rules to enable collective action on the issue at hand. The primary tool towards this end is establishing obligations and standards of behaviour to which parties subscribe. Parties to international institutions thus agree to certain reciprocal obligations, which can be of more procedural ("obligations of conduct") or of more substantive nature ("obligations of result") (see discussion in Oberthür and Bodle 2016). The implementation of such obligations by individual parties is then expected to lead to behavioural effects that contribute to the resolution of the problem at hand (and to achieving the related objectives; see previous section).

Obligations and standards of behaviour directed at addressing the issue at hand can take different forms (depending on problem characteristics and the political choice of parties). They may prohibit or prescribe certain behaviour. They may also harmonise (technical) standards – implying behavioural adaptations of actors. Prescriptions could directly address the behaviour causing the problem or could try to provide incentives for adapting this behaviour (e.g. when determining rules for the labelling of products to facilitate consumer choice). In short, international obligations and standards of behaviours may span the whole range of (environmental) policy instruments and approaches from "command and control" over market instruments to informational instruments (A. Jordan, Benson, Wurzel, & Zito, 2012; Sterner & Coria, 2013; Wurzel, Zito, & Jordan, 2013).

Different problems may generate varying demands for international rules. In fact, some problems may not require such collective action at all (e.g. reform of local public administrations). Addressing other problems may imply stronger or weaker levels of international interdependence so that one actor's behaviour may be contingent on another actor's behaviour to varying degrees. For example, one country's restrictions on GHG emissions of certain industries may imply direct costs that immediately affect the international competitiveness of this industry. In other cases, such costs may arise more indirectly (e.g. because of regulatory burden). Under such circumstances, international institutions allow actors to codify obligations to enable and facilitate collective action.

The difficulty of achieving agreement on related obligations not least arises because of the distributional conflicts involved. Agreement on rules requires agreement on the contribution of each individual party and hence on a burden-sharing. It not only requires an understanding that collective action is required or beneficial but also what each individual actor's fair contribution should be. As a result, individual parties will not only try hard to get the best deal for them, but issues of equity and fairness also lurk (with considerable potential for diverging views on what these may mean in practice).

Their process dimension implies that negotiated dynamic international institutions can make the infrastructure available for reaching agreement on rules – and for developing them further. They provide forums for discussions and a framework for the preparation and making of collective decisions. Hence, they provide the opportunity to synchronise discourses and develop common understandings and to further develop rules and obligations over time.

3.3 Transparency and Accountability

International institutions frequently contribute to enhancing the transparency of actions of their parties, collecting and analysing relevant data and identifying and addressing problems in implementation

(hereinafter referred to as "transparency and accountability"). They (i.e. their bureaucracies/secretariats) may themselves collect and aggregate relevant data or may rely on reporting by individual parties to the institution, with the latter providing a rationale for review/verification in order to ensure data quality and comparability (Gupta & van Asselt, 2017). Such "measuring, reporting and verification" (MRV) also provides for a form of implementation review as a basis for identifying possible implementation problems. International institutions can furthermore entail specific mechanisms for addressing such implementation problems. Not least, modern multilateral environmental agreements commonly include compliance procedures/mechanisms to this end (Bulmer, 2012; Treves et al., 2009) and international treaties generally foresee mechanisms for the settlement of disputes between parties.

The transparency at stake here relates specifically to the implementation of agreed rules by the parties. It should not be confused with broader notions of transparency. For example, labelling rules and other informational policy instruments may support transparency of certain product characteristics for consumers. While this may qualify as a specific policy approach under the function of "setting rules", the function of "transparency and accountability" in this case would relate to whether members of the institution had properly implemented the labelling scheme/informational instrument.

The level of demand for specific mechanisms to enhance/ensure transparency and accountability depends on the problem at hand. For example, "coordination problems" require less oversight and verification since all parties have an incentive to implement the international rules once they are agreed. In contrast, "cooperation problems" involve mixed motives of actors and consequently an incentive to take a "free ride". Hence, they are considered to entail a strong demand for mechanisms to ensure transparency and accountability (Snidal, 1985). Furthermore, some activities are intrinsically more transparent than others so that the need for specific mechanisms to ensure transparency varies. For example, it is far more difficult to establish whether an oil tanker released oil at sea than whether it has segregated ballast tanks that reduce the incentive for releasing oil at sea (Mitchell, 1994). Finally, the demand for specific mechanisms for addressing implementation problems (and related conflicts) depends on the incentive structure relevant actors are facing. In some instances, ensuring transparency may be sufficient to ensure effective implementation. For example, long-standing non-compliance by Soviet whaling boats in Antarctic waters with catch limits under the International Whaling Convention ceased in the 1970s when new inspection arrangements ensured that such non-compliance would be detected (Oberthür, 2000). Put positively, mechanisms ensuring transparency and accountability also have the potential that effective implementation receives visibility and acknowledgement and is thereby encouraged (on the basis of public support for the objectives pursued).

Overall, high levels of transparency and accountability are generally considered to support trust among parties as well as effective implementation. This does neither imply that they would be easily achieved nor that there could not be problematic implications. Devising appropriate mechanisms frequently is marred with similar conflicts as discussing the actual substantive obligations. Moreover, it has been argued that being held to account may limit the ambitiousness of the targets actors are willing to adopt (Bodansky, 2012). On balance, however, transparency and accountability are widely held to enhance trust, provide certainty to actors that others will reciprocate and promote learning and common understanding (Bodansky, 2010; Mitchell, 1998).

Whereas transparency and accountability are known to constitute major issues in the UN negotiations on climate change (since they require agreement on related rules), less is known about their role with respect to specific sectoral systems. Reporting, review and verification and compliance have been major issues in the context of the UNFCCC, the Kyoto Protocol and the Paris Agreement. How to measure and account for GHG emissions and sinks has major implications for the amount of emissions and the achievement of related targets. Appropriate data collection and reporting is fundamental to any attempt at addressing climate change and governing the climate transition. In the context of international climate agreements, they enable to address and remedy the danger of lack of implementation

("free riding") by individual countries. Less is known about how the demand for transparency and accountability (and, by implication, the need to facilitate collective action – see above) in a sectoral perspective put central here.

3.4 Capacity Building, Technology and Finance (means of implementation)

The provision of capacity building, technology (transfer), and financial resources is especially relevant in a North-South context. It is based on the insight that frequently implementation is deficient because of a lack of these means of implementation, especially in developing countries (Chayes & Chayes, 1993). A more recent additional rationale for providing such means concerns "compensation" for loss and damages suffered as a result of environmentally detrimental behaviour. Accordingly, various multilateral environmental agreements do engage in relevant programmes and have financial mechanisms and various international financial institutions exist to this end, including the World Bank, several Multilateral Development Banks, the Global Environment Facility, the Green Climate Fund and others (Bodansky, 2010; Keohane & Levy, 1996).

The rationale for providing such means of implementation through international institutions is indirect. One may question why capacity building, technology and finance should be provided through international institutions – and other (bilateral) channels do indeed exist. However, international cooperation brings at least two important advantages. First, it allows donors to coordinate and thereby address the second-order collective-action problem of who is going to provide how much to the overall effort. Second, it allows to reap efficiency gains rooted in the fact that similar issues need to be and can be addressed in various countries and contexts drawing on similar expertise and lessons (thereby reducing "transaction costs"). Resources can thereby be pooled and duplication of effort minimised (Keohane & Levy, 1996).

3.5 Knowledge and Learning

Finally, international governance institutions can create knowledge and provide platforms for individual and social learning. Knowledge can relate to scientific, economic, technical and policy aspects. It can concern the understanding of the problem at hand or possible solutions to this problem (including technological development or other kinds of solutions). Learning can emanate from such information and its exchange at the international level, for example on best practices. The function of knowledge and learning includes awareness raising and may contribute to a change of values and cultural predispositions (Haas 1990; Young & Levy 1999; Hasenclever et al. 1997).

International institutions can enhance knowledge and information as well as learning in various ways, primarily in their process dimension. They may collect and aggregate relevant data and other knowledge (e.g. the World Energy Outlook published annually by the International Energy Agency, IEA). Actors may also establish certain international institutions mainly for the purpose of a collective appraisal of available knowledge (e.g. the Intergovernmental Panel on Climate Change, IPCC). Or they may establish particular processes and bodies to this end in the framework of a broader institution (Parson, 2003). As mentioned above, mechanisms to provide for transparency may also generate relevant knowledge. While these processes allow individual actors to learn, policy learning may be promoted by exchange and discussion of relevant information in the context of such international institutions.

The effectiveness and influence of this knowledge and information not least depends on its acceptance by individual actors. This acceptance is not least supported through the process of collective appraisal that allows parties to strive for consensual knowledge (see also Mitchell et al. 2006). It may also be furthered by the general authority of the institution in question (such as the IEA on matters of energy).

Actors may especially be open to learning which policies work if they are interested in addressing the issue targeted by these policies.

The effects of knowledge creation and learning may be felt both in the international process and in the implementation by individual actors. Consensual knowledge has the potential to help advance international discussions on collective action/setting rules since it provides a common basis and frames and limits policy options considered (Gehring, 2007). It may also help shape implementing behaviour of individual actors by affecting how they perceive their interests, and policy learning may help develop actors' policies.

3.6 Conclusion

We have here derived five main functions of international governance institutions from the general literature on international (environmental) institutions and cooperation. Accordingly, international governance institutions can provide important guidance and signals to both public and private actors. They can also set rules to facilitate collective action across borders. Transparency and accountability provisions can enhance mutual trust and ensure against "free riding". International institutions also allow to enhance assistance to countries and actors in need by permitting donors to coordinate and reduce transaction costs. And they can contribute to an improved and collectively appreciated and accepted understanding of the problem and its possible solutions as well as to learning about effective policies. Table 3.1 presents the key features and potential added value of the performance of these functions by international institutions.

Table 3.1: Overview of Main Functions of International Governance Institutions

Functions	Key features	Main added value
Guidance and Signal	• Results from overall agreement, including targets/objectives	• Aligns actors across countries
Setting Rules	• Various forms of obligations and standards	• Harmonises/aligns obligations for actors thereby addressing interdependence & competitiveness
Transparency and Accountability	• Reporting, review/verification, compliance	• Contributes to effective reciprocity and implementation (addressing free riding) & mutual trust
Means of Implementation	• Capacity building, technology transfer and finance (North-South)	• Enhancing capabilities by coordinating donors and reducing transaction costs
Knowledge and Learning	• Generation and collective appreciation of information/knowledge • Science and policy learning	• Improved and shared understanding (authoritative knowledge) • Improved policies (learning)

Source: authors' own compilation.

While our analysis is meant to cover the main functions international institutions *can* perform, not all institutions necessarily fulfil all of these functions. Rather, different institutions may perform varying mixes of these functions depending on the specific issue they address and the way in which members designed the institution in response. For example, insurance against free-riding will only be required in cases of “cooperation” problems (as opposed to “coordination” problems). Also, transparency and accountability mechanisms will most likely require obligations in the first place (even though these could emanate from broadly accepted social norms rather than the explicit provisions of the institution). Hence, the need and demand for the provision of these functions depends on the governance challenges and conditions faced with respect to the particular cooperative project pursued. This also implies that governance in international institutions can take different forms and vary in its depth, ranging from “shallow” exchanges of national experiences to the setting/harmonisation of common binding standards. There is no minimum of core functions an arrangement needs to fulfil in order to qualify as an institution. However, it might be worth reminding that the overall definition of international governance institutions implies that they derive from negotiated normative systems that include decision-making procedures and shape actors’ behaviour and/or expectations.

The five main functions of international governance institutions introduced here will guide our analysis of the sectoral systems in the next section. As a result, the next section will investigate to what extent there is demand and scope for such functions in the sectoral system considered and to what extent the functions that international governance institutions may perform may promise added benefits in terms of advancing to decarbonisation in the sectoral system.

4. Sectoral Analysis

4.0 The selection of sectors

As indicated in section 2.4 above, our effort involves identifying and selecting a limited number of sectoral systems for further analysis. Starting from a number of established, widely recognised sector distinctions (as for example reflected in reporting to the UNFCCC, the European Commission, Eurostat, the US Environmental Protection Agency, and sector divisions of the IPCC), we pragmatically identified a number of open sectoral systems of interacting and inter-related actors, technologies, infrastructures, institutions and ideas that fulfil specific identifiable societal functions.

As a large number of sectoral systems could potentially be distinguished on this basis, we also paid attention to the following considerations. First, we attempted to cover the anthropogenic sources and sinks of GHG emissions as comprehensively as possible. Second, we rather opted for larger systems (e.g. for energy–intensive industries together rather than individual such industries such as the steel, cement, chemical etc. industries) for pragmatic reasons of feasibility (i.e. to keep the number of sectoral systems manageable). Finally, we strove to capture important emerging concepts and perspectives (namely "wedges") with a significant potential for addressing GHG emissions (e.g. circular economy, urban settlements/systems).

On this basis, we include the following 14 sectoral systems in our analysis:

- Agriculture (animal husbandry and cultivation of plants);
- Land use, land-use change and forestry (LULUCF - including deforestation, afforestation, deforestation, crop land, grassland etc.);
- Waste (waste treatment and disposal);
- The circular economy (especially product design, recycling, reuse, etc. – closely related to the waste sector);
- Power sector;
- Energy-intensive industry (with a focus on iron and steel, aluminium, cement, and chemicals);
- Extractive industries ('losers' – especially mining, fossil fuel production, phase down of coal, fossil fuels, etc., subsidies);
- Transport (car manufacturing; passenger and freight transport, including infrastructure);
- International transport (aviation and maritime);
- Urban systems/settlements;
- Buildings (especially spatial heating and cooling);
- Products and appliances;
- Finance and investment;
- Fluorinated GHGs (production and consumption).

We wish to acknowledge that this selection is inescapably to some extent arbitrary and limited. Sectoral systems could have been defined in different ways (including distinction of subsystems as systems) and other areas of activity might have been included (e.g. we did not include climate geoengineering). However, we are confident that we are capturing sectoral systems that are important to address for the move toward decarbonisation, as called for by the Paris Agreement.

For each of the sectoral systems, the analysis in the following proceeds in three steps. We first provide important background information on the structure of the sectoral system and its relevance for GHG emissions and emission reductions, including existing options for decarbonisation. Subsequently, the main technological, economic, political and social challenges and barriers toward decarbonisation are explored. Finally, the analysis attempts to pinpoint the promise and potential of international cooperation by investigating which of the identified five key functions of international governance could contribute to advancing toward decarbonisation and in what way. In order to avoid a reductionist piecemeal approach, linkages with other sectoral systems are also identified.

4.1 Agriculture

4.1.1 Current status and prospect

In 2010, the agriculture sector accounted for approximately 13 per cent of global GHG emissions which includes principally methane (CH_4) and nitrous oxide (N_2O) (Searchinger, 2013). Emissions from crop and livestock production stood at over 5.3 billion tonnes in 2011, growing 14 per cent from 4.7 billion tonnes of CO_2 equivalent in 2001 (FAO, 2014).

Enteric fermentation (CH_4 production by livestock during digestion), the application of synthetic fertilizers and biological processes in rice paddies account for more than 60 per cent of the sector's GHG emissions. Enteric fermentation accounted for 39 per cent of total sectoral emissions in 2011 (plus 11 per cent since 2011). Emissions generated during the application of synthetic fertilisers accounted for 13 per cent of agricultural emissions in 2011, and are the fastest growing emissions source in the sector, having increased some 37 per cent since 2001. GHGs resulting from biological processes in rice paddies emit CH_4 which constitutes ten per cent of total agricultural emissions, while the burning of savannahs accounts for five per cent of total agricultural emissions (FAO, 2014). In 2014 agriculture accounted for 9.5 per cent of world trade with a value of USD 1,765 billion (WTO, 2017b). The top ten importers and exporters of agricultural products account for around 70 per cent of trade (WTO, 2017a). The European Union (EU) is both the biggest exporter and importer of agricultural products. China, India, Brazil, and the US accounted for 39 per cent of global non-carbon dioxide (CO_2) agricultural emissions in 2015, whereas all European countries together made up 11-13 per cent of global non-CO_2 agricultural emissions (Richards, Gluck, & Wollenberg, 2015).

The main drivers of change in the agricultural sector are climate change, population growth, technological innovation, public policies, economic growth and the cost/price squeeze (IPCC, 2007). Population growth and globalisation have significantly affected agricultural production and consumption patterns, while technological progress has boosted agricultural productivity (Steduto, Faurès, Hoogeveen, Winpenny, & Burke, 2012). This growth, however, has been at the expense of increased pressure on the environment, and depletion of natural resources (IPCC, 2007). Due to climate change and an increasing world population, drought has been the most important environmental stress affecting agriculture worldwide, particularly in terms of the productivity of field crops (Hu & Xiong, 2014). Agriculture accounts for 70 per cent of global freshwater and more than 90 per cent of consumptive use (Steduto et al., 2012). Breeders have made great progress in improving and developing drought-tolerant crops, but these still cannot meet the demands of food security in the face of an increasing world population, global warming, and water shortage. Other exogenous pressures on the agriculture sector are the competition between urban and agricultural lands (Seto, Lin, & Deng, 2014) and the inefficient use of land to generate energy via bioenergy (Searchinger & Heimlich 2015; on the role of bioenergy in power and transport, see sections 4.5 and 4.8).

Various options for reducing emission from the main subsectors (enteric fermentation, fertilisation, rice production) already exist. For example, adding a CH_4 inhibitor to the dry matter feed can in principle safely reduce CH_4 emissions from high-producing dairy cows by 30 per cent (Hristov et al., 2015). Recent advances in fertiliser technology could help to reduce between 30 per cent and 60 per cent of N_2O emissions depending on the irrigation of the crops. Recent results also suggest that combining no-tillage agriculture (in which soils are not turned over with farm implements) with the use of slow-release fertiliser can result in a reduction of 75 per cent or more in soil N_2O emissions from irrigated systems (Parton, Del Grosso, Marx, & Swan, 2011). Also, capturing and burning the CH_4 from livestock manure (for energy) can greatly reduce related GHG emissions and even contribute to electricity production. According to the World Resources Institute (WRI), perfect water management can theoretically reduce emissions of rice paddies up to 90 per cent compared to full flooding (Adhya, Linquist, Searchinger, Wassmann, & Yan, 2014). In reality, farmers in the Philippines and many other Asian countries have limited technical ability to drain their fields during the rainy season so technical opportunities remain generally unexplored.

Broader incentives will be necessary to enable and encourage farmers to implement available technologies and best practices at the necessary scale. At the same time, technologies developed so far are not capable of completely phasing out GHG emissions; hence, more research will be needed to develop new options.

Enhancing the sink capacity of soil will also be important as soils currently offset about 15 per cent of agricultural GHG emissions (Parton et al., 2011). However, soils, like other biological sinks (e.g. vegetation), are believed to have an inherent upper limit for storage. The total amount that can be stored is crop and location-specific and the rate of sequestration declines over several years before eventually reaching this limit (FAO, 2002). In future, it may be possible to to increase the stability of soil organic matter and thereby retain carbon in the soil for a longer period of time (Wollenberg et al., 2016).

Also, a shift of dietary patterns holds significant potential for reducing agricultural GHG emissions. In particular, reduced demand for meat and dairy products could significantly reduce agriculture's climate footprint. Widespread adoption of vegetarian diet could cut food-related emissions by more than 50 per cent (Milmann & Leavenworth, 2016; Springmann, Godfray, Rayner, & Scarborough, 2016). A shift to the diet recommended by the World Health Organization could help prevent 0.31–1.37 Gigatonnes of CO_2 equivalent ($GtCO_2eq$) or 6.2-23.6 per cent of the global agricultural GHG emissions per year in 2030 (Wollenberg et al. 2016; Smith et al. 2014).

Decreasing food loss and waste constitutes another option with significant potential. Current loss and waste is 30-50 per cent of global food production. Reducing this loss and waste by 15 per cent could reduce emissions by 0.79-2.00 $GtCO_2eq$ per year (Wollenberg et al., 2016).

Wide regional and country differences are evident. Agriculture contributes a smaller portion of total emissions in developed countries (12 per cent) than in developing countries (35 per cent) (Richards et al., 2015). In 2011, 44 per cent of agriculture-related GHG emissions occurred in Asia, followed by the Americas (25 per cent), Africa (15 per cent), Europe (12 per cent), and Oceania (four per cent) – with an increased share in Asia and an decreased share from Europe (FAO, 2014). As regards livestock, beef and chicken play the main role in Latin and North America, whereas the dairy cattle sector dominates in Western Europe (FAO, 2017). The world's livestock sector is growing at an unprecedented rate with a strong positive relationship between the level of income and the consumption of animal protein, with the consumption of meat, milk and eggs increasing at the expense of staple foods (WHO, 2008). The Organisation for Economic Cooperation and Development (OECD) predicts a further increase in the production of meat of 15.5 per cent by 2025 (OECD/FAO, 2016).

4.1.2 Main challenges and barriers toward decarbonisation

Agriculture is heavily dependent on physical and human factors. The approaches that best reduce emissions depend on local conditions and therefore vary from region to region. Best practices for intensive commercial farming such as pig farming in Western Europe is not of interest for intensive subsistence farming such as rice cultivation in South-East Asia.

The adoption of available technologies and best management practices by agricultural producers is, despite their potential benefits, lagging for several reasons. One of the reasons is high costs: In the long run, reduced tillage can be expected to reduce fuel expenses and personnel time while maintaining or increasing crop yields, but the upfront cost of converting tillage equipment may prohibit farmers from adopting the practice. Another example are stabilised fertilisers which cost approximately 30 per cent more than conventional fertilisers (Parton et al., 2011). Dissemination of new technologies and best practices to local farmers also constitutes a formidable challenge. Incentives to adapt practices may especially be lagging where changing practices does not promise immediate benefits to farmers (while carrying considerable transaction and opportunity costs). Adequate incentives would thus need to be created by appropriate policies.

To maximise the contribution of agriculture to climate mitigation, further technological advances will also be required. The potential of currently available technologies to reduce emissions is limited. Wollenberg et al. (2016) suggest a preliminary global target for reducing emissions from agriculture of about 1 GtCO2eq per year by 2030 to limit warming in 2100 to 2°C above pre-industrial levels. This global target is based on a comparison of several models for meeting the 2°C target in a coherent least-cost approach across sectors. Yet plausible agricultural development pathways with mitigation co-benefits deliver only 21–40 per cent of this target (Havlik et al., 2014; Pete Smith et al., 2008, 2013; Wollenberg et al., 2016). There is particular demand for high-impact, quickly implementable technical options, especially for new breeds and varieties that can be easily accessed and do not require completely new management practices or inputs (Wollenberg et al., 2016).

Achieving a wide-spread adoption of climate-friendly diets faces an uphill battle under current market conditions, as demand for meat is growing rather than declining. A lack of awareness by consumers and cultural predispositions constitute barriers as do the lacking reflection of the external effects in the prices of intensive agricultural products. Incentives are also lacking for reducing food waste. Consumers who are willing to opt for climate-friendly products may face informational hurdles as it is not easy to identify the climate impacts of different like-products.

4.1.3 The promise and potential of international cooperation

Guidance and Signal Function

A sectoral target and goals related to core emission-causing activities in the sector could provide important guidance to sectoral actors, including national governments responsible for designing various related policies. The impact and feasibility of clear targets and goals is limited because (1) the sector cannot reduce its emissions to zero anytime soon and (2) what the own contribution to achieving the 2/1.5°C target should be is hence not immediately clear. A preliminary contribution of the sector could be to reduce emissions from agriculture by 1 $GtCO_2eq$ per year by 2030 (Wollenberg et al., 2016). A more comprehensive target for the 2°C limit could include soil carbon and agriculture-related mitigation options (Wollenberg et al., 2016). Further objectives for sectoral activities such as fertilisation (reducing the use of traditional nitrogen fertiliser), emissions from rice paddies and from livestock could further concretise the guidance, as could deriving national targets therefrom.

Setting rules

Rule-making at the international level could also significantly contribute to facilitating emission reductions. For example, labelling schemes could help create markets for low-emission products (given international trade in agricultural products). International agreement could also help establishing a carbon price in agriculture and aligning countries toward a reduction of the use of traditional nitrogen fertiliser (including support for the introduction of alternatives in countries of need), which otherwise faces cost hurdles.

Capacity Building, Technology and Finance (means of implementation)

International cooperation can help disseminate new technologies and best practises to local farmers, including through the provision of financial assistance. More ambitious policy mechanisms will be needed to create incentives for improved information systems and for farmers to use new practices at large scales. Policies supporting more productive agricultural practices, finance of low-emission agricultural development, innovative means for valuing carbon reductions, and use of government or supply chain incentives to meet sustainability standards for reduced emissions will all likely be needed (Wollenberg et al., 2016). While many of the solutions need to be adapted to national and local circumstances, international cooperation can play an important role in developing and diffusing available technologies and providing targeted finance and investment.

Transparency and Accountability (including compliance)

To the extent that rules are set internationally (see above), there would also be a need to create transparency and accountability for implementation of any labelling schemes, a carbon price or restrictions on the use/production of fertilizer.

Knowledge and Learning

Coordinated international research and investment toward high-impact, quickly implementable technical low-emission options are needed, especially for new breeds and varieties that can be easily accessed and do not require completely new management practices or inputs (Wollenberg et al., 2016). As there are a lot of different farming styles, there is a need of differentiated and adapted technologies to address GHG emissions. More research could help increase the affordability and adoption of mitigation practices and identify how to best exploit the potential for reducing the consumption of livestock products (Herrero et al., 2016). International stimuli can especially provide incentives for low-emission innovation for a wide-range of farming contexts.

International institutions can also contribute to awareness raising regarding more climate-friendly diets and reducing food waste.

Linkages

Transport: GHG emissions associated with food are dominated by the production phase. Transportation as a whole represents 11 per cent of life-cycle GHG emissions, and final delivery from producer to retail contributes four per cent (Weber & Matthews, 2008). The agriculture sector is linked to transport through the production of biofuels from certain crops, which in turn enhances pressure for land-use change.

Waste: Reducing food waste has a considerable potential for reducing emissions. Furthermore, while plastic packaging helps prevent food losses, the production of such plastic packaging consumes itself considerable amounts of energy and fossil fuels (Pilz, Brandt, Fehringer, & Fehringer, 2010).

Land use change, which contributes about 11 per cent to the global GHG emissions (Searchinger, 2013) is primarily driven by agriculture.

The chemical industry is linked through 'agrichemicals' which includes a broad range of pesticides, herbicides, insecticides and fungicides, as well as synthetic fertilisers, hormones and other chemical growth agents.

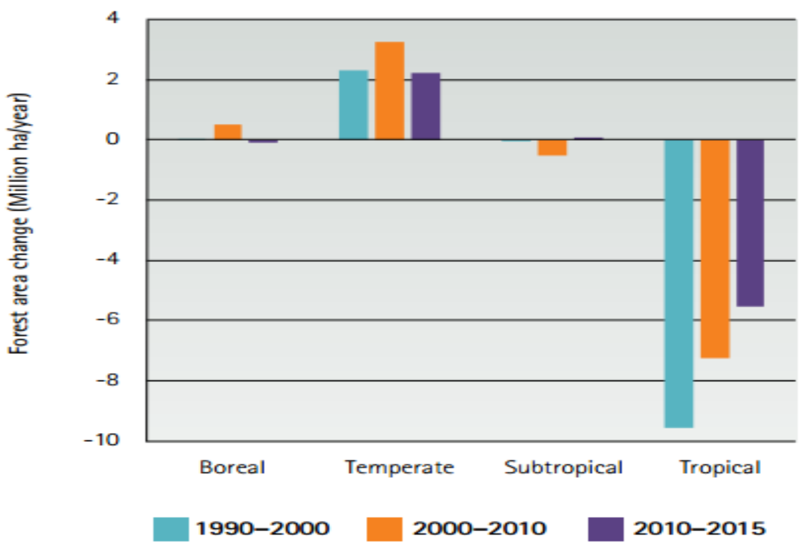
4.2 LULUCF

4.2.1 Current status and prospect

Land use, land-use change and forestry (LULUCF) covers emissions and removals of GHGs resulting from direct human-induced LULUCF activities. The rate of build-up of CO_2 in the atmosphere can be reduced by taking advantage of the fact that atmospheric CO_2 can accumulate as carbon in vegetation and soils in terrestrial ecosystems. Any process, activity or mechanism which removes a GHGs from the atmosphere is referred to as a "sink" (UNFCCC, 2017). Land use refers to the sum total of activities undertaken on a certain land area, including grazing and timber extraction, which release carbon trapped in terrestrial sinks, and conservation efforts, which lead to increased CO_2 sequestration. Clearing forests for agricultural use, conversion of grassland to cropland and abandoning cropland or pastureland qualify as land use change activities. Forestry includes a wide range of activities like planting, and tending of growing trees, pest control, fire management and wildlife protection (Gaan, 2008). Land converted to cropland is the dominant source of CO_2, and land converted to forest land is the dominant sink (UK Department of Energy and Climate Change, 2012).

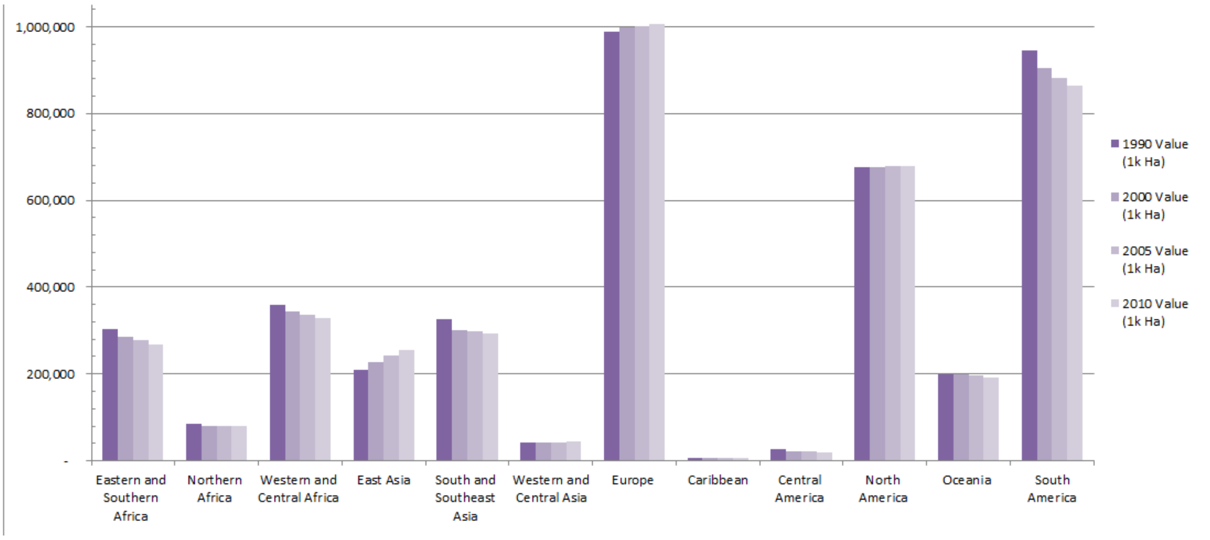
Land use change contributed about 11 per cent of global GHG emissions in 2010 (Searchinger, 2013). Forestry and land use contributed 12 per cent of GHG emissions between 2000-2009 (P Smith et al., 2014). GHG emissions due to land use change and deforestation registered a nearly ten per cent decrease over the 2001-2010 period, averaging some 3 billion tonnes CO_2eq per year over the decade. This was the result of reduced levels of deforestation and increases in the amount of atmospheric carbon being sequestered in many countries (FAO, 2014). In 2014, land use accounted for 2.74 $GtCO_2$ and 3.15 $GtCO_2$eq (FAOSTAT, 2014).

Figure 4.1: Annual Forest Area Net Change by Climatic Domain, 1990-2015



Source: (FAO 2015).

Figure 4.2: Global Forest Cover



Source: (FAO, 2010).

Land use change is strongly driven by agriculture. Subsistence farming, commercial agriculture, logging and fuelwood removals are responsible for 48 per cent, 32 per cent, 14 per cent, and five per cent of deforestation, respectively (UNFCCC, 2007). There are several causes of contemporary deforestation, including population growth, globalization, increased levels of urbanization, area development, forest burning and climate change (Kummer 1992; Mather & Needle 2000; Butler 2012a; Butler 2012b).

Deforestation is an important factor. The net loss of 129 million hectares since 1990 – an area the size of South Africa – has been a major source of CO_2 emissions (FAO, 2016). While global forest cover has decreased from 31.6 per cent in 1990 to 30.6 per cent in 2015, the net annual rate of deforestation has declined from 0.18 per cent in the early 1990s to 0.08 per cent between 2010-2015. As a result, total carbon emissions from forests decreased by 25 per cent between 2001 and 2015 (FAO, 2015). Rates of deforestation vary from region to region around the world (Figures 1 and 2). Today about 30 per cent of Earth's land surface is covered by forests (WWF, 2017) and in 2015 two thirds of the world forests were in the following ten countries: Russia (20 per cent), Brazil (12 per cent), Canada (nine per cent), United States of America (US) (eight per cent), China (five per cent), Congo (four per cent), Australia (three per cent), Indonesia (two per cent), Peru (two per cent) and India (two per cent) (FAO, 2015). Deforestation occurs around the world, though tropical rainforests are particularly targeted. The US National Aeronautics and Space Administration (NASA) predicts that if current deforestation levels proceed, the world's rainforests may be completely gone in as little as 100 years. Countries with significant deforestation include Brazil, Indonesia, Thailand, the Democratic Republic of Congo and other parts of Africa (Bradford, 2015). Although Brazil has reduced its deforestation rate by more than 60 per cent since 1970, in absolute numbers it stays number one in deforestation with 8000 sq km in 2016 (Butler, 2017). Nonetheless, the world's planted forest cover (which accounts for seven per cent of the world's overall forest area), has increased by 110 million hectares since 1990 (FAO, 2015).

4.2.2 Main challenges and barriers toward decarbonisation

The degradation of forest ecosystems has been traced to economic incentives that make forest conversion appear more profitable than forest conservation (Pearce, 2001). Many important forest functions have no markets, and hence, no economic value that is readily apparent to the forests' owners or the communities that rely on forests for their well-being (Pearce, 2001). From the perspective of the developing world, the benefits of forests as carbon sinks or biodiversity reserves go primarily to richer

developed nations and there is insufficient compensation for these services. Moreover, the right to development/growth paradigm is often put forth, i.e. that the poor shouldn't have to bear the cost of preservation when the rich created the problem (Bulte, Joenie, & Jansen, 2000). Another analysis suggests that demographic shifts, economic development, and technological change in less developed countries will result in continued growth in the rate of deforestation in the medium-term (Ehrhardt-Martinez, 2003).

There is no agreement on the definition of a forest. Different organisations use different definitions. Defining a forest simply in terms of tree cover – rather than complex ecosystems and the livelihoods of peoples interacting with them – such as the UNFCCC allows to, has been used as a cover for the expansion of industrial-scale plantations. While there is a safeguard against the conversion of natural forest by the UNFCCC, parties are free to include plantations of commercial tree species, agricultural tree crops, or even non-tree species such as palms and bamboo (Cardona & Avendano, 2010). In order to have a transparent monitoring of the sector, a single definition is needed.

Some regional policies in place are simply shifting the GHG emissions across the globe. Under the Common Agricultural Policy (CAP) of the EU, the agricultural production is distorted in favour of the EU economy which has had a direct impact on a broader scale on LULUCF outside of the EU. In the absence of tariffs for animal feed, the EU cheaply imports animal feed from Latin America, including soybeans that are among the main causes of deforestation in the Amazon and the Cerrado region (Khatun, 2012).

Another major concern is the potential for leakage of LULUCF projects. Leakage refers to the indirect impact that a LULUCF project or activity has on the carbon storage or GHG emissions in another area outside the project. For instance, efforts to reduce deforestation in one area may be offset by increased deforestation elsewhere. Tools to address leakage include discounting, project-eligibility criteria, and the use of “aggregate baselines”. Baselines, the development of national, regional or sector ‘standards’ have been one proposed way to address leakage. But this tool is likewise hampered by poor background information for many developing countries as well as political opposition (Schwarze, Niles, & Olander, 2002).

Overall LULUCF generates a lot of uncertainties which arise both from natural variability in vegetation and soils and incomplete knowledge about the extent of activities and the underlying processes affecting sinks and sources. Typically, uncertainties in the estimates associated with the soil carbon pool are much greater than those related to above the ground standing biomass in trees (UK Department of Energy and Climate Change, 2012). Environmental risk and uncertainty analysis must be integrated into the management plan of each LULUCF project (Madlener, Robledo, Muys, & Freja, 2006).

In many countries, implementing policy involves high transaction costs, mostly because of poor coordination and overlapping functions among ministries, and lack of transparent financial monitoring (Murdivarso, Brockhaus, Sunderlin, & Verchot, 2012). There is also a need to have clear land tenure and land-use rights regulations and a certain level of enforcement, as well as clarity about carbon ownership to prevent corruption. Implementation challenges, including institutional barriers and inertia related to governance issues, make the costs and net emission reduction potential of near-term mitigation uncertain (IPCC, 2014c).

4.2.3 The promise and potential of international cooperation

Guidance and Signal Function

A global objective for the LULUCF sector could provide important guidance to countries and relevant sectoral actors. Such a target could be to halt and reverse deforestation and, more generally, to turn

the LULUCF sector from a net source to a net sink of GHGs, e.g. by 2030. An important challenge consists in making such a global objective concrete for specific contexts taking into account biophysical, geographical, and socio-economic variability and differences.

Setting Rules to Facilitate Collective Action

The primary need for international action in the LULUCF sector is about providing economic incentives to preserve forests, re- and afforestation. This can especially be achieved by schemes of "results-based payments" (payments per tonne of mitigation achieved), which can be arranged for internationally through concrete agreements between forest countries as recipients and donor countries or international organisations providing the necessary resources. The inclusion of social and environmental safeguards is important to prevent and contain social and environmental externalities. The value of forests goes much beyond their role in the global carbon cycle and prioritising climate change mitigation runs the risk of limiting the livelihoods especially of poorer and weaker segments of the population relying on forests and of sacrificing other important environmental and sustainability objectives (such as biological diversity). Lack of an international agreement that supports a wide implementation of mitigation measures can become a major barrier for realising the mitigation potential from the sector globally (IPCC, 2014c).

Transparency and Accountability (including compliance)

The effectiveness of the aforementioned results-based payments entails important requirements regarding transparency and accountability. Reference levels need to be defined as baselines against which the success of efforts to preserve and enhance forests cover can be measured. Also, monitoring of actual results is required in order to verify achievements, including monitoring beyond project boundaries to control for possible leakage. Providers of results-based payments typically seek reliable verification (UNFCCC, 2007). Remotely sensed data supported by ground observations are key to effective monitoring (DeFries et al., 2007).

Means of implementation

As mentioned, financial incentives adapted to regional/national and local circumstances will be needed to achieve significant reductions in emissions through reduced deforestation and forest management.

Given the lack of institutional capacity amongst a number of developing countries to ensure the sustainability of LULUCF activities, capacity building mechanisms are needed. These need to address in particular the legal frameworks that regulate land tenure and ownership of environmental services that are essential for designing and implementing LULUCF projects, as well as the required coordination between the responsible institutions at the national and sub-national level.

Knowledge and Learning

Important knowledge gaps with respect to the LULUCF sector can be addressed by internationally coordinated efforts, including regarding the accounting methodologies for forests and soils (see also on Transparency and Accountability above), appropriate regulatory frameworks at national and subnational levels, how to address and control carbon leakage, social and environmental externalities, etc. A geographical information system integrating inventory, monitoring, mapping, etc. of all environmental data concerning a project area would also be useful (Madlener et al., 2006).

Linkages

Agriculture, and more specifically the food industry, causes indirect GHG emissions by being the primary cause of global deforestation (Friends of the Earth, 2007).

There is also a link with the transport sector through bioenergy which is energy derived from biofuels. Biofuels are fuels produced directly or indirectly from organic material – biomass – including plant materials and animal waste. Rising demand for biofuels produced from palm oil, soy and other play a major part in the loss of forests (The World Counts, 2014).

The power sector is implicated since forests are one (potentially growing) source of biomass for electricity production. In the future, burning biomass in power stations could be one way of achieving negative emission if the resulting Carbon is captured a stored underground (bio-energy carbon capture and storage – BECCS).

Both the industry and buildings sector are big consumers of wood. Logging is responsible for 14 per cent of the emissions in the LULUCF sector (UNFCCC, 2007).

4.3 Waste

4.3.1 Current status and prospect

The global waste sector (waste and wastewater) contributed three per cent of global GHG emissions or about 1.5 $GtCO_2eq$ in 2010/12 (IPCC, 2014d; WRI, 2012). Major GHG emissions from the waste sector are CH_4 from landfills, CH_4 and N_2O from wastewater, and small amounts of CO_2 (from the incineration of fossil carbon) (IPCC, 2014d). Minor levels of emissions are released through waste treatment and disposal (UNEP 2010). CH_4 is the second most abundant GHG after CO_2, accounting for 14 per cent of global emissions with an impact 25 times greater than CO_2 when a time horizon of 100 years is considered. Global anthropogenic CH_4 emissions for 2010 stood at 6,875 million metric tonnes of CO_2 equivalent of which CH_4 emissions from landfills was 11 per cent while that from wastewater was nine per cent (Global Methane Initiative, n.d.).

The waste sector is a USD 1.5 trillion per annum market and is expected to grow to USD 2 trillion by 2020 (Stiehler, 2017). According to Hoornweg and Bhada-Tata (2012), 1.3 billion tonnes of solid waste are generated each year by cities around the world, a figure expected to grow to 2.2 billion tonnes by 2025. Globally, waste volumes have risen from 0.68 billion tonnes in 2002 (Hoornweg & Bhada-Tata, 2012). Key drivers include population growth, industrialization and urbanization particularly in emerging markets, Gross Domestic Product (GDP) growth, and shorter product shelf life of electronic devices.

There are four key categories of waste: municipal solid waste (MSW) (which includes residential waste, industrial waste, commercial and institutional waste, construction and demolition waste, and municipal services waste), process waste, medical waste, and agricultural waste (World Energy Council, 2016). MSW represents the largest type of waste and is predominantly an urban phenomenon with waste per capita rising as economies develop. Industrial, commercial, and institutional (ICI) wastes usually represent more than half of MSW (Hoornweg & Bhada-Tata, 2012).

The type and quantity of waste differs amongst countries (and within countries) according to levels of economic development, degree of industrialization, public habits, and local climate. In 2010, high income countries generated half of global MSW (IPCC, 2014d). However, waste generation rates are set to more than double over the next twenty years in lower income countries. In 2004, China overtook the US as the world's largest waste generator. Organic waste tends to be higher in low-income countries' MSW, while paper, glass, and metals are higher in high-income countries' MSW (Hoornweg & Bhada-Tata, 2012).

Solid waste management (SWM) is an essential utility service. The waste management sector has followed a hierarchy of "reduce, reuse, recycle, and recovery" which can be adapted to financial, envi-

ronmental, social and management considerations while also encouraging minimization of GHG emissions (Hoornweg & Bhada-Tata, 2012). However, much of global effort has focused on recovery instead of the first three.

The IPCC (IPCC, 2007) advises that GHG emissions from waste can be mitigated by effectively addressing integrated waste management given that most technologies for waste management are mature and have been successfully implemented for decades in many countries. There are eight main kinds of waste disposal methods/technological options: landfills, incineration/combustion, recovery and recycling, plasma gasification[4], composting, Waste to Energy (WtE)[5], and waste minimisation[6] (Conserve Energy Future, n.d.). Other methods include anaerobic digestion[7] and pyrolysis[8]. On the high end of the spectrum are technologies like pyrolysis and gasification, which are already applied in a number of OECD countries, especially in the EU (IPCC, 2007).

Small wastewater treatment systems include pit latrines, composting toilets and septic tanks (inexpensive and most widely used around the world). Activated sludge treatment is the most conventional method for large-scale treatment of sewage. (IPCC, 2007).

However, waste to landfills continues to be the most common method of MSW management in developed countries while in developing countries MSW is generally disposed off in open dumps. In the US, 52.9 per cent of MSW generated is disposed off in 1,908 landfills (EPA 2015) which annually emit over 426 million metric tonnes of CO_2 equivalent to the GHG emissions from 124 coal-fired power plants over a 20-year impact (Bailey, 2017). Nonetheless there has also been progress. In the EU, the landfill directive (Council Directive 1999/31/EC), strictly enforced by member states has helped reduce waste to landfills from 220kg/capita in 2006 to 122kg/capita in 2015 (Eurostat, 2016). Landfills are also prevalent in certain developing countries. In 2013, almost 70 per cent of China's household MSW was still ending up in landfills (Zhang, Huang, Xu, & Gong, 2015). In the rural areas of low-income countries, it is common to have no controlled disposal. However, waste collection is a challenge and fluctuates from 98 per cent in OECD countries, to as low as 20 per cent in low income countries (Hoornweg & Bhada-Tata, 2012). It is closely linked to income levels. In low income countries, waste collection services can take up almost 80-90 per cent of a municipality's SWM budget while the same could represent around ten per cent of a municipality's budget in a high-income country where collection is more mechanized, efficient, and frequent (Hoornweg & Bhada-Tata, 2012).

One part of the solution can be WtE (Florin & Madden, 2017). WtE technologies are a viable option for disposal of MSW and energy generation with the possibility for every region to adequately assess its specific context to implement the most reasonable solution (IPCC, 2007). The global WtE market is fast growing. Europe is the largest and most sophisticated WtE technologies market (47.6 per cent of total market revenue in 2013) but China is fast catching up (World Energy Council, 2016). It is estimated that for every ton of waste that goes through a WtE facility, a ton of GHG emissions is avoided. Paul Hawken

---

4 Use of plasma torches operating at +10,000 °F to create a gasification zone of 3,000 °F to convert solid or liquid wastes into a syngas, typically used for hazardous materials and generates renewable energy.

5 Conversion of non-recyclable waste items into useable heat, electricity, or fuel through various processes, which can help carbon offsetting by reducing the need for fossil fuels.

6 Reducing the creation of waste materials

7 Used for mainly organic material like industrial effluent, wastewater and sewage sludge treatment to reduce organic matter in the absence of oxygen

8 Thermochemical decomposition of organic material at high temperatures in the absence of oxygen or any halogen, used mainly by the chemical industry to for instance turn plastic waste to liquid fuel or recover fuel from tires

(2017) estimates that if 62.6 gigawatts of WtE plants are installed globally between 2020-2050, avoided emissions would equal 1.1 Gt CO2e.

4.3.2 Main challenges and barriers toward decarbonisation

Waste management systems in low and middle-income countries where the majority of the waste growth is expected to come from by 2030, continue to be under-developed and largely inefficient.

- Waste is either transferred to landfills or, as mentioned above, disposed off in open dumps. China is facing a "waste siege" with two-thirds of China's 668 cities surrounded by garbage (Zhang et al., 2015).
- SWM costs remain high, especially in most low-income countries (Hoornweg & Bhada-Tata, 2012) while SWM services serve less than half of the population and cover only between 40–70 per cent of all urban solid wastes (Scarlat, Motola, Dallemand, Monforti-Ferrario, & Mofor, 2015). Problems also typically start at the grass roots level with a start absence of dustbins and community garbage cans even in major cities in the developing world.
- Costs are likely to increase. Globally, SWM costs will rise to about USD 375.5 billion in 2025 from annual USD 205.4 billion currently and will be 5 times more severe in low income countries and 4 times more severe in lower-middle income countries (Hoornweg & Bhada-Tata, 2012).
- Waste collection and recycling in developing countries remains largely unorganised and often involves a large number of informal sector waste pickers – up to one per cent of urban population or at least 15 million people (WIEGO, 2013). In many cities in developing countries, waste pickers at times perform between 20-100 per cent of all waste collection (UNEP, 2010).

In most developing countries, regulations may not be stringent and in the case they are, implementation may remain poor. The lack of effective legislation for SWM partially results in unclear roles/functions of relevant national agencies and lack of coordination among them (Ogawa, 2010). Moreover, SWM legislation in developing countries is usually fragmented, and is spread across clauses on rules/regulations in several laws (e.g., Public Health Act, Local Government Act, Environmental Protection Act, etc.). Enforcement also ensues via different agencies which often results in duplication of responsibilities and gaps/missing elements in effective SWM systems (Ogawa, 2010).

There is also a critical lack of expertise amongst the human resources dealing with waste management planning and operation in developing countries. Many SWM personnel, particularly at the local level, have little technical background or training in engineering or management (Ogawa, 2010).

Awareness remains low in developing countries (Ferronato et al., 2017). Behavioural change through awareness campaigns is one of three measures that can encourage community involvement in cleanliness and waste management along with information diffusion and tax incentives. In civic spaces in some countries, touching waste may produce a social stigma or reflect upon one's social norms or identities (Najib, 2007). A number of developing country governments have indeed initiated cleanliness and awareness campaigns. India for instance has initiated one of the world's biggest cleanliness awareness campaign called Swachh Bharat (Clean India).

One of the biggest barriers to effective waste management is the cost of high technology in comparison with landfilling (World Energy Council, 2016) (which remains the most financially-effective way of waste disposal). While WtE may be an effective solution to both reducing GHG emissions from landfills and in carbon offsetting, quality high-performance WtE remains costly for much of the developing world. Incineration is the most prominent WtE technology in practise globally and is likely to continue (World Energy Council, 2016). Sophisticated WtE can involve a large capital investment and incurs high

operating costs (Zheng et al., 2014). Imported incineration equipment is very expensive. For instance, the total cost of the Shanghai Pudong Waste Incineration Power Plant based on Alstom equipment and technology cost nearly USD 110 million, and the Shanghai Jiangqiao Waste Incineration Power Plant based on Seeger equipment cost USD 144 million. Moreover, WtE can also undermine recycling and can result in GHG emissions and the release of toxic gases (Florin & Madden, 2017).

Quantifying mitigation costs and potentials for the waste sector remains a challenge due to national and regional data uncertainties as well as the variety of mature technologies whose diffusion is limited by local costs, policies, regulations, available land area, public perceptions and other social development factors (IPCC, 2007).

4.3.3 The promise and potential of international cooperation

Guidance and Signal Function

A vision for full decarbonisation of the waste sector and goals to end key emission-causing activities in the sector (uncontrolled dumping and burning, and landfills) (e.g. by the second half of the century) could provide important overall guidance to national governments responsible for designing relevant policies and other actors (UNEP, 2015). This could be accompanied by targets differentiated by region. A global pledge to phase out waste-to-landfills would make the most dramatic impact given that CH_4 from landfills is the main source of emissions in the sector.

Setting Rules to Facilitate Collective Action

International rules hold a rather limited potential. While implementing appropriate waste policies has significant costs, the local benefits that accrue are also significant. Proper waste management systems hence create rather limited competitiveness concerns. Having said that, international regulation could – in combination with providing appropriate means of implementation – in principle help align governments toward the development of efficient national level frameworks for SWM, especially in less developed regions.

Transparency and Accountability

Appropriate provisions would be required to monitor and verify the implementation of any international regulation. In addition, regular monitoring of policies and emissions would allow to take stock of progress.

Capacity Building, Technology and Finance (means of implementation)

The provision of means of implementation (in combination with or independently of international regulation) could help address some of the key barriers to decarbonisation of the waste sector. Capacity building programmes could provide technical expertise, skills building, better management abilities that remain poor across a number of countries/regions, in particular mid-to-low income countries, and raise awareness. One particular aspect concerns the integration of the informal sector waste pickers – approximately 15 million people – into waste collection and recycling services. Mobilising international finance and investment towards effective waste management and recycling across the entire lifecycle of waste will also be necessary to mitigate costs that low-mid income countries face. Accordingly, the United Nations Environment Programme (UNEP) and the International Solid Waste Association (ISWA) advocate increasing “the level of funding on waste management by a factor of 10, from the 0.3 per cent achieved since 2000 to an average of three per cent of total international aid funding in the period from 2015 to 2030” (UNEP, 2015). International cooperation can also play an important role in developing and diffusing available waste management technologies, including affordable WtE technologies.

Knowledge and Learning

Policy and technical knowledge platforms can also help promote awareness, education, and knowledge of available means and promising policies for better waste management. An international database of national and regional data, a progress measurement system, existing financial opportunities, relevant technologies and innovations, efficient treatment methods can also be useful in particular for low-mid income countries**.** International Research and Development (R&D) funding may help further develop adapted WtE technologies.

Linkages

Power: Greater, more widespread use of WtE would help further decarbonise the power sector given the conversion of non-recyclable waste items into useable heat, electricity, or fuel, which help carbon offsetting by reducing the need for fossil fuels. Concerted efforts at a global scale to encourage better SWM coupled with WtE could become a driver for renewable energy in the power sector.

Industry and Appliances: More "reduce, reuse, recycle, and recovery" of waste at a global scale would also positively impact decarbonisation in the (energy intensive and manufacturing) industry and appliances sectors. Greater use of organic waste in the agriculture sector would also reduce the demand for chemicals-based fertilisers.

Agriculture: Less food waste through better management and awareness would help reduce the production pressure in the agriculture sector (also as regards first generation biofuels), thereby reducing emissions.

Circular Economy: A shift to a circular economy which underscores recycling, reuse, less demand for and efficient use of primary resources, including through the use of higher quality materials, products, systems, would reduce emissions in the waste sector.

4.4 Circular Economy

4.4.1 Current status and prospect

The concept of a circular or closed loops economy advocates a transition from the current "take, make, dispose linear economic model" to one which is restorative and regenerative in design (Ellen MacArthur Foundation, 2015). It "preserves and enhances natural capital, optimises resource yields, and minimises system risks by managing finite stocks and renewable flows, working effectively at every scale" (Ellen MacArthur Foundation, 2015). The economic benefits of transition to the circular economy could amount to USD one trillion in material savings (Ellen MacArthur Foundation, 2014). Ecofys and Circle Economy estimate that circular economy strategies can help mitigate around 11-13 billion tonnes of CO2e by 2030, given that production of basic materials generate more than half of the world's GHG emissions and only seven per cent of the materials used by the global economy are currently reused (Ecofys & Circle Economy, 2016).

While the concept is thus broad, we here focus on recycling, reuse, less demand for and efficient use of primary resources, including through the use of higher quality materials, products, systems and business models as core elements of the circular economy (Ellen MacArthur Foundation, 2013).

The circular economy model underpins the shift to business models that combine competitiveness, environmental benefits and product-service systems; and seeks to rebuild capital thereby enhancing the flow of goods and services. It makes an excellent business case by fostering innovation, competitiveness, economic gains, energy savings, environmental benefits, enhanced security of raw materials

supply, social integration, jobs, investment, and more. It also strengthens efforts towards reduced energy consumption and decarbonisation by advocating recycle, reuse, sharing and elimination of waste (European Commission, 2017b).

Key drivers of the shift towards circularity will be urbanisation and population growth, the finite nature of resources, rising production costs, climate change and favourable alignment of enablers (like consumer preference shift to sharing and technological advances) (Ellen MacArthur Foundation, 2014).

Circular economy strategies (recycle, reuse, less demand for primary resources, efficient use of resources, elimination of waste, new business models) can help mitigate emissions. Each year, 60 billion tonnes of raw materials are extracted (W. Haas, Krausmann, Wiedenhofer, & Heinz, 2015). About 30 billion tonnes represent fossil fuels or food. Construction materials account for the second largest share of the extracted raw materials wherein ‘virgin’ materials are exclusively prioritised and reuse options are limited (Ecofys & Circle Economy, 2016). The last group represents most of the other items of daily use (automobiles, appliances, chemicals, and so on). A large proportion of these products have a high potential for recovery, reuse and recycle, lifetime extension and sharing. The biggest impact of circular economy thus can be felt in the energy intensive industrial sector, agriculture, buildings, transport, power and waste.

In the energy intensive industrial sector, recycling can be a particularly potent strategy. Both steel and aluminium are 100 per cent recyclable without loss of quality and with a potentially endless lifecycle. Recycling aluminium and steel requires around five per cent and a third of the energy used and emit five per cent and a quarter of the GHG emissions when compared to primary production (Cullen, 2010; Kechichian, Pantelias, Reeves, Henley, & Liu, 2016). Similarly, currently, only 14 per cent of plastic packaging is recycled globally although it is possible to recycle up to 70 per cent (Ellen MacArthur Foundation, 2016).

In the waste sector, e-waste is one of the fastest-growing type globally at 41.8 million tonnes (Mt) worldwide in 2014, a 25 per cent jump from 2010 figures. Moving from a linear to a circular economy helps manage e-waste which in 2014 represented around USD 52 billion of potentially reusable resources of which little was collected for recovery, or disposed of in an eco-friendly manner (see also section 4.3).

In the agriculture sector, circular strategies like more efficient use of resources and recycling can help reduce emissions, decrease the pressure on production, free up land, water and resources, and foster biodiversity (Ecofys 2016; see also section 4.1). In the transport sector, enhanced use of electric vehicles and sharing services can dramatically lower emissions and help green the system. Automobiles which dominate the transportation and mobility industry (there are 1.2 billion motor vehicles on the road) normally remain idle for nearly 95 per cent of their lifetime (Ecofys 2016; see also section 4.8). Circular strategies can drastically help reduce emissions in the buildings, waste and power sector too (see respective sections).

4.4.2 Main challenges and barriers toward decarbonisation

Some of the key criticisms of the circular economic model relate to the fact that the concept is too broad, it is difficult to assess impact, the shift to new business models is a largely underestimated challenge, the emphasis laid on social aspects is inadequate, and that the environmental impact may be overestimated (in particular longer shelf life of products may require longer energy to create, solar panels and wind farms are difficult to recycle, and that recycling also has an end) (Behrens, Rizos, & Tuokko, 2017).

The time frame to shift to a circular economy at a global scale remains unquantified and assumedly large. Mainstreaming the concept of "circular economy" also presents numerous challenges including

financing, key economic enablers (like pricing systems that support efficient resource reuse, incentives for producers and recyclers to cooperate across specific value chains; and markets for secondary raw materials) (Bourguignon, 2016), skills, remoulding consumer behaviour and business models, and multi-level governance. Transforming the linear economy, into a circular one will entail a radical transformation of entire existing production and consumption patterns (Behrens et al., 2017).

Political barriers exist. In today's globalised world, it is quite common to have parts of one product made in diverse geographic locations including different countries. Closing the loop on products and value chains characterised by geographic dispersion is challenging. Moreover, moving to circularity would impact exporting countries that engage in primary manufacturing, like China, which may turn into a political and competitiveness barrier (Ellen MacArthur Foundation, 2014).

Technical barriers include material complexity (transformation of materials along the value chain rendering it more difficult "to identify and separate materials, maintain quality and ensure purity"), misaligned incentives, sub-scale markets, limited reverse capabilities and infrastructure and lack of enablers (Ellen MacArthur Foundation, 2014). Customers do not always have the right incentives to adopt alternatives models which may be longer-lasting at lower usage costs thereby more economical.

Economic barriers are equally challenging. Establishing more circular business models are inhibited by factors such as competitiveness, higher investments required to change a product design and move from a sales-based to a usage-based model without transfer of ownership, the need to create an integrated reverse supply chain, and achieving scale (Ellen MacArthur Foundation, 2014). Reverse cycles or supply chains are the link between points of recycle, (re-manufacturing) and usage and are difficult to conquer. The absence of markets of scale in reverse cycles, makes it challenging or even impossible for companies to secure quality-controlled and reliable secondary materials and components to complement or replace primary stock (Ellen MacArthur Foundation, 2014). Reverse cycle infrastructure and logistics capabilities remain poor. Moreover waste management mechanisms (landfills and incinerators) remain localised, sorting and efficiently handling different types of materials remains poor, limiting opportunities further (Ellen MacArthur Foundation, 2014). Regulatory measures like Extended Producer Responsibility (where the producers have the responsibility of managing equipment after its end of life), certification programmes, labels and product passports can be a useful tool but do not exist across the board. Moreover, transition will be a costly affair especially for poor and developing countries. More R&D will also be necessary to inform the transition and its requisites.

4.4.3 The promise and potential of international cooperation

Guidance and Signal Function

For a global circular economy, goals related to recycling, reuse, less demand for and efficient use of primary resources in core emission-causing sectors can help achieve progress towards the circular economic model and harness potential benefits given deep interdependence generated by globalisation and the geographic and sectoral dispersion of value chains. A roadmap underscoring different circular economy strategies (across value chains) at a global level will be required to support the shift to a circular economy (Bourguignon, 2016) and can clear some of the vagueness of the concept and the time frame required to shift to a circular economy. In essence, hence, circular economy thinking should be integrated in sectoral strategies and visions (rather than a separate circular economy objective).

Setting Rules to Facilitate Collective Action

Regulatory measures like EPR, passports (with information regarding the components and materials a product including disassembly or recycling at the end of the product's life), labelling and clear materials pricing (to display the real costs of materials including externalities in order to drive efficient use of

resources) (WEF, 2016) can be developed at the international level given the globalised nature of a number of value chains which can help inform consumers about the sustainability of products while helping encourage innovative forms of consumption (e.g. sharing or consuming services) and promoting 'green' public procurement (Bourguignon, 2016). Certification programmes can help confirm the "viability or safety of circular products; optimize and control the use of incinerators to avoid negative effect on materials recycling; and revisit current trade barriers and regulatory grey zones to facilitate transboundary materials flows" (WEF, 2016). Initiatives would most likely have to proceed sector by sector and/or value chain by value chain.

Transparency and Accountability

Related transparency and accountability measures would be needed for implementation of any regulatory mechanisms agreed at the international level, and could include reporting tools which allow stocktaking, confidence building and mutual encouragement.

Means of Implementation

Given the scale of change involved in the transition to a global circular economy, significant international cooperation will be required to develop technical skills which remain currently absent among the workforce at large (Bergema, de Jong, Kraak, Usanov, & van der Gaast, 2016). Quantifying the economic impact and benefits will also be essential.

The shift will require significant international financing options for concrete projects, R&D, asset investments, subsidy payments to promote new business models, and public investment in infrastructure, in particular in developing countries (Bourguignon, 2016) which can also alleviate competitiveness concerns. Bergema et al. (Bergema et al., 2016) estimate that countries with the highest resource rents and few other sectors to fall back on (like many of the African raw material exporters) will be most exposed to a shift to the circular economy in developed regions. They will require assistance.

Knowledge and Learning

Given that the transition to a circular economy involves tremendous transformation across value chains and industries in a score of areas, it will be essential to initiate policy and technical dialogue platforms bringing together various stakeholders, in particular government and business leaders, across the globe. Involvement of business leaders will be essential in order to specify precise criteria for connecting different sectors. Supporting cross-industry collaboration will be critical (WEF, 2016). Sharing of knowledge, best practises, knowhow and expertise with less developed countries is also essential in particular with most of the raw material exporting developing countries given that circularity in one region, say Europe, will have a significant impact on developing countries (Bergema et al., 2016).

4.5 Power

4.5.1 Current status and prospect

The CO_2 emissions from the energy sector contribute some 61 per cent of global GHG emissions. Within that sector, electricity generation is the single largest subsector accounting for some 38.2 per cent of CO_2 emissions from fuel combustion (IEA, 2016a).[9] With respect to the global transformation challenge,

[9] Differentiating CO_2 emissions from heat and electricity generation is challenging, since data is not reported separately in the IEA's CO_2 emissions from fuel combustion data set. We have calculated CO_2

global power supply is a key sector for two reasons: (1) with maturing renewable energy technologies, solutions for zero-carbon electricity are already technically available and (2) for many other sectors electrification of processes is the most promising mitigation strategy. This holds for example for transport and emission intensive basic materials such as steel and cement (Ahman, Lechtenbohmer, Nilsson, & Schneider, 2016).

Despite the availability of low-carbon alternatives, global CO_2 emissions from electricity generation have been rising at an average rate of around three per cent annually between 2000 and 2014. Only after 2011 has this trend started to level off somewhat. While growth in electricity demand (and hence electric output) remained largely stable, the emission intensity of global electricity has started to slightly decrease after 2011 (IEA, 2016a). Since the latest data is available only for 2014, it is at this point difficult to assess whether this trend is robust, although recent developments with respect to coal consumption in China and India (see more below) indicate that in fact it may be robust.

Historically, electricity has been supplied by five energy sources: coal (hard coal and lignite), natural gas, oil, (large) hydro power, and nuclear power. Only recently have other renewable energy sources (wind, solar, geothermal, tidal, and bioenergy) started to assume a more significant share of the global power mix. While the stock global power generation capacity is still heavily dominated by fossil fuel, nuclear and large hydro power plants, the lion's share of investments has shifted towards renewable energies in recent years, both in terms of dollars spent as well as in terms of capacities added (Frankfurt School/UNEP/Bloomberg, 2016). The following paragraphs synthesise key developments with respect to all of the above-mentioned technologies.

Coal used to be the backbone of the majority of the world's power systems. And coal still is both abundant as well as relatively cheap. For many developing countries therefore, investing in coal capacities was considered a viable way of fuelling their rapid economic growth. Consequently, coal capacities were expanded dramatically. If existing capacities and only a fraction of generation capacities currently in the planning are utilized to their full technical life-time, the remaining global carbon budget will already be consumed entirely (Ottmar Edenhofer, 2015). However, there are some signs that the coal boom may come to an end. In the US, coal consumption and production has plummeted in recent years, partly due to regulation under the Obama administration and partly by stiff competition from shale gas and renewable energies (see below). In the wake of this downturn, Peabody Energy, the largest private coal mining enterprise had to file bankruptcy in its domestic US market (Reuters, 2016). The most dramatic turn away from coal was witnessed in the United Kingdom (UK). On 21 April 2017 the UK saw the first working day without coal power since the onset of the industrial revolution (Brown, 2017). Also China and India drastically cut their respective coal project pipelines and China even halted ongoing constructions on new coal power plants (Shearer, Ghio, Myllyvirta, Yu, & Nace, 2017).

Ever since the IPCC's Special Report on CCS in 2005, there has been profound hope that CCS would make a substantial contribution to reducing CO_2 emissions from the power sector (IPCC, 2005). There was particular hope that CCS would help to bring about "clean coal".[10] CCS is a combination of mostly

---

emissions of electricity generation by multiplying the reported CO_2 emission factors per electricity output [tonnes CO_2/kWh electricity generated] with reported global electricity output [TWh]. For 2014 this calculation yields a total of 12360 Mt CO_2, i.e. some 9.3 per cent less than the 13,625 Mt reported jointly for electricity and heat.

10 The issue of CCS is not restricted to emissions from fuel combustion but may also cover industrial emissions (see section 4.6). Furthermore, many scenario modelling exercises come to the conclusion that negative emissions will be necessary to attain the well below 2/1.5°C target. These negative emissions could be achieved by combining the combustion of bio-energy with CCS (BECCS). However, we do not consider BECCS as an integral part of the power sector's transformation challenge and therefore do not cover this important issue here.

proven technologies. However, to date there are no commercial scale projects in the power sector that proof that the concept is working not only technical theory but also in socio-economic reality. To change this, the IEA has set a goal to establish 100 CCS demonstration projects across the globe in 2009. However, in 2013 the IEA had to change this goal to only 30 projects in 2020. And given the current pipeline of CCS projects it may be even difficult to meet this much humbler target. Overall, there are only three demonstration projects operational in the power sector and only one of them has come online after 2010 (Gaede & Meadowcroft, 2016).

Among fossil fuels, natural gas has the lowest specific emission factor at combustion. However, gas extraction and in particular hydraulic fracturing (fracking) can lead to inadvertent diffuse CH_4 emissions that necessitate a significant increase of the emission factor. The recent boom in natural gas production was driven primarily by this technology. Annual production rose from 21.23 million terajoules (TJ) in 2010 to 29.43 million TJ in 2015 in the US alone (IEA, 2016d). Cheap natural gas was one of the main reasons for the decline of coal consumption in some regions such as the US. With respect to global trade of natural gas, another trend was observed in the recent decade: increasing investments in liquefied natural gas (LNG) technology and infrastructure. LNG terminals and supertankers unshackled natural gas from pipeline infrastructure and made natural gas a globalized commodity (IEA, 2016e).

The global share of nuclear power has been in decline over the last decade (EIA, 2017). While 60 reactors are currently being built, mostly in developing countries and emerging economies, numerous reactors are rapidly approaching the end of their technological lifetime (IAEA, 2017). What is more, a number of countries have reversed their nuclear energy policy after the Fukushima catastrophe and committed to phase out (e.g. Germany) or reduce the reliance on (e.g. France) nuclear energy. A common thread among all nuclear reactors currently under construction, at least in industrialized countries, is heavy cost overruns. This holds for example for constructions in Finland, the US, and France (Gilbert, Sovacool, Johnstone, & Stirling, 2017). In the UK, the planned nuclear station in Britain, Hinckley Point C, could only attract investors after the government had guaranteed a hefty feed-in tariff. The rate is already now much higher than what is usually paid for wind power and will not decrease over time but automatically increase with inflation (UK Department of Energy and Climate Change, 2013). All things considered, the "nuclear renaissance" that was proclaimed repeatedly in the past is far from materializing.

Renewable energy represents the most dynamic part of the global power sector. Technology costs for solar and wind power have been falling sharply. For example, global average utility-scale levelised cost of electricity of solar photovoltaics (PV) fell by around 58 per cent between 2010 and 2015 and the cost are projected to continue to fall (IRENA, 2016). When levelised costs of electricity are considered, renewable energies are already competitive in many markets. In particularly well-suited locations, renewable energies are providing some of the cheapest electricity ever produced. Examples include solar PV in United Arab Emirates that was recently contracted at 2.4 ct/kWh (USD) and wind power in Morocco at ~3 ct/kWh (USD) (Dipaola, 2016; Parkinson, 2016). In the wake of this development, there has been a strong uptake in investments in renewable energy, particularly in emerging economies. India and China are not only among the leading markets, but have considered the renewable energy industry a priority for industrial policy and hence have become leading suppliers for renewable energy technologies (REN21, 2016).

Cleaning up power supply is, however, only one strategy. Clean renewable energy supply simply cannot or at least not economically ramped up fast enough to maintain current consumption levels. This is particularly true if it is assumed that developing countries will catch up to levels comparable to current consumption in industrialized countries. 2°C-compatible IPCC scenario therefore generally project steep increases in energy efficiency on the consumption side (IPCC, 2014a). While energy efficiency improvements are an essential element of the transformation of the global power sector, they have

to be realized in the consuming sectors. For the sake of clarity, energy efficiency measures are therefore discussed in various other sectors.

Beyond these technical challenges, there are a number of other developments with relevance to the power sector that are worth mentioning here. One issue is the central role that electric power plays in human development. Basic access to electricity can be considered a necessary condition for the eradication of poverty (IPCC, 2012). Still more than 1.2 billion people, predominantly in rural areas in Africa and Asia still do not have access to electrical energy (IEA, 2015b). Providing electricity to these people is therefore considered a priority and was therefore included as a separate Sustainable Development Goal and is reflected in the majority of NDCs submitted under the Paris Agreement.

Another issue of importance to the power sector is the global fossil fuel divestment campaign that has been relatively successful in convincing (institutional) investors to remove shares in companies that generate a large part of their revenue in the fossil energy industry from their investment portfolios (see section 4.13 for a more detailed treatment of the divestment campaign) Additional to these general trends, the sectoral transformation challenges are very diverse in different countries. Key characteristics that determine these differences are the following:

- renewable energy potentials;
- existence of domestic fossil fuel reserves;
- structure and ownership of the power market;
- state of the power system (grid infrastructure, current power mix).

4.5.2 Main challenges and barriers toward decarbonisation

The physical pre-conditions for renewable energy deployment differ greatly across countries. Correspondingly, differ the transformation challenges and barriers. Countries with a high share of hydro power for example have the advantage in that hydro power can typically dispatched flexibly to accommodate variable power supply from intermittent renewable energy sources like wind and solar power. For countries without such endowments other technical solutions will need to be developed.

With respect to technological aspects the need for storage capacities is one of key challenges. Two different types of storage will be necessary to ensure the stability of power systems with high shares of intermittent RE, particularly wind and solar power: (1) short-term storage that can substitute large rotating masses in thermal plants who used to help buffering variability in frequency and voltage in a matter of split seconds up to a couple of minutes (ancillary services). In the shorter term, the need for storage can be reduced by making electricity demand more responsive (Palensky & Dietrich, 2011). Currently, power demand is largely inelastic and does hardly respond to short-term price hikes. Enabled by smart grids (and smart appliances) demand could be managed in order to shift some of it from peak load hours to hours with lower demand and/or more abundant renewable energy supply. (2) long-term storage will be required to balance out seasonal variability in the availability of RE. Energy storage is still dominated globally by pumped hydropower. Still, both research spending as well as investments in battery storage have been skyrocketing in recent years. As a matter of consequence, battery costs have plummeted at rates similar to those seen in the cost reductions of Solar PV (IEA, 2016c).

Another key technical challenge to be addressed is the update and re-build of existing grid infrastructures. In countries that historically relied on fossil fuelled power generation, power plants typically where built at locations that are close to the centres of electricity demand (i.e. major industrial centres). Contrastingly, renewable energy generation units will be located wherever the potentials are highest. This is often in rather rural areas without large amounts of demand. While in prototypical

fossil fuelled power systems the role of distribution networks was mainly one of interconnecting industrial hubs and thus hedging against the risk of black outs, the task in a prototypical RE-based power system is one of connecting centres of supply to the centres of demand. This may require fundamentally different grid layouts and enormous investments over the coming decades (IEA, 2016c).

This leads us to economic barriers. In the economic realm, two broad challenges are standing in the way of a global transformation of the power sector: an investment challenge as well as a market-design and dispatch challenge. The investment challenge directly relates to Art. 2.1c of the Paris Agreement, "[m]aking finance flows consistent with a pathway towards low GHG emissions and climate-resilient development." Current investments in renewable energy in 2015 amounted to nearly USD 286 billion (REN21, 2016). Yet, in order to have a chance of limiting global warming well below 2°C annual investments in the ballpark of one trillion will be required (Ceres, 2014). At the same time, investments in fossil fuel infrastructure need to be phased down and out.

The issue of high costs for renewable energy technologies has become much less important recently. Technology costs have plummeted in particular for solar PV and wind and this likely to continue (IRENA, 2016). This is not to say, that costs have become a non-issue. Despite low cost for the hardware, renewable energy can become excessively expensive if an unfavourable general investment climate (high prime lending rates) drives up capital costs and if a lack of local expertise and skilled workers drives up the soft costs of installing and maintaining renewable energy systems. Also, cost distribution may be an issue, including regarding equity and fairness.

The second challenge is one of market design. Since the early 1980s numerous countries have started to liberalize (and privatize) their respective power markets. Typically, these markets are organized with power spot markets at their core. Prices at the spot market are based primarily on marginal generation costs. Most forms of RE, however, do not feature marginal generation costs. Wind and solar energy is generated when the wind blows or the sun shines, irrespective of the wholesale price for electricity. In markets with particularly high shares of electricity with zero marginal costs, the market design approaches its limits. Prices are generally low and can even become negative. In consequence, the spot market loses to essential functions. Firstly, the spot market cannot ensure that investments – irrespective of whether in renewable energy or fossil fuel capacities – cannot be recouped over the project lifetime without other revenues streams. Secondly, the spot market loses its ability to organize the dispatch of power plants, i.e. signalling which plant should be generating power to satisfy the exact current level of demand and which plant should not be running. Creating a competitive market system that ensures that long-term investments can be recouped and that efficiently organizes dispatch for systems with very high shares of intermittent renewable energy is still not on the horizon.

The challenges and barriers differ among countries also in the way the power sector is structured. While in some countries, the sector is dominated by privately owned utilities, in many countries utilities are state-owned. In some countries, institutional linkages between government and utilities is particularly close and amount to what Unruh has called a "techno-industrial complex" from which strong systemic change resistance must be expected (Unruh, 2000). Increasing deployment of renewable energy can contribute to a diversification of the ownership structure in the power sector. For example, in Germany investments in renewable energy were largely driven by municipal utilities, small energy cooperatives and even individuals (Schmid, Knopf, & Pechan, 2016).

Last but not least, human capital and social barriers need to be highlighted. Implementing global energy transformation towards renewable energy requires a skilled workforce. In many developing countries technical capabilities and skilled workers are still a bottleneck for the scaled-up renewable energy deployment (Hirsch, 2015). Social barriers include issues such as energy poverty. Changes in the provision of electricity may result in shifting costs and payments. In the course of the transformation of global power sectors, particular attention needs to be paid to avoiding potential effects that policies

may have on marginalized communities so as to avoid increased incidence of energy poverty (Cherian, 2015).

4.5.3 The promise and potential of international cooperation

Guidance and Signal Function

The signalling function of international governance is of particular relevance for the power sector. Investments in the sector are extremely long-lived. On the one hand, this means that investments in fossil fuel infrastructure today may literally cement a carbon-intensive pathway for the next decades. On the other hand, this long-term perspective requires investors to make investment decisions to a large extent on the basis of long-term expectations of the sector and the economy in general as opposed to the market conditions of the day. When countries credibly agree on long-term visions and goals for the sector, this may alter the investors' expectations about the viability of their projected investments and hence their investment decisions of today. The more specific the vision is, the more impact it is likely to have on the investment decisions.

One particular example relates to investments in CCS. One of the key barriers is that potential investors face split incentives. Investing in CCS may help to "future-proof" the sector, yet this may come at significant short-term financial risks (Gaede & Meadowcroft, 2016). Also, the countries that have the strongest interest in developing CCS are those that have vested interests and/or large fossil fuel reserves. Yet, this interest is contingent on ambitious climate policy. In the past, many of those countries have rather focused on delaying aggressive climate action (de Coninck & Bäckstrand, 2011). A strong international signal could help shift the political economy so that interest and consequently investment in developing CCS increases.

Setting Rules to Facilitate Collective Action

There are various ways in which the power sector transformation in one country interrelates with the sector transformation in other countries. The most direct interdependence relates to global trade and competition. Power systems are connected through markets for fossil fuels, as well as globalized technology markets for all types of energy technologies, including renewable energy technologies and battery storage. Since electricity is an essential input to almost all industries, there may be indirect competition among countries: if in the course of a sector transformation a country experiences (temporary) electricity price increases, energy intensive industries may migrate to another country with lower electricity prices. A power sector transformation can thus become an issue of industrial competitiveness for the country. Moreover, international direct interdependencies may exist in the form of multinational corporations. However, in the power sector this may be less of an issue than for example in the extractive industries sector. While some multinational utilities exist, the majority of the power sectors are dominated by nationally operating utilities. Last but not least, regional spill-overs exist, where power systems are physically interconnected.

Rule-setting to facilitate collective action is a second key function for international governance, particularly to address concerns of industrial competitiveness. Coordinated target setting could address such concerns at least partially. Moreover, possible approaches for international cooperation include joint research programmes, patent pooling and removing trade barriers.

Where power grids are regionally interconnected, regional governance approaches may be conducive. Inter alia, coordinated investments in the grid infrastructure could minimize the need for storage capacities as variability in renewable energy supply to some extent balances itself out over large geographic distances.

Transparency and Accountability

Transparent reporting and monitoring can support and help reinforce rules, targets and/or standards collectively agreed as outlined above.

Means of Implementation

Another leverage point for international governance is mobilizing the means of implementation of the sector transformation. In particular, international cooperation could help address the investment challenges described above. Typically, renewable energy investments incur the lion's share of their lifetime cost in the form of upfront investment costs while featuring low or even close to zero operating costs later on. For countries in which difficult investment conditions prevail, this becomes a critical barrier for renewable energy investment. Due to high prime lending rates and currency related risks, capital cost can render renewable energy technologies, which would otherwise outcompete the alternatives, uneconomical. This argument also holds for any highly capital intensive component of the energy system including storage and grid infrastructure. At the same time, there is no lack of investors looking for opportunities to invest. If ways were found to enhance the attractiveness of investments in sustainable power systems, this could strongly expedite the transformation of power sectors across the globe. International governance may especially contribute through arrangements for sharing the increased financial risks for investments in developing countries.

Means of implementation in terms of international transfer of renewable energy and energy storage technologies as well as capacity building both (administrative and technological) as well are highly conducive for a successful transformation of power systems.

Knowledge and Learning

Learning and knowledge diffusion can also make a significant positive contribution to expediting global power sector transformations. For example, a successful sector transformation in one country may demonstrate the feasibility of transformation. Ideally, more success would demonstrate that there are numerous configurations that work, encouraging other countries to pursue the transformation of their sectors and at the same time providing orientation. This includes for example governance learning: which policies work and which political processes are promising in order to forge alliances and align interests. It also pertains to learning of management and organizational practices including for example effective market designs for high RE-share power markets. Furthermore, if successful transformations take place in large enough markets, this can lead to de-facto standard setting of technological parameters.

These kinds of spill-overs could be supported inter alia by creating (international) fora in which experimentation and good practice sharing with respect to policies and political processes can be facilitated, e.g. with respect to market designs and long-term planning procedures.

4.6 Energy-intensive industries

4.6.1 Current status and prospect

The global energy-intensive industry sector contributes 21 per cent of total global GHG emissions (IPCC, 2014a). Global industrial emissions have grown from 5.4 Gt CO_2eq in 1970 to 8.8 GtCO_2eq in 2010 or around 63 per cent (Kechichian et al., 2016). Emissions from the energy-intensive industry sector comprise mainly of direct energy-related emissions, indirect emissions from electricity and heat production, process emissions and a tiny percentage from waste/wastewater (IPCC, 2014a). Other GHG emissions from industry are mainly N_2O emitted during the production of ammonium and adipic acid and sulphur

hexafluoride (SF_6) from aluminium production. The sector accounted for around 29 per cent of the final global energy consumption in 2012 (IEA, 2014b), more than 70 per cent of which comes from fossil fuels (Kechichian et al., 2016). Fossil fuels account for 74 per cent, 85 per cent and 85 per cent of the iron and steel, cement and chemical industries' energy consumption respectively (Kechichian et al., 2016). Aluminium is the only energy-intensive industrial subsector that relies mostly on electricity as its energy supply (Kechichian et al., 2016).

Table 4.1: GHG Emissions Overview of Energy-Intensive Industries in 2010

Sub-Sector	Total Emissions (in $MtCO_2$)	% of Industry Emissions
Iron and Steel	2410	24.05 per cent
Cement (as part of non-metallic minerals)	1910	19.06 per cent
Chemicals	1880	18.76 per cent
Aluminium (as part of non-ferrous metals)	690	6.89 per cent

Source: Kechichian et al. 2016 (total emissions) and Ecofys 2013 (share of industry emissions)

This section focuses on four key energy-intensive industry subsectors: iron and steel, cement, chemicals and aluminium which constitute 68.76 per cent of industrial emissions (Kechichian et al., 2016); Table 4.1). These four subsectors have grown sharply in the past decades driven primarily by globalisation and dramatic growth in developing countries and countries with economies in transition. One of the most important raw materials used today, global crude steel production stands at 1,628.5 million metric tonnes (Mt) (2015) (World Steel Association, 2017), up from just 200mt in 1950. Cement, the second most consumed material on the planet, has seen a dramatic growth – from 133mt in 1950 (U.S. Geological Survey, 2015) to nearly 4.1 billion metric tonnes in 2015 (Olivier, Janssens-Maenhout, Muntean, & Peters, 2016). The chemicals industry, the largest amongst the industrial subsectors in monetary value, has also expanded significantly, from USD 171 billions in 1970 (Perlitz, 2008) to USD 4.1 trillion in 2013 (Consultancy.uk, 2015). Aluminium is a key enabling metal and is the world's third largest consumed metal after steel and copper and production of new aluminium results in one per cent of total global annual GHG emissions (Tyabji & Nelson, 2012).

Over the past half century, industry emissions have risen sharply amongst the low to upper middle income countries as compared to a gradual decline amongst high income countries. Some of the key exogenous trends driving developments in these subsectors have been the pursuit of growth in the developing world strongly supported by public policy incentives and globalisation, lower production costs, population rise alongside growing per capita income. Production growth of energy intensive materials (in particular steel and cement) in emerging economies, closely linked to large infrastructure construction and urbanisation.

Few countries dominate these industrial subsectors – China, the EU, the US, Japan and India. China is currently overwhelmingly the largest producer and consumer in all the four subsectors and one of the top five importers and exporters. Asia is the most important region accounting for nearly 65 per cent of steel use (World Steel Association, 2016), more than 75 per cent of global cement consumption, and 61 per cent of total global chemical sales. Production and demand is highly concentrated in Asia, although it is growing in other developing regions like the Middle East, Latin America and Africa. For

instance, the most rapid growth in the cement sector is seen in Sudan, Peru, Nigeria, Turkey, Colombia, and Brazil (Kechichian et al., 2016). These "fastest risers" between 2003 and 2013 have compensated recent contraction in mature markets, such as the EU and the US Industrialised nations although innovative, face a comparative disadvantage in these subsectors given lower input (e.g. energy costs, labour or raw material) and larger domestic demand in the global south.

Next to a geographic concentration in Asia, these industries are also dominated by a few private sector companies. The World Steel Association lists 94 global steel companies who produced almost 60 per cent of the total global crude steel production of 1,628.5mt in 2015 (World Steel Association, 2017). Fifty of these companies are based in China while fourteen others are based in India (5), Japan (4), South Korea (3), Taiwan (1) and Australia (1) (World Steel Association, 2016). Similarly, just 10 companies produce almost half the world's aluminium. More than half of the top 50 chemicals companies are headquartered in just eighteen countries. Twelve are in the US, eight in Japan and six in Germany. BASF, headquartered in Germany is the world's largest chemical company since a decade, with USD 63.7 billion sales in 2015, down from USD 78.7 billion in 2014 (Tullo, 2016). The cement subsector is more speckled in comparison. According to the Global Cement Directory 2016, there were 2273 active integrated cement plants around the world in 2015 (Saunders, 2015).

Trade in the iron and steel and chemicals subsectors is highly globalised: nearly a third of all steel produced is traded (US Department of Commerce, 2016). In the aluminium sector, most aluminium products are traded with regions or countries. For instances, China which produces nearly half of global aluminium is self-sufficient while no single country accounts for more than 13 per cent of the import or export market (Ludwig & Van Houwelingen, n.d.). However, the trade intensity of products using aluminium (e.g. cars, laptops, …) is of a much higher trade intensity. Finally, the cement subsector is predominantly regional. Cement production is significantly local: virtually every country produces cement and only three per cent of global production is traded internationally (The Economist, 2013).

Deep decarbonisation potential and drivers

The model used by the IEA's (2017) Energy Technology Perspectives (IEA, 2017a) shows that a 2°C scenario requires global direct CO2 emissions from industry to be reduced by 44 per cent by 2050 and halved by 2060 compared with its baseline scenario. However, to reach net-zero CO2 emissions at the system level, by 2060, which is required for a beyond +2°C scenario, industry would need to further reduce its carbon emissions by 69 per cent by 2050 and 80 per cent by 2060 compared with the baseline scenario (IEA, 2017a).

Technology solutions for decarbonisation and modernisation across industrial sectors can be categorised broadly in three areas (Kechichian et al., 2016); energy efficiency improvements (in processes), low-carbon substitutes (for materials and fuels) and innovative and alternative processes.

For most existing industrial processes there still is an overall potential to improve energy and process efficiency (e.g. by closing old inefficient plants and investing in best available technologies and best practice solutions already exist that focus largely on relatively easy retrofits which have quick paybacks (Kechichian et al., 2016). However, energy and process efficiency will meet the law of diminishing returns (i.e. more effort required to achieve lower gains), the closer these processes get to thermodynamic or chemical optimisation.

Low-carbon substitutes for materials and fuel inputs are being explored on a global scale (e.g. use of municipal waste and biomass in cement production). The future potential of this option can be significant in some sectors (e.g. biomass based feedstock or use of waste gases from other industries in chemicals production), but will depend on the (limited) availability of these substitutes. (CEFIC, 2013, p. 112).

Table 4.2: Deep Decarbonisation Options

Sector	Deep decarbonisation options
Steel	• Improving energy efficiency beyond best available technologies • New Smelting Reduction Technologies • Direct Reduction of iron ore using natural gas or hydrogen • Using electricity for iron ore reduction • Use of biomass in steel production • Higher levels of steel recycling (while maintaining quality) • Use of waste gases from cokes/iron/steel production as feedstock for chemicals production • Carbon capture and storage
Cement	• Higher energy efficiency of processes and fuel switching (to low carbon fuels) • Reducing clinker content in concrete • Innovative changes to the composition of concrete • Enhanced concrete and cement recycling • Extend lifetime of concrete (e.g. through self-healing concrete) • Carbon capture at process level or during concrete formation • CO_2 utilisation
Chemicals	• Major improvements in resource/energy efficiency of processes • Higher use of (renewable) electricity e.g. for production of H_2 • Higher use of biomass (waste), waste and recycled materials including utilisation of waste gases from e.g. steel industry and industrial symbiosis • Development of advanced (plastics) recycling processes
Aluminium	• Use of non-oxidising anodes in primary aluminium production in combination with highly efficient processes. • Improvement of recycling technologies to maintain different aluminium type qualities • Establishment of circular value chains and leasing of metals.

Source: Based on European Commission 2017a.

The use of innovative and alternative processes will be essential for deep decarbonisation of industrial sectors. This includes higher levels of electrification of energy intensive processes (using renewable energy sources) and the use of carbon capture, utilisation and/or storage. Table 4.2 below gives a brief overview of some major new (or improved) processes that would enable deeper emission reductions in industrial sectors.

Next to the (process) technology solutions, deep emission reductions in industrial sectors will also require a value chain approach that covers the supply and value chains across different sectors. Steel, cement, chemicals and aluminium producers mostly make intermediate products and hence have limited impact on the use of intermediate goods in the final consumer or other products (e.g. cars, airplanes, buildings, …). Therefore, reducing the basic materials' intensity in these end products through smarter design, efficient consumption and enabling a circular resource model will need to be part of the over-all mitigation efforts related to the emissions of the basic materials sectors. A behavioural switch to a circular economy can make its mark on the wider market and the carbon footprint of the industrial sector by reducing demand, recycling and underscoring greater efficiency. The concept of a circular economy which is "a continuous positive development cycle that preserves and enhances natural capital, optimises resource yields, and minimises system risks by managing finite stocks and renewable flows" (Ellen MacArthur Foundation, 2015) can potentially have a direct impact on emissions

reduction[11]. While the concept of a circular economy is pervading the regional level and at best the national echelon (mostly limited to certain sectors), it remains largely absent at the global level. A transition towards more circularity (recycling, waste to energy, and so on) would certainly aid decarbonisation efforts. However, circularity remains poorer in the developing countries than in the developed ones (see also Section 4.4 on the circular economy).

4.6.2 Challenges and Barriers towards deep Decarbonisation

Activating low-carbon interventions in industrial sectors depends on the presence of a combination of variables (Kechichian et al., 2016). These include the ability to provide quick paybacks from low-carbon investments and a minimal operational disruption; the capital expenditure (CAPEX) of the intervention together with access to finance (and the cost of capital); the cost of current inputs in processes compared to the low-carbon substitutes; a strong and globally implemented carbon policy and the extent to which competitors around the world are implementing GHG mitigation measures.

The main barriers or challenges for deep decarbonisation are a combination of technological inertia, the high capital expenditure and risk associated with new (process) technologies, the reluctance to impose ambitious GHG regulations or CO_2 costs due to fear of loss of international competitiveness or impeding development and the complexity of global value and supply chains (Bennett & Heidug, 2014).

Technological inertia and R&D mismatch

The basic materials industries such as the ones covered in this section almost all saw their major disruptive process innovations happen by 1970-1980 (Freeman & Soete, 1997). Large production installations mostly see incremental, but still important, improvements in energy and mitigation of GHG emissions. Since these sectors use large (and costly) process installations the investment cycles are long. This prevents an accelerated take-up of new breakthrough technologies, especially if these replace incumbent installations. Furthermore, the basic materials industries (with the exception of chemicals) have an over-all low R&D intensity (expressed as R&D expenditure over revenues) compared to other industrial sectors[12]. One can even see an R&D mismatch with smaller new entrants in these sectors showing more interest in R&D but having lower means to do so compared to larger incumbent companies. These smaller companies also lack sufficient market access (into e.g. consolidated cement, steel and chemicals markets) to further their innovative products and processes.

High Capex and technology risk of new breakthrough process technologies

Beyond the relative low R&D spending and the possible R&D mismatch there exists also an important barrier at the latter, demonstration to commercialisation, stage of R&D into low carbon technologies (e.g. technology readiness level 6-9). These large scale pilot and demonstration plants, the final steps towards commercialisation, require a high level of capital expenditure. At the same time, the still experimental nature of these installations comes with an important technology risk.

---

11 Both steel and aluminium are 100 per cent recyclable without loss of quality and with a potentially endless lifecycle. Recycling aluminium requires around five per cent of the energy used to produce primary aluminium and emits as little as five per cent of the GHG emissions when compared to primary aluminium production (Kechichian et al., 2016). Steelmaking from scrap uses one-third of the primary energy and emits a quarter of the emissions as compared to steelmaking from iron ore (Cullen, 2010). However only a third of all aluminium produced today comes from old, traded and new scrap (International Aluminium Institute, 2009). Similarly, 650 million tonnes of steel are recycled globally every year or only less than one-third of global production.

12 See the JRC's EU and global R&D scorecards 2016 http://iri.jrc.ec.europa.eu/scoreboard16.html

The innovative technologies, while promising, are therefore generally not yet deployable, financially less attractive, require longer paybacks and may necessitate longer operational shutdown periods to integrate changes in production process/existing assets. Some promising technology options may therefore never become mainstream solutions.

Competitiveness and development concerns

Across most countries in the world there is resistance by these industrial sectors to externalities being priced (fully) in or being faced with a stringent regulatory environment related to GHG mitigation. In industrialised nations, incumbent producers fear that a high(er) price on CO_2 emissions and/or a full exposure to a CO_2 price would, in the absence of similar measures in most other countries around the world, deter further investments, leading to so called investment leakage. Commonly accepted regulations and standards could create a global level playing field which could foster competitiveness in the right direction (Kechichian et al., 2016).

In developing countries (that see high levels of growth in basic materials production), on the other hand, introducing price on CO_2 emissions is often seen as stunting development and the construction of necessary infrastructure for an increasing and more affluent population. Notwithstanding these concerns, a growing number of industrialised and developing countries are adopting a form of carbon pricing. While it is hard to quantify or even prove the above-mentioned concerns, they are clearly part of the political discourse and hence shape both domestic and international positioning and policies.

Global complex value chains vis à vis the national bottom up approach of the Paris Agreement

Finally, as stated before, deep decarbonisation in industrial sectors will require addressing the whole value and supply chains related to these industries. Over the past decades these value chains have grown to become more complex but also more global in scale. This issue is connected to the problem of accounting for embedded emissions (i.e. the GHG emissions embedded in imported goods). In practice, this means that a basic materials company is not (always) able to track and control the end use of its products. This makes closing value chains (circularity) difficult and/or expensive. It therefore prevents the wide-scale introduction of new business models such as the transition from a sales-based model to one in which basis materials are leased and returned to the original producer for re- or upcycling. Future governance for these highly globalised sectors operating across borders does not fully match the approach under the Paris agreement which asks each country to develop *nationally* determined commitments and long-term decarbonisation plans.

Some of the above-mentioned barriers can be negatively reinforcing. For instance, the low R&D intensity of (many) energy intensive industries in combination with the large CAPEX need for breakthrough technologies. The high technology and financial risks related to these technologies can, in case of failure, hamper the competitiveness on companies and hence make them more risk averse.

4.6.3 The Promise and Potential of International Cooperation

Guidance and Signal Function

A clear international 'decarbonisation' objective with firm timelines and differentiated (national, regional and global) mitigation pathways could provide important guidance to decision-makers in industrial sectors. This could be achieved through the construction of global roadmap(s) for decarbonisation of energy intensive industries, e.g. built up from national, regional and existing sectoral roadmaps. These roadmaps should present an integrated view of how the industries can transform their supply, production and value chains while maintaining competitiveness (Ahman et al., 2016) and not infringing economic development.

Given the disparities highlighted between regions, each economic region may need a low carbon roadmap including trajectories for the industrial sectors which need to be embedded within the other parts of the economy that form the downstream demand for the products of the energy intensive sectors. Resource efficiency linked to a (global) circular economy will need to be a part of the development of such roadmaps. Coordinating these (sectoral) global and regional roadmaps with national decarbonisation plans (developed under the Paris Agreement) will be a requirement.

Setting Rules to Facilitate Collective Action

Given the globalised nature of energy-intensive industries, there is a clear rationale for international regulation (to address competitiveness and carbon leakage concerns). Collective action to enable the decarbonisation of industrial sectors can be realised through (a combination of) different (regulatory) instruments. Regulation could take the form of carbon pricing (be it a (coordinated) CO_2 tax or a global emissions trading system, e.g. through linking regional trading systems) or (coordinated) international regulations and/or standards. These can be targeting the production processes (e.g. CO_2 emission limits per tonne of product produced) or the consumption side (limit on embedded emissions in final product; see Neuhoff et al. 2014). Short of international agreement, national and regional frontrunners can pave the way to broader approaches. Regulating embedded emissions in final products could help create a level playing field between global industrial producers because 'end of the value chain' pricing would not discriminate between local and foreign production.

Transparency and Accountability

For any international regulatory approach, it is important to have common MRV standards for industrial emissions, preferably even including the whole supply and value chain, as a basis for comparing and verifying efforts. Transparency of GHG impact in semi- and finished products across complex and global value chains would require common/global GHG accounting standards.

Means of Implementation

Global cooperation on innovative technology deployment (including the financing thereof) is urgent. According to the IEA, going beyond 2°C will require OECD countries to transfer innovative technologies for industry to non-OECD countries where new capacity installations increase the potential to widely deploy innovative industrial process technologies. This has to happen very soon to avoid carbon lock-in/stranded assets (IEA, 2017a). Processes and platforms enhancing bilateral and multilateral diffusion of technology and research cooperation – such as the Mission Innovation[13] initiative – could foster such cooperation.

Such international cooperation would also need to address the high capital cost and risk associated with large industrial breakthrough technologies. One option would be R&D cooperation that combines the knowhow and finance present in different countries and at different stages in the technology readiness level. Such an approach could make use of the different stages of industrialisation around the world to make use of available resources efficiently. While potential for building new large low-carbon demonstration plants particularly exists in emerging economies, more advanced economies could pioneer circular economy related technologies. Such international innovation program could be implemented through a global industrial innovation fund in combination with coordinated international technology projects (along the lines of the ITER nuclear fusion project). Leveraging private capital to enable these investments will require the active participation of large national or regional investment banks.

---

[13] http://mission-innovation.net

Knowledge and Learning

To the extent the aforementioned technology cooperation involves the development of innovative technology, it will also support the creation of technical knowledge. Beyond that, decarbonising industrial sectors (at a global level) will also require a significant investment in circular economy policies and the realisation of domestic enabling conditions for industrial innovation (e.g. innovation and industrial policies). Global coordination and dissemination of knowledge and learning in relation to industrial decarbonisation is therefore relevant, in particular given the complexity of supply and value chains of industrial sectors. For instance, sharing best practices on circular economy, industrial and innovation policies through a *global knowledge & learning depository/platform* can accelerate the implementation of enabling conditions in a wider group of countries.

Linkages

Power: Substituting fossil fuels in the production process with electricity would increase the demand for electricity, which if not decarbonized would result in higher emissions in this sector.

Agriculture and LULUCF: Some of the possible substitution/innovation options involve higher demand for biomass.

4.7 Extractive industries ('losers')

4.7.1 Current status and prospect

Remaining within a 2°C carbon budget requires most global fossil fuel reserves to remain unexploited. McGlade and Etkins (McGlade & Etkins, 2015) find that a third of oil, half of gas and over 80 per cent of coal reserves should remain untouched from 2010 to 2050 (see fig. 1). Achieving this, however, is a daunting challenge. In 2012, the IEA warned that on current trends, enough new fossil fuel-based infrastructure – mines, power plants, pipelines, refineries etc. – would come online by 2017 to lock-in the remainder of emissions allowable (IEA, 2012). Fossil fuel extraction and trade are widely perceived as central to energy security and economic development, especially in developing countries with large unmet energy needs (Manley, Cust, & Cecchinato, 2017; Whitley & van der Burg, 2015). Both production and consumption of fossil fuels continue to be widely subsidised. Multinational companies in the sector(s) are significant wealth generators and underpin the returns to many pension funds in developed counties. Given this context, climate policy, at domestic and international levels, has focused almost exclusively on curtailing demand for fossil fuel energy, neglecting supply - at least until recently. But it is increasingly recognised that effective climate policy requires action on both (SEI, 2015).

Governments own over 50 per cent of global production of fossil fuels through full or majority-stake ownership of producing companies (Whitley & van der Burg, 2015). National oil companies control 80-90 per cent of proven global oil reserves (up from less than ten per cent in the 1970s), with most engaging international oil companies in a variety of contractual arrangements. Because of this shifting ownership, international oil companies have focused on hard-to-access (e.g. deepwater) and hard-to-recover (e.g. oil sands, shale oil) reserves that cost more than the current price of oil to develop (Holmes, 2017).

Coal production has grown since 2000, particularly in China (see figure 2). However, China's National Bureau of Statistics suggests the world's biggest producer and user reduced its consumption in 2016

(for the third year running) by 4.7 per cent (ref). China is also reducing huge subsidies to coal power, although the figure is still double what is received by renewables.[14]

Figure 4.3: 'Unburnable' Fossil Fuels to Remain within 2°C Carbon Budget

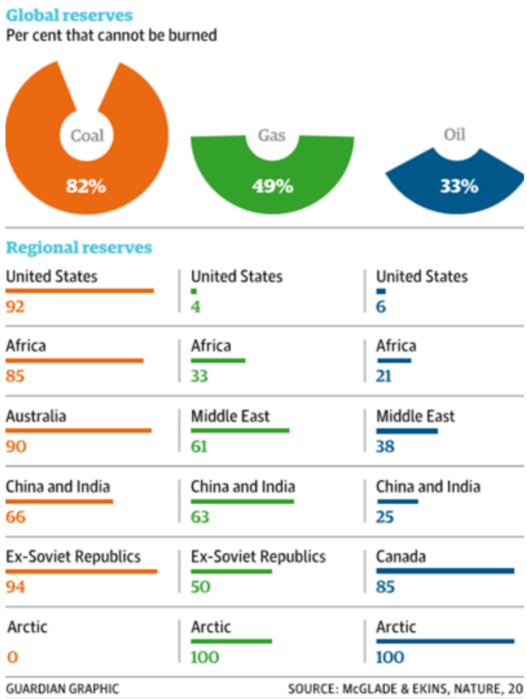
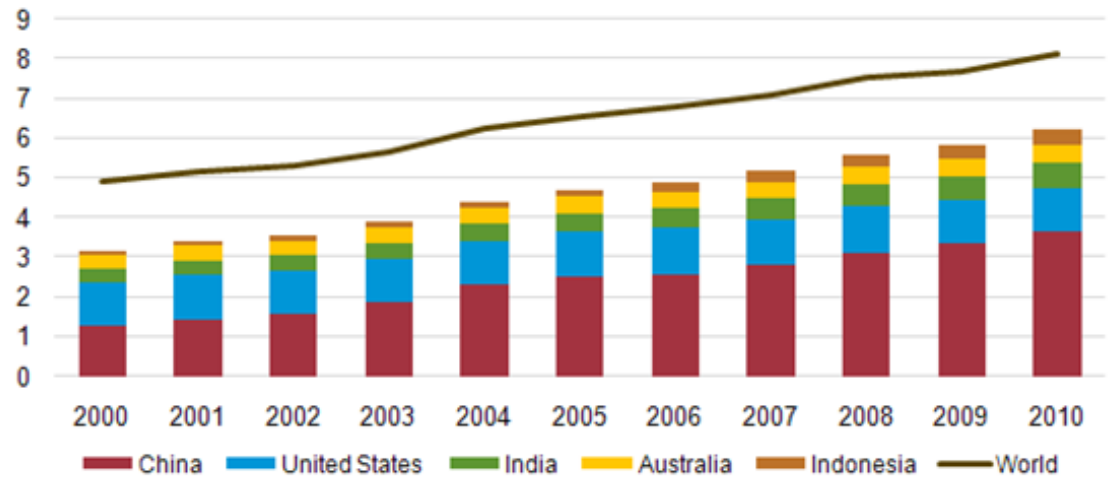


Figure 4.4: Top 5 Coal Producers (billion short tonnes)

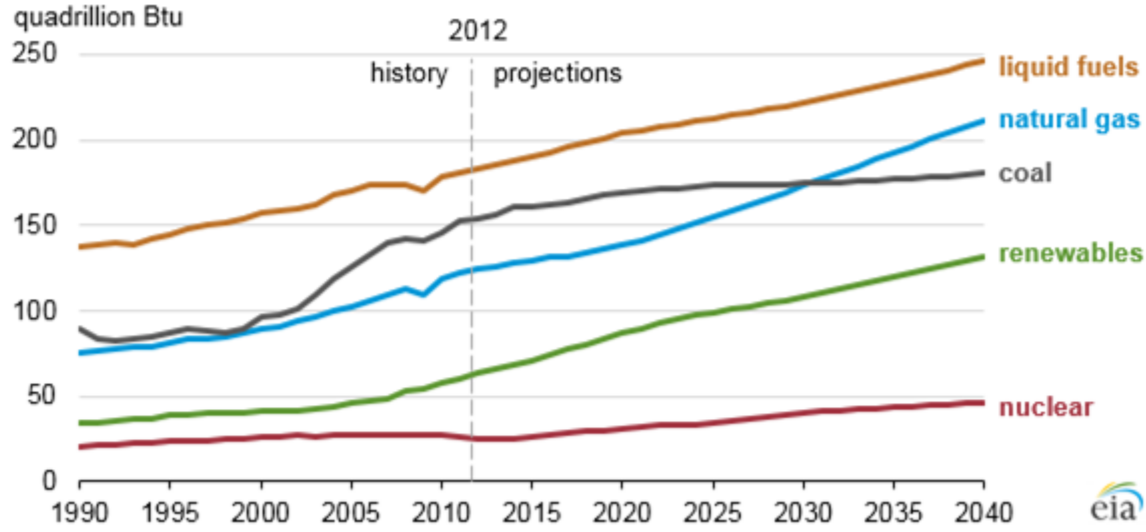


Source: US Energy Information Administration. *https://www.eia.gov/todayinenergy/detail.php?id=3350*

[14] The value of Chinese government subsidies to coal-fired generation was estimated as at least CNY 252 billion (USD 37.7 billion) in 2014 and CNY 120 billion (USD 18 billion) in 2015 (Denjean et al., 2016).

Consumption of coal, however, looks set to level out (figure 4.5).

Figure 4.5: World Energy Consumption by Source, 1990 – 2040.



Source: US Energy Information Administration https://www.eia.gov/todayinenergy/detail.php?id=26212

A particular focus in this section is the role of subsidies to fossil-fuel extractive industries, and prospects for their reduction. This is because extraction (and current consumption levels) depend to a significant extent on subsidy. Continuing current levels of subsidy to production globally has been estimated to lead to the emission of over 37 $GtCO_2$ from 2017 to 2050 that would otherwise not occur - roughly equivalent to burning all proven US and Norwegian oil reserves (Gerasimchuk et al. 2017). G20 public finance for exploration of new reserves averages USD 13.5 billion annually (Doukas, DeAngelis, & Ghio, 2017). Consumption subsidies also undermine mitigation efforts, potentially making other sectors of the economy (e.g. transport) more dependent on fossil fuels (Manley et al., 2017). Other damaging effects of production and consumption subsidies include undermining the attractiveness of low-carbon investments, discouraging private research and development (R&D) on new low-carbon energy technologies, and obstructing technology transfer (Whitley & van der Burg, 2015). Subsidies tend to lock-in patterns of activity, preventing dynamic responses to changing circumstances (Whitley & van der Burg, 2015). Although originally intended to be short-term, they often become embedded in planning and expectations, prices (including of capital), resource allocation etc., creating new vested interests.

Though estimates vary - because precise definitions are not agreed - the IEA estimates that fossil fuel subsidies (FFS) amounted to USD 493 billion in 2014 (up from USD 300 billion in 2009) and exceed renewable energy subsidies by more than four to one (IEA, 2015c). Estimating their extent is complicated by substantial data gaps because of limited transparency at the national level, and a full accounting of global energy subsidies (for all types) has never been completed. As a result, it is likely that existing figures are under-estimates (Whitley & van der Burg, 2015). Production is supported by a wide range of subsidies that include, *inter alia*: direct payments; preferential access rights to energy deposits; credit and insurance support; caps on liabilities; tariffs or export restrictions; government ownership of power generation (Koplow & Charles, 2010). Consumption subsidies may improve access to

affordable energy, but tend to benefit higher income groups more (Asmelash, 2017; Whitley & van der Burg, 2015).

Signs of destabilisation

In the oil and gas sector, demand is falling in many regions as energy efficiency measures take effect. In future, substitution with other fuels, the development of lower cost low-carbon technologies as well as increased efficiency will further reduce demand, and also limit price rises in the longer term (Holmes, 2017). Declining oil prices from 2014 have encouraged Middle East and North African (MENA) countries to undertake economic diversification efforts; all regional oil exporters now have strategies in place (Tagliapietra, 2017). Reforms have been undertaken in almost 30 countries in 2013 and 2014, in several cases spurred by falling oil prices. Many have seen the recent drop in oil prices as a 'once-in-a-generation opportunity' to slash subsidies and introduce a carbon price. However, others warn that falling commodity prices lead to a parallel rise in demands for production subsidies, as demonstrated by calls from UK North Sea oil producers for tax breaks (Whitley & van der Burg, 2015).

The G7/G20 and APEC, among other multi-lateral institutions, have strongly urged decarbonisation. The G20 (G20, 2009) committed to phasing out 'inefficient FFS,' and encouraged national strategies to do so while protecting the most vulnerable. The G7 subsequently pledged to end all fossil fuel use by the end of the century (G7, 2015).

Shareholder activism and legal challenges represent a further, increasing threat to 'business as usual'. A 2017 shareholder resolution requires annual assessments of the impact that the 2°C goal will have (by reducing future oil and gas demand) on Exxon's business (Darby, 2016). Two of the world's largest asset managers, BlackRock and Vanguard, voted in favour. However, institutional investors are unlikely to divest *en masse*. Instead, annual assessments are more likely a first step towards energy companies diversifying into clean technology or returning money to shareholders (Darby, 2016).

What needs to change?

Precise recommendations for 'roadmaps' towards decarbonisation of extractive industries depend on the scenario envisaged for wider mitigation efforts (for example, how widespread will CCS technology become, how will growth in e-mobility disrupt the oil market) and economic/ societal pathways.[15] As noted in the introduction, McGlade & Etkins (McGlade & Etkins, 2015) offer one possible breakdown, sectorally and by region, of what needs to be left 'in the ground'. This makes clear that the biggest 'contribution', in terms of assets left unrecovered, will need to be from coal, given its higher carbon content.

For oil, there is a degree of consensus that exploration does not need to stop entirely in the lowest-income countries (Manley et al., 2017; Tagliapietra, 2017). Costs of development and extraction vary significantly across different geology, so it may be worthwhile for certain countries to allow exploration for reserves that may be less expensive to extract - even after a carbon tax is factored in (Manley et al., 2017; Tagliapietra, 2017). In the IEA's '450 scenario' (consistent with a 50 per cent chance of 2°C), demand falls sharply after 2020. Lower production costs that allow export competitiveness to be maintained mean that Middle Eastern exports, however, are assumed to continue at 2020 levels until 2040 (IEA, 2016e). But lower prices over this timescale will see oil rents decline significantly. Thus, oil exporting MENA countries' entire economic, social and political models must change (at a time of significant demographic change), to transform them from 'rentier states' into more economically diverse 'production states' (Tagliapietra, 2017).

---

15 On disruption to oil markets caused by changes in the transport sector, see Arbib & Seba 2017.

4.7.2 Challenges and barriers toward decarbonisation

Decisions about fossil fuel production and consumption are closely linked to national sovereignty and perceived interests, and energy policy questions more broadly remain largely the prerogative of national decision-makers (Van Asselt & Kulovesi, 2017). This applies even to relatively well-integrated regions, such as the EU.

The likelihood of stranded assets raises public policy concerns about financial instability and a growing pension deficit, particularly in developed countries such as the UK (Holmes & Orozco, 2017). Unlike the large coal-based energy companies, their oil and gas counterparts – both international and national – can be regarded as too big to be allowed to fail.[16] Countries are more vulnerable than private companies. Diversification by international oil companies could potentially address developed country governments' concerns around loss of oil revenue and the need to shore up of companies in the short term through tax credits. On the other hand, pension funds and insurers would need to develop other sources of reliable returns as dividends paid by the oil companies dwindle (Holmes & Orozco 2017. The situation for countries is more challenging: not only is it more difficult to shift capital and capabilities, they are also tied, geographically and constitutionally, to ownership of reserves which cannot be sold outright but only licensed to companies for development. By contrast, companies could, if they wanted, run down their existing reserves in less than 15 years (Manley et al., 2017).

A further obvious challenge relates to equity considerations and the importance of securing a 'just transition' (L. Hermwille, 2017). But 'while there is growing interest … in supply-side climate policy options, the attendant equity questions have received relatively little attention' (Kartha, 2016, p. 1). Trillions of dollars in 'foregone rents' may be at stake, constituting a substantial share of GDP in many cases (Kartha, 2016). Control over fossil resources is unevenly distributed among countries, and often also among regions and individual economic entities within them. So too are the benefits of exploiting them. That some stand to lose much more than others from any future constraints on extraction (McGlade & Etkins, 2015) constitutes a huge challenge to multi-lateral efforts.[17]

As Hermwille (L. Hermwille, 2017) notes, phasing out of coal, oil, and gas 'would have to be planned and executed in a proactive, long-term way and systematic new economic perspectives would have to be developed for the affected regions'. But to date, a lack of incentives encouraging economic diversification is evident (Tagliapietra, 2017). For MENA oil exporters, this problem is exacerbated by private investors' unwillingness to invest in non-oil, potentially import-substituting sectors, for fear that when oil prices rise, so will value of the currency of foreign exchanges, making exports less competitive.

On the specific issue of FFS, though widely recognised as desirable from efficiency and climate protection perspectives, their removal also raises serious equity issues. Benefits of subsidy reform – particularly in the short term – will be unevenly distributed and strongly dependent on the approach and complementary (compensatory) measures adopted (Whitley & van der Burg, 2015). Complementary measures should aim to improve the competitiveness or viability of those who stay in the sector(s), support those who want to leave the industry or to diversify into other activities, and take into consideration the potential of the private sector to create new opportunities (Caldecott, Sartor, & Spencer,

---

16 For example RWE's market cap is around USD 8.4 billions compared to Exxon Mobil's USD 314.5 billions (Holmes, 2017).

17 Edenhofer et al. (O. Edenhofer, Flachsland, Jakob, & Lessmann, 2013) estimate the value of the GHG emission endowments that are created by establishing a cap-and-trade system ('climate rents') at around US USD 1 trillion per year. They argue that 'a major and so far perhaps underappreciated challenge of climate policy negotiations is to deal with what may be largest distributional negotiations the global community has ever engaged in'. As Kartha (Kartha, 2016) notes, this applies even more to fossil fuel extraction rents.

2017; Whitley & van der Burg, 2015). FFS are particularly high in the MENA region, where they are estimated at 13 per cent of GDP and 35 per cent of government revenues (Caldecott et al., 2017; Whitley & van der Burg, 2015).

The main challenges to multilateral action will be to define what constitutes FFSs, achieve transparency about their application, bridge the developed-developing country gap, and to set out enforceable obligations with implementation timelines (Asmelash, 2017). The cross-cutting nature of the issue means that the global effort to phase out FFSs lacks an obvious, single institutional home at the international level (Asmelash, 2017). Arguably, a single international organization is needed to coordinate otherwise fragmented efforts, provide a forum for negotiations towards an international agreement, and oversee its implementation.

Researchers have identified several reasons for the persistence of subsidies (Whitley & van der Burg, 2015), together creating a dangerous inertia. A principal reason for lack of progress regarding both producer and consumer subsidies is lack of information. A 2015 inventory of FFS uncovered about 800 types of subsidy, mainly in national budgets, but even that did not cover all factors causing artificially lower prices (OECD, 2015b). Most are not clearly identified in standard government budget documents (Whitley & van der Burg, 2015). In order for governments to be fully accountable for their commitments, there is an urgent need for more transparent and comparable information. The important role of special interests also needs mention. Because the benefits of subsidies are often concentrated, while the costs are spread across the general population (i.e. consumers and taxpayers), political leaders face asymmetric incentives. The lack of countervailing a lobby strengthens vested interests' chance of blocking subsidy reforms (Asmelash, 2017). The economic and political power of the fossil fuel sector has enabled them to strongly influence domestic (and indeed international) climate and energy policies, and to be successful shapers of public opinion (Kartha, 2016). A further implicit reason lies in the weakness of institutions: governments sometimes subsidise fossil fuels because they lack other effective means and institutional capacity to implement more targeted policies (Whitley & van der Burg, 2015).

4.7.3 Promise and potential of international cooperation

Here we try to describe the role and importance of each international governance function, first for extractive industries in general, then specifically concerning FFS reform.

Guidance and Signal Function

In principle, there is a clear need to signal the resolve of governments and others, indicating 'likely policy trajectories to business, investors and other actors operating at all levels' (see section 3 above). Consensual and deliberate transition away from extraction of fossil fuels requires a common understanding of its necessity and urgency. Strong international signals can help to achieve this common understanding, based on the learning and knowledge described under the previous heading. The section above on barriers notes how pension funds and insurers would need to develop other sources of reliable returns as dividends paid by the oil companies dwindle. Strong signals from global institutions would facilitate this.

Setting rules to facilitate collective action

Ideally targets would be set and implemented through a global instrument, recognised as equitable. As stated in Section 3, 'agreement on collective action requires agreement on the contribution of each individual party and hence on a burden-sharing'. To date, international climate negotiations have focussed on determining *who can emit* how much from fossil fuels. Theoretically, they could go on to ask *who can extract* how much in terms of fossil fuels, establishing a form of 'burden sharing agreement'.

The *Kyoto 2* concept (Tickell, 2008) suggests a global system, implemented through the UNFCCC, whereby the bulk of GHG production rights are allocated by regular global auction open to all bidders. Producers of fossil fuels and industrial GHGs would need to hold sufficient rights to match their production. Auctioning of permits could credibly raise a sum of about EUR 1 trillion per year for a multipurpose Climate Change Fund, with an emphasis on addressing the needs of the poor and most adversely impacted. The concept would be a bold re-orientation of current international efforts, and thus a great challenge to negotiate.

Transparency and Accountability

Global regulation would require monitoring and verification of implementation. It makes most sense to discuss this predominantly in terms of FFS (see dedicated discussion below).

Capacity Building, Technology and Finance (means of implementation)

It has been suggested that the problem of lack of investment in boosting the private sectors of MENA countries, which perpetuates their status as 'rentier' rather than 'production' states could be remedied by strategic investment by sovereign wealth funds (Tagliapietra, 2017). This would require 'strong governance and forward-looking visions on the part of governments' (Tagliapietra, 2017), and would benefit from international-level coordination.

See also specific discussion of subsidy reform, below.

Knowledge and Learning

To help overcome the current stalemate over the supply-side of climate policy, Kartha (2016) suggests improving knowledge and understanding around particular questions (the current absence of which prevents strong recommendations on improved international cooperation in this section as a whole). Such improved knowledge could begin to shift engrained perceptions of the 'national interest' in fossil-fuel production-reliant countries. Relevant questions include, *inter alia*:

- How far does fossil fuel extraction really contribute to development, given documented 'negatives' including environmental and human rights impacts, concentration of wealth and power, Dutch disease[18] and geopolitical instability? Such an assessment could inform efforts to decide how extraction could be distributed so as to maximize development benefits.
- What are the distributional impacts of policies constraining extraction? When are domestic steps sufficient, and when might international support be appropriate to help alleviate regressive impacts?
- What 'just transition' lessons can be learned from other sectors? What obligations may some nations bear to support just transitions in other nations, analogous to support for mitigation and adaptation?
- Which countries' resources should stay in the ground, and which should be exploited?
- How to decide on the above: based on economic efficiency, ethical principles, a combination, mediated by tradeable "extraction rights"? Is there a role for command-and-control approaches, e.g. a 'coal non-proliferation treaty'?[19]

---

18 A situation where growth in national income from natural resource extraction damages other sectors of a country's economy, by raising the value of the currency.

19 See e.g. https://thinkprogress.org/a-simple-proposal-a-coal-power-non-proliferation-treaty-a7132622a7dd

International cooperation on fossil fuel subsidy (FFS) reform

In the more specific field of FFS reform, the following governance functions can be highlighted as requiring attention if the kind of barriers we have identified are to be addressed seriously, and as areas where feasible policy actions exist.

Knowledge and Learning, and Transparency and Accountability

As noted above, one of the main challenges is to define what actually constitutes FFSs, to pre-empt denials that they exist.[20] Then, international institutions will be in a position to help address them. As Whitley and van der Burg (Whitley & van der Burg, 2015) observe, while domestic reforms can proceed without internationally comparable data, this information can facilitate valuable lesson learning and evaluation of progress, creating peer pressure and enabling cross-country comparisons of the effectiveness of different interventions on FFS. They set out a range of possible initiatives, from mandatory to voluntary. Mandatory reporting on FFS (following the model for agriculture) is conceivable. Among the more voluntary proposals is to include reporting on FFS in UNFCCC National Communications. Country commitments to transparency can also be widened and strengthened when government's already committed to reform insist on subsidy reform in bilateral or multilateral trade agreements (Whitley & van der Burg, 2015).

Guidance and Signal Function

Language on language on phasing down "high-carbon investments and FFS" could be included in the negotiated outputs of the UNFCCC in order to widen and strengthen country commitments (Whitley & van der Burg, 2015).

Setting rules to facilitate collective action

Some suggest that stronger regulatory steps beyond the voluntarism reflected in recent inter-governmental initiatives will be necessary:

> 'Past precedent suggests that such commitments may not translate into actual subsidy reforms, and, even when they do, the reforms tend to be vulnerable to oil price shocks, public protest, and changes of political regime. Without any mechanism that ties their hands, reluctant governments often find it easier to renege on their voluntary commitments …' (Asmelash, 2017; Tagliapietra, 2017).

Asmelash and Birhanu suggest that it may take a core group of 'like-minded' countries to push for multilateral, binding action. Others (J. Smith & Urpaleinen, 2017) see the feasibility of coercion as limited, and prefer peer pressure through international organisations such as G20 and Asia Pacific Economic Cooperation (APEC).

Means of Implementation

There is a strong need for this function to be fulfilled in terms of FFS reform. Whitley and van der Burg (Whitley & van der Burg, 2015) suggest the need to increase technical and financial support for national efforts, and to ensure climate finance is not used to support fossil fuels. Resources and finance for 'complementary measures' in developing countries, such as support for health services, education, social protection, energy-sector development and economic diversification, need to be linked to sub-

[20] Saudi Arabia, for example, has reported that it had no inefficient FFS and therefore 'phasing out inefficient FFS does not apply to Saudi Arabia' (J. Smith & Urpaleinen, 2017).

sidy reform processes, either in terms of institutional arrangements or careful timing. It will be important to not only increase these resources, but to also foster linkages between existing support mechanisms and the processes of reforming FFS.

International institutions can put in place financial and other economic incentives, particularly for developing countries: by indicating clearly that fossil fuel subsidy reform is part of a country's mitigation portfolio, the likelihood increases that such actions can be eligible for support. Even though national–level subsidy reform is more likely to be triggered by economic and fiscal motivations, the climate regime could strengthen the case for reform by offering these incentives (Van Asselt & Kulovesi, 2017).

Overall, the primary channels for greater international ambition and action on FFS reform may be summarised as: 'bodies for reporting, tracking and accountability; financial and technical support, which must be diverted from providing subsidies and towards reform; multilateral and bilateral agreements (including on trade); and a greater understanding of the processes being undertaken by regions and countries that are already leading by example in reforming subsidies to fossil fuels' (Whitley & van der Burg, 2015).

4.8 Transport

4.8.1 Current status and prospect

The transport sector is one of the fastest-growing emission sources worldwide. In the period 1990-2014, total sectoral emissions from fuel combustion grew by 71 per cent and reached 23 per cent of global CO_2 emissions (7.5 $GtCO_2$) in 2014 (IEA figures, including emissions from road, domestic navigation, domestic aviation, and other domestic transport, but also marine bunkers and aviation bunkers, see section 4.9) (IEA, 2016a).

5.7 $GtCO_2$ of these were emitted by road transport alone (IEA, 2016a). And the role of the transport sector is set to become more prominent even if the world manages to embark on a 2°C compatible pathway. The majority of 2°C-compatible scenarios analysed for the fifth IPCC report indicate that transport will contribute the single largest share of emissions in 2050 as emissions from industry, buildings and electricity generation decrease (IPCC, 2014c).

Passenger transport accounted for 60 per cent, freight transport for 40 per cent of global transport energy demand. Urban transport emissions (currently 40 per cent emissions share) are projected to double by 2050 despite technological improvements in the absence of aggressive mitigation policies (Gota, Huizenga, Peet, & Kaar, 2015).

Private road transport is dominated by privately-owned individual vehicles with low use effectiveness and high emissions per person kilometre. Especially in cities, travel distances are comparably low (cf. (Chapman, 2007), and section 4.10).

Nearly all growth in the transport sector, both passenger and freight, is expected to occur in developing countries and emerging economies (SLoCaT, 2015). One of the main challenges of the near future will therefore be to decouple expected growth in transport figures from emissions in these countries. This will not be an easy task, as transport in its current form is highly dependent on combustion of oil products.

- Road transport is almost completely dependent on internal combustion engines running on gasoline or diesel. Electrical power and hydrogen fuel cells are alternative propulsion options, but are not in very high use as of yet.[21]
- Navigation almost exclusively relies on heavy oil.
- Aviation is completely dependent on kerosene, another oil derivative.
- Rail transport to a large extent also relies on diesel fuel, but electricity as an energy source is widely used as well.

Decarbonising transport in industrialised countries will not be any less difficult, but the problem structure is somewhat different. While in developing and emerging countries the main task is to make new transport capacities independent of oil products, transport in industrialised countries already has both the vehicles and the infrastructure that locks in high carbon practices. The task in industrialised countries therefore will be to switch existing transport modes. This means large scale replacement of a system that is largely geared towards servicing combustion-based vehicles with a new system that minimises transport emissions.

Current strategies in the sector to foster more sustainable forms of transport very often rely on the Avoid-Shift-Improve framework towards infrastructure and services (Bakker, van Asselt, Gupta, Haug, & Saidi, 2009; SRU, 2005):

- Avoid travel or reduce travel-length: Ideally, transport infrastructure should be designed in a way that minimises the need to travel, and minimises the length of travel in case of unavoidable travels. This can best be achieved by optimised infrastructures, especially in urban environments (see section 4.10). For freight, this also means infrastructural planning and decisions if (parts of) raw materials or pre-products can be sourced nearer to the areas of production or refinement.
- Shift travel to more climate-friendly modes: If travel cannot be avoided, policies should encourage or regulate that low-emission transport options are favoured over high emission ones. For personal transport, this means to encourage walking and bicycling for shorter travels, and public transport systems for longer distance ones. Policies here often include economic incentives and disincentives (Road pricing, public transport subsidies), and regulations (e.g. car-free zones). For freight, this can mean incentivising the use of rail or boat transport over road freight, which again may take the form of economic (dis-)incentive schemes (e.g. toll systems), but also making sure that needed infrastructures (e.g. rail lines) are in place. For motorised transport in general, electric vehicles have to be made the preferred, and in the medium term only, option. However, to render electric vehicles truly emissions-free will depend on the decarbonisation of the power sector (see section 4.5).
- Improve the energy efficiency of vehicles and fuels**:** Technologically, both fuels and vehicles, but also transport infrastructures such as road surfaces have not yet reached their limits of energy efficiency. Consequentially, policies that foster energy efficiency should be put in place to reap the highest-possible efficiency. Most efficiency improvements are economically positive – policy makers should therefore closely scrutinise barriers to efficiency improvements. It should be clear, however, that energy efficiency improvements tend to lock in certain technological pathways. Therefore, if governance frameworks are to strongly push electro-mobility,

[21] Personal scooters are a bit of an exception, as there is a strong push, especially in China, for electrified scooters. Also, electrically assisted bicycles are increasingly popular and have gained a significant share of the global bicycle market.

it may be counterproductive to spend large resources on efficiency improvements of combustible fuels and engine technologies.

Barring disruptive innovations in the sector that combine technological breakthroughs with societal reconfigurations, these approaches continue to be a promising avenue to "greening" the transport sector. However, it is possible that such an innovation is imminent. A recent prognosis (Arbib & Seba, 2017) comes to the conclusion that the emergence of autonomous road vehicles in conjunction with distributed passenger services (Lyft, Uber) and a growing rate of electric vehicles will lead to a runaway transport revolution towards autonomous transport services that are no longer reliant on personally-owned vehicles, but rather fleets of robotic taxis (Transport-as-a-Service) that are vastly more efficient both in terms of energy use and utilisation. The authors hold that such services would allow vastly cheaper costs per travelled kilometre than current forms of personal and freight transport, and would lead to a significant decrease in vehicle numbers, effectively eliminating congestion and making personally-owned internal combustion vehicles more or less obsolete by 2025, at least in industrialised countries. At the same time, batteries in those autonomous cars would be utilised as storage for the electricity grid, further strengthening option to completely decarbonise power production by alleviating current constraints of power storage. The authors foresee a resulting drop in oil demand by 30 per cent in 2023, leading to a global oil price collapse to about USD 25 per barrel.

The analysis currently is an outlier, though. Most other studies foresee a much slower change towards forms of sustainable transport, though the authors claim that by using systems analysis tools, they are much better able to predict trends in the transport sector. A research note by Bloomberg New Energy Finance from early 2016 predicts a sales of electric vehicles to reach at most 50 per cent of the market in 2040 in the most optimistic scenario (Morsy, 2016).

What is certain is that the combustion engine is under pressure. Transport contributes strongly to local air pollution enhancing pressure on the sector to clean up. At the same time, battery technology is advancing rapidly both in terms of costs and in terms of driving range. Increasing numbers of countries (China, France, India, the Netherlands, Norway, the UK) are mulling plans to phase out or even outright ban sales of new diesel or gasoline vehicles in timeframes ranging from 2025 to 2040 (Chrisafis & Vaughan, 2017; Stumpf, 2017). Some incumbent manufacturers are starting to move more strongly towards electrification. Volvo has announced that all new models will be electric or hybrid vehicles starting in 2019 (Ewing, 2017). VW recently announced plans to invest €50 billion to develop 80 new electrified models by 2025 (von Germis, 2017).

4.8.2 Main challenges and barriers toward decarbonisation

The transport sector does, however, face serious challenges that bar the way to change. Powerful incumbent actors profit immensely from the status quo, and will likely put up strong resistance against the emergence of a radically changed transport concept. Among them are:

- The car-manufacturing industry. This industry is a major economic power in vehicle-producing countries, often with strong historical and personal ties to politicians, but also to workers, and sometimes the military as well. The car industry also is surrounded by a long production chain that would stand to lose its core business.
- The oil industry. As most transport vehicles, be it cars, planes, ships, or trains, historically and currently rely on oil products to run, the oil industry stands to lose massively if the internal combustion engine were to be replaced by electrical or hydrogen propulsion.
- The motorist lobby. Especially in industrialised countries, there are often highly traditional car clubs and associations that are strongly conservative and highly sceptic concerning changes of

transportation systems, especially for personal vehicles. Completely depersonalised car-sharing would threaten their power base.

- The freight business. Companies in the freight business do not have an interest in a radically changing transport sector, as this would potentially threaten their base of business, and in any case, would mean a large set of lost investments, e.g. in trucks.

Apart from these actors there are a number of barriers that stand against change.

Technological: Technologies as such are mostly not a problem, as most innovations needed to foster more sustainable transport systems are in place. The largest barrier on a technological level is the development of high-yield battery systems. However, a "techno-cultural" barrier can potentially be that many engineers and designers implicitly favour systemic improvements to existing, combustion-based technologies over the more radical changes needed for a large-scale decarbonisation of the transport sector.

Two other barriers are "techno-political" in nature: Customers are currently faced with standardisation problems in electrical propulsion systems, as there are currently no real standards set for charging, e.g. currents, connectors etc., which vary widely across manufacturers, countries, and even models (Pereirinha & Trovão, 2016). This lack of standardisation may deter costumers from adopting innovative technologies early on. The other one concerns the change in infrastructure that is needed - current infrastructures are strongly geared towards servicing combustion engines (fuel stations etc.). In order to foster a change e.g. towards electrical propulsion, the infrastructure needs to be changed almost completely. Another "socio-technical" barrier to change can be the absence of viable alternatives - as much depends on infrastructures, especially rural or remote areas may face difficulties of access (no public transport, no railway lines for freight transport etc.).

Economic: As current mobility patterns rely heavily on individual ownership of units, replacement costs fall towards individual users. This does impose a high economic burden to owners that especially poorer people will not be able to afford. Another economic barrier concerns the state - fuel taxes can be a large source of income to states, making them hesitant to push too strongly for sun-setting fossil-based transport modes. (On the other hand, FFS constitute a large portion of many states' expenditures, so there may be a net positive at least in some cases).

Institutional: As all forms of (motorised) transport depend to large extents on infrastructures, and infrastructures constitute large, long-term investments, any infrastructure development constitutes a potential institutional lock-in. A radical change in transport infrastructure as necessitated by a low- or zero-carbon paradigm triggers investment needs that are too high to shoulder for many countries, especially in the developing world, on their own.

Linkages: As pointed out above, transport and oil industries strongly depend on one another. Changes in one will very likely lead to change in the other. This constitutes potential to swat two flies at once, but also double opposition by two strong incumbents. Sector-wise, the transport sector is closely linked to national power sectors, especially if a future strengthening of transport electrification is taken into account. Also, due to infrastructure needs, any change in the transport sector will have to be accompanied by adapting urban settlements and in extension national infrastructures to accommodate shifting paradigms in transport systems. Therefore, common targets and solutions will very likely be more effective and have higher probabilities to limit carbon emissions than isolated sectoral institutions.

Cultural barriers: Vehicle ownership is often connected with a sense of personal freedom, and an attachment to the vehicle. Moreover, in many countries cars are seen as a status symbol. Some countries (US, Germany) have a strong historical and cultural background as car producers in so much that it is often perceived as unthinkable to sunset individual car ownership.

4.8.3 The promise and potential of international cooperation

Guidance and Signal

As evident from national discussions about ending the use of combustion engine vehicles, targets and timetables can be a strong lever to redirect sectoral developments. International agreement on a target to completely end the use of fossil fuels in the transport sector would send a strong signal to all car manufacturers to either change direction or be put out of business. The ongoing scandal related to Diesel technology may provide a window of opportunity in this respect. A sectoral decarbonisation target would also support avoid and shift strategies as these minimise the need for energy inputs in the first place. Agreement on a new paradigm centred on transit-oriented development and prioritising public and non-motorised transport over individual motorised transport could be even more effective but is probably less realistic politically (see also section 4.10).

International cooperation could set a common roadmap for the sector, with differentiated decarbonisation target years for different countries with different levels of development. Targets and roadmaps to reach them would have to distinguish between different capacities of countries, and ensure technical and financial aid and cooperation to achieve the goals. Milestones for achieving ever higher levels of carbon neutrality could be set for different country groups, with a quicker pace for developed countries, and some more slack for less developed.

Setting Rules to Facilitate Collective Action

Defining common standards is a classic collective action problem that profits from coordination. International governance can play a large role in removing barriers that arise from a lack of standardisation. Once a standard is set, it is likely that it will be adhered to provided there is some enforcement by national entities in the beginning. On the other hand, leaving standardisation to the private sector regimes often leads to divergent strategies and complications in finding a common ground (see e.g. phone charging), but may also ensue competition that, in turn, further drives innovation.

A common regulatory approach of as many countries as possible strengthens the chance to pave the way towards a global shift towards sustainable transport systems once a critical juncture is reached. Harmonisation of rules and regulations, such as common fleet emission limits, or the formulation of common emission trading systems or other forms of carbon pricing can significantly improve the viability of such a change, as it addresses concerns of economic competitiveness and free-riding for individual countries.

Transparency and Accountability

Transparency requirements in the transport sector would likely vary with the scope of international cooperation, and consequently the rules set. Common standards will not require strong accountability, as standards are mostly self-enforcing once they have reached a certain point of penetration.

Emission limits should be monitored by global institutions, creating a common knowledge base. However, such a transparency framework would need to stay on a rather high and abstract level, as national transport systems will most probably not easily be harmonised. The design of a transparency framework would need to get more detail if a common decarbonisation roadmap is agreed internationally. In that case, a transparency framework monitoring the compliance e.g. with agreed milestones would need to be put in place.

Finally, if a harmonised system for carbon pricing and a trading system is extended to national transport sectors, an international registry will need to be installed in order to ensure that agreed emission limits and thresholds are respected in order to ensure the integrity of the system. Such a

registry would most probably not only cover the transport sector, but all regulated sectors under a common emission limit.

Means of Implementation

As regards the build-up of large-scale infrastructures, international cooperation could take the form of risk sharing arrangements that help to bring down capital costs in developing countries with generally difficult investment climates. This may enable developing countries to shoulder the incremental costs of making the required investments climate change resilient and with a focus on low-carbon solutions. Technology cooperation could also be useful in order to implement best practices jointly.

Likely, risk-sharing will not suffice to enable all countries to completely overhaul their transport infrastructure. Therefore, international cooperation will most likely also have to include arrangements for targeted financial, technical and capacity assistance where it is most needed.

Knowledge and Learning

Current studies indicate that many developing/emerging countries mimic infrastructure developments of industrialised countries, albeit at often a much grander scale (Arndt et al., 2014). International cooperation, mainly but not limited to North-South cooperation, on best practices through partnerships such as Local Governments for Sustainability (ICLEI) or through the Non-State Actor Zone for Climate Action, would help leapfrogging such suboptimal solutions. This would include common technical knowledge, but would also extend to exchanges on policies that have shown high effectiveness. While policies will always need to be shaped according to national circumstance, policy dialogues will provide useful starting points for transport decarbonisation.

4.9 International transport (aviation and maritime)

4.9.1 Current status and prospect

Global aviation (domestic and international combined) currently produces around two per cent of global CO2 emissions; global shipping about three per cent (Gencsu & Hino, 2015).[22] In combination, however, the international shipping and aviation sectors constitute a significantly growing share of global emissions; growing by around 80 per cent in terms of carbon emitted between 1990 and 2010, while growth of other sectors in the world economy was approximately 40 per cent (CDIAC 2013a; CDIAC 2013b; UNFCCC 2013 cited in Bows-Larkin 2015). In part this was driven by rapid growth in emerging economies, but also arose as a consequence of the lack of coverage of these sectors in the national mitigation policies of UNFCCC Annex I nations (Bows-Larkin, 2015). This high growth is likely to continue. For shipping, CO2 emissions are expected to rise by 50-250 per cent by 2050 under current policies (IMO, 2014). For aviation, a range of scenarios is possible in which CO2 emissions rise by up to 515 per cent between 2000 and 2050 (Gudmundsson & Anger, 2012), although more typical figures are around 220 per cent (Bows-Larkin, 2015).

The implications for the global temperature targets are serious: a 50 per cent chance of avoiding 2℃ entails a reduction of 71–76 per cent by 2050 for aviation, calculates Bows-Larkin (Bows-Larkin, 2015). Bringing shipping into line would require a 50 per cent reduction from 2012 levels (T. W. P. Smith et al., 2015). Under current policy and projections, assuming that total emissions fall sufficiently to hold

22 However, aviation's non-CO_2 emissions at high altitudes intensify the impact of aviation emissions on global warming, making them much greater than that of CO_2 alone. Black carbon emissions, inter alia, from ships are also rising (Azzara, Minjares, & Rutherford, 2015).

warming at 2℃, the (international) aviation and shipping sectors combined could contribute nearly 40 per cent of total CO2 output by 2050 (Cames, Graichen, Siemons, & Cook, 2015). Governance efforts to contain or reverse these trends face the difficulty of allocating responsibility for international emissions, which make up the majority of emissions, but which are not covered under domestic-level policy arrangements (Bows-Larkin, 2015).

Trade flows and globalisation represent important exogenous trends driving sectoral developments. Total international seaborne cargo, for example, has risen from 2.6 billion tonnes in 1970 to 9.5 billion tonnes in 2013 (Gencsu & Hino, 2015). Many stakeholders suggest that because the maritime industry serves demands originating in other sectors, management of the demand for shipping should not be attempted directly.

The structure of the aviation industry – featuring two dominant manufacturers and a few key airlines – is somewhat conducive to decarbonisation efforts (Bows-Larkin, 2015). Major regional shifts are also notable, with growth of air travel in developing markets, notably in Latin America and Asia. In the case of shipping, a complicated industry structure - many ship builders, owners, operators, shippers, charterers and end-users – makes steps to encourage decarbonisation more problematic (Bows-Larkin 2015). Following Bows-Larkin (Bows-Larkin, 2015), in the discussion below we distinguish technological aspects from practice/operational and demand-side aspects.

Aviation

Concern over energy costs has driven development and relatively widespread deployment of better technology in the form of extremely efficient gas turbine engines. Opportunities for ongoing improvements are, however, in decline (Bows-Larkin, 2015). Further gains would require a fundamental shift in design, e.g. open-rotor engines or propfans, which could cut fuel intensity per aircraft by up to a 50 per cent (Akerman, 2005), but which are currently held back by high noise and vibration levels. New construction materials can also deliver better fuel efficiency, but real benefits only materialize as the fleet renews. Biofuels are being developed and may also offer some benefits. The industry's own targets (see below) suggest that combined technological developments offer a one–two per cent improvement in fuel efficiency per year (Bows-Larkin, 2015) (insufficient of itself to be compatible with the 2℃ target, although recently figures of 3.7 per cent have been recorded (IEA, 2017b).

In terms of practices/ operations', unlike shipping aviation continues to be largely oriented towards leisure passengers - although according to some estimates only five per cent of the world population has ever flown (PeakOil.com, 2014). Industry pressure to expand airport capacity has met with success. While increases in airport capacity (and improved air traffic control) can reduce fuel consumed per passenger-km, they carry the risk of rebound effects, maintaining or raising growth rates, increasing absolute energy consumption (Bows-Larkin, 2015).

Shipping

Relatively high engine efficiency makes shipping a relatively low-carbon freight mover. Nevertheless, a wide range of incremental technologies, many of which could be retrofitted, are yet to be widely exploited (Mofor, Nuttall, & Newell, 2015). Efficiency can be disaggregated into technical design and operational aspects; even ships with similar design efficiencies can have vastly different operational efficiencies (Gencsu & Hino, 2015). Speed is a critical factor: a ten per cent reduction corresponds to a 27 per cent drop in fuel use per unit of time (Gencsu & Hino, 2015). 'Slow steaming' practices, widely adopted from 2007–2012 in response to the global economic downturn, reduced daily fuel use by an average of 27 per cent, but by over 70 per cent in some ship size categories (IMO, 2014).

Biofuels are currently the most relevant alternative for replacement or blending with fossil fuels in the sector. Although experience with their use and the scale of their application in the shipping sector is

still minimal, recent technology learning regarding second and third generation biofuels makes these the most viable renewable option with the highest long-term penetration potential (Mofor et al., 2015).

What needs to change to phase out GHG emissions?

Despite some encouraging recent developments, including commitments by the aviation sector to cap net emissions at 2020 levels (principally by offsetting) (Gencsu & Hino, 2015), progress in both sectors has been slow. The latest assessment by the IEA of progress towards interim 2°C scenario targets in 2025 warns that international shipping is 'off-track' while aviation shows some improvement but more effort is needed (IEA, 2017b). Although lower carbon alternatives certainly exist, phasing out GHG emissions entirely in these sectors is a distant prospect. Mitigation potentials vary significantly: while shipping has many technological and operational options that could be effective in the short to medium term, aviation does not. In this section, we again distinguish technological measures from interventions based on changing operations and demand-side measures. We begin with shipping.

Meeting the IEA's 2℃ scenario requires the global shipping fleet to improve fuel efficiency per vehicle-km at an annual rate of 2.3 per cent between 2015 and 2025. In its current form, the IMO's Energy Efficiency Design Index mandates a one per cent annual improvement in the efficiency of the global fleet from 2015 to 2025 (IEA, 2017b). Further improvements to efficiency, through a wide range of incremental technologies, many of which could be retrofitted to existing ships, are possible (Mofor et al., 2015). In addition, pioneering wind power technologies – include Flettner rotors, kites, and fixed or rigid sails - could offer fuel savings of up to 50 per cent (Mofor et al., 2015). Regarding the range of alternative fuels, LNG cuts the emissions intensity of operations in the short term, and is favoured by the sector as a transitional fuel; a suitable bunkering network is rapidly evolving on established transport routes (Mofor et al., 2015). However, a fleet-wide switch to LNG would be insufficient to deliver 2℃-type decarbonisation, and would risk further carbon lock-in. Biogas, biofuels, and micro-algae are subject to the same sustainability concerns expressed about them in other sectors (Bengtsson, Fridell, & Andersson, 2012).

Various concepts and prototypes exist for electric and hydrogen fuel cell-powered vessels. However, emission savings depend on the primary source of energy being used (Mofor et al., 2015). Potential for solar-power has also been noted (Mofor et al., 2015), as well as for alternative fuels such as hydrogen and ammonia. Development of hydrogen fuel cell technology has made significant advances, although sustainability of hydrogen production is a critical issue, with almost all current commercial production coming from fossil fuels (Mofor et al., 2015). At least in principle , nuclear power could have a significant decarbonising effect (Walsh, Mander, & Larkin, 2017), benefiting from development of modular nuclear reactors in the power sector. To develop successful marine mitigation, 'it is essential to consider the interdependencies between ship speed, level and pattern of demand for services, and the extent and rate of innovation in propulsion technology' (Walsh et al., 2017). The rate of technological innovation is too slow, meaning that 'it is difficult to foresee how deep decarbonisation can be achieved without an immediate, fleet-wide speed reduction; and a land-based energy-system transition strongly influences shipping demand, which in turn, influences the extent of required low-carbon propulsion technology change' (Walsh et al., 2017). Reducing power requirements improves the proportion that could be provided by renewable technologies, and also allows immediate cuts in CO_2 to be delivered (IMO, 2014; Psaraftis & Kontovas, 2013).

The scale of the technological challenge for aviation is much greater. Here, emission cuts cannot be made by reducing speed or introducing on-board renewable energy sources. Although biofuels are regularly touted, and initiatives and research partnerships are under way to scale up renewable jet fuel and reduce costs (Gencsu & Hino, 2015) they fail to address the impact of contrails on cloud formation and aerosol deposition (T. Smith, 2015), and provoke the aforementioned sustainability con-

cerns . Arguably, the aviation sector repeatedly succumbs to technology 'myths', which 'must be recognised, confronted and overcome as a critical step … to sustainable aviation climate policy' (Peeters, 2016).

Less controversially, wider efficiency improvements in aviation are possible and cost-effective: the difference between the fuel efficiency of the least and most efficient US airlines was 27 per cent in 2013, and there was no improvement in fuel efficiency in US passenger airlines on domestic flights in 2012–2013 (Gencsu & Hino, 2015). In 2017, the International Civil Aviation Organisation (ICAO) adopted an international CO_2 standard, applicable to new aircraft type designs from 2020, and to designs already in-production as of 2023 (ICAO, 2017).

On the demand-side, although investments in high-speed rail may serve to reduce demand for air travel, its role is limited in that around 80 per cent of all aviation emissions are from flights over 1,500 km (ATAG, 2014). Technological innovations, such as video-conferencing, can also serve to manage demand in some circumstances, saving time and money for businesses and individuals.

To summarise, '[o]nly electrical propulsion, demand reduction … or offsetting remaining emissions will enable full decarbonisation of the aviation sector' (Cames et al., 2015). Biofuels could also contribute if sensitively handled.

4.9.2 Main challenges and barriers toward decarbonisation

With shipping, a complex set of barriers to the adoption of lower carbon energy (including improved efficiency measures) can be categorised in terms of organisational/structural, behavioural, market and non-market factors (Mofor et al., 2015). This complexity, in part, reflects the unique and international nature of the shipping industry, with underlying constraints and factors beyond the ability of individual states to modify (Mofor et al., 2015). Most ship building has occurred in jurisdictions without climate targets, with many diverse manufacturers, as well as charterers, owners, operators, and other global stakeholders (Bows-Larkin, 2015).

With regard to organisational, structural and behavioural barriers, limited R&D financing, particularly for initial proof-of-concept technologies, is a major factor, together with ship owners' concerns over the risk of hidden and additional costs, as well as opportunity costs of renewable energy solutions. Historically, a lack of reliable information on costs and potential savings of specific operational measures or renewable energy solutions has been noted (Gencsu & Hino, 2015; Mofor et al., 2015). The fundamental market failure is one of split incentives between ship owners and hirers, limiting the motivation of owners to invest in solutions since benefits may not accrue to the investing party. Investors tend to be risk averse, especially after the shipping boom collapsed in 2006. Significant levels of fleet turnover/ retrofitting must be achieved, the maintenance of which across extended periods has historically proved difficult (Walsh et al., 2017). Sufficiently rapid fleet-wide retrofit arguably requires adequate dry-docking services around the world and opportunities for demonstrating new technologies (Walsh et al., 2017). Moreover, widespread technological uptake necessitates extensive knowledge exchange to ensure newly fitted technologies are operated correctly. North-South technical co-operation and transfer of technology may be necessary. Early-adopters would need to be strongly incentivised (Walsh et al., 2017). Furthermore, the shipping sector's low public profile results in less societal pressure to change. Of the non-market barriers, the different classes and scales of ships, the markets and trade routes served and the lack of access to capital are some of the key barriers (Mofor et al., 2015).

In terms of specific technologies, the high potential of advanced biofuels to transform the shipping sector ultimately depends on a number of factors, including the global availability of sustainable feedstock. Hydrogen fuel cells also hold great potential but the sustainability of the energy source used to produce the hydrogen, as well as lack of cost-effective and reliable low-pressure storage options for

the fuel, remain critical issues (Mofor et al., 2015). A radical technological change such as nuclear propulsion would be contingent on both the development of appropriate modular reactors, and addressing wider regulatory and acceptability challenges at a global scale.

In terms of slow steaming, compensation in the form of increased ship size or numbers to maintain freight flows might be required to ensure acceptability to the industry. Global supply chains must be capable of accommodating speed reductions over all journey legs (Walsh et al., 2017), which might require restructuring of some industries.

The simpler industry structure of aviation, compared to shipping, means that other things being equal, incentivizing change should be relatively practical (Bows-Larkin, 2015). However, significant commercial, technological and cultural barriers exist. For example, current prices of biofuels are around three times higher than conventional jet fuel. Although the industry favours off-setting measures, uncertainty exists over long-term availability and cost of credits (Gencsu & Hino, 2015). Flying is higher in public consciousness than the shipping of goods - making demand management a sensitive issue. The perceived 'right to fly' is becoming more widely engrained around the world, even among those otherwise engaged in more pro-environmental behaviour (Alcock, 2017).

For both international shipping and aviation, the power of incumbent actors in the political institutions involved in sectoral governance (to be explored further in Task 4.2) is a further important challenge to decarbonisation. National delegations to, and technical working groups of the International Maritime Organisation (IMO) often include industry representatives. Industry voices exert influence through particular Member States (Darby, 2016). Industry groups have embraced the 'fair share' concept for emissions reduction (Vidal, 2016), but insist that any outcome must not inhibit development. Refusal of large developing countries to accept reduction targets (at least until 2014), in particular China, Brazil and India, has also impeded progress. The important lobbying role of commercial airlines, represented by the Air Transport Action Group (ATAG) and the International Air Transport Association (IATA), an association encompassing more than 80 per cent of the sector, may be highlighted. Overall, the aviation industry may be regarded as trying to drive some relatively limited kinds of change – such as off-setting - in order to head-off more fundamental change that would be more detrimental to its interests (Goncalves, 2017).

Another barrier affecting decarbonisation efforts in both sectors is the major perverse subsidy at the international level constituted by the absence of taxation of aviation and shipping fuels. In the case of aviation fuel, this is due to long-standing legal bilateral air service agreements which effectively prohibit such taxation and would require renegotiations to alter. The incentive for reducing fuel use is thus considerably lower than it could be. In the shipping sector, although marine fuel represents 50 per cent or more of a ship's operating cost, the fact that it is untaxed is one factor behind the lack of progress in shipping efficiency, particularly design efficiency (Gencsu & Hino, 2015). In discussions of measures to internalise carbon externalities for both aviation and shipping, such as carbon taxation, compensating developing countries for the economic harm they might suffer - ensuring that they bear 'no net incidence' - is widely recognized as critical to their acceptability (IMF, 2011).

4.9.3 The promise and potential of international cooperation

Since the vast majority of aviation and shipping activity takes place across national borders, international harmonisation of policy responses is essential to effective governance. Imposition of stricter requirements on ships registered in one jurisdiction may simply prompt owners to re-register elsewhere, harming one state's competitive position to little environmental benefit. Meanwhile, the transaction costs of national regulatory variation can be high for shipping companies. The literature notes how fierce global competition, particularly in shipping but also in aviation, makes international cooperation essential for raising mitigation ambition (Gencsu & Hino, 2015). Given its complexity, directly

influencing change in the international shipping sector is arguably most effectively encouraged by combining global-led policies with measures implemented at the port-state level (Bows-Larkin, 2015; IEA, 2017b)

Guidance and Signal

Given the projections for emissions growth, and the trends towards international aviation and shipping taking up more and more of the available 2/1.5°C carbon budget, there is a significant need to signal more strongly what level of emissions constitutes the sectoral 'fair share'. In the case of shipping, parts of the industry have themselves expressed interest in setting such a target (Vidal, 2016).

Setting Rules to Facilitate Collective Action

There is significant need for regulation (standards, rules) at international level to incentivise global-scale action. In both sectors, global emission limits could be implemented globally by market-based instruments such as taxation and emissions trading, or more direct technological regulation through standard setting – or a combination. International agreement to tax aviation and shipping fuel (with revenues potentially recycled into research and development for decarbonisation) could facilitate collective action. In principle, it is also possible for states to remove tax exemption from air service agreements on a bilateral basis. The emergence of new technologies will likely require adequate standards (agreed upon by global institutions and ship classification companies). In shipping, requiring verified vessel efficiency ratings, taking into account the effect of new technologies, may incentivise the installation of such technologies through enhancing the competitive resale value of a vessel. In both sectors, ensuring that offset schemes and the production of alternative fuels adhere to high quality standards is critical, as side-effects could undermine the effectiveness of such measures.

Addressing distributional equity issues (esp. in North-South context) is also necessary, and may be promoted by international agreements that are phased in over time for certain actors, or by explicit finance and technology transfer measures (see also discussion below).

Transparency and Accountability

To the extent that international regulation is introduced, implementation would require appropriate transparency (monitoring and verification) and accountability (enforcement). International, industry-wide efforts are needed to improve transparency and strengthen incentives, including on use of alternative jet fuels and to account for changes in life cycle GHG emissions in order to assess progress toward achieving global goals.

Means of Implementation

Policies that provide finance for new technologies can incentivise innovative solutions. This may assist in combating the 'landlord tenant problem' in shipping (Walsh et al., 2017).

Gençsü and Hino (Gencsu & Hino, 2015), while echoing the advocacy of port-level measures, also highlight the importance of the banking sector in incentivising efficiency. Two leading shipping banks, HSH Nordbank and KfW-IPEX Bank, use RightShip/Carbon War Room's rating scheme when evaluating the risk and return of a loan, favouring efficient ships.

Knowledge and Learning

Given the evident market failures, particularly in shipping, significant international level measures are needed to overcome lack of reliable information on costs and potential savings of specific operational measures or renewable energy solutions.

(Joint) R&D for low-carbon technologies, involving airlines, governments and other stakeholders has been recommended, particularly for new aircraft design and sustainable biofuels (Gencsu & Hino, 2015).

In shipping, the need for improved information on costs/ savings/ correct operation of new technologies and operational measures may be highlighted.

Linkages

The literature notes how decarbonisation of international shipping can be greatly facilitated by wider decarbonisation of the economy. For a country such as the UK, as much as 50 per cent of the tonnage imported may be fossil fuels (the figure from 2010). Changes to the levels of fossil fuel consumption and the growth in biomass/biofuels could therefore have a significant impact on shipping demand (Bows-Larkin, 2015; Mander, Walsh, Gilbert, Traut, & Bows, 2012).

Inter-linkages are also evident in terms of the potential effects of slow steaming. While compensation in the form of increased ship size or numbers to maintain freight flows might help ensure acceptability to the industry, the effects on global supply chains might require restructuring of some industries (Walsh et al., 2017).

Regarding aviation, although the industry favours off-setting measures, uncertainty exists over long-term availability and cost of credits (Gencsu & Hino, 2015). The availability depends on linkages with the carbon markets associated with other economic sectors. Scarcity issues also arise for both aviation and shipping in terms of the need to compete for supplies of biofuel with alternative uses.

4.10 Urban Systems/Settlements

4.10.1 Current status and prospect

Urban areas are the locus of the majority of GHG-emitting activities. They are sites of habitation, commerce, energy supply and use, transport, waste management and energy-intensive industries. Taking into account direct and indirect emissions, urban areas currently account for about three-fourths of global energy use and energy-related CO_2 emissions. Accounting only for direct emissions, the share is 44 per cent. There have so far been only few attempts to quantify the urban contribution to all GHGs, arriving at an estimate of 37-49 per cent for the year 2000 (Seto, Dhakal, et al., 2014).

Per capita levels of energy use and emissions tend to be higher than national averages in developing countries and lower in developed countries. Per capita emission levels vary strongly among cities, even within the same country. There is not one single factor responsible, relevant factors include income, population dynamics, urban form, locational factors, economic structure, and market failures (Seto, Dhakal, et al., 2014). Within these framework conditions, each urban area pursues its own technological, political, social and cultural innovation logic and transition pathway (Schneidewind et al., 2015).

To achieve the international climate objectives, urban energy and mobility systems as well as systems for heating and cooling buildings and waste management will need to be decarbonised as soon as possible. As electricity, transport, buildings and waste are discussed in other chapters of this report, the following will focus on urban form and infrastructure. These are especially relevant for limiting transport volumes, the 'avoid' part of the avoid-shift-improve strategy discussed in the transport chapter.

Urban form and infrastructure are strongly interlinked and, given their long lifetimes, lock-in patterns of land use, transport choice, housing, and behaviour. Once in place, they are difficult to change. Key aspects of urban form and infrastructure that impact GHG emissions are settlement density, land-use

mix, connectivity of urban design, and accessibility (for employment, shopping etc.). These factors are interrelated and interdependent, e.g. highly connected places are highly accessible (Seto, Dhakal, et al., 2014).

Urban mitigation needs to be squared with the breakneck urbanisation dynamics in the global South, particularly in Africa and Asia. While currently roughly half of the global population, about 3.6 billion people, lives in urban areas, this is expected to increase to 5.6-7.1 billion, about two-thirds of the global population, by 2050 (United Nations, 2014). As result, the increase in urban land cover during the first three decades of this century is expected to be greater than the cumulative urban expansion in all of human history. In China alone, more cement was used in the three years from 2008 to 2010 than in the entire 20th century in the US (Smil, 2013). Based on projections for population densities and economic and population growth, world-wide urban land cover is expected to expand by 56–310 per cent between 2000 and 2030. Most of this growth is expected to take place in small- to medium-size cities in developing countries. In a scenario where global population increases to 9.3 billion by 2050 and developing countries expand their built environment and infrastructure to current global average levels using currently available technology, the production of infrastructure materials alone would generate about 470 Gigatonnes of CO_2 emissions (Seto, Dhakal, et al., 2014). This corresponds to about half the cumulative 'budget' of CO_2 that may still be emitted if average global temperature increase is to be limited to below 2°C with a likelihood of more than 66 per cent (IPCC, 2013).

The key challenge therefore is to guide this breakneck urbanisation onto sustainable pathways. Business as usual – incremental approaches and less structured, quasi-automatic urbanization – would lead to growth of highly unsustainable cities. What is required is transformative strategies departing from conventional infrastructure patterns (WBGU, 2016).

At national and regional level, a polycentric approach to urban development can have considerable advantages. The emerging mega-cities frequently feature overtaxed infrastructures, overburdened municipal administrations, hostile-to-life settlement structures and socio-economically polarized urban societies. Strengthening small and medium-sized towns and networking them with larger cities can combine the advantages of agglomeration and decentralization, allowing for better use of resources as water, food and energy do not have to be transported over long distances into the few centres (WBGU, 2016).

At the level of individual urban areas, given the wide variety of local situations, there can be no schematic masterplan for urban change. The task of low-emission development varies fundamentally depending on the current level of urbanisation:

- In established urban areas, the task is to re-develop urban form and infrastructure. The key strategy is transit-oriented (re-)development, that is, the creation of compact, pedestrian-oriented mixed-use residential, business and leisure areas centered around high quality public transport systems
- In areas that are urbanising, the task is to shape urban form and infrastructure development towards sustainable pathways, establishing transit-oriented development as the baseline, limiting urban sprawl, and providing affordable, dignified, safe and low eco-impact housing.
- Established urban areas that are still growing dynamically face both challenges at the same time.
- Finally, low-lying cities that are frequently hit by strong storm systems face the double challenge of achieving low-emission and climate-resilient development (Huang, Busch, He, & Harvey, 2015; Seto, Dhakal, et al., 2014; WBCSD, 2010).

Given the central role of localised urban strategies, a core element of sustainability governance is granting cities the right to self-government and providing them with the means to chart their own local

transformation pathways. Moreover, cities should be involved in national decision-making processes wherever national decisions are relevant for them. (WBGU, 2016).

Given the huge volumes of emissions associated with the production of currently used infrastructure material, one key factor of relevance for all urban areas is the development of materials and designs that feature renewable resources, recycled materials and/or low-impact processes (WBCSD, 2010).

4.10.2 Main challenges and barriers toward decarbonisation

The main challenge of achieving urban low-emission transformations is to get ahead of the rapid transformation that is already taking place in the global South, breakneck urbanisation. Infrastructure decisions that are taken over the next 10-20 years will determine the urban emission profiles of the future.

In doing so, urban development will have to overcome enshrined paradigms. Most cities in the world today have been built as 'zoned' cities, where different types of land use (residential, commercial, manufacturing, service, recreational) have been largely kept separate. Another dominant paradigm has been the equation of mobility with (individual) transport, with building of ever more infrastructure for cars at the heart of transportation strategies and policies (United Nations Human Settlements Programme, 2013).

The ability of urban areas to steer their development onto a low-emission course depends on their governance, technical, financial, and institutional capacities. While the most accessible mitigation opportunities are in rapidly urbanizing areas where urban form and infrastructure are not yet locked in, these often dispose of the most limited capacities (Seto, Dhakal, et al., 2014; WBCSD, 2010).

Many cities are implementing climate action plans, but their impact on urban emissions is unclear. There has so far been little systematic monitoring and evaluation. More fundamentally, consistent and comparable emissions data at local scales is lacking, and there is little consistency and comparability on local emissions accounting methods. Moreover, current initiatives focus largely on energy efficiency. Relatively few action plans address land-use planning and cross-sectoral measures to reduce urban sprawl and promote transit-oriented development. This reflects traditional urbanisation in general, where development usually occurs piece by piece instead of integrated land-use and transportation planning (Seto, Dhakal, et al., 2014).

In addition, all urban areas and especially fast growing ones struggle with more immediate challenges, such as providing adequate housing and employment opportunities, ensuring access to energy, water and sanitation, limiting air and water pollution. In developing countries and emerging economies, one-third of the urban population does not have adequate housing, in Sub-Saharan Africa it is two-thirds. The ability to mobilise urban mitigation actions therefore often depends on the ability to relate mitigation efforts to local development benefits. Stand-alone mitigation approaches will fail; mitigation needs to be embedded in overall concepts of sustainable urban development and quality of life (Seto, Dhakal, et al., 2014; WBGU, 2016).

As result, crucial factors for successful mitigation are:

- institutional arrangements that enable the integration of mitigation with other high-priority urban development objectives;
- a multilevel governance system that empowers cities to steer their transformations by themselves;
- spatial planning competencies and political will to support integrated land-use and transportation planning; and
- sufficient financial and institutional capacities (Seto, Dhakal, et al., 2014).

4.10.3 The promise and potential of international cooperation

International interdependence of mitigation in urban areas is low, there are no competitiveness concerns or technology spill-overs. Nonetheless, there is substantial scope for international governance to provide guidance and means of implementation and to promote transparency and mutual learning among cities.

Guidance and Signal

Where urban development does not suffer from a lack of planning, it often suffers from planning done on the basis of high-emission paradigms, such as zoning and orientation of transport infrastructure towards cars. Climate-friendly urban development could profit strongly if international governance developed a new paradigm of sustainable urban development. This paradigm will have to integrate mitigation with other high-priority urban development objectives. Key elements of such a paradigm should include an objective of net zero emissions by 2050, to be achieved through means such as limiting urban sprawl, transit-oriented development, development of mixed-use areas, use of renewable energy resources and others.

Rule-Setting to Facilitate Collective Action

Given the huge variety of local situation there seems little scope for uniform rules or standards for how urban systems should be designed.

Nonetheless, international governance might recommend granting cities the right to self-government to enable them to chart their own local transformation pathways in line with their local circumstances.

Transparency and Accountability

As noted above, while there are many urban climate initiatives, there so far is little systematic monitoring and assessment of their impacts. International cooperation could work to enhance monitoring methodologies and contribute to building capacities for their implementation.

In addition, an international process of review and consultation could help to promote implementation. Cities or national governments could be asked or made to report on their progress in sustainable urban development and these reports could be made subject of expert or peer reviews.

Means of Implementation

Many urban areas in the world are committed to do more on climate change but are short of cash and institutional capacities. Increased provision of means of implementation could therefore unlock substantial potential for more action. Resources should in particular be used for strengthening administrative capacity.

Knowledge and Learning

Key elements of the transition to sustainability, such as development of energy, mobility, waste and sanitation infrastructure, will be decided in cities. It would therefore be helpful if cities were enabled to play a role in international cooperation. They should be allowed to participate and speak at relevant international forums in order to improve exchanges between the different governance levels and to develop transnational city networks (WBGU, 2016). This would facilitate mutual learning among cities as well as help national delegations to better tailor instruments of the international regime, such as means of implementation, to the needs of cities

Despite the huge variation of urban conditions, there is substantial potential for policy learning across cities which has so far not been mobilised. An especially promising approach lies in comparative learning at the level of urban quarters. At this level, there are comparable structures that are largely independent of urban size and thus allow for international learning processes. A specific approach is organising learning partnerships among cities (Schneidewind et al., 2015).

4.11 Buildings

4.11.1 Current status and prospect

The global buildings and construction sector accounts for more than half of global wealth (Global Alliance for Buildings and Construction, 2016). In 2010, the buildings sector consumed 32 per cent of total global final energy use (51 per cent of global electricity consumption) and produced 19 per cent of GHG emissions or 9.18 $GtCO_2eq$ (including electricity-related, while direct emissions stood at 6.4 per cent of the global total) (Lucon et al. 2014, p. 687). GHG emissions from the building sector have more than doubled since 1970 (Lucon et al. 2014, p. 678). Most of the GHG emissions in the buildings sector are indirect CO_2 emissions that emanate from electricity use in buildings and are projected to grow faster than any other sector, in particular emissions from commercial buildings—1.8 per cent a year through 2030 (Knox, 2015).

Population growth, urbanisation, rising per capita incomes, and climate change are key factors that will dramatically impact this sector and drive an increase of energy use. The United Nations Department of Economic and Social Affairs (UNDESA) estimates global population to grow to 9.7 billion by 2050 of which approximately 2.5 billion will be new urban inhabitants, mainly in Africa and Asia (UNDESA, 2015). Urban areas will comprise 85 per cent of growth in building energy use until 2050, 70 per cent of them in developing countries (Diana Urge-Vorsatz, Cabeza, Serrano, Barreneche, & Petrichenko, 2015). As global temperature rises, the demand for space cooling amongst warmer countries is expected to triple between 2010 and 2050 (IEA, 2013). Moreover, urbanisation is typically associated with a shift from traditional biomass fuels (such as wood and waste) to more modern fuels (such as natural gas or electricity), but also with greater potential for energy efficiency measures. Overall, the IPCC has warned that, in the absence of action, the use of energy in buildings could double or in worse case, triple by 2050 (Lucon et al., 2014). In order to meet the 2°C objective set out by the Paris Agreement, the buildings sector would have to reduce energy and process-based CO_2 emissions by 60 per cent in 2050 compared to 2012 (Dean, Dulac, Petrichenko, & Graham, 2016).

Spatial heating and cooling, cooking and water heating in the buildings sector account for the lion's share of the buildings sector's final energy consumption. In 2012, the respective shares in residential and commercial buildings were: 32 and 33 per cent for space heating, 24 and 12 per cent for water heating, two and 32 per cent for cooling and 29 per cent for cooking (residential buildings only) (IEA 2013 in Lucon et al. 2014, p.681). The relatively large share of cooking ensues as a result of the use of traditional biomass (in combination for water heating) by approximately 3 billion people with low conversion efficiencies in developing countries (IEA, 2013).

The buildings sector varies both regionally and within regions, depending on climate, economy, energy access, availability of energy sources, and energy-related policies (Knox, 2015). Per capita final energy use in buildings in countries like the US and Canada can be as much as five to ten fold higher than in Africa or Latin America per se (D. Urge-Vorsatz et al., 2012). Space heating continues to dominate building energy use in OECD countries, while cooking and water heating account for nearly 60 per cent of building energy demand in non-OECD countries. In the non-OECD nations, consumption of delivered energy in buildings is estimated to grow by 2.1 per cent per year from 2012 to 2040, nearly three times the growth rate for the OECD nations (Knox, 2015). Three quarters of the final energy consumption for

heating and cooling is fossil fuel based including the generation mixes for electricity used for heating and cooling, and for commercial heat. Renewables constitute the remaining of which almost 90 per cent is traditional biomass (IEA, 2015a).

Achieving the goals of the Paris Agreement will require an ambitious mix of mainstreaming highly energy-efficient near-zero or net-zero energy and energy-plus buildings in new construction, a massive retrofit of the existing building stock and a switch to greener sources of energy in particular electricity from renewables (Dean et al., 2016). Although the buildings sector is currently one of the largest GHG emitting sectors, it offers large low-cost potential for reducing energy demand and associated emissions in all world regions by 2030 (Lucon et al., 2014). Although definitions vary, net-zero energy buildings (NZEBs) are buildings with on-site renewable energy systems (such as PV, wind turbines, or solar thermal) that generate an equivalent amount of energy as is consumed by the building (Lucon et al., 2014). In the case of energy-plus buildings, such renewable energy generation exceeds consumption.

Enormous potential for reducing energy consumption and GHG emissions can be realised through retrofitting existing buildings as well as, even more so, in constructing new buildings. Buildings envelopes are key. According to the IEA, a high-performance building envelope for existing and new buildings in OECD countries can reduce energy required for heating to 20-30 per cent of current consumption while it can boost energy savings potential for cooling between 10-40 per cent in hot countries (IEA, 2013). Holistic retrofits can result in 50–90 per cent final energy savings in thermal energy use in existing buildings, with the cost savings usually surpassing investments (D. Urge-Vorsatz et al., 2012). As regards new buildings, cost-effective technology and materials now make it possible to construct buildings that use 10–40 per cent of the final heating and cooling energy of conventional new buildings in all world regions and climate zones (D. Urge-Vorsatz et al., 2012).

Leadership in Energy and Environmental Design certification is the most widely used third-party verification for green buildings and ensures that buildings use one third less electricity (Knox, 2015). The World Green Building Trends 2016 study finds that globally, green building construction is steadily rising, most of the growth coming from emerging economies in Asia. Smart building technology spending is also expected to rise from USD 6.3 billion in 2014 to USD 17.4 billion in 2019 (Feblowitz & Levine, 2015).

As regards cookstoves, biomass used in open fire or basic cook stoves, still represents two-thirds of energy consumption for cooking globally. More efficient biomass stoves can deliver fuel savings of 30–60 per cent and chimney-included models can reduce indoor air pollution levels by 80–90 per cent (D. Urge-Vorsatz et al., 2012). and transition from traditional biomass to modern fuels could save 3.5 EJ of energy, (or around or 34 per cent of total buildings energy consumption in 2010 (IEA, 2013).

4.11.2 Main challenges and barriers toward decarbonisation

There is a palpable paucity of strong regulatory measures or incentives across all regions and countries, even though a number of affordable technologies and efficiency improvements that can help decarbonise the sector exist. Even in most developed countries, policies that mandate energy-efficient retrofits typically result in savings of only 20–40 per cent of the building energy use (Guneralp et al., 2017). Low efficiency targets risk resulting in a decades long lock in for energy use and corresponding GHG emissions (D. Urge-Vorsatz et al., 2012). Moreover, even in most developed regions like the EU even where policies exist, implementation is poor (Boasson & Dupont, 2015). The rate of retrofitting in the EU is currently a mere one per cent annually, which would require a century to decarbonise the sector. Many OECD members have indeed pursued NZEBs for the past 10-12 years, but progress remains low including inside the EU (Boasson & Dupont, 2015; IEA, 2015a). Introducing policies that mandate state-of-the-art deep retrofits could save 70-90 per cent of building energy use (Guneralp et al., 2017). At

the policy level, ambition is low in non-OECD nations too, where the emphasis will be on new constructions rather than on retrofits.

The lack of training, awareness of existing technology costs and capacity building measures constitute an important non-financial barrier (IEA, 2013). The sector involves a large number of stakeholders (constructors, building product producers, building managers, architects, engineers, owners, occupants, investors, trades people, equipment manufacturers, suppliers, architects, lenders, insurers, codes and standards setters, zoning officials, realtors and others) (Boasson & Dupont, 2015; IEA, 2013) and is deeply fragmented (between the national or local level). Consumer-awareness programmes, standards and labelling while effective tools to encourage purchase of the most efficient available technologies, are not prevalent across the globe, in particular in developing countries. In the absence of awareness, easy access to knowledge and technology, and organized training, the large number of private construction companies may either entirely perceive otherwise affordable decarbonisation measures to harm their competitiveness in a highly competitive real estate market or overlook them entirely.

Transitioning to NZEBs would be difficult even though it may be the most efficient solution. NZEBs remain largely unaffordable, especially in the developing world. Moreover, there is a distinct lack of designers or builders with the necessary skills or experience to construct NZEBs. Technical challenges also inhibit the widespread construction of true NZEBs and NZEB communities given their suitability for only certain building types and settlement patterns, primarily low-rise buildings and less densely populated residential areas. Moreover, their economics are presently typically unfavourable, as opposed to high-efficiency buildings (D. Urge-Vorsatz et al., 2012). In a 2010 study cited by the IPCC only about 300 both commercial and residential net zero or almost NZEBs existed worldwide at the time (Lucon et al., 2014).

The continued widespread use of solid fuels — including wood, charcoal, coal, animal dung, and crop waste — for cooking and heating energy supply remains an important source of buildings sector GHG emissions. Globally, there remains a lack of adequate support for the sustainable production of clean biomass fuels and renewable fuel alternatives alongside the current focus on stove efficiency and emissions given that demand-side solutions alone are not enough (Putti, Venkata, Tsan, Mehta, & Kammila, 2015). The drive to increase the focus on clean cooking solutions remains arbitrary across the world. Globally, more than 3 billion people, particularly in rural areas in the developing world, still use solid fuels as their primary cooking and heating energy supply. And only about 200 million have access to improved or clean cookstoves (Putti et al., 2015). Access to finance, consumer education, quality standards, policy reform, and market intelligence will be needed for a transition to more efficient cooking and heating energy supply (Putti et al., 2015).

Although improving building efficiency is often profitable, investments are hindered by various barriers: "market barriers (like high initial costs and low priority of energy efficiency in decision-making – and market failures e.g. principal-agent problems, transaction costs, search costs, regulatory compliance issues) (IEA, 2013), misplaced incentives, distorted energy price/tax regimes, limited access to financing, lack of information and awareness of benefits, regulatory failures, and so on (Lucon et al., 2014). Regulatory failures can include policies that have inhibited the deployment of technologies. For instance, in some countries, building codes prohibit the installation of solar thermal collectors on roofs or local regulations exist that may not foster innovative building solutions (IEA, 2013). Decision makers themselves at times do not have accurate or adequate information on varied aspects.

The principal-agent problem is also important especially in OECD countries where either building developers seek to minimise costs without the long-term interests of owners or occupiers in mind or where landlords make purchase heating and cooling equipment for tenants without regard to life-cycle costs (Murtishaw & Sathaye, 2006). Strong and diverse market oriented policies that can overcome these hurdles will help in catalysing potentially cost-effective investments (Lucon et al., 2014). The lack

of robust data and large-scale demonstration projects that evaluates the performance of energy-efficient and low/zero-carbon technologies in each market segment also compose a barrier (IEA, 2011).

Financial challenges also remain. According to the IEA (IEA, 2013), decarbonisation in the sector would require an estimated USD 31 trillion by 2050.

4.11.3 The promise and potential of international cooperation

Guidance and Signal Function

A common international goal of full decarbonisation of the sector (e.g. by the second half of the century) with targets differentiated by region could help to align the diversity of actors in the sector. This could be an important signal "to consumers and manufacturers, both to maximise efficiency and to limit the cost of future changes" (IEA, 2011). A well-defined global carbon neutral strategy for the buildings sector with differentiated targets can provide a roadmap for sustainable buildings subsectors (like heating and cooling, cooking, heating water, where challenges are indeed shared across a number of countries and/or regions) (Global Alliance for Buildings and Construction, 2016).

Setting Rules to Facilitate Collective Action

International regulation can play a complementary role by addressing competitiveness concerns. Such concerns exist to the extent that decarbonising buildings cause significant net costs. This is especially the case for the more advanced transition to NZEBs. Having said that, many of the options for significantly reducing emissions in the sector do not involve significant net costs, but even generate net benefits. One challenge in developing any international rules will be to take into account the widely varying conditions in different countries and regions. An additional potential may exist with respect to the international harmonisation of certain building materials.

Transparency and Accountability

International agreement on differentiated targets/rules would require a transparency framework for performance assessment. Collection of data will be essential for regular tracking of progress.

Means of Implementation

The provision of adequate means of implementation can help address some of the key barriers to the decarbonisation of the buildings sector at the global level. International training, capacity building and awareness programmes for the large number of stakeholders involved in the buildings sector can help raise awareness and enhance skills and expertise. Such capacity building can help inform stakeholders in particular in low-mid income countries about otherwise overlooked affordable decarbonisation measures. International finance has a key role to play in delivering the enormous finance and investment required to bring about the transition in the buildings sector, in particular amongst low-mid income countries. International banks can help promote decarbonisation by prioritizing green buildings through soft loans, better interest rates or green bonds (WEF 2011). Multilateral development banks can help ensure that investments are available in all countries/regions. A particular potential exists regarding the distribution of clean cookstoves that can help reduce emissions in the sector at a large scale in many developing countries.

Knowledge and Learning

Policy and technical knowledge platforms can help increase information and awareness, allow the sharing of best practices, enable diffusion of technical know-how, develop solutions to common concerns like the principal-agent problem and empower policy makers to develop effective policies and

low-carbon technology priorities (IEA, 2013). These platforms can also help promote awareness and knowledge of available financial incentives for high-performing products and systems (IEA, 2015a). A global database can help build and maintain reliable information, sectoral mapping, existing financial opportunities, climate compatible innovations, and a progress measurement system (Global Alliance for Buildings and Construction, 2016). The IEA also recommends an array of standardised information packages that can allow decision makers to compare the potential of technology alternatives, identify performance targets and energy and CO_2 savings at the time of design or purchase (IEA, 2013).

Interlinkages to other sectors

Power Sector: A fuel switch to electricity for heating would increase the consumption of electricity in buildings (beyond an increase already projected on the basis of current trends). The growth of energy efficient or green buildings, including generation and use of renewable energy, will conversely reduce the demand in the power sector.

Construction: Greater efficiency in buildings may increase the need for more efficient construction material and perhaps less waste.

4.12 Appliances

4.12.1 Current status and prospect

Appliances make up a major share of residential electricity demand: refrigerators (14 per cent), televisions (TVs) (seven per cent), and washing machines (two per cent). Collectively, these three types of appliances accounted for ~761 $MtCO_2e$ in 2010 (bigEE, 2013a) equivalent to about 2.5 per cent of total CO_2 emissions from fuel combustion. Substantial emission reduction potential exists, if consumers opted for the most efficient model every time one of these appliances is purchased. The potential amounts to almost 0.5 $GtCO_2$ per annum by 2020 (bigEE, 2013a; IPCC, 2014b). This does not even cover embodied emissions that occur in the process producing and recycling of appliances. For big appliances, depending on the emission intensity of the electricity used during the use phase associated emissions of production and recycling are estimated to amount to ~20 per cent of the emissions that occur over the product's life cycle. For TVs and Information and Communication Technology (ICT) equipment the share may be even greater (GEA & IIASA, 2012). For refrigerators, there is another challenge as most refrigerants entail highly potent GHGs that may enter the atmosphere if not recycled properly.[23]

According to UNEP's "en.lighten" initiative lighting accounts for 15 per cent of global electricity consumption translating into roughly five per cent of global GHG emissions (UNEP, 2016). Efficiency improvements in lighting have made particular advances with costs of Light Emitting Diode (LED) lighting plunging and investments soaring (see below). Consequently, substantial energy savings have been realized over conventional lighting setups (145 terawatt hours or TWh in 2016). Yet, these savings represent only a fraction of the total remaining savings potential of an estimated 1600 TWh (IEA, 2016b).

Cooking is the most universal residential energy service. It is responsible for around five per cent of all GHG emissions worldwide, which is about 2 $GtCO_2eq$ annually. The lion's share of this is due to inefficient biomass- or coal-based cooking predominantly in developing countries. Energy consumption for this type of solid-fuel cooking can be cut in half at relatively low cost and simultaneously realize substantial co-benefits (bigEE, 2013a).

---

[23] The issue of fluorinated hydrocarbons (HFC) that are common in refrigerants is further addressed in section 4.14.

Annual emissions are likely to grow further in the coming decades as the proliferation of appliances increases in developing countries. Typically, the appliance penetration increases with levels of income, but other factors such as wealth, affordability but also cultural factors may play a role. In developed countries, there is almost ubiquitous penetration of TVs and refrigerators, but greater variability for domestic washing machines. While 95 per cent of European and Japanese households own washing machine, the penetration rate seems to have levelled off in the US at ~80 per cent and there is some indication that this may also occur in emerging economies such as South Africa and Brazil (Rao & Ummel, 2017).

The market for energy efficient appliances already is a massive one, but is driven primarily by public policies. In 2015 just over USD 90 billion was spent on energy efficient appliances and lighting, an incremental investment of USD 44 billion over average efficiency products (IEA, 2016b). Despite this development, still this has not led to a decrease in electricity consumption, because the increase in uptake and use of appliances outpaces efficiency gains. For example, in TVs, increasing ownership and in particular ever larger screens have worked against efficiency improvements (IEA, 2016c).

Two global trends are approaching that may have significant impact on the energy consumption and hence associated GHG emissions with respect to appliances and electronic consumer goods. One trend is digitalisation: increasingly smart appliances are introduced into the market. While this may cause higher energy demand both as the smart components in the appliances require additional electricity as compared to non-smart appliances of the same level of efficiency regarding the original service as well as for the ICT infrastructure necessary to connect the smart appliances. On the other hand a smart "internet of things" may leverage systemic mitigation potentials e.g. because they make appliances responsive parts of the energy system that can help reduce peak demand and thus limit demand for energy storage (Palensky & Dietrich, 2011). Which of the two effects will prevail over the other is at this stage impossible to project.

The second general trend is still far on the horizon, but may nevertheless have a strong impact. Currently, most electricity infrastructure is based on alternating current (AC). The increasingly fragmented generation of electricity based on decentralized renewable energy systems may challenge this. Solar PV produces direct current (DC) that currently has to be transformed in AC to be fed into the grid. At the same time, many appliances (e.g. LED lighting and ICT equipment) also require DC that needs to be converted by external power supplies. Each AC/DC conversion reduces efficiency. To avoid conversion losses, it has therefore been proposed to introduce DC-based domestic power systems alongside the existing AC infrastructure (Pantano, May-Ostendorp, & Dayem, 2016).

4.12.2 Main challenges and barriers toward decarbonisation

The challenges for increasing energy efficiency are similar across various sectors. For the uptake of energy efficient appliances is hindered inter alia by the following key barriers (bigEE, 2013b):

- Economic and financial barriers: efficiency measures typically require substantial upfront investments while the payoffs materialize only over time. Also for manufacturers there is a risk that new highly efficient products do not meet sufficient demand and hence investments cannot be recouped.
- Lack of knowledge: in many cases, there is simply no information available or easily accessible at the point at which investment/purchase decisions are being taken.
- Lack of interest: typically, operating costs for appliances make up only a small share in household budgets. At the same time, searching for efficient alternatives may produce significant transaction costs. Also, the priority of those making consumption decisions is on providing a

specific energy service to their household and not to minimize cost and/or energy consumption.

Even if energy efficiency improvements are realized, there further challenges that need to be addressed to curb absolute emissions in the sector. A major one is the rebound effect: when energy services become more affordable because of efficiency improvements, this may lead to an increase of demand in the same services. There may also be an indirect rebound effect in that households may spend financial savings realized through more efficient energy services on other forms of emission intensive consumption (Gillingham, Rapson, & Wagner, 2016) .

Another issue regards sufficiency. Sachs defines sufficiency in relation to efficiency: "While efficiency is about doing things right, sufficiency is about doing the right things" (Sachs, 2015). The concept of sufficiency thus entails restrictions on absolute demand for goods and services (Samadi et al., 2016). In other words, there may be unsustainable levels of demand for energy services and hence a need to reduce absolute consumption levels. In practice, this would mean that the trend to ever bigger TV screens or more voluminous refrigerators is reduced and eventually reversed. While first advances with respect to sufficiency enabling policies have been made (Thema, Thomas, Kopatz, Spitzner, & Ekardt, 2017), the issue remains still a marginal one.

Markets for efficient appliances and consumer electronics is highly dependent on policy interventions. Demand is driven to a great extent by policies (IEA, 2016c). The policies can target at various stages of the value chain of appliances. The most common approaches are (4E, 2016; bigEE, 2013b):

- Policies that reduce uncertainty for manufactures by signalling credible long-term demand. This can be achieved through political commitments and long-term goals.
- Regulation of manufactures so as to prohibit the production of the least efficient appliances (Minimum Energy Performance Standards – MEPS). This also reduces complexity for consumers.
- Enabling consumers to compare efficiency of different models by setting information requirements for retailers and/or efficiency labelling.
- Monetary incentives to replace old inefficient appliances with new efficient ones.

Prominent examples for policies that address energy efficiency of appliances are the EU's Ecodesign Directive, the US energy star label and the Japanese top-runner initiative. The number of countries that have introduced similar regulations on the various types of appliances has increased substantially over recent years, still a large number of countries lack such regulations and or lack the capacities to adequately implement and enforce regulations (IEA, 2016b).

As regards the interdependencies with other sectoral systems, the appliance and consumer goods sector has an obvious relation to the power sector. Reducing electricity demand through energy efficiency in appliances and consumer goods is a critical component for a successful transformation of global power systems.

4.12.3 The promise and potential of international cooperation

The potential leverage for international cooperation is largely limited to those instruments that target the manufacturing industry for appliances and consumer goods. There is very limited scope to address consumer decision making from the international level. Also, not all appliances and consumer goods are created equal: the degree to which markets are globalized vary for the different types of appliances. While for most consumer electronics, including TVs, the market is largely a homogenous global market, this is not true for white goods where traditionally at least three largely separated markets existed in terms of products sold and consumer preferences alike: a European, a North American, and an Asian

market. However, in recent years this has started to change as especially Chinese and Korean brands have started to take hold also in Europe and North America.

Guidance and Signal Function

The first way in which international governance could advance the transformation of appliances and consumer good markets would be through signalling clear and credible commitment for long-term efficiency improvements (guidance and signal function). As discussed above, one key barrier is the high degree of uncertainty faced by manufacturers with respect to demand for energy efficient products. Political statements and long-term goals for energy efficiency improvements in combination with credible short-term policies to achieve the set goals can help reduce risks and incentivize manufacturers to invest in innovating and diffusing high efficiency models. For example, the EU included the overall target to improve energy efficiency by 20 per cent over business-as-usual projections by 2020 in its 2020 climate and energy package, alongside goals to reduce GHG emissions and to increase renewable energy deployment. Including an explicit target for energy efficiency alongside other targets could provide the required signal for the sector (Sterk & Hermwille, 2013). An alternative to such an international goal might be a requirement to establish such targets at lower governance levels.

Apart from abstract policy goals and political commitments, another way to convey the (investment) signal to the manufacturers is to set up strong MEPS and set up clear and ambitious energy labelling schemes. The importance of the guidance and signal function of international climate governance is hence regarded highly important.

Setting Rules to Facilitate Collective Action

Internationally harmonized MEPS, efficiency labels, information requirements and measuring standards could not only help to convey investment signals but would also serve to fulfil the governance function of enabling collective action and would help to address the other two remaining key barriers for increased uptake of efficient appliances, namely lack of knowledge and to some extent lack of interest on the part of consumers. Efficiency labelling addresses the former. Minimum performance standards can be seen as a way to overcome the latter as it would increase the energy performance of default choices for those who have no strong interest in searching for the most efficient alternative to procuring energy services.

What is more, the harmonization of labels and standards may help reduce cost on the part of the industry. On the other hand, a common standard for efficiency assessments may create the foundation also for common minimum energy performance standards. But there is also a potential downside to a global harmonization of efficiency standards. In the past, the various efficiency standards have engaged in competition on the most stringent efficiency labels. A harmonization of global efficiency standards cut curtail this kind of competition and hence curtail an important driver of the evolution of efficiency standards. Given the ambivalence of the potential effect of international harmonization of efficiency labelling and standards, the collective action function for the appliances sector is considered to be of medium importance.

Knowledge and Learning

While the number of countries that have introduced some form of efficiency regulation on the various types of appliances has increased significantly, there is still a large number of particularly developing countries that lack such policies and/or lack capacities to implement and enforce them. International cooperation can contribute to redeem this by facilitating knowledge production and learning both in terms of technologies and policies and measures for driving energy efficiency improvements. The contribution that international institutions could make to knowledge and learning is considered to be of medium importance

Means of Implementation

Given the nature of the sector challenge and since efficient appliances can often pay for themselves in many cases due to energy savings, supplying financial means of implementation are not considered a central governance challenge. The same holds for technology transfers. However, capacity building on how to establish MEPS and other types of efficiency policies at the national level should be considered. Hence, the means of implementation function is considered of medium importance.

Transparency and Accountability

The transparency and accountability function of international governance is only relevant to the extent that common standards (MEPS) are adopted internationally. In this case, it can help enforce those standards.

4.13 Financial sector

4.13.1 Current status and prospect

If the world is to hold global temperature increase to well below 2°C and limit this to 1.5°C, as agreed to in Paris, investment patterns have to change drastically. Significant additional investment in low-emission infrastructure and technologies needs to be mobilised. At the same time, broader financial flows have to be aligned with climate objectives by phasing out high-carbon infrastructure investments. Estimates of the investments needed to decarbonize the energy sector are based on different methodologies and are relative to different timeframes and sectors, and are thus not directly comparable. Nevertheless, as a common trend, these estimates identify the order of magnitude for annual investments needs in climate action by 2020 to be well beyond USD 1 trillion (Mission 2020, 2017). Given the long lifespan of energy and transport infrastructure, investment choices to 2030 that are inconsistent with the goals of the Paris Agreement risk both a lock in of future GHG emissions as well as financial instability and large-scale stranding of assets (OECD, 2017).

Global financial flows going to low-carbon and climate-resilient development have been growing in recent years from USD 97 billion in 2009/10 (Buchner, Falconer, Hervé-Mignucci, & Trabacchi, 2011), to an annual average of USD 367 billion in 2013/2014, with the majority (93 per cent) of these funds going to efforts to reduce GHG emissions in three main areas: renewable energy generation, energy efficiency, and sustainable transport-(Buchner et al., 2016). Although the tracking of financial flows to low-carbon development has been improving, a wide range of definitions and methodologies are still used. However, most data aggregators report similar levels of annual renewable energy investment in a range of USD 250 to 265 billion for the period 2013/14. (Buchner et al., 2016; IEA, 2014a; UNFCCC, 2016).

Nevertheless, investments still fall significantly short of what is needed to achieve national climate targets and global goals. There are different estimates for how much investment is needed to shift the world on to a well below 2°C pathway, and very little literature is available on investment needed to shift to a pathway consistent with the goal to limit global temperature increase to 1.5°C. Reports that use scenarios that are not compatible with the 1.5°C limit will therefore underestimate the actual scale of investments needed.

There are varying estimates of investments required ranging from USD 2.5-6.9 trillion per year, with different estimates reached depending on variables considered such as atmospheric GHG concentration, total investment, additional investment, and coverage of countries and/or sectors. The Global Green Growth Institute has estimated that the climate finance gap between current investment and

the investment required over the next fifteen years in non-OECD countries to stay below an atmospheric GHG concentration of 450 parts per million is USD 2.5 – 4.8 trillion. Bridging this gap would require an additional USD 166 – 322 billion per year (Global Green Growth Institute, 2016).

The OECD, building on IEA and the International Renewable Energy Agency's (IRENA) joint analysis of additional investment required in low-carbon technologies to achieve the 66 per cent probability of 2°C scenario, estimated that the investment required to remain below 2°C will be USD 6.9 trillion per year over the next 15 years for new infrastructure, which represents merely a ten per cent increase relative to the USD 6.3 trillion of annual infrastructure investment needs before taking into account climate issues (OECD, 2017). This number is to be compared with current infrastructure spending of around USD 3.4 to USD 4.4 trillion. The majority of infrastructure investments are required in transport and power, two critical sectors that are also at the heart of decarbonisation strategies.

In this context, a new paradigm of "shifting the trillions" has emerged, in which the necessary investment shift for decarbonisation requires trillions of private finance dollars to be redirected instead of only billions being mobilised by mainly public resources for climate-specific investments. This points to the indispensability of the nexus between targeted climate action and the "greening" of broader economic and financial policies for financial stability and economic growth, requiring both long-term climate strategies and climate-aligned investment environments. This has been acknowledged in the Paris Agreement's goal of making finance flows consistent with a pathway towards low GHG emissions and climate-resilient development (Article 2.1(c)), which will require both scaling down funding for high-emission activities and scaling up the flow of climate finance.

Globally, energy investment is not yet consistent with the necessary transition away from fossil fuel financing. Between 2000 and 2014, capital expenditure on fossil fuel supply has been increasing steadily, tripling in real terms and interrupted only in 2009 by the financial crisis and more recently by the steep drop in global energy prices. More recent estimates of "brown" finance (i.e. high-carbon financing and investments) put global investments in oil, gas and coal supply in 2015 at USD 900 billion, representing a decline of 18 per cent from the USD 1.1 trillion in the peak year 2014 (OECD/IEA, 2016). It remains to be seen whether this is a lasting change in the investment flows.

On the "green" finance side, renewable energy investments reached a record of USD 312.2 billion in 2015 and accounted for nearly a fifth of total energy spending in that year, establishing renewables as the largest source of power investment. While spending on renewable power capacity has decreased to USD 241.6 billion in the subsequent year, the installed capacity in 2016 increased to reach 161 gigawatts, including 136 gigawatts from non-hydro, mainly wind and PVs (REN21, 2017). This discrepancy between decreasing investments and increasing capacity reflects the steep cost declines in wind turbines and solar PV (Lazard, 2016).

Despite the positive trends towards a growing mobilisation of climate financing, on a global net level both public and private finance are currently still dominated by high-carbon investments. For example, while the public and private mobilized climate finance for developing countries has been growing over the past decade reaching an average for the two years of USD 57 billion per year for 2013/2014 (OECD, 2015a), it remains a small portion of government subsidies for fossil fuel consumption which reached around USD 513 billion a year globally in the same period (IEA, 2014a). Public support by G20 governments in subsidies to fossil fuel production has been estimated at USD 444 billion a year (Bast, Doukas, Pickard, van de Burg, & Whitley, 2015). A global removal of fossil fuel production subsidies would result in estimated GHG emissions reductions of up to 37 GtCO_2eq over the period 2017–2050 (Gerasimchuk et al., 2017). To put this in context, total global GHG emissions in 2014 were 51 GtCO_2eq (Gütschow, Jeffery, Gieseke, & Gebel, 2017).

Public financing to mitigate climate change remains key because it directly mobilises and leverages private sector investment and indirectly creates scaled up and commercially sustainable markets for

low-carbon technologies (Maclean, Tan, Tirpak, Sonntag-O'Brien, & Usher, 2008). Shifting the trillions of global assets controlled by private entities, including the global banking sector worth USD 140 trillion; institutional investors, such as pensions funds and insurance companies, managing over USD 100 trillion; and capital markets including bonds and equities of over USD 100 trillion and USD 73 trillion respectively (Buchner et al., 2016) from high to low-carbon alternatives remains the key challenge for greening the financial sector.

The financial sector has seen a number of developments in recent years with relevance to the "shifting the trillions" challenge. Major credit rating agencies such as Moody's and Standards & Poor are beginning to incorporate climate risks in their rating criteria. Still these risks have not yet been fully included in credit ratings, which signal investors the relative credit risks of financial obligations issued by corporations in a comprehensive manner. Carbon thus remains a hidden risk to these investors and has often been referred to as the "carbon asset bubble", which some analysts have concluded poses similar systemic risks to the financial market as the housing crisis that led to the global financial crisis in 2008 (Carbon Tracker, 2011). Risks that are caused by "stranded assets" (i.e. assets that have experienced unanticipated write-downs or devaluation) are recently receiving more attention by the investment industry. The value of global financial assets at physical risk from impacts of climate change has been estimated at USD 2.5 trillion by the London School of Economics, and USD 4.2 trillion by the Economist (EY, 2016).

The need for better transparency has also been recognized by, for example, regulatory bodies such as the Bank of England, and the establishment of the Financial Stability Board (FSB) Task Force on Climate-related Financial Disclosures that is developing voluntary climate-related financial risk disclosures for use by companies in providing information to investors, lenders, insurers and other stakeholders (TCFD, 2016). In one high-profile recent example, over 63 per cent of Exxon shareholders voted in favour of a proposal calling on the world's biggest oil company to disclose the risk it faces from climate change and stress-test its assets for climate risk each year (Rushe, 2017).

Further, climate specific financial instruments such as green or climate bonds, including the introduction of standards and certification, have successfully been added as financial products within the financial sector in recent years. Annual issuance of Green Bonds reached USD 81 billion in 2016, which represents a 92 per cent growth on 2015 figures (Climate Bonds Initiative Markets Team, 2016) and overall the market still remains in its initial phase of development.

Beyond these developments, several major financial institutions have repeatedly expressed their need for clear, stable and long-term policy frameworks to accelerate and further scale-up investments in climate solutions, showing their willingness to drive an investment shift. In addition, a coalition of institutional investors (CDP, 2017; UN Climate Summit 2014, 2014) committed ahead of the Paris Agreement to decarbonizing USD 100 billion in institutional equity investments. Several individual banks have also pledged decarbonisation measures. For example, Deutsche Bank has committed to end new coal investments and to gradually reduce the exposure of its current portfolio to such investments (The Guardian, 2017). Funding for 'extreme fossil fuels' dropped by 22 per cent from the previous year in 2016 from 37 of the largest private banks in North America, Europe, Japan, China, and Australia. While this steep drop in funding is a positive development, it has to be the start of a sustained and rapid phase-out rather than a temporary decline (RAN, Banktrack, SierraClub & OCI 2017).

Among grass-root initiatives targeting the financial sector, the global fossil fuel divestment movement has gained momentum through decisions of some major insurance companies, pension funds, and foundations in several countries to divest from fossil fuel assets, including the Rockefeller Brothers Fund (Rockefeller Brothers Fund, 2017), France's largest insurance company AXA (AXA, n.d.), and the Norwegian Government Pension Fund (The Storting, 2015) (Stadelmann, Roberts, & Michaelowa, 2011). At the end of 2016, and one year after the adoption of the Paris Agreement, institutions with a total value of USD 5.45 trillion have joined the divestment movement (Arabella Advisors, 2016).

In the arena of multilateral development assistance and international cooperation for supporting climate change actions in developing countries, multilateral development banks (MDBs) continue to play a critical role in bridging the flow of funds between public and private actors. In 2015, the six largest MDBs mobilized a total of USD 81 billion, including USD 56 billion leveraged from other investors (The World Bank, 2016). Despite this, MDBs could better align their financing for infrastructure with low-emission pathways, particularly in the transport and water sectors (OECD, 2017).

4.13.2 Main challenges and barriers toward decarbonisation

Despite the above developments and emerging shifts that demonstrate the potential for climate-aligned investments, a significant acceleration in "shifting the trillions" towards green sources of energy is needed to avoid exceeding the Paris Agreement's temperature limit. Such a transformation requires reforms in a number of areas, including for example, disclosure of information about climate risks to financial markets, mainstreaming risks and impacts associated with climate change into investment decisions, and moving from short-term towards long-term investment horizons. Further, policy frameworks influencing investments in the energy sector may need to be reformed so that fossil fuel externalities are internalised into production and consumption practices. This should include setting strong carbon prices and eliminating distorting FFS and other support to fossil fuels. Developing climate-compatible financial instruments and investment criteria will also help to inform investment decisions that will contribute toward decarbonisation and improve transparency of those decisions.

However, there are challenges and barriers to achieving these outcomes, including economic, political, institutional and knowledge barriers.

Inconsistent policy signals by governments are significant barriers for a decisive and orderly low-carbon transition. The Paris Agreement has given a clear signal that strengthening the global response to the threat of climate change needs to make financial flows consistent with a pathway towards low GHG emissions and climate-resilient development. However, a number of studies have concluded that governments' backing and support to fossil fuel production create energy market distortions by sending contrary signals to investors that continue to depend on fossil fuels (Gerasimchuk et al., 2017). Clear long-term policies and sufficient regulatory frameworks are needed to send appropriate signals to markets and investors, and to incentivize the engagement of the private sector (OECD/IEA and IRENA, 2017).

While various efforts and initiatives such as carbon trading and reforming and shifting FFS have started the shift to low-carbon development, these are generally at insufficient scale and still in early phases. For instance, G20 countries, which account for 75 per cent of global GHG emissions and about 82 per cent of global energy-related CO_2 emissions, have not lived up to their commitment to phasing out inefficient FFS. While these countries have decreased the energy and carbon intensity of their economies, they are still at the early stages of decarbonisation and their collective efforts are not yet sufficient to lead to an overall reduction in GHG emissions. While renewable energy in these countries is on the rise, fossil fuels still dominate the energy market with coal being the primary energy supply for most G20 countries (Burck et al., 2017).

Subsidies to fossil fuel production further distort energy markets by lowering costs of oil, coal and gas production, thereby encouraging fossil fuel consumption. This is one of the main reasons why energy efficiency and clean energy investments still remain less competitive in some markets (Gerasimchuk et al., 2017). Some studies have found that a barrier for removing FFS, particularly in developing countries, is the rising cost of energy which is usually transferred to household consumers, which are most sensitive to price rises (Roberts, 2016). However, there are other studies that indicate eliminating FFS does not affect all households equally and usually it is the higher income groups that benefit most from FFS (Coady, Parry, Sears, & Shang, 2015).

Subsidies for fossil fuels and other market distortions that do not reflect the externalities of the full economic, social and environmental cost of fossil fuels can in part be addressed with market-based mechanisms intended to price carbon through, for example, emission trading schemes or carbon taxes. However, remaining barriers to the market penetration of such mechanisms include low prices of carbon and their insufficient coverage relative to global GHG emissions. Prices under carbon-pricing schemes remain too low in G20 countries to encourage a substantial shift to low carbon economies (Burck et al., 2017).

Carbon pricing, if well designed, could be a tool that helps to lower GHG emissions and shift investments to low-carbon sources of energy. Various studies indicate that carbon is generally still priced very low where carbon-pricing schemes are in place. Currently 60 per cent of CO2 emissions are priced at zero and less than ten per cent of the emissions are priced at EUR 30 or more (OECD, 2017). The High-Level Commission on Carbon Prices has stated that. a carbon price level that is consistent with holding global temperature increase below 2°C is at least USD 40-80 per tonne of CO2 by 2020 and USD 50–100 per tonne of CO2 by 2030, with a supportive policy environment in place (Carbon Pricing Leadership Coalition, 2017). Since the study used scenarios to limit warming below 2°C with a greater than 66 per cent probability, holding global temperature increase to well below 2°C and limit this to 1.5°C would imply carbon prices at the high range or above these estimates.

According to Carbon Pricing Watch (2017), the number of carbon pricing initiatives implemented or scheduled has almost doubled over the past five years, including 40 national and 25 subnational jurisdictions, responsible for about a quarter of global GHG emissions. However, only about half of the total emissions from these jurisdictions are covered by the carbon-pricing initiatives, leading to a total coverage of only about 15 per cent of global GHG emissions or about 8 GtCO2eq (World Bank & Ecofys, 2017).

Lack of information and knowledge is another barrier that institutional investors and central banks face. Though the awareness and responsiveness to climate related risks of asset owners and investors has increased, most of them still lack in-house capacity and experience to develop an informed view about climate change scenarios and strategize accordingly. Moreover, many of these investors find it difficult to incorporate climate risks into their investment strategies (EY, 2016). One study even found that central banks do not consider mainstreaming climate change into their operational decisions is their responsibility, with one stated reason being the need to avoid distorting the market (Matikainen et al. 2017).

Another major barrier is the fact that financial investors are prioritizing financing short-term liabilities which has negative impact on green investments, which often require high upfront investment costs (Matthew Scott, van Huizen, & Jung, 2017). High perceived risks, limited financial viability and limited long-term capital form barriers for the private sector to invest in capital intense renewable energy projects. Green investments typically suffer higher risk perceptions due to a dependence on public policy and, often, the relative immaturity of technologies, markets, and industries, especially in developing countries (Frisari, Hervé-Mignucci, Micale, & Mazza, 2013). However, investors often do not take into account that delayed action would have a significant impact on stranded assets, created by physical climate change impacts and the transition to a low-carbon economy (IRENA 2017b). An overarching challenge is therefore how to leverage the financial system to support the low-carbon transition in the real economy. The public sector can help to overcome these barriers through the use of public financing mechanisms such as risk mitigation instruments including risk pooling and transfer, public concessional financing and guarantees.

While there is growing momentum for financial institutions to disclose climate risks in their investment portfolios to investors, the lack of coherent, comparable and standardized approach to assess and disclose risks remains the biggest barrier. In order to address this concern, the G20 in 2015 requested the FSB to review how the financial sector can take account of climate related issues (TCFD, 2016). The

Task Force on Climate-related Financial Disclosures, established by the FSB, designed a coherent but voluntary framework for disclosing clear, comparable and consistent information about the risks and opportunities of climate change. The Task Force recommended that climate-related financial disclosures should be mainstreamed into financial institutions' public annual financial filings to inform investors and others on climate-related risks and opportunities (TCFD, 2017). The fact that it is voluntary continues to create challenges - with the exception of France, that became the first country to introduce mandatory climate change related reporting for institutional investors in 2016 (Rust, 2016).

4.13.3 The promise and potential of international cooperation

Guidance and Signal

An overall internationally agreed objective to bring international finance and investment fully in line with climate objectives ("greening" of international finance and investment) could send a strong signal to investors.

Apart from that, the signal could also emanate from and be reinforced by consistent and coherent climate policy actions by governments (OECD/IEA and IRENA, 2017). Providing strategic environmental and economic policy signals and frameworks for investors was identified by the G20 as one of the options to scale-up green financing (Matthew Scott et al., 2017). Such climate policy signals and guidance can influence finance flows and drive investments towards a low-emission and climate resilient pathway, which in turn will contribute to the degree of decarbonisation globally (Burck et al., 2017).

The removal of FFS and pricing of carbon in particular can send signals to markets and investors that governments are creating long-term regulatory frameworks and enabling environments for aligning investments with the goals set out in the Paris Agreement.

More generally, targeted international initiatives and cooperation aimed at decarbonisation of economies or specific sectors can help send signals to investors regarding investment and portfolio decisions (e.g. phasing out coal plants in the electricity mix, renewable energy targets, electric vehicle targets and phase out of combustion engines, green building standards).

Setting Rules to Facilitate Collective Action

The absence of any international burden sharing mechanism or rules regarding the provision and mobilization of financial resources to developing countries raises the question of whether developed country Parties with obligations to provide financial support follow through with delivery of such support. In order to ensure that all industrialised nations provide their fair share of support to developing countries in line with their historical responsibility and capacity to pay, the feasibility of developing fair burden sharing approaches could be considered. However, in previous international negotiations, contributors could neither agree on the concept nor formulas for burden sharing.

Reaching international consensus on concepts, definitions and methodologies related to what counts as climate finance and setting common rules for reporting on climate finance provided, needed and received is a prerequisite for improved transparency of climate finance flows for enhancing trust and mobilizing cooperation among countries.

Shared commitments and targets for reforming and eliminating FFS and pricing carbon in line with a distributed global carbon budget offer protection against exploitation by free-riders. A lack of international cooperation may decrease the competitiveness of countries taking climate action and discourage governments relying on fossil fuels to internalize the full costs of carbon. A global price target such as an internationally agreed minimum carbon price would create a strong market signal and incentives to increase action "to shift the trillions" (Cramton, MacKay, Ockenfels, & Stoft, 2017). For purposes of

accountability and tracking progress of fossil fuel subsidy reforms and carbon pricing mechanisms, common reporting systems should be established.

International cooperation in multilateral organisations, institutions and fora such as OECD, G20, UNFCCC, and multilateral climate funds can shape international norms by setting rules on which type of financial investments are socially, economically and environmentally beneficial and acceptable. In addition to shared targets between countries, MDBs and International Financial Institutions have a key role to play by setting targets for phasing out fossil fuel investments and mainstreaming climate consideration into their entire portfolios. Similarly, common rules such as excluding coal and other fossil fuel activities are necessary for export credit agencies who currently still provide guarantees for coal investments in developing countries.

Transparency and Accountability

International transparency and accountability are key elements for tracking progress on the fulfilment of developed countries' obligations to mobilize and provide climate finance to developing countries, as well as for tracking progress on global efforts of shifting all financial flows from brown towards green investments. Existing transparency efforts lack two main elements that could benefit from increased international cooperation: firstly, accounting for both sides of the climate finance ledger, including not only the climate-compatible investments but also the high-carbon investments or "brown finance" going to fossil fuel extraction and production, for measuring the net climate benefit (Bodnar, Ott, Thwaites, De Marez, & Kretschmer, 2017); and secondly coherent and standardized approaches for financial institutions to assess and report climate-related financial risk and to provide disclosure reporting.

Means of Implementation

Public finance is needed to leverage and mobilize additional climate finance, particularly from the private sector. Coordination and cooperation among donor countries and bilateral/multilateral funds and institutions (e.g. Green Climate Fund, Global Environment Facility, MDBs including the World Bank) is required to ensure coherence and minimize duplication of efforts in the provision of climate finance, capacity-building and technology transfer. The building of institutional capacity in governments and financial institutions is critical for putting in place regulatory frameworks and policy reforms to align public and private financing with global climate targets. Especially the financial sector currently lacks capacity for developing appropriate methodologies for assessing climate-related risks in all investment decisions.

Knowledge and Learning

Decoupling emissions from economic growth is a new path of development that requires more generation and dissemination of relevant data, knowledge and adaptive learning (Burck et al., 2017). In this regard, international cooperation to facilitate platforms for exchange of knowledge and learning about which policies work best to mobilize climate finance and divest assets from fossil fuels will be critical. International cooperation among financial institutions and investors is needed to facilitate sharing of knowledge and examples of best practice, including in developing scenarios and new methodologies related to climate-related risk analysis and management in the financial sector.

4.14 Fluorinated GHGs

4.14.1 Current status and prospect

Fluorinated GHGs or F-gases are a family of manmade gases used in mainly industrial applications. There are four types of F-gases: hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3). While F-gases are energy efficient and safe for users given their low levels of toxicity and flammability, they have (due to their very long atmospheric lifetimes) very high global warming potentials – thousands of times greater than CO_2. HFCs were developed in the 1990s as substitutes to ozone-eroding chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) which are to be phased out under the Montreal Protocol for the protection of the ozone layer. PFCs and SF_6 were already in use prior to the Montreal Protocol.

F-gases represented less than two per cent of anthropogenic GHG emissions in 2010 (Blanco G. et al., 2014), but have almost doubled from an estimated 1.1 per cent (or 0.5 $GtCO_2eq$) of anthropogenic GHG emissions in 2004 (IPCC, 2007). In the absence of mitigation measures, the total global emissions of F-gases have been estimated to amount to about 4 $GtCO_2eq$ by 2050 (Gschrey, Schwarz, Elsner, & Engelhardt, 2011; IPCC/TEAP, 2005; Purohit & Höglund-Isaksson, 2017; TEAP, 2016). HFCs are the fastest-growing GHGs with an annual estimated global growth rate of ten to 15 per cent (Andersen, 2015). While by 2002 80 per cent of HFC emissions had originated from industrialized countries (UNEP, 2002), the share of developing countries by 2012 had increased to more than 50 per cent (Rigby, 2014). Developing countries are also expected to lead future growth in HFC emissions (Duncan Brack, Andersen, & Sun, 2016; Purohit & Höglund-Isaksson, 2017; TEAP, 2016; Velders, Fahey, Daniel, Andersen, & McFarland, 2015).

F-gases are used in a limited number of applications. HFCs are primarily used as refrigerants (including in air conditioning systems in vehicles and buildings), aerosol propellants, foam blowing agents, solvents, and fire retardants (TEAP, 2016). They are released into the atmosphere during manufacturing processes and through leaks, servicing, and disposal of equipment in which they are used. PFCs are emitted as a by-product of various industrial processes associated with aluminium production and the manufacturing of semiconductors. SF_6 is used in electrical transmission and distribution equipment, including circuit breakers, magnesium processing, semiconductor and flat panel displays manufacturing, as a tracer gas for leak detection and filler for sound-insulated windows (Purohit & Höglund-Isaksson, 2017; TEAP, 2016).

Drivers for growth in use of F-gases include climate change, growth in population and GDP, growth in commercial and industrial value, and growth in number of vehicles (Blanco G. et al., 2014; Purohit & Höglund-Isaksson, 2017). Climate change in particular, with ever increasing global temperatures, will boost the need for more refrigeration and air conditioning.

Alternatives for the use of F-gases are already widely commercially available and tested and are being further developed. They already enable significant emission reductions at low cost and should even make a phase out of F-gases possible. Newly developed hydrofluoroolefins (HFOs) are currently being introduced as new refrigerants, aerosol propellants and foam blowing agents that could replace traditional HFCs (Greenpeace, 2016; TEAP, 2016). They are a subset of HFCs but with short atmospheric lifetimes and low global warming potentials, although they may still pose threats to the environment (Greenpeace, 2016). Iso-butane, n-propane, propene, ammonia, Fluoro-ketone, and others can also replace HFCs in a host of applications like aerosols, air-conditioning, heat pumps or foams. They have long been proven as alternatives to CFCs and HCFCs and could thus also replace HFCs. Retrofitting and switching to new conversion models can help mitigate PFC emissions from aluminium production while NF3 can replace PFCs in semi-conductors. Sulphur dioxide can replace SF_6 in magnesium production and casting. Good practice measures like leakage control and end-of-life recollection and recycling can

also contribute to reducing F-gas emissions (Purohit & Höglund-Isaksson, 2017; Seidel, Ye, Andersen Stephen, & Hillbrand, 2016; TEAP, 2016).

Costs differ across different applications and alternatives (at times even being negative), but overall phasing down/out F-gases will require additional investments and come at a (low) net cost (not taking into account the avoided environmental damage). By 2050, most F-gas uses could thus be phased out technically and cumulative emissions be reduced by more than 70 per cent at a marginal abatement cost of less than 10 Euro per tonne of CO_2eq (leading to a reduction of more than 50 per cent from current levels) (Purohit & Höglund-Isaksson, 2017; TEAP, 2016).

4.14.2 Main challenges and barriers toward decarbonisation

A first major economic barrier concerns the costs and investments incurred by switching from F-gases. As mentioned above, while some alternatives promise net savings, overall costs will need to be born and investments will be required. While smaller emission reductions may be achieved fairly easily by either substituting gases or implementing marginal efficiency improvements, deeper reductions involve increasing marginal costs and require new capital or alternative processes coming in at higher costs. Some technologies remain prohibitively expensive. There is limited incentive for individual actors to cover such costs and investments. In addition, user industries will partially have to adapt technical routines and practices and install new equipment (to the extent drop-in alternatives are not available), contributing to an inertia in the deployment of available alternative technologies (Purohit & Höglund-Isaksson, 2017).

Political opposition by parts of the F-gas industry has also been an important obstacle. The chemical industry, an important influence in many countries, has argued against F-gas controls as long as this seemed to lead to a loss of business to them. This opposition has softened and even disappeared with the investment cycle for F-gases coming to an end (and related intellectual property rights expiring) and with the industry making progress on the development of substitutes such as HFOs promising future business (and new intellectual property rights). This follows a pattern also observed with respect to the regulation and phase-out of CFCs and other ozone-depleting substances.

Regulatory hurdles are relatively limited. Regulatory frameworks exist worldwide as a result of three decades of efforts to phase out ozone-depleting substances, which especially HFCs partially replaced. Substituting F-gases in large parts constitutes a similar challenge that can build on the existing frameworks for CFCs and other ozone-depleting substances. Accordingly, regulations to tackle certain F-gases exist in certain countries and regions, including the EU, Japan, the US, Australia, Norway, Switzerland and China (Purohit & Höglund-Isaksson, 2017).

Finally, differences in capacity between developed and developing countries need to be acknowledged. Patents on HFO processes and applications held by industry in developed countries limit opportunities for a wide range of industry in developing countries (in both production and consumption sectors). Patent challenges create technology and legal uncertainties (World Bank, 2015). Moreover, technologies pertaining to natural substances, which are a technically feasible alternative and would help developing countries leapfrog HFCs altogether, are costly and primarily available in industrialized countries (Greenpeace, 2016). Overall, especially the limited availability of technology and finance as well as the overall costs put constraints on efforts to reduce and phase out F-gases in developing countries.

4.14.3 The promise and potential of international cooperation

Guidance and Signal Function

A global phase-out goal for the production and consumption of F-gases and a related roadmap with interim steps may provide guidance to the actors producing and consuming F-gases. A specific goal for F-gases would be more tangible for relevant actors than a general global GHG emission target, as it might not be clear from such a global target what the more specific aim for F-gases should be. A differentiation of the global goal by regions and countries would add value in view of varying capacities and national circumstances (e.g. varying role of refrigeration and air conditioning in different regions).

Setting Rules to Facilitate Collective Action

Given the cost implications of phasing down F-gases and lacking incentives for countering the inertia involved in the deployment of commercially available, affordable technologies, there is a high demand for international regulation to align countries and other actors toward a phase-don/out roadmap.

Transparency and Accountability

Global rules for phasing out F-gases will consequently require appropriate provisions for ensuring transparency and accountability so that any free riding can be discovered and addressed. In this regard, it may be noted that, a danger of illicit trade in relevant substances notwithstanding, the relevant regulated activities (production and use of these chemicals) is intrinsically relative transparent (production is concentrated in few large facilities and use in large part occurs in products that are widely available).

Capacity Building, Technology and Finance (means of implementation)

There is a high demand for multilateral funding and technology transfer in order to enable and ensure that developing countries can phase out F-gases. A successful blueprint exists in the form of the Multilateral Fund for the Implementation of the Montreal Protocol. Financial support would allow developing countries to adopt technological alternatives more easily.

Capacity building could perform complementary functions. Training and skills development in particular for developing countries will be beneficial in order to enhance the uptake of new technologies and practices and increase the mitigation potential of good practice measures like leakage control and end-of-life recollection and recycling.

Knowledge and Learning

While many of the technologies required already exist and relevant solutions are in large part known, international cooperation may help transfer relevant knowledge (e.g. by establishing a global database and clearing house that can help build and maintain reliable information, regional mapping, existing technologies and financial opportunities).

Linkages

Power: Some of the alternative substances/technologies may lead to a higher consumption of electricity. However, technological advances are likely to make up for such increased power demand to a large extent.

5. Conclusions

This report has undertaken to shed further light on the specific functions that cooperation in international governance institutions can perform so as to contribute to mitigating global climate change. From the relevant literature, we have to this end derived five general governance functions of international institutions: guidance and signal, setting rules, transparency and accountability, means of implementation, and knowledge and learning. This has provided a solid basis for separately analysing 14 key sectoral systems as to the need and demand for international governance institutions to perform these five governance functions. This sectorally differentiated approach follows from the increasingly shared insight that mitigating climate change faces very varied challenges and opportunities in different sectors and fields of action. It should and did allow us to identify and specify in greater detail the potential of international governance institutions to contribute to mitigating climate change.

It should be worth pointing out that our analysis at this stage abstracts from the world of existing international institutions (both intergovernmental and transnational). It does not include or imply an assessment of the performance of the various existing international institutions in addressing climate change and contributing to the governance functions distinguished. We have hence here aimed to identify and specify the *potential* of international institutions in general to contribute to mitigating climate change in light of the specific challenges and circumstances characterising the sectoral systems in focus. This is meant to enable us to contrast this potential with the actual contribution international institutions make, in order to identify the scope for enhancing this contribution and to identify related gaps – an analysis that is to be conducted as part of task 4.2 of the project. We have here not evaluated existing international governance efforts.

We provide a snapshot summary of our results in Matrices 5.1, 5.2 and 5.3. Matrix 5.1 provides an overview of main challenges and barriers to decarbonisation by sectoral system. The overview backs up our hypothesis that challenges differ considerably among them. All such systems feature a number of specific barriers relating to the sector-specific actors and options. Nonetheless, some common patterns can be identified.

In many sectoral systems, **economic barriers** such as higher marginal costs of climate-friendly technologies and practices are key, including in agriculture, LULUCF, waste, energy-intensive industries, and F-gases. In some of these sectors, a high trade intensity fuels concerns (agriculture, energy-intensive industries, F-gases) that the cost of climate action would endanger international competitiveness. In other sectors, mitigation options such as renewable electricity, efficient buildings and appliances increasingly have low or even negative marginal costs over their lifetime, but upfront investment requirements are higher, which creates a bias towards less efficient options and poses problems for actors and countries with limited access to capital.

Political and institutional barriers are particularly pronounced in sectoral systems that are dominated by large incumbent corporations, such as power, energy-intensive industries, national and international transport and F-gases. These incumbents often fiercely try to protect their established business models. Unclear division of labour among relevant national agencies and/or lack of enforcement of regulations have been identified as barrier in a number of sectors including LULUCF, waste, urban systems and buildings (especially in less capacitated countries).

Technological barriers are not a key concern in many sectoral systems, but in some full decarbonisation will require substantial further technological research and development. These sectors include agriculture, power, energy-intensive industries, international and national transport and buildings (regarding net zero-emission buildings).

Awareness, information and capacity are key barriers in most sectors. Awareness of problems, information about mitigation options and effective policies, and the technical skills of the work force need

to be improved across the board (with somewhat varying prominence of these elements across sectoral systems).

Based on the analysis of sectoral barriers, Matrix 5.2 provides a very rough grading of the significance of the five different governance functions in each of the 14 sectoral systems into "high", "medium" and "low". This grading is based on a qualitative expert assessment (rather than any quantified criteria). Grading as high indicates that the governance function in question is considered as a crucial priority to be addressed by international cooperation (climate mitigation may not be able to advance without such cooperation). Medium significance implies that providing this function is also important so that cooperation in this respect has considerable potential (without necessarily being crucial for progress). Grading as low implies that the governance function has little potential and may at best make a complementary contribution. We readily admit that such a grading only delivers a crude picture, which furthermore is subject to challenge by other experts.

The textual entries in Matrix 5.3 provide some further detail on the specifics regarding the potential contribution of international institutions to the governance functions per sectoral system. Inescapably, this matrix/table cannot reflect the nuances as contained in the preceding sectoral analysis, but has to focus on providing brief summaries of the main points. The interested reader is referred to the sectoral analyses in section 4 for further details.

With respect to the **guidance and signal** function, the synopsis shows that there is a general demand for such guidance and signal in the different sectoral systems. The circular economy that is itself not contributing to climate change constitutes the sole exception, as it would best be driven by targets and visions for the sectoral systems that are key for a sectoral economy (including waste, energy intensive industries, etc.). Agriculture scores somewhat lower because of the specific characteristics of this sectoral system and in particular since a full phase-out of emissions in this sector seems technologically and socio-economically unfeasible (which hinders the determination of clear-cut overarching guiding targets). In the large majority of sectoral systems, there is a clear added value of establishing/having internationally agreed targets and visions. Such targets and visions have the potential to align actors globally towards decarbonisation.

This potential is not least rooted in the need to completely phase out net GHG emissions as early as possible in the second half of this century in order to enable holding the increase of global average temperature to well below 2/1.5° C, as recognised in Articles 2 and 4 of the Paris Agreement. This opens up the opportunity of establishing general targets that can provide direct guidance to individual actors within sectoral systems. For example, the need to achieve net-zero emissions within the next few decades translates into the need to immediately halt investment into fossil fuel power stations, a clear target providing direct guidance to any investor. In contrast, a hypothetical target of halving emissions would not necessarily provide such clear guidance to individual investors as each one of them may assume the 50% reduction would be realised by others.

The entries in Matrix 5.3 illustrate that the added value lies in particular with targets and visions that are concrete enough for the relevant sectoral actors. Hence, the LULUCF sector could benefit from an agreed target to halt deforestation and to turn the sector from a net source to a net sink of GHGs. Similarly, the buildings sector could be guided by a clear vision of a full decarbonisation of this sector and its components (heating, cooling, cooking, heating water). As this example indicates, guidance and signal to sectoral actors might even best involve a further differentiation of targets and visions beyond the sector in general towards sub-sectors and key activities in the sectoral system. As a further example, greening finance and investment might benefit from a related overall objective, but the signal arguably also results from specific, concrete objectives to fully remove FFS by a specific date and to introduce carbon pricing. Given the crosscutting nature of financing, the signal arguably emanates from the mix of specific finance objectives and cross-sectoral and sectoral climate objectives and policy frameworks

at both national and international levels. Overall, the sectoral targets under consideration in the analysis hence go much beyond the general objectives enshrined in the Paris Agreement that remain at a rather abstract level when it comes to sectoral action.

As concerns **setting rules**, we find a more varied picture, with the grades in Matrix 5.2 spanning the full spectrum. In understanding this grading and the overall picture, it may be useful to appreciate that the need and demand for international regulation can be traced back to at least three very different sources that are not mutually exclusive: First, in a few sectors international competition and interdependence provide a strong and even compelling rationale for an international burden sharing and reassurance of implementation (energy-intensive industries, F-gases, …) as well as for a common approach (international transport). Second, in some cases the establishment of international rules/standards seems to enable cooperative action and progress by actors. For example, international standards seem to be required to enable the establishment of related exchange relationships (results-based payments) in the LULUCF sector. Similarly, labelling and certification may be required in order to enable the circular economy given global value chains. Third, international regulation could serve to make even governments act who may not otherwise see this as a priority. This may, for example, be the case especially as regards waste and buildings and would need to go hand in hand with the provision of sufficient means of implementation (this third case would in itself lead at best to a grading as "medium" since international regulation could hardly be seen as crucial). Overall, there is clearly a lower need and demand for international regulation in some sectoral systems (including waste, urban systems, transport, and appliances) because action in these is driven by other factors.

As in the case of the guidance and signal function, a closer look at the specific needs per sectoral system is required, taking into account potentially different situations as regards different components of this system. An overarching, aggregate assessment (as reflected in Matrix 5.2) cannot do justice to the frequently varying characteristics of different components of the sectoral systems in focus. For example, while many causes of agricultural GHG emissions may not crucially need to be addressed by means of international regulation (e.g. CH_4 emissions from rice paddies), reducing and modifying use of fertiliser may benefit from international rules since it is a component affecting the competitiveness on international markets. Similarly, removing FFS may be one particular area regarding extractive industries and finance and investment for which international agreement/regulation may be required. In general, any added value of international regulation in most cases relates to particular components and specific elements of a sectoral system and its governance (rather than the sector as a whole; for details, see Matrix 5.3 and the analyses in section 4). A meaningful analysis thus needs to further disaggregate beyond the level of sectoral systems, for which the distinction between different sectoral systems would appear to provide a useful entry point.

Transparency and accountability are generally closely linked to the need for international regulation and its underlying rationale. This link should not come as a surprise since the transparency and accountability at stake specifically relate to the implementation of agreed rules (rather than to transparency in general; see section 3.4 above). The demand for such transparency and accountability is particularly pronounced where international competition and interdependence provide a strong motivation for free-riding and, consequently, the setting of rules and checks on their implementation. It may be for this reason that international transport and energy intensive industries high on this function. Also, addressing LULUCF seems to require high levels of transparency to ensure trust in the exchange relationship implied in results-based payments on the basis of international rules.

There would appear to be three conditions under which a sectoral system scores lower on transparency and accountability. First, the demand for an institution to perform this function may be dampened even in case of high demand for international regulation and high competition, if the regulated activities are intrinsically relatively transparent themselves (extractive industries, F-gases, also transport). Second, demand for international governance of transparency and accountability may be

rather low because of a low demand for international regulation that would require implementation in the first place (e.g. waste, urban systems, appliances). Third, the international regulation required may itself not primarily address competitiveness issues but enable and facilitate action to reduce emissions (e.g. circular economy).

In some sectoral systems, these rationales mix (power, buildings, agriculture). This is also again a consequence of the different needs and conditions of different segments and components of the sectoral systems investigated that are more obvious in some areas than in others, even though they may be a common feature overall. A possible international agreement on limiting the use of fertiliser may, due to its implications for international competition, require international transparency and accountability provisions. In contrast, international food labelling regulation may (depending on its design) be self-enforcing. Similarly, international technical standards for electric vehicles may be quasi self-enforcing, whereas compliance with international emission standard may require close scrutiny and follow-up.

The demand for the provision of adequate **means of implementation** is overall relatively high across the sectoral systems, especially since many developing countries require some form of assistance in order to advance sufficiently fast. Most sectoral systems hence score "high" on this function. Some are rated "medium" or "medium-high", mainly because the intrinsic incentives and the economic rationale for action are so strong that additional means of implementation are considered less crucial (buildings, appliances, financial sector). In the case of international transport and extractive industries, the relevant sectoral actors even in developing countries are arguably relatively well-resourced in order to take action even without full provision of means of implementation. For example, many developing country airlines successfully compete with their developed country competitors and many fossil fuel exporting countries (including many members of the Organisation of Petroleum Exporting Countries – OPEC) have significant capital reserves. Even in these cases, some measure of support for advancing the transition, including access to capital, may be required.

Again, there are significant differences between the various sectoral systems so that a closer, differentiated look is required for identifying the specific needs. In some sectors, technology diffusion may be a prominent challenge (e.g. agriculture, waste), in others technology development or transfer (e.g. shipping, power, energy-intensive industries, transport, F-gases). In several sectors, capacity building (of various kinds) is much needed (LULUCF, waste, power, transport, urban systems, buildings, appliances, financial sector). In most sectoral systems, the need for either direct financing options or access to finance and investment looms large (exception: appliances), and there is a general cross—sectoral need for more long-term financing options (to be advanced by international cooperation). In a few cases, the related need specifically concerns risk-sharing (power and transport). Overall, the variation in the need profiles of various sectoral systems hence derives from the different needs for the three means of implementation distinguished (technology, finance, capacity building – all of these or only some part/mixture) as well as varying needs for the specific form of each of these means of implementation.

There is also some level of demand for internationally coordinated **knowledge and learning** across the sectoral systems. In most sectoral system, this demand is "high" or "medium". Lesser scores exist only with respect to: (1) F-gases where knowledge about alternatives and effective policies is widely available, also as a result of the long-lasting efforts to phase out ozone-depleting CFCs; and (2) the power sector where renewable energy technologies have spread and matured as has knowledge about related policy frameworks. In the other sectoral systems, international cooperation can significantly advance technology development, the design of effective policies and awareness raising. For agriculture, the circular economy, energy-intensive industries, urban systems, and the financial sector, knowledge and learning seem a central challenge with respect to decarbonisation (in the case of the circular economy and urban systems also due to the relatively recent nature of their framing).

As this overview already indicates, also in regard to this function, the aggregation as "knowledge and learning" masks a significant variance as to what the specific demand for this function entails for different sectoral systems. In some such systems, there is a particular need for awareness raising supported by international institutions (agriculture, buildings, waste, financial sector). For some, technology development and research coordination seem crucial (agriculture, international transport, energy-intensive industries). In several areas, there is a more or less specific potential for promoting technical and/or policy learning across countries and jurisdictions (LULUCF, waste, circular economy, power, buildings, extractive industries, transport, urban systems, appliances, financial sector). In some cases, specific demand for the creation of particular information or data exists (LULUCF, waste, extractive industries, international transport, financial sector). Overall, there appears to be, next to the differences of the general importance of knowledge and learning, a specific focus and mix of more specific needs identifiable for each sectoral system.

While we may group sectoral systems along key demands for international governance per functions (as per above), there are few clear patterns emerging. A high demand for international regulation does not correlate with a low or high demand for knowledge and learning or means of implementation. Nor does a high or low demand for means of implementation correlate with a high or low demand for promoting knowledge and learning. A few correlations get visible if we sub-divide and disentangle the governance functions as done above. Hence, a demand for promoting policy and technical learning as well as for capacity building seems to correlate to some extent with a lower degree of international competition and interdependence. As already mentioned, a high demand for international regulation rooted in high interdependence and competition usually leads to a relatively high demand for transparency and accountability. Apart from these relatively few correlations and links, the specific need and demand for the fulfilment of the governance functions would appear to be rather rooted in the specific characteristics and conditions of the respective sectoral systems that are largely independent of the of the various governance functions and their components.

Overall, the application of our framing of the governance functions of international institutions in the sectoral analysis reveals its potential, but also some limitations. It enables a more targeted, differentiated and detailed analysis of the varying demand for the performance of certain governance functions by international institutions in specific sectoral systems. It therefore advances from an overall aggregate perspective on international climate governance that treats it as one integrated problem towards a more appropriate outlook that takes into account the multifaceted nature of this challenge in various relevant sectors and contexts. Such a more detailed diagnosis enables us to identify more appropriate and more targeted cures for the different aspects of the challenge. It also provides an opportunity to investigate and take into account the further differentiation that exists within sectoral systems. As demonstrated in our analysis, setting rules, means of implementation and knowledge and learning can each mean various things. This differentiation should be investigated since it requires appropriately adapted responses and creates varying demands for international governance.

This need for further disaggregation and differentiation can also be considered one of the limitations of the approach chosen. It demonstrates that the distinction of various sectoral systems is not necessarily enough to get a grip on analysing the underlying problem structures and related demands for international governance. As mentioned, however, it may be considered to facilitate getting to the bottom of the problem structures and related needs and potentials. A further limitation concerns the transparency and accountability function that appears to be closely linked to the demand for setting international rules and its underlying rationales. For example, the demand for this function is particularly pronounced where international regulation is to address issues involving competitiveness concerns and international interdependence. This raises the question to what extent this function may form part of the analysis of the function of setting international rules in the first place.

All in all, the sectorally differentiated approach developed in this report promises to constitute a innovative and sound basis for analysing the effectiveness and adequacy of international climate governance. The objective of the overall work package and project is to help identify options for enhancing the effectiveness and adequacy of international climate protection. Our approach advances the state of the art by systematically disaggregating the overall governance challenge into the specific sectoral and sub-sectoral elements of this challenge. It thereby enables us to deliver a more differentiated picture of the barriers and opportunities that exist in different fields of action and can or need to be addressed by international institutions and cooperation. This should enable us to clearly identify existing gaps and potentials to be addressed in varying international governance institutions, which will need to be further substantiated in Task 4.2 of the project.

Hence, our analysis of the demand for international governance across different sectoral systems should constitute a sound basis for the next steps and tasks in Work Package 4 of the COP21 RIPPLES project. It provides suitable benchmarks for investigating existing international institutions and the contribution they make to meeting the demand for international governance identified. This investigation is to enable us to identify remaining gaps and underdeveloped potentials and to suggest priorities in this respect. Such an analysis should provide useful input and guidance to policy makers in the EU and beyond for identifying scope and priorities for action to improve international climate governance to accelerate the decarbonisation of our societies so as to enhance the chances to hold global temperature increase well below 2/1.5° C, in line with the Paris Agreement.

Sectoral Governance Matrix 5.1: Barriers and Challenges to Decarbonisation

Sectors	Financial and Economic	Institutional and Political	Technological	Awareness/Inform./Capacity
Agriculture	• Lower productivity of some alternative practices • High upfront costs of converting practices		• Limited potential of current technologies, need for new breeds and varieties	• Slow dissemination of best farming practice • Social preference for meat • Lack of information about climate impacts
LULUCF	• Lack of internalisation of forest benefits • Demand pull especially from wealthy countries • Pressure from overall economic and demographic development	• Insistence on right to exploit national natural resources • Overlapping responsibilities of national ministries • Lack of clear land tenure and land-use rights and enforcement		• No agreed definition of forests • Uncertainties about carbon content of forests, particularly soils
Waste	• Cost of sustainable waste management	• Lack of stringent waste regulation and enforcement • Unclear division of labour among national agencies		• Lack of organisation of waste collection • Lack of technical training • Lack of awareness
Circular economy	• High upfront investments for changing business models, designs, supply chains • Underdeveloped markets • High upfront costs of durable products	• Regulation of international value chains difficult • Impact on exporters of manufacturing	• Complexity of materials	• Poor reverse cycle logistics • Lack of information on flows of materials/product composition • Poor sorting and handling of waste • Consumer preferences

Sectors	Financial and Economic	Institutional and Political	Technological	Awareness/Inform./Capacity
Power	• High upfront investment for RE • High overall cost for CCS • Cost of re-building grid infrastructure	• Blocking power of incumbents, “techno-industrial complex” • Appropriate market regulation/design	• Deployability of CCS • Intermittency of wind and solar • Storage solutions • New grid infrastructure	• Lack of skilled workers
Energy-i. industry	• Long investment cycles, high investment requirements and risks and long paybacks of new technologies	• Fear of losing competitiveness / stunting development • Complexity of global value chains	• Technological inertia, insufficient R&D spending • Innovative technologies still at experimental stage	
Extractive Industries	• Resource curse: unwillingness by investors to invest in other sectors • “Just transition” of regions relying on fossil fuel extraction	• Power of fossil fuel companies • Distributional conflicts around foregoing resource rents and subsidy reform • Risk of stranded assets – oil and gas companies “too big to fail”		• Lack of transparency on FFS • Lack of government capacity to substitute FFS by more targeted policies
Transport	• Very high infrastructure expenditure required (change) • Higher upfront costs of new vehicle technologies	• Power of car and oil companies, motorist lobbies, freight business • Lack of standards for electric vehicles • Fuel taxes a major source of public income	• Development of high-yield batteries	• Car culture • Engineer bias towards incremental improvement of existing technologies
International transport	• No taxation of aviation and shipping fuels • Split incentives between ship owners and hirers • High price of biofuels	• Effort sharing controversy • Power of incumbents • Low public profile of shipping sector (lack of pressure)	• Technical problems regarding use of biofuels, hydrogen, electricity • Insufficient R&D spending	• Lack of information on reduction potential • Perceived ‘right to fly’

Sectors	Financial and Economic	Institutional and Political	Technological	Awareness/Inform./Capacity
		• Restructuring of supply chains needed for slow steaming		
Urban Systems	• Very high infrastructure expenditure required • Lock in of high-emission infrastructure through ongoing urbanisation	• Lack of integrated land-use and transportation planning • Enshrined paradigms such as zoning and equating mobility with (car) transport		• Limited capacities and competing priorities of cities • Lack of local emissions data and monitoring/ evaluation of local climate actions
Buildings	• High upfront investment • Lacking access to finance, particularly in developing countries	• Lack of regulations/incentives and enforcement • Large number of stakeholders, strong fragmentation of sector • Split incentives between builders, landlords and tenants	• Technical challenges of NZEBs	• Lack of technical skills among designers and builders • Lack of awareness of options • Low priority of efficiency
Appliances	• High upfront costs			• Lack of information for buyers • Low priority of efficiency in purchase decisions • Preference for ever larger appl.
Financial sector	• High risk perception of green investment • Lack of long-term capital	• Short-term investment horizons • Lack of adequate regulatory frameworks • FFS		• Lack of information about / standards to assess climate risks • Lack of capacity to assess climate risks
Fluorinated GHGs	• Deep reductions require new technologies with high costs	• Resistance by (chemical) industry	• Access to new technologies (patents)	

Sectoral Governance Matrix 5.2: Significance of Governance Functions

Sectors	Guidance and Signal	Setting Rules	Transparency and Accountability	Means of Implementation	Knowledge and Learning
Agriculture	Medium	Medium	Low	High	High
LULUCF	High	High	High	High	Medium
Waste	High	Low-Medium	Low	High	Medium
Circular economy	(-)	High	Low	High	High
Power	High	Medium-High	Medium	High	Low-Medium
Energy-i. industry	High	High	Medium-high	High	High
Extractive Industries	High	High	Medium (FFS: High)[24]	Medium-High	Medium
Transport	High	Medium-High	Low	High	Medium
International transport	High	High	High	Medium	Medium
Urban Systems	High	Low	Medium	High	High
Buildings	High	Medium-High	Medium	Medium-High	Medium
Appliances	High	Medium	Low	Medium	Medium
Financial sector	High	High	Medium (FFS: High)[24]	Medium	High
Fluorinated GHGs	High	High	Medium	High	Low

[24] Separate entry for fossil-fuel subsidy reform which has a high need for transparency and accountability to underpin international agreement.

Sectoral Governance Matrix 5.3: Main Potential Contributions of International Institutions

Sectors	Guidance and Signal	Setting Rules	Transparency and Accountability	Means of implementation	Knowledge and Learning
Agriculture	• Sector-specific reduction target and subtargets for fertiliser use, emission reduction from enteric fermentation – national targets	• Labelling • Reduction of fertiliser use (including assistance) • Carbon price	• Implementation of any rules (see rules)	• Technology diffusion and adaptation • Finance and investment	• International research efforts • Awareness raising (waste, diets)
LULUCF	• Target to halt and revert deforestation and to turn sector from a net source to a net sink	• Economic incentives to preserve and regrow forests (results-based payments)	• Reference levels and monitoring of results	• Finance • Capacity building for legal and institutional frameworks	• Joint accounting methodologies • Policy learning (legal and institutional frameworks) • Geographical information system
Waste	• Sector-specific decarbonisation target and subtargets such as ending uncontrolled dumping, burning, and landfilling	• Common global regulations and standards (e.g. prohibition of landfilling)	• Would be required for monitoring of international regulation • Transparency of sector developments	• International capacity building • International finance • Technology diffusion	• Policy and technical knowledge exchange • International database
Circular economy	• Best integrated into vision for core emission-causing sectors	• EPR, passports, labelling and clear materials pricing (by value chain)	• Implementation of any regulatory mechanisms	• Technical skills development • International financing options	• Policy and technical dialogue platforms

Sectors	Guidance and Signal	Setting Rules	Transparency and Accountability	Means of implementation	Knowledge and Learning
		• Certification programmes			• Support for cross-industry collaboration
Power	• Signal for low-carbon investments in energy infrastructure.	• coordinated target setting (decreasing importance due to increasingly competitive renewable energy technologies) • coordination at the regional level (especially grid development)	• required to support collective action function	• risk sharing for capital intensive investments in sustainable power systems, especially in developing countries • international transfer of renewable energy and energy storage technologies • administrative and technological capacity building	• sharing of good practice policies e.g. on market designs and long-term planning
Energy-intensive industry	• Sectoral decarbonisation objectives and related national, regional, global roadmaps	• International emission limits and/or carbon pricing (production or consumption)	• Required to monitor and verify implementation of rules	• Financial support/incentives and technology transfer	• Global knowledge and learning platform(s) (policy learning) • International R&D

Sectors	Guidance and Signal	Setting Rules	Transparency and Accountability	Means of implementation	Knowledge and Learning
Extractive Industries	• Phase out of fossil fuel extraction asap after 2050 • Phase out of FFS by firm deadline	• Global regulation of FF extraction (rights) • Agreement on FFS phase down/out	• Global regulation would require T&A (but relatively high intrinsic transparency of regulated activities) • Required for monitoring of FFS reform • To track progress, create peer pressure	• Technical and financial support for national reform efforts (transition away from FF extraction)	• Definition of FFS • International comparable data (especially on FFS) • Enhance policy learning re. 'national interests'
Transport	• International transport decarbonisation target and roadmap (differentiated) • New mobility paradigm (transit-oriented development & prioritising public and non-motorised transport)	• Common technical standards (e.g. for electric vehicles) • Common regulation, e.g. emissions control, carbon pricing	• No need for monitoring of common standards • Needed for emission limits and carbon pricing	• Financial risk-sharing for large infrastructure projects • Finance, technology and capacity building	• Learning partnerships (especially North-South cooperation) on technologies and policy design (including policy integration with other sectors such as power and urban settlements)
International transport	• Global limits and phase-out of (net) emissions (with differentiation)	• Global limits on emissions • Internalisation of externalities in fuel prices /carbon	• To ensure effective implementation of international rules	• Access to capital/fi-nance, e.g. to imple-ment retrofits (ship-ping) • Incentivising of early technology adoption	• (Joint) R&D for low-carbon technologies • Information on costs/ savings/ new technologies and

Sectors	Guidance and Signal	Setting Rules	Transparency and Accountability	Means of implementation	Knowledge and Learning
		pricing/ emissions trading • Operational and technological prescriptions (e.g. speed limits)		• Technical cooperation/transfer (shipping)	operational measures (shipping).
Urban Systems	• New paradigm of sustainable urban development integrating mitigation and other development objectives (including zero emissions goal)	• Little scope for uniform rules or standards	• Need for systematic monitoring and assessment of and international consultation on urban climate actions	• Strong need for building urban planning capacity and financial support for mitigation measures	• Participation of cities in international forums to promote mutual learning • Establishment of learning partnerships between cities
Buildings	• Sector-specific decarbonisation target and sub-targets for subsectors (like heating, cooling, cooking and heating water)	• International technical standards and agreement on far-reaching decarbonisation objectives	• Monitoring of implementation of rules	• Training, capacity building and awareness raising • Finance and investment	• Policy and technical knowledge platforms • Global database
Appliances	• International energy efficiency target and/or requirement to establish such target	• harmonization of standards and label-ling (but could also limit upward competi-tion among different labels/schemes)	• May help to enforce commonly agreed MEPS	• Capacity building for policy makers for the introduction of MEPS regulation / efficiency labelling	• knowledge diffusion on technology and effective efficiency labelling

Sectors	Guidance and Signal	Setting Rules	Transparency and Accountability	Means of implementation	Knowledge and Learning
Financial sector	• Overall objective to "green" financial flows • Pricing of carbon and removal of FFS • Sectoral decarbonisation targets	• Fair burden sharing approaches • Minimum carbon price and fossil fuel subsidy removal • Agreement on acceptable types of financial investments • Coherent and standardized approaches for financial institutions to assess and report climate-related financial risk	• Monitoring of implementation of rules • Common rules for accounting for and reporting on climate finance provided, needed and received • Accounting of both climate compatible and high carbon investments to track progress	• Public finance to leverage and mobilize private finance • Coordination and cooperation among donor countries and climate finance delivery institutions • Building institutional capacity in governments and financial institutions	• Exchange of knowledge on policies • Exchange knowledge among financial institutions for climate risks analysis and management • Systematic data collection on costs of climate risks
Fluorinated GHGs	• Phase out target for F-gases (production and consumption)	• Regulatory mechanisms/phase-out obligations	• Implementation of any rules (see rules)	• Financial incentives • Technology transfer	• Global information sharing

References

4E. (2016). Achievements of Appliance Energy Efficiency Standards and Labelling Programs - A Global Assessment in 2016. No place: IEA Technology Collaboration Programme on Energy Efficient End-Use Equipment. Retrieved from http://www.superefficient.org/Research/PublicationLibrary/2016/IEA-4E-Achievements-of-national-EESL-programs-report-2016

Abbott, K. W. (2012). The transnational regime complex for climate change. *Environment and Planning C: Government and Policy*, *30*(4), 571–590. Retrieved from http://journals.sagepub.com/doi/abs/10.1068/c11127

Abbott, K. W., Genschel, P., Snidal, D., & Zangl, B. (Eds.). (2015). *International Organizations as Orchestrators*. Cambridge: Cambridge University Press.

Adhya, T. K., Linquist, B., Searchinger, T., Wassmann, R., & Yan, X. (2014). *Wetting and Drying: Reducing Greenhouse Gas Emissions and Saving Water from Rice Production* (Creating a Sustainable Food Future No. 8). Washington DC. Retrieved from http://www.wri.org/sites/default/files/wetting-drying-reducing-greenhouse-gas-emissions-saving-water-rice-production.pdf

Ahman, M., Lechtenbohmer, S., Nilsson, L. J., & Schneider, C. (2016). Decarbonising the Energy Intensive Basic Materials Industry through Electrification - Implications for Future EU Electricity Demand. *Energy*, *115*(3), 1623–1631. https://doi.org/10.1016/j.energy.2016.07.110

Akerman, J. (2005). Sustainable Air Transport - On Track in 2050. *Transportation Research D: Transport and the Environment*, *10*(2), 111–126.

Alcock, I. (2017). "Green" on the Ground but not in the Air: Pro-environmental Attitudes are Related to Household Behaviours but not Discretionary Air Travel. *Global Environmental Change*, *42*, 136–147.

Andersen, S. O. (2015). Lessons from the Stratospheric Ozone Layer Protection for Climate. *Journal of Environmental Studies and Sciences*, *5*(2), 143–162. https://doi.org/doi:10.1007/s13412-014-0213-9.

Arabella Advisors. (2016). The Global Fossil Fuel Divestment and Clean Energy Investment Movement. No place: Arabella Advisors. Retrieved from https://www.arabellaadvisors.com/wp-content/uploads/2016/12/Global_Divestment_Report_2016.pdf

Arbib, J., & Seba, T. (2017). Rethinking Transportation 2020-2030. The Disruption of Transportation and the Collapse of the Internal-Combustion Vehicle and Oil Industries. San Francisco: RethinkX. Retrieved from https://www.rethinkx.com/transportation

Arndt, W.-H., Bei, X., Günter, E., Fahl, U., Jain, A., Lah, O., … Tomaschek, J. (2014). Mobility and Transportation Concepts for Sustainable Transportation in Future Megacities. In W.-H. Arndt (Ed.), *Mobility and Transportation: Concepts for Sustainable Transport in Future Megacities* (pp. 108–122). Berlin: jovis Verlag GmbH.

Asmelash, H. B. (2017). Falling Oil Prices and Sustainable Energy Transition towards a Multilateral Agreement on Fossil-Fuel Subsidies. In D. Arent, C. Arndt, M. Miller, F. Tarp, & O. Zinaman (Eds.), *Political Economy of Clean Energy Transitions* (pp. 349–367). Oxford: Oxford University Press.

ATAG. (2014). Aviation Benefits Beyond Borders. Geneva: Air Transport Action Group. Retrieved from https://aviationbenefits.org/media/26786/ATAG__AviationBenefits2014_FULL_LowRes.pdf

AXA. (n.d.). AXA Group Policy on Investments in Coal Mining and Coal-based Energy. No Place: AXA Group. Retrieved from https://cdn.axa.com/www-axa-com%2Fab00881a-160f-434f-b76d-ef46d1b85843_axa_coal_policy_b.pdf

Azzara, A., Minjares, R., & Rutherford, D. (2015). *Needs and Opportunities to Reduce Black Carbon Emissions from Maritime Shipping* (No. 2015–2). Washington DC. Retrieved from

http://www.theicct.org/sites/default/files/publications/ICCT_black-carbon-maritime-shipping_20150324.pdf

Bailey, K. (2017). How the Waste Industry Can Lead on Climate Change. Retrieved from http://www.waste360.com/emissions/how-waste-industry-can-lead-climate-change

Bakker, S. J. A., van Asselt, H., Gupta, J., Haug, C., & Saidi, M. A. R. (2009). *Differentiation in the CDM: Options and Impacts*. Amsterdam: Energy Research Centre of the Netherlands, Vrije Universiteit Amsterdam. Retrieved from http://www.mnp.nl/bibliotheek/rapporten/500102023.pdf

Barrett, S. (2011). *Why Cooperate?: The Incentive to Supply Global Public Goods*. *Why Cooperate?: The Incentive to Supply Global Public Goods*. New York: Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199211890.001.0001

Bast, E., Doukas, A., Pickard, S., van de Burg, L., & Whitley, S. (2015). *Empty promises: G20 subsidies to oil, gas and coal production*. *ODI & Oil Change International*. London, Washington DC. Retrieved from https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/9957.pdf

Behrens, A., Rizos, V., & Tuokko, K. (2017). The Circular Economy - A Review of Definitions, Processes and Impacts. Brussels: Centre for European Policy Studies. Retrieved from https://www.ceps.eu/system/files/RR2017-08_CircularEconomy.pdf

Bengtsson, S., Fridell, E., & Andersson, K. (2012). Environmental Assessment of Two Pathways Towards the Use of Biofuels in Shipping. *Energy Policy*, *44*, 451–463. https://doi.org/10.1016/J.ENPOL.2012.02.030

Bennett, S., & Heidug, W. (2014). CCS for Trade-exposed Sectors: An Evaluation of Incentive Policies. *Energy Procedia*, *63*, 6887–6902. https://doi.org/10.1016/J.EGYPRO.2014.11.723

Bergema, R., de Jong, S., Kraak, J., Usanov, A., & van der Gaast, M. (2016). A Circular Economy and Developing Countries: A Data Analysis of the Impact of a Circular Economy on Resource-Dependent Developing Nations. *Issue Brief 3*. The Hague: Centre of Expertise on Resources. Retrieved from http://hcss.nl/sites/default/files/files/reports/CEO_The Circular Economy.pdf

Biermann, F., Pattberg, P., Van Asselt, H., & Zelli, F. (2009). The Fragmentation of Global Governance Architectures: A Framework for Analysis. *Global Environmental Politics*, *9*(4), 14–40. Retrieved from http://muse.jhu.edu/journals/gep/summary/v009/9.4.biermann.html

bigEE. (2013a). Appliances Guide - Residential Appliances. Retrieved from http://www.bigee.net/en/appliances/guide/residential/group/2/

bigEE. (2013b). Why Policy Needs to Assist Building and Appliance Markets to Become Energy-Efficient. Wuppertal: Wuppertal Institute for Climate, Environment and Energy. Retrieved from http://www.bigee.net/media/filer_public/2013/11/28/bigee_txt_0005_pg_why_policy_is_needed.pdf

Blanco G., Gerlagh, R., Suh, S., Barrett, J., Coninck, H. C. de, Morejon, C. F. D., … P. Zhou. (2014). Drivers, Trends and Mitigation. In R. Edenhofer, O., Pichs-Madruga, E. F. Y. Sokona, S. Kadner, K. Seyboth, A. Adler, … J. C. Minx (Eds.), *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge/New York: Cambridge University Pres.

Boasson, E., & Dupont, C. (2015). Buildings: Good Intentions Unfulfilled. In C. Dupont & S. Oberthur (Eds.), *Decarbonization of the EU: Internal Policies and External Strategies* (pp. 137–158). London: Palgrave Macmillan. https://doi.org/DOI https://doi.org/10.1057/9781137406835_7

Bodansky, D. (2010). *The Art and Craft of International Environmental Law*. Cambridge, MA/London: Harvard University Press.

Bodansky, D. (2012). The Durban Platform: Issues and Options for a 2015 Agreement. Arlington, VA: Center for Climate and Energy Solutions. Retrieved from https://www.c2es.org/docUploads/durban-platform-issues-and-options.pdf

Bodansky, D. (2017). The Paris Climate Change Agreement: A New Hope? *The American Journal of International Law*, *110*(2), 288–319. https://doi.org/10.5305/amerjintelaw.110.2.0288

Bodnar, P., Ott, C., Thwaites, J., De Marez, L., & Kretschmer, B. (2017). Net Climate Finance: Reconciling the Clean and Dirty Sides of the Finance Ledger. No Place: Rocky Mountain Institute. Retrieved from https://d231jw5ce53gcq.cloudfront.net/wp-content/uploads/2017/07/RMI_Net_Climate_Finance_Discussion_Paper_2017-1.pdf

Borrás, S., & Edler, J. (Eds.). (2014). *The Governance of Socio-Technical Systems: Explaining Change* (Eu-SPRI Fo). Cheltenham/Northampton, MA: Edward Elgar Publishing. Retrieved from http://www.e-elgar.com/shop/the-governance-of-socio-technical-systems

Bourguignon, D. (2016). Closing the Loop - New Circular Economy Package. Brussels: European Parliament/European Parliamentary Research Service. Retrieved from http://www.europarl.europa.eu/RegData/etudes/BRIE/2016/573899/EPRS_BRI(2016)573899_EN.pdf

Bows-Larkin, A. (2015). All Adrift: Aviation, Shipping, and Climate Change Policy. *Climate Policy*, *15*(6), 681–702. https://doi.org/10.1080/14693062.2014.965125

Bradford, A. (2015). Deforestation: Facts, Causes and Effects. Retrieved from http://www.livescience.com/27692-deforestation.html

Brown, G. (2017, April 22). British Power Generation Achieves First Ever Coal-Free Day. *The Guardian*. Retrieved from https://www.theguardian.com/environment/2017/apr/21/britain-set-for-first-coal-free-day-since-the-industrial-revolution

Buchner, B., Falconer, A., Hervé-Mignucci, M., & Trabacchi, C. (2011). *The Landscape of Climate Finance*. Venice. Retrieved from https://climatepolicyinitiative.org/wp-content/uploads/2011/10/The-Landscape-of-Climate-Finance-120120.pdf

Buchner, B., Stadelmann, M., Wilkinson, J., Mazza, F., Rosenberg, A., & Abramskiehn, D. (2016). *Global Climate Finance: An Updated View on 2013 & 2014 Flows*. No Place. Retrieved from https://climatepolicyinitiative.org/wp-content/uploads/2014/11/The-Global-Landscape-of-Climate-Finance-2014.pdf

Bulkeley, H., Andonova, L. B., Betsill, M. M., Compagnon, D., Hale, T., Hoffmann, M. J., … Vandeveer, S. D. (2014). *Transnational Climate Change Governance*. New York: Cambridge University Press.

Bulkeley, H., & Newell, P. (2015). *Governing Climate Change* (2nd ed.). London and New York: Routledge.

Bulmer, J. (2012). Compliance Regimes in Multilateral Environmental Agreements. In J. Brunnée, M. Doelle, & L. Rajamani (Eds.), *Promoting Compliance in an Evolving Climate Regime* (pp. 55–73). Cambridge: Cambridge University Press.

Bulte, E., Joenie, M., & Jansen, H. (2000). Is There Too Much or Too Little Natural Forest in the Atlantic Zone of Costa Rica? *Canadian Journal of Forest Research*, *30*(3), 495–506.

Burck, J., Höhne, N., Hagemann, M., Gonzales-Zuñiga, S., Leipold, G., Marten, F., … Nakhooda, S. (2017). *Brown to Green: Assessing The G20 Transition to a low-carbon economy*. Berlin. Retrieved from http://www.climate-transparency.org/wp-content/uploads/2016/08/Brown-to-Green-Assessing-the-G20-transition-to-a-low-carbon-economy.pdf

Butler, R. (2012a). Human Threats to Rainforests - Economic Restructuring. Retrieved from http://rainforests.mongabay.com/0805.htm

Butler, R. (2012b). Population, Poverty, and Deforestation. Retrieved from http://rainforests.mongabay.com/0816.htm

Butler, R. (2017). Calculating Deforestation in the Amazon. Retrieved from http://rainforests.mongabay.com/amazon/deforestation_calculations.html

Caldecott, B., Sartor, O., & Spencer, T. (2017). *Lessons from Previous "Coal Transitions" – High-Level Summary for Decision-Makers. Part of "Coal Transitions: Research and Dialogue on the Future of Coal" Project*. Paris, London. Retrieved from https://coaltransitions.files.wordpress.com/2016/09/coal_synthesisreport_v04.pdf

Cames, M., Graichen, J., Siemons, A., & Cook, V. (2015). Emission Reduction Targets for International Aviation and Shipping. Brussels: European Parliament Directorate General for Internal Policies Policy Department. https://doi.org/IP/A/ENVI/2015-11

Carbon Pricing Leadership Coalition. (2017). *Report of the High-Level Commission on Carbon Prices*. No Place. Retrieved from https://static1.squarespace.com/static/54ff9c5ce4b0a53decccfb4c/t/5949402936e5d3af64b94bab/1497972781902/ENGLISH+EX+SUM+CarbonPricing.pdf

Carbon Tracker. (2011). *Unburnable Carbon – Are the world's financial markets carrying a carbon bubble?* No Place. Retrieved from https://www.carbontracker.org/wp-content/uploads/2014/09/Unburnable-Carbon-Full-rev2-1.pdf

Cardona, D., & Avendano, T. (2010). Extractive Industries and REDD - Sinning Then Praying Evens the Score or How to Legitimise Pillaging and Destruction. In J. Cabello & T. Gilbertson (Eds.), *No REDD! A Reader* (pp. 60–68). Cancun: Carbon Trade Watch. Retrieved from http://no-redd.com/wp-content/uploads/2015/01/REDDreaderEN.pdf

CDIAC. (2013a). Fossil-Fuel CO2 Emissions by Nation. Roane County, TN: Carbon Dioxide Information Analysis Centre, US Department of Energy Office of Science & Oak Ridge National Laboratory. Retrieved from http://cdiac.ornl.gov/trends/emis/tre_coun.html

CDIAC. (2013b). Kyoto-Related Fossil-Fuel CO2 Emission Totals. Roane County, TN: Carbon Dioxide Information Analysis Centre, US Department of Energy Office of Science & Oak Ridge National Laboratory. Retrieved from http://cdiac.ornl.gov/trends/emis/annex.html

CDP. (2017, May 22). Press release: Over 280 global investors (managing more than $17 trillion in assets) urge G7 to stand by Paris Agreement and drive its swift implementation. CDP. Retrieved from https://www.cdp.net/en/articles/media/press-release-more-than-200-global-investors-managing-over-15-trillion-in-assets-urge-g7-leaders-to-stand-by-paris-agreement-and-drive-its-swift-implementation

CEFIC. (2013). *European chemistry for growth: Unlocking a competitive, low carbon and energy efficient future*. No Place: European Chemicals Industry Council CEFIC.

Ceres. (2014). *Investing in the Clean Trillion: Closing the Clean Energy Investment Gap*. *Ceres*. Boston. Retrieved from https://www.ceres.org/sites/default/files/reports/2017-03/Ceres_CleanTrillion_Report_012114.pdf

Chapman, L. (2007). Transport and Climate Change: A Review. *Journal of Transport Geography*, *15*(5), 354–367. https://doi.org/10.1016/j.jtrangeo.2006.11.008

Chayes, A., & Chayes, A. (1993). On Compliance. *International Organization*, *47*(2), 175–205. https://doi.org/10.1017/S0020818300027910

Cherian, A. (2015). *Energy and Global Climate Change: Bridging the Sustainable Development Divide*. West Sussex: John Wiley & Sons.

Chrisafis, A., & Vaughan, A. (2017, July 6). France to ban sales of petrol and diesel cars by 2040. *The Guardian*. Retrieved from https://www.theguardian.com/business/2017/jul/06/france-ban-petrol-diesel-cars-2040-emmanuel-macron-volvo

Climate Bonds Initiative Markets Team. (2016). Green Bonds Highlights 2016. No Place: Climate Bonds Initiative. Retrieved from https://www.climatebonds.net/files/files/2016 GB Market Roundup.pdf

Coady, D., Parry, I., Sears, L., & Shang, B. (2015). *How Large Are Global Energy Subsidies?* (IMF Working

Paper No. WP/15/105). Washington, DC. Retrieved from https://www.imf.org/external/pubs/ft/wp/2015/wp15105.pdf

Conserve Energy Future. (n.d.). What is Waste Management and Methods of Waste Disposal? Retrieved from http://www.conserve-energy-future.com/waste-management-and-waste-disposal-methods.php

Consultancy.uk. (2015). Global chemicals market to grow to 5.1 trillion by 2020. Retrieved from http://www.consultancy.uk/news/2745/global-chemicals-market-to-grow-to-51-trillion-by-2020

Cramton, P., MacKay, D. J., Ockenfels, A., & Stoft, S. (Eds.). (2017). *Global Carbon Pricing: The Path to Climate Cooperation*. Cambridge, MA/London: The MIT Press.

Cullen, J. (2010). *WellMet2050's Findings and Recommendations on Reusing Steel and Aluminium Without Melting* (Steel and Aluminium Facts).

Darby, M. (2016). Offshore Carbon: Why a Climate Deal for Carbon is Sinking. Retrieved from http://www.climatechangenews.com/2016/07/15/offshore-carbon-why-a-climate-deal-for-shipping-is-sinking/

De Búrca, G., Keohane, R. O., & Sabel, C. (2014). Global Experimentalist Governance. *British Journal of Political Science*, *44*(3), 477–486. https://doi.org/10.1017/S0007123414000076

de Coninck, H., & Bäckstrand, K. (2011). An International Relations perspective on the global politics of carbon dioxide capture and storage. *Global Environmental Change*, *21*(2), 368–378. Retrieved from https://doi.org/10.1016/j.gloenvcha.2011.03.006

Dean, B., Dulac, J., Petrichenko, K., & Graham, P. (2016). Global Status Report 2016: Towards Zero-Emission Efficient and Resilient Buildings. Nairobi: United Nations Environment Programme. Retrieved from https://wedocs.unep.org/rest/bitstreams/45611/retrieve

DeFries, R., Achard, F., Brown, S., Herold, M., Murdivarso, D., Schlamadinger, B., & De Souza, C. (2007). Earth Observations for Estimating Greenhouse Gas Emissions from Deforestation in Developing Countries. *Environmental Science & Policy*, *10*(4), 385–394.

Denjean, B., Su, T., Attwood, C., Bridle, R., Duan, H., & Gerasimchuk, I. (2016). Subsidies to Coal Power Generation in China. Winnipeg: International Institute for Sustainable Development. Retrieved from https://www.iisd.org/sites/default/files/publications/subsidies-coal-power-generation-china.pdf

Dipaola, A. (2016). Cheapest Solar on Record Offered as Abu Dhabi Expands Renewables. *Bloomberg.com*. Bloomberg. Retrieved from ttps://www.bloomberg.com/news/articles/2016-09-19/cheapest-solar-on-record-said-to-be-offered-for-abu-dhabi

Doukas, A., DeAngelis, K., & Ghio, N. (2017). Talk is Cheap: How G20 Governments are Financing Climate Disaster. No Place: Oil Change International, Friends of the Earth U.S., the Sierra Club and WWF European Policy Office. Retrieved from http://priceofoil.org/content/uploads/2017/07/talk_is_cheap_G20_report_July2017.pdf

Duncan Brack, Andersen, S. O., & Sun, X. (2016). *National Hydrofluorocarbon (Hfc) Inventories: A summary of the key findings from the first tranche of studies*. No Place. Retrieved from http://www.ccacoalition.org/en/resources/national-hydrofluorocarbon-hfc-inventories-summary-key-findings-first-tranche-studies

Dupont, C. (2016). *Climate Policy Integration into EU Energy Policy: Progress and Prospects*. London: Routledge.

Dupont, C., & Oberthür, S. (Eds.). (2015). *Decarbonization in the European Union: Internal Policies and External Strategies*. Houndmills: Palgrave MacMillan.

Ecofys. (2013). World GHG Emissions Flow Chart 2010. Retrieved from

https://www.ecofys.com/files/files/asn-ecofys-2013-world-ghg-emissions-flow-chart-2010.pdf

Ecofys & Circle Economy. (2016). Implementing Circular Economy Globally Makes Paris Targets Achievable. No Place: Ecofys & Circle Economy. Retrieved from http://www.ecofys.com/files/files/circle-economy-ecofys-2016-circular-economy-white-paper.pdf

Edenhofer, O. (2015). King Coal and the Queen of Subsidies. *Science*, *349*(6254), 1286–1287. https://doi.org/10.1126/science.aad0674

Edenhofer, O., Flachsland, C., Jakob, M., & Lessmann, K. (2013). *The Atmosphere as a Global Commons – Challenges for International Cooperation and Governance* (The Harvard Project on Climate Agreements, Discussion Paper No. MCC Working paper 1-2013). Berlin. Retrieved from https://www.mcc-berlin.net/fileadmin/data/pdf/Final_revised_Edenhofer_et_al_The_atmosphere_as_a_Global_Commons_2013.pdf

Ehrhardt-Martinez, K. (2003). Demographics, Democracy, Development, Disparity and Deforestation: A Crossnational Assessment of the Social Causes of Deforestation. Paper presented at the annual meeting of the American Sociological Association, Atlanta Hilton Hotel, Atlanta, GA, Aug 16, 2003. Retrieved from http://www.allacademic.com/meta/p107488_index.html

EIA. (2017). International Energy Statistics. Retrieved from https://www.eia.gov/beta/international/

Ellen MacArthur Foundation. (2013). Towards the Circular Economy 1 and 2: Economic and business rationale for an accelerated transition. No Place: Ellen MacArthur Foundation. Retrieved from https://www.ellenmacarthurfoundation.org/assets/downloads/publications/Ellen-MacArthur-Foundation-Towards-the-Circular-Economy-vol.1.pdf

Ellen MacArthur Foundation. (2014). *Towards the Circular Economy, Accelerating the Scale-up Across Global Supply Chains* (No. Volume 3). No Place: Ellen McArthur Foundation. Retrieved from https://www.ellenmacarthurfoundation.org/assets/downloads/publications/Towards-the-circular-economy-volume-3.pdf

Ellen MacArthur Foundation. (2015). Circular Economy Overview. Retrieved from https://www.ellenmacarthurfoundation.org/circular-economy/overview/concept

Ellen MacArthur Foundation. (2016). The New Plastics Economy – Rethinking the Future of Plastics. No Place: Ellen MacArthur Foundation. Retrieved from https://tinyurl.com/msp6fb4

EPA. (2015). Advancing Sustainable Materials Management: Facts and Figures 2013. *EPA*. No Place: United States Environmental Protection Agency (EPA). Retrieved from https://www.epa.gov/sites/production/files/2015-09/documents/2013_advncng_smm_rpt.pdf

European Commission. (2017a). Finance for Innovation, Towards the ETS Innovation Fund. Brussels: European Commission. Retrieved from https://ec.europa.eu/clima/sites/clima/files/events/docs/0115/20170612_report_en.pdf

European Commission. (2017b). Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the implementation of the Circular Economy Action Plan. Brussels: European Commission. https://doi.org/COM (2017) 33 final

Eurostat. (2016). Municipal Waste Generation and Treatment, by Type of Treatment Method. Retrieved from http://ec.europa.eu/eurostat/tgm/refreshTableAction.do?tab=table&plugin=1&pcode=tsdpc240&language=en

Ewing, J. (2017, July 5). Volvo, Betting on Electric, Moves to Phase Out Conventional Engines. *The New York Times*. No Place. Retrieved from https://www.nytimes.com/2017/07/05/business/energy-environment/volvo-hybrid-electric-car.html

EY. (2016). Climate change: The investment perspective. No Place: EY Financials Climate Change & Sustainability.

Falkner, R. (2016). The Paris Agreement and the new logic of international climate politics. *International Affairs*, *92*(5), 1107–1125. https://doi.org/10.1111/1468-2346.12708

FAO. (2002). World Agriculture towards 2015/2030: An FAO Perspective. London: Earthscan. Retrieved from http://www.fao.org/3/a-y4252e.pdf

FAO. (2010). Global Forest Resources Assessment 2010. Rome: Food and Agriculture Organization of the United Nations. Retrieved from http://www.fao.org/docrep/013/i1757e/i1757e.pdf

FAO. (2014). Agriculture's Greenhouse Gas Emissions on the Rise. Retrieved from http://www.fao.org/news/story/en/item/216137/icode/

FAO. (2015). The Global Forest Resources Assessment 2015. Rome: Food and Agriculture Organization of the United Nations. Retrieved from http://www.fao.org/3/a-i4808e.pdf

FAO. (2016). *FAO, Forests and Climate Change: Working with countries to mitigate and adapt to climate change through sustainable forest management*. Rome. Retrieved from http://www.fao.org/docrep/017/i2906e/i2906e00.pdf

FAO. (2017). Global Livestock Environmental Assessment Model - Results. Retrieved from http://www.fao.org/gleam/results/en/

FAOSTAT. (2014). Land Use Total Data. Retrieved September 25, 2017, from http://www.fao.org/faostat/en/#data/GL

Feblowitz, J., & Levine, S. (2015). Business Strategy: Global Smart Building Technology Spending 2015-2019 Forecast. *IDC Energy Insights: Smart Building Strategies*. No Place: International Data Corporation (IDC). Retrieved from https://www.idc.com/getdoc.jsp?containerId=EI254932

Ferronato, N., D 'avino, C., Ragazzi, M., Torretta, V., De Feo, G., & Rada, E. C. (2017). Social Surveys about Solid Waste Management within Higher Education Institutes: A Comparison. *MDPI Sustainability*, *9*(3), 1–17. https://doi.org/10.3390/su9030391

Florin, N., & Madden, B. (2017). Here's Why We Should Be Turning Our Rubbish Into Fuel. *World Economic Forum*. No Place: World Economic Forum. Retrieved from http://amp.weforum.org/agenda/2017/05/heres-why-we-should-be-turning-our-rubbish-into-fuel?utm_content=buffer602b5&utm_medium=social&utm_source=facebook.com&utm_campaign=buffer

Frankfurt School/UNEP/Bloomberg. (2016). Global Trends in Renewable Energy Investment. Frankfurt am Main: Frankfurt School-UNEP Collaborating Centre for Climate & Sustainable Energy Finance, UNEP's Division of Technology, Industry and Economic (DTIE), Bloomberg New Energy Finance. Retrieved from http://fs-unep-centre.org/sites/default/files/publications/globaltrendsinrenewableenergyinvestment2016lowres_0.pdf

Freeman, C., & Soete, L. (1997). *The economics of industrial innovation* (3rd ed.). Cambridge, MA: MIT Press.

Friends of the Earth. (2007). Food and Climate Change. No Place: Friends of the Earth. Retrieved from https://www.foe.co.uk/sites/default/files/downloads/food_climate_change.pdf

Frisari, G., Hervé-Mignucci, M., Micale, V., & Mazza, F. (2013). *Risk Gaps: A Map of Risk Mitigation Instruments for Clean Investments*. No Place. Retrieved from http://climatepolicyinitiative.org/wp-content/uploads/2013/01/Risk-Gaps-A-Map-of-Risk-Mitigation-Instruments-for-Clean-Investments.pdf

G20. (2009). Leaders' Statement. In *Pittsburgh Summit*. Pittsburgh: G20.

G7. (2015). Leaders' Declaration. *G7 Summit 7-8 June*. Schloss Elmau: G7.

Gaan, N. (2008). *Climate Change and International Politics* (1st ed.). New Delhi: Kalpaz.

Gaede, J., & Meadowcroft, J. (2016). Carbon Capture and Storage Demonstration and Low-Carbon Energy Transitions: Explaining Limited Progress. In T. Van de Graaf, Benjamin K. Sovacool, Arunabha Ghosh, Florian Kern, & Michael T. Klare (Eds.), *The Palgrave Handbook of the International Political Economy of Energy* (pp. 319–340). London: Palgrave Macmillan. https://doi.org/https://doi.org/10.1057/978-1-137-55631-8_13

GEA, & IIASA. (2012). Energy End-Use: Buildings. In *Global Energy Assessment - Toward a Sustainable Future* (pp. 649–760). Cambridge, Laxenburg: Cambridge University Press, International Institute for Applied Systems Analysis. Retrieved from http://www.globalenergyassessment.org/

Gehring, T. (1994). *Dynamic International Regimes: Institutions for International Environmental Governance*. Frankfurt/M., Berlin, Bern, New York, Paris, Wien: Peter Lang.

Gehring, T. (2007). Treaty-Making and Treaty Evolution. In Daniel Bodansky, Jutta Brunnée, & E. Hey (Eds.), *The Oxford Handbook of International Environmental Law* (pp. 469–497). New York: Oxford University Press.

Gehring, T., & Faude, B. (2014). A theory of emerging order within institutional complexes: How competition among regulatory international institutions leads to institutional adaptation and division of labor. *Review of International Organizations*, *9*(4), 471–498. https://doi.org/10.1007/s11558-014-9197-1

Gencsu, I., & Hino, M. (2015). Raising Ambition to Reduce International Aviation and Maritime Emissions. London, Washington, DC: New Climate Economy. Retrieved from http://newclimateeconomy.report/misc/working-papers

Gerasimchuk, I., Bassi, A., Ordonez, C., Doukas, A., Merrill, L., & Whitley, S. (2017). Zombie Energy: Climate Benefits of Ending Subsidies to Fossil Fuel Production. Winnipeg: International Institute for Sustainable Development.

Gilbert, A., Sovacool, B. K., Johnstone, P., & Stirling, A. (2017). Cost Overruns and Financial Risk in the Construction of Nuclear Power Reactors: A Critical Appraisal. *Energy Policy*, *102*, 644–649. https://doi.org/10.1016/j.enpol.2016.04.001

Gillingham, K., Rapson, D., & Wagner, G. (2016). The Rebound Effect and Energy Efficiency Policy. *Review of Environmental Economics and Policy*, *10*(1), 68–88. https://doi.org/10.1093/reep/rev017

Global Alliance for Buildings and Construction. (2016). Towards, Low Carbon and Resilient Real-Estate. No Place: Global Alliance for Buildings and Construction. Retrieved from https://www.climatechance2016.com/uploads/media/57dbaad92eee8.pdf

Global Green Growth Institute. (2016). Mind the Gap: Bridging the Climate Financing Gap with Innovative Financial Mechanisms. No Place: Global Green Growth Institute. Retrieved from http://gggi.org/wp-content/uploads/2017/03/Mind-the-Gap_web.pdf

Global Methane Initiative. (n.d.). Global Methane Emissions and Mitigation Opportunities. Retrieved from http://www.globalmethane.org/documents/analysis_fs_en.pdf

Goncalves, V. K. (2017). Climate Change and International Civil Aviation Negotiations. *Contexto Internacional*, *39*(2), 443–458. Retrieved from http://dx.doi.org/10.1590/S0102-8529.2017390200012

Gota, S., Huizenga, C., Peet, K., & Kaar, G. (2015). Intended Nationally-Determined Contributions (INDCs) Offer Opportunities for Ambitious Action on Transport and Climate Change. Bangkok: Partnership on Sustainable Low Carbon Transport. Retrieved from http://slocat.net/sites/default/files/indc_report_-final_version_-_2015-11-25_-_unformatted-2.pdf

Greenpeace. (2016). HFOs: the new generation of F-gases, Greenpeace Position Paper. Retrieved from

http://www.greenpeace.org/international/Global/international/documents/climate/HFOs-the-new-generation-of-f-gases.pdf%0A

Grin, J., Schot, J., & Rotmans, J. (2010). *Transitions to Sustainable Development. New Directions in the Study of Long term transformative change*. New York/London: Routledge.

Gschrey, B., Schwarz, W., Elsner, C., & Engelhardt, R. (2011). High increase of global F-gas emissions until 2050. *Greenhouse Gas Measurement and Management*, *1*(2), 85–92. https://doi.org/10.1080/20430779.2011.579352

Gudmundsson, S. V., & Anger, A. (2012). Global Carbon Dioxide Emissions Scenarios for Aviation Derived from IPCC Storylines: A Meta-analysis. *Transportation Research D: Transport and Environment*, *17*(1), 61–65.

Guneralp, B., Zhou, Y., Urge-Vorsatz, D., Gupta, M., Yu, S., Patel, P. L., … Seto, K. C. (2017). Global Scenarios of Urban Density and Its Impacts on Building Energy Use Through 2050, *114*(34), 8945–8950. https://doi.org/10.1073/pnas.1606035114

Gupta, A., & van Asselt, H. (2017). Transparency in multilateral climate politics: Furthering (or distracting from) accountability? *Regulation & Governance*, *(early view)*. https://doi.org/10.1111/rego.12159

Gütschow, J., Jeffery, L., Gieseke, R., & Gebel, R. (2017). The PRIMAP-hist national historical emissions time. *GFZ Data Services.*, *series v1.* Retrieved from https://doi.org/10.5880/PIK.2017.001

Haas, E. B. (1990). *When Knowledge Is Power: Three Models of Change in International Organizations*. Berkeley: University of California Press.

Haas, W., Krausmann, F., Wiedenhofer, D., & Heinz, M. (2015). How Circular is the Global Economy? An Assessment of Material Flows, Waste Production, and Recycling in the European Union and the World in 2005. *Journal of Industrial Ecology*, *19*(5), 765–777. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/jiec.12244/full

Hasenclever, A., Mayer, P., & Rittberger, V. (1997). *Theories of International Regimes*. Cambridge: Cambridge University Press.

Havlik, P., Valin, H., Herrero, M., Obersteiner, M., Schmid, E., Rufino, M. C., … Notenbaert, A. (2014). Climate Change Mitigation Through Livestock System Transitions. *Proceedings of the National Academy of Sciences*, *111*(10), 3709–3714. https://doi.org/10.1073/pnas.1308044111

Hawken, P. (2017). *Drawdown: The Most Comprehensive Plan Ever Proposed to Reverse Global Warming*. New York: Penguin Books. Retrieved from http://www.drawdown.org/solutions/energy/waste-energy

Hermwille, L. (2017). En Route to a Just Global Energy Transformation? – The Formative Power of the SDGs and the Paris Agreement. Berlin: Friedrich Ebert Stiftung. Retrieved from http://library.fes.de/pdf-files/iez/13453.pdf

Hermwille, L., Obergassel, W., Ott, H. E., & Beuermann, C. (2017). UNFCCC before and after Paris – What's Necessary for an Effective Climate Regime? *Climate Policy*, *17*(2), 150–170.

Herrero, M., Henderson, B., Havlik, P., Thornton, P. K., Conant, R. T., Smith, P., … Stehfest, E. (2016). Greenhouse Gas Mitigation Potentials in the Livestock Sector. *Nature Climate Change*, *6*(5), 452–461.

Hirsch, T. (2015). *Learning from the "Energiewende" - What Developing Countries Expect from Germany* (Study). Berlin: Friedrich-Ebert-Stiftung.

Holmes, I. (2017). Pathways to 1.5/2°C-Compatible Oil: Is Managed Decline the Only Way? London: E3G. Retrieved from https://www.environmental-finance.com/assets/files/research/E3G_Briefing_Future_pathways_2degC_oil_FEB2017.pdf

Holmes, I., & Orozco, D. (2017). What Happened to the International Oil Companies? Simulating

the1.5/2°C Transition. London: E3G.

Hoornweg, D., & Bhada-Tata, P. (2012). What a Waste - A Review of Solid Waste Management. *World Bank Urban Development Series*. Washington DC: World Bank. Retrieved from http://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1334852610766/What_a_Waste2012_Final.pdf

Hristov, A. N., Oh, J., Giallongo, F., Frederick, T. W., Harper, M. T., Weeks, H. L., … Duval, S. (2015). An Inhibitor Persistently Decreased Enteric Methane Emission from Dairy Cows With No Negative Effect on Milk Production. *Proceedings of the National Academy of Sciences*, *112*(34), 10663–10668. https://doi.org/10.1073/pnas.1515515112

Hu, H., & Xiong, L. (2014). Genetic Engineering and Breeding of Drought-Resistant Crops. *Annual Review of Plant Biology*, *65*(1), 715–741. https://doi.org/10.1146/annurev-arplant-050213-040000

Huang, C., Busch, C., He, D., & Harvey, H. (2015). *12 Green Guidelines. CDBC's Green and Smart Urban Development Guidelines*. No Place: China Development Bank Capital. Retrieved from http://energyinnovation.org/wp-content/uploads/2015/12/12-Green-Guidelines.pdf

IAEA. (2017). PRIS - Power Reactor Information System. Retrieved from https://www.iaea.org/pris/

ICAO. (2017). ICAO Council Adopts New CO2 Emissions Standard for Aircraft. Retrieved from https://www.icao.int/Newsroom/Pages/ICAO-Council-adopts-new-CO2-emissions-standard-for-aircraft.aspx

IEA. (2011). Technology Roadmap Energy-efficient Buildings: Heating and Cooling Equipment. Paris: International Energy Agency. Retrieved from https://www.iea.org/publications/freepublications/publication/buildings_roadmap.pdf

IEA. (2012). World Energy Outlook 2012. Paris: International Energy Agency.

IEA. (2013). Transition to Sustainable Buildings: Strategies and Opportunities to 2050. Paris: International Energy Agency. Retrieved from https://www.iea.org/publications/freepublications/publication/Building2013_free.pdf

IEA. (2014a). World Energy Investment Outlook. Paris: International Energy Agency.

IEA. (2014b). *World Energy Outlook 2014*. Paris: International Energy Agency.

IEA. (2015a). Energy Technology Perspectives 2015 Mobilising Innovation to Accelerate Climate Action. Paris: International Energy Agency. Retrieved from http://www.iea.org/t&c/

IEA. (2015b). WEO 2015 Energy Access Database. Retrieved from http://www.worldenergyoutlook.org/resources/energydevelopment/energyaccessdatabase/

IEA. (2015c). World Energy Outlook 2015. Paris: International Energy Agency.

IEA. (2016a). CO2 Emissions from Fuel Combustion. Paris: International Energy Agency. Retrieved from http://www.oecd-ilibrary.org/content/serial/22199446

IEA. (2016b). Energy Efficiency Market Report 2016. Paris: International Energy Agency. Retrieved from http://www.oecd-ilibrary.org/content/book/9789264266100-en

IEA. (2016c). *Energy Technology Perspectives 2016 - Towards Sustainable Urban Energy Systems*. Paris: International Energy Agency.

IEA. (2016d). Natural Gas Information 2016. Paris: International Energy Agency. Retrieved from http://www.oecd-ilibrary.org/content/book/nat_gas-2016-en

IEA. (2016e, November). World Energy Outlook. Paris: International Energy Agency.

IEA. (2017a). Energy Technology Perspectives. Paris: International Energy Agency.

IEA. (2017b). Tracking Clean Energy Progress 2017. Retrieved from

http://www.iea.org/etp/tracking2017/internationalshipping/

IMF. (2011). Market-Based Instruments for International Aviation and Shipping as a Source of Climate Finance. No place: International Monetary Fund and World Bank.

IMO. (2014). Third IMO GHG Study 2014. London: International Maritime Organisation. Retrieved from http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Third Greenhouse Gas Study/GHG3 Executive Summary and Report.pdf

Incropera, F. P. (2015). *Climate Change: A Wicked Problem: Complexity and Uncertainty at the Intersection of Science, Economics, Politics, and Human Behavior*. New York: Cambridge University Press,.

International Aluminium Institute. (2009). Global Aluminium Recycling: A Cornerstone of Sustainable Development. No Place: International Aluminium Institute. Retrieved from http://www.world-aluminium.org/media/filer_public/2013/01/15/fl0000181.pdf

IPCC. (2005). *IPCC Special Report on Carbon Capture and Storage*. Cambridge/New York: Cambridge University Press.

IPCC. (2007). *Climate Change 2007: Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. (B. Metz, O. Davidsond, P. Bosch, R. Dave, & L. Meyer, Eds.). Cambridge and New York: Cambridge University Press. Retrieved from https://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4_wg3_full_report.pdf

IPCC. (2012). Renewable Energy in the Context of Sustainable Development. In O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, … C. von Stechow (Eds.), *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation* (pp. 707–789). Cambridge/New York: Cambridge University Press. Retrieved from http://www.cro3.org/cgi/doi/10.5860/CHOICE.49-6309

IPCC. (2013). Summary for Policymakers. In T. F. Stocker, D. Qin, G. K. Plattner, M. Tignor, S. K. Allen, J. Boschung, … P. M. Midgley (Eds.), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 3–29). Cambridge, New York: Cambridge University Press.

IPCC. (2014a). Chapter 7: Energy Systems. In *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 511–598). Cambridge, New York: Cambridge University Press.

IPCC. (2014b). Chapter 9: Buildings. In *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 671–738). Cambridge, New York: Cambridge University Press.

IPCC. (2014c). *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. (O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, … J. C. Minx, Eds.). Cambridge, New York: Cambridge University Press.

IPCC. (2014d). Summary for Policymakers. In O. Edenhofer, R. Pichs-Madruga, Sokona Y., E. Farahani, S. Kadner, Seyboth K., … J. C. Minx (Eds.), *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1–30). Cambridge, New York: Cambridge University Press.

IPCC/TEAP. (2005). Safeguarding the Ozone Layer and the Global Climate System: Issues Related to Hydrofluorocarbons and Perfluorocarbons. Bonn: UNFCCC/SBSTA. Retrieved from https://www.ipcc.ch/pdf/special-reports/sroc/sroc_full.pdf

IRENA. (2016). The Power to Change: Solar and Wind Cost Reduction Potential to 2025. Bonn: International Renewable Energy Agency. Retrieved from

http://www.irena.org/DocumentDownloads/Publications/IRENA_Power_to_Change_2016.pdf

IRENA. (2017). Stranded Assets and Renewables: how the energy trabsition affects the value of energy reserves, buildings and capictal stock. Abu Dhabi: International Renewable Energy Agency.

Jordan, A., Benson, D., Wurzel, R., & Zito, A. (2012). Policy Instruments in Practice. In J. S. Dryzek, R. B. Norgaard, & D. Schlosberg (Eds.), *The Oxford Handbook of Climate Change and Society*. New York: Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199566600.003.0036

Jordan, A. J., Huitema, D., Hildén, M., van Asselt, H., Rayner, T. J., Schoenefeld, J. J., … Boasson, E. L. (2015). Emergence of polycentric climate governance and its future prospects. *Nature Climate Change*, *5*(11), 977–982. https://doi.org/10.1038/nclimate2725

Jordan, A., & Lenschow, A. (2010). Environmental policy integration: a state of the art review. *Environmental Policy and Governance*, *20*(3), 147–158.

Kanie, N., & Biermann, F. (Eds.). (2017). *Governing through Goals: Sustainable Development Goals as Governance Innovation*. Cambridge, MA: MIT Press.

Kartha, S. (2016). Fossil fuel production in a 2°C world: The equity implications of a diminishing carbon budget. Somerville: Stockholm Environment Institute. Retrieved from https://www.sei-international.org/mediamanager/documents/Publications/Climate/SEI-DB-2016-Equity-fossil-fuel-production-rents.pdf

Kechichian, E., Pantelias, A., Reeves, A., Henley, G., & Liu, J. (2016). A greener path to competitiveness : policies for climate action in industries and products. Washington, DC: World Bank Group. Retrieved from http://documents.worldbank.org/curated/en/835691472028683380/A-greener-path-to-competitiveness-policies-for-climate-action-in-industries-and-products

Keohane, R. O. (1989). *International Institutions and State Power*. London: Westview Press.

Keohane, R. O., & Levy, M. A. (Eds.). (1996). *Institutions for Environmental Aid. Pitfalls and Promises*. Cambridge, MA: MIT Press.

Keohane, R. O., & Victor, D. G. (2011). The Regime Complex for Climate. *Perspectives on Politics*, *9*(1), 7–23. https://doi.org/10.1017/S1537592710004068

Keohane, R. O., & Victor, D. G. (2016). Cooperation and discord in global climate policy. *Nature Climate Change*, *6*(6), 570–575. https://doi.org/10.1038/nclimate2937

Khatun, K. (2012). Reform or Reversal: Implications of the Common Agricultural Policy (CAP) on Land Use, Land Use Change, and Forestry (LULUCF) in Developing Countries. *Conservation Letters*, *5*(2), 99–106.

Knox, N. (2015). Buildings and Climate Change. No Place: US Green Buildings Council. Retrieved from https://www.usgbc.org/articles/green-building-and-climate-change

Koplow, D., & Charles, C. (2010). Untold Billions: Fossil Fuel Subsidies, Their Impacts and the Path to Reform: Mapping the Characteristics of Producer Subsidies – A Review of Pilot Country Studies. Geneva: Global Subsidies Initiative (GSI) of the International Institute for Sustainable Development (IISD). Retrieved from http://earthtrack.net/files/uploaded_files/mapping_ffs.pdf

Kummer, D. M. (1992). *Deforestation in the Postwar Philippines*. London: University of Chicago Press.

Lazard. (2016). Levelized Cost of Energy Analysis 10.0. No Place: Lazard. Retrieved from https://www.lazard.com/media/438038/levelized-cost-of-energy-v100.pdf

Levin, K., Cashore, B., Bernstein, S., & Auld, G. (2012). Overcoming the tragedy of super wicked problems: constraining our future selves to ameliorate global climate change. *Policy Sciences*, *45*(2), 123–152.

Levy, M. A., Young, O. R., & Zürn, M. (1995). The Study of International Regimes. *European Journal of International Relations*, *1*(1), 267–330.

Loorbach, D. A. (2010). Transition Management for Sustainable Development: A Prescriptive, Complexity-Based Governance Framework. *Governance*, *23*(1), 161–183.

Lucon, O., Urge-Vorsatz, A., Ahmed, Z., Akbari, H., Bertoldi, P., Cabeza, L. F., … Vilarino, M. V. (2014). Buildings. In O. Edenhofer, Pichs-Madruga R., Sokona Y., Farahani E., Kadner S., Seyboth K., … J. C. Minx (Eds.), *Climate Change 2014 Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, New York: Cambridge University Press. Retrieved from http://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_full.pdf

Ludwig, H., & Van Houwelingen, J. (n.d.). Global Aluminium Recycling: A Cornerstone of Sustainable Development. No Place: International Aluminium Institute. Retrieved from http://www.world-aluminium.org/media/filer_public/2013/01/15/fl0000181.pdf

Luterbacher, U., & Sprinz, D. F. (Eds.). (2001). *International Relations and Global Climate Change*. Cambridge, MA: MIT Press.

Maclean, J., Tan, J., Tirpak, D., Sonntag-O'Brien, V., & Usher, E. (2008). Public Finance Mechanisms to Mobilize Investment in Climate Change Mitigation. Paris: United Nations Environment Programme (UNEP). Retrieved from http://fs-unep-centre.org/sites/default/files/media/uneppublicfinancereport.pdf

Madlener, R., Robledo, C., Muys, B., & Freja, J. (2006). A Sustainability Framework for Enhancing the Long-Term Success of Lulucf Projects. *Climatic Change*, *75*(1–2), 241–271.

Mander, S., Walsh, C., Gilbert, P., Traut, M., & Bows, A. (2012). Decarbonising the UK Energy System and the Implications for UK Shipping. *Carbon Management*, *3*, 601–614. https://doi.org/10.4155/cmt.12.67

Manley, D., Cust, J., & Cecchinato, G. (2017). *Stranded Nations? The Climate Policy Implications for Fossil Fuel-Rich Developing Countries* (OxCarre Policy Paper No. 34). Oxford. Retrieved from https://www.oxcarre.ox.ac.uk/images/stories/papers/PolicyPapers/oxcarrepp201634.pdf

Mather, A., & Needle, C. (2000). The Relationships of Population and Forest Trends. *The Geographical Journal*, *166*(1), 2–13.

Matikainen, S., Campiglio, E., & Zenghelis, D. (2017). The climate impact of quantitative easing. No Place: Grantham Research Institute on Climate Change and the Environment.

Matthew Scott, van Huizen, J., & Jung, C. (2017). *The Bank of England's response to climate change*. *Quarterly Bulletin 2017 Q2*. London. Retrieved from http://www.bankofengland.co.uk/Pages/reader/index.aspx?pub=qb17q2article2&page=1

McGlade, C., & Etkins, P. (2015). The Geographical Distribution of Fossil Fuels Unused When Limiting Global Warming to 2 Degrees C. *Nature*, *517*(7533), 187–190.

Miles, E. L., Underdal, A., Andresen, S., Wettestad, J., Skjærseth, J. B., & Carlin, E. M. (2002). *Environmental Regime Effectiveness: Confronting Theory with Evidence*. Cambridge, MA and London: MIT Press.

Milmann, O., & Leavenworth, S. (2016). China's plan to cut meat consumption by 50% cheered by climate campaigners. *The Guardian*. Retrieved from https://www.theguardian.com/world/2016/jun/20/chinas-meat-consumption-climate-change

Mission 2020. (2017). 2020: The Climate Turning Point. No Place: Mission 2020. Retrieved from http://www.mission2020.global/2020 The Climate Turning Point.pdf

Mitchell, R. B. (1994). Regime design matters: intentional oil pollution and treaty compliance. *International Organization*, *48*(3), 425–458. https://doi.org/10.1017/S0020818300028253

Mitchell, R. B. (1998). Sources of Transparency: Information Systems in International Regimes. *International Studies Quarterly*, *42*(1), 109–130. https://doi.org/10.1111/0020-8833.00071

Mitchell, R. B., Clark, W. C., Cash, D. W., & Dickson, N. M. (Eds.). (2006). *Global Environmental Assessments: Information and Influence*. Cambridge, MA and London: The MIT Press.

Mofor, L., Nuttall, P., & Newell, A. (2015). Renewable Energy Options for Shipping: Technology Brief. Bonn: International Renewable Energy Agency (IRENA).

Morseletto, P., Biermann, F., & Pattberg, P. (2016). Governing by targets: reductio ad unum and evolution of the two-degree climate target. *International Environmental Agreements: Politics, Law and Economics*, *17*(5), 655–676. https://doi.org/10.1007/s10784-016-9336-7

Morsy, S. (2016). Global EV Sales Outlook to 2040. *Advanced Transport - Research Note*. Bloomberg New Energy Finance.

Murdivarso, D., Brockhaus, M., Sunderlin, W., & Verchot, L. (2012). Some Lessons Learned from the First Generation of REDD+ Activities. *Current Opinion in Environmental Sustainability*, *4*(6), 678–685.

Murtishaw, S., & Sathaye, J. (2006). Quantifying the Effect of the Principal-Agent Problem on US Residential Use. No Place: ACEEE Summer Study on Energy Efficiency in Buildings. https://doi.org/LBNL-59773

Najib, M. (2007). India's "Untouchable" Waste Collectors. Retrieved from http://news.bbc.co.uk/2/hi/south_asia/7073187.stm

Neuhoff, K., Acworth, W., Ancygier, A., Branger, F., Christmas, I., Haussner, M., … Schopp, A. (2014). Carbon Control and Competitiveness Post 2020: The Steel Report. No Place: Climate Strategies. Retrieved from http://climatestrategies.org/wp-content/uploads/2014/10/20141014-Steel-report-Final-ms.pdf

North, D. (1991). Institutions. *The Journal of Economic Perspectives*, *5*(1), 97–112.

Oberthür, S. (2000). The International Convention for the Regulation of Whaling: From Over-Exploitation to Total Prohibition. *Yearbook of International Co-Operation on Environment and Development 1998/99*, 29–37.

Oberthür, S. (2009). Interplay management: Enhancing environmental policy integration among international institutions. *International Environmental Agreements: Politics, Law and Economics*, *9*(4), 371–391.

Oberthür, S. (2016). Regime-interplay management. In K. Blome, A. Fischer-Lescano, H. Franzki, N. Markard, & S. Oeter (Eds.), *Contested Regime Collisions: Norm Fragmentation in World Society* (pp. 49–87). Cambridge: Cambridge University Press.

Oberthür, S., & Bodle, R. (2016). Legal Form and Nature of the Paris Outcome. *Climate Law*, *6*(1), 40–57. https://doi.org/10.1163/18786561-00601003

Oberthür, S., & Justyna, P. (2013). Managing Institutional Complexity and Fragmentation: The Nagoya Protocol and the Global Governance of Genetic Resources. *Global Environmental Politics*, *13*(3), 100–118.

Oberthür, S., & Schram Stokke, O. (2011). *Managing Institutional Complexity: Regime Interplay and Global Environmental Change*. Cambridge, MA: MIT Press.

OECD. (2015a). Climate finance in 2013-14 and the USD 100 billion goal. No Place: Organisation for Economic Co-operation and Development (OECD) in collaboration with Climate Policy Initiative (CPI). Retrieved from http://www.keepeek.com/Digital-Asset-Management/oecd/environment/climate-finance-in-2013-14-and-the-usd-100-billion-goal_9789264249424-en#.Wc0KTBOCzdQ#page1

OECD. (2015b). OECD Companion to the Inventory of Support Measures for Fossil Fuels 2015. Paris: Organisation for Economic Co-operation and Development (OECD) in collaboration with Climate Policy Initiative (CPI).

OECD. (2017). Investing in Climate, Investing in Growth. No Place: Organisation for Economic Co-operation and Development (OECD). Retrieved from https://www.oecd.org/environment/cc/g20-climate/synthesis-investing-in-climate-investing-in-growth.pdf

OECD/FAO. (2016). Agricultural Outlook 2016-2025. *OECD Publishing*. Paris: OECD/FAO. Retrieved from http://www.keepeek.com/Digital-Asset-Management/oecd/agriculture-and-food/oecd-fao-agricultural-outlook-2016_agr_outlook-2016-en#.WUFPQlKB2i4%23page3

OECD/IEA. (2016). *World Energy Investment*. Paris: International Energy Agency.

OECD/IEA and IRENA. (2017). Perspectives for the Energy Transition. No Place: OECD/IEA and IRENA.

Ogawa, H. (2010). Sustainable Solid Waste Management in Developing Countries. Retrieved from http://www.soc.titech.ac.jp/uem/waste/swm-fogawal.htm 26/9/2012

Olivier, J. G. J., Janssens-Maenhout, G., Muntean, M., & Peters, J. A. H. W. (2016). Trends in Global CO2 Emissions: 2016 Report. The Hague.

Orsini, A., Morin, J. F., & Young, O. R. (2013). Regime complexes: A buzz, a boom, or a boost for global governance? *Global Governance: A Review of Multilateralism and International Organizations*, *19*(1), 27–39. https://doi.org/10.5555/1075-2846-19.1.27

Ostrom, E. (2010). Beyond markets and states: Polycentric governance of complex economic systems. *American Economic Review*, *100*(3), 641–672. https://doi.org/10.1257/aer.100.3.641

Pacala, S., & Socolow, R. (2004). Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies. *Science*, *305*(5686), 968–972. https://doi.org/10.1126/science.1100103

Palensky, P., & Dietrich, D. (2011). Demand Side Management: Demand Response, Intelligent Energy Systems, and Smart Loads. *IEEE Transactions on Industrial Informatics*, *7*(3), 381–388. Retrieved from 10.1109/TII.2011.2158841

Pantano, S., May-Ostendorp, P., & Dayem, K. (2016). *Demand DC: Accelerating the Adoption of DC in the Home*. Retrieved from http://clasp.ngo/~/media/Files/DemandDC/CLASP DemandDC White Paper - May 2016.pdf

Parkinson, G. (2016). New Low for Wind Energy Costs: Morocco Tender Averages $US30/MWh. Retrieved January 18, 2016, from https://cleantechnica.com/2016/01/18/new-low-for-wind-energy-costs-morocco-tender-averages-us30mwh/

Parson, E. A. (2003). *Protecting the Ozone Layer. Science and Strategy*. New York: Oxford University Press.

Parton, W. J., Del Grosso, S. J., Marx, E., & Swan, A. L. (2011). Agriculture’s Role in Cutting Greenhouse Gas Emissions. *Issues in Science and Technology*, *27*(4). Retrieved from http://issues.org/27-4/p_parton/

PeakOil.com. (2014). Only 5% of the World’s Population Have Ever Been on an Airplane. Retrieved from http://peakoil.com/consumption/only-5-of-the-worlds-population-have-ever-been-on-an-airplane

Pearce, D. (2001). The Economic Value of Forest Ecosystems. *Ecosystem Health*, *7*(4), 284–296.

Peeters. (2016). Are Technology Myths Stalling Aviation Climate Policy? *Transportation Research Part D*, *44*, 30–42.

Pereirinha, P. G., & Trovão, J. P. (2016). Electric Propulsion Vehicles Standardization: Where Are We? *Electrical Engineering*, *1*(3), 186–191. Retrieved from http://www.aedie.org/papers/16116-pereirinha.pdf

Perlitz, U. (2008). World Chemicals Market: Asia Gaining Ground. No Place: Deutsche Bank Research

publications.

Pilz, H., Brandt, B., Fehringer, R., & Fehringer, R. (2010). The Impact of Plastic Packaging on Life Cycle Energy Consumption and Greenhouse Gas Emissions in Europe. Vienna: Denkstatt.

Psaraftis, H. N., & Kontovas, C. A. (2013). Speed Models for Energy-efficient Maritime Transportation: A Taxonomy and Survey. *Transportation Research C*, *26*, 331–351.

Purohit, & Höglund-Isaksson. (2017). Global emissions of fluorinated greenhouse gases 2005–2050 with abatement potentials and costs. *Atmospheric Chemistry and Physics*, *17*, 2795–2816. https://doi.org/17, 2795-2816.

Putti, Venkata, R., Tsan, M., Mehta, S., & Kammila, S. (2015). The State of the Global Clean and Improved Cooking Sector. Washington DC: Energy Sector Management Assistance Program, Global Alliance for Clean Cookstoves, The World Bank. Retrieved from https://openknowledge.worldbank.org/bitstream/handle/10986/21878/96499.pdf

RAN, Banktrack, S., & OCI. (2017). Banking on Climate Change: Fossil Fuel Finance Report Card 2017. No Place: Rainforest Action Network (RAN), BankTrack, the Sierra Club, and Oil Change International. Retrieved from http://priceofoil.org/content/uploads/2017/06/Banking_On_Climate_Change_2017.pdf

Rao, N. D., & Ummel, K. (2017). White Goods for White People? Drivers of Electric Appliance Growth in Emerging Economies. *Energy Research & Social Science*, *27*, 106–116. https://doi.org/10.1016/j.erss.2017.03.005

Raustiala, K., & Victor, D. G. (2004). The Regime Complex for Plant Genetic Resources. *International Organization*, *32*(58), 147–154.

REN21. (2016). Renewables 2016 - Global Status Report. Paris: REN21 – Renewable Energy Policy Network for the 21st Century. Retrieved from http://www.ren21.net/status-of-renewables/global-status-report/

REN21. (2017). Renewables 2017 Global Status Report. Paris: REN21 – Renewable Energy Policy Network for the 21st Century. Retrieved from http://www.ren21.net/wp-content/uploads/2017/06/17-8399_GSR_2017_Full_Report_0621_Opt.pdf

Reuters. (2016). Leading Global Coal Miner Peabody Files for Bankruptcy. Retrieved from http://www.reuters.com/article/us-peabody-energy-bankruptcy-idUSKCN0XA0E7

Richards, M., Gluck, S., & Wollenberg, E. (2015). *Agriculture's Contribution to National Emissions*. *Info Note*. Retrieved from https://cgspace.cgiar.org/rest/bitstreams/61660/retrieve

Rigby, et. al. (2014). Recent and future trends in synthetic greenhouse gas radiative forcing. *Geophys Res Lett*. https://doi.org/41(7):2623–2630

Roberts, D. (2016, April). The political hurdles facing a carbon tax — and how to overcome them. *Vox*. Retrieved from https://www.vox.com/2016/4/26/11470804/carbon-tax-political-constraints

Rockefeller Brothers Fund. (2017). Divestment Statement. Retrieved from https://www.rbf.org/sites/default/files/rbf-divestment_statement-2017-03-mar.pdf

Roger, C., Hale, T., & Andonova, L. (2017). The Comparative Politics of Transnational Climate Governance. *International Interactions*, *43*(1), 1–25. https://doi.org/10.1080/03050629.2017.1252248

Rotmans, J., Kemp, R., & Van Asselt, M. (2001). More Evolution than Revolution: Transition Management in Public Policy. *Foresight*, *3*(1), 15–31. https://doi.org/10.1108/14636680110803003

Rushe, D. (2017, May 31). Shareholders force ExxonMobil to come clean on cost of climate change. *The Guardian*. Retrieved from https://www.theguardian.com/business/2017/may/31/exxonmobil-climate-change-cost-

shareholders

Rust, S. (2016, February 1). France aims high with first-ever investor climate-reporting law. *IPE*. Retrieved from https://www.ipe.com/countries/france/france-aims-high-with-first-ever-investor-climate-reporting-law/10011722.fullarticle

Sachs, W. (2015). *Planet Dialectics Explorations in Environment and Development* (2nd ed.). London: Zed Books. Retrieved from http://www.myilibrary.com?id=746112

Samadi, S., Grone, M.-C., Schneidewind, U., Luhmann, H.-J., Venjakob, J., & Best, B. (2016). Sufficiency in Energy Scenario Studies: Taking the Potential Benefits of Lifestyle Changes into Account. *Technological Forecasting and Social Change*. Retrieved from http://www.sciencedirect.com/science/article/pii/S0040162516303006

Sanderink, L., Widerberg, O., Kristensen, K., & Pattberg, P. (2017). Mapping the Institutional Architecture of the Climate-Energy Nexus. Amsterdam: IVM Institute for Environmental Studies.

Saunders, A. (2015). Preview: The Top 100 Global Cement Companies and Global Per Capita Capacity Trends. Retrieved from http://www.globalcement.com/magazine/articles/964-preview-the-top-100-global-cement-companies-and-global-per-capita-capacity-trends

Scarlat, N., Motola, V., Dallemand, J. F., Monforti-Ferrario, F., & Mofor, L. (2015). Evaluation of energy potential of Municipal Solid Waste from African urban areas. *Renewable and Sustainable Energy Reviews*, *50*, 1269–1286. https://doi.org/http://dx.doi.org/10.1016/j.rser.2015.05.067

Schmid, E., Knopf, B., & Pechan, A. (2016). Putting an Energy System Transformation into Practice: The Case of the German Energiewende. *Energy Research & Social Science*, *11*(January), 263–275. Retrieved from 10.1016/j.erss.2015.11.002

Schneidewind, U., Fischedick, M., Lucas, R., Muller, M., Reutter, O., Schule, R., … Wanner, M. (2015). Städte in Schwung bringen. *Ökologisches Wirtschaften - Fachzeitschrift*, *30*(2), 20. https://doi.org/10.14512/OEW300220

Schot, J., & Laur, K. (2016). *Deep Transitions: Emergence, Acceleration, Stabilization and Directionality* (SPRU Working Paper No. 2016–15). Brighton. Retrieved from https://papers.ssrn.com/abstract=2834854

Schwarze, R., Niles, J., & Olander, J. (2002). Understanding and Managing Leakage in Forest-based Greenhouse-Gas-Mitigation Projects. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *360*(1797), 1685–1703.

Scoones, I., Leach, M., & Newell, P. (Eds.). (2015). *The Politics of Green Transformations*. New York: Routledge.

Searchinger, T. (2013). The Great Balancing Act. Washington, DC: World Resources Institute. Retrieved from http://www.worldresourcesreport.org

Searchinger, T., & Heimlich, R. (2015). Avoiding Bioenergy Competition for Food Crops and Land. Washington, DC: World Resources Institute. Retrieved from http://www.worldresourcesreport.org

SEI. (2015). The SEI Initiative on Fossil Fuels and Climate Change. Stockholm: Stockholm Environment Institute.

Seidel, S., Ye, J., Andersen Stephen, O., & Hillbrand, A. (2016). Not-In-Kind Alternatives to High Global Warming HFCS. Arlington, VA: Center for Climate and Energy Solutions. Retrieved from https://www.c2es.org/docUploads/not-in-kind-alternatives-high-global-warming-hfcs.pdf

Seto, K. C., Dhakal, S., Bigio, A., Blanco, H., Delgado, G. C., Dewar, D., … Ramaswami, A. (2014). Human Settlements, Infrastructure and Spatial Planning. In *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E.*

Farahani, S. Kadner, K. Seyboth, A. Adler, . Cambridge, New York: Cambridge University Press.

Seto, K. C., Lin, Y., & Deng, X. (2014). Land-Use Competition between Food Production and Urban Expansion in China. In K. C. Seto & A. Reenberg (Eds.), *Rethinking Global Land Use in an Urban Era* (pp. 71–85). Cambridge, MA: The MIT Press.

Shearer, C., Ghio, N., Myllyvirta, L., Yu, A., & Nace, T. (2017). *Boom and Bust 2017 - Tracking the Global Coal Plant Pipeline*. Retrieved from http://endcoal.org/wp-content/uploads/2017/03/BoomBust2017-English-Final.pdf

Simmons, B. A., & Martin, L. L. (2002). International Organizations and Institutions. In W. Carlsnaes et al. (Ed.), *The Handbook of International Relations* (2nd ed., pp. 195–96). London: Sage Publications.

SLoCaT. (2015). *Contribution of Transport Commitments to Global Goals on Sustainable Development*. Bangkok. Retrieved from http://www.slocat.net/sites/default/files/u13/2015_transport_commitments_report_2.pdf

Smil, V. (2013). *Making the Modern World, Materials and Dematerialization*. Chichester: Wiley.

Smith, J., & Urpaleinen. (2017). Removing Fuel Subsidies: How Can International Organizations Support National Policy Reforms? *International Environmental Agreements: Politics, Law, and Economics*, *17*(3), 327–340. https://doi.org/10.1007/s10784-017-9358-9

Smith, P., Bustamante, M., Ahammad, H., Clark, H., Dong, E. A., Elsiddig, H., … Tubiello, F. (2014). *Agriculture, Forestry, and Other Land Use (AFOLU)*. New York, Cambridge: Cambridge University Press.

Smith, P., Haberl, H., Popp, A., Erb, K., Lauk, C., Harper, R., … Rose, S. (2013). How Much Land-based Greenhouse Gas Mitigation Can Be Achieved Without Compromising Food Security and Environmental Goals? *Global Change Biology*, *19*(8), 2285–2302. https://doi.org/10.1111/gcb.12160

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., … Smith, J. (2008). Greenhouse Gas Mitigation in Agriculture. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1492), 789–813. https://doi.org/10.1098/rstb.2007.2184

Smith, T. (2015). Two Crucial Omissions That Could Jeopardise Paris Climate Deal. Retrieved from https://theconversation.com/two-crucial-omissions-that-could-jeopardise-paris-climate-deal-52341

Smith, T. W. P., Traut, M., Bows-Larkin, A., Anderson, K., McGlade, C., & Wrobel, P. (2015). CO2 Targets, Trajectories and Trends for International Shipping. Retrieved from https://www.research.manchester.ac.uk/portal/files/31961273/FULL_TEXT.PDF

Snidal, D. (1985). Coordination versus prisoners' dilemma: implications for international cooperation and regimes. *American Political Science Review*, *79*(4), 923–942. https://doi.org/10.2307/1956241

Springmann, M., Godfray, H., Rayner, M., & Scarborough, P. (2016). Analysis and valuation of the health and climate change cobenefits of dietary change. *Proceedings of the National Academy of Sciences*, *113*(15), 4146–4151. Retrieved from http://www.pnas.org/content/113/15/4146.abstract

SRU. (2005). *Umwelt und Straßenverkehr. Hohe Mobilität - Umweltverträglicher Verkehr* (Sondergutachten). Berlin: Sachverständigenrat für Umweltfragen.

Stadelmann, M., Roberts, J. T., & Michaelowa, A. (2011). Accounting of Private Climate Finance - Types of Finance, Data Gaps and the 100 Billion Dollar Question. Cambridge: Climate Strategies.

Stavins, R., Zou, J., Brewer, T., Conte Grand, M., den Elzen, M., Finus, M., … Winkler, H. (2014). International Cooperation: Agreements and Instruments. In *Climate Change 2014: Mitigation of*

Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 1001–1082). Cambridge and New York, Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. Retrieved from https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_chapter13.pdf

Steduto, P., Faurès, J., Hoogeveen, J., Winpenny, J., & Burke, J. (2012). *Coping with Water Scarcity*. Rome: Food and Agriculture Organization of the United Nations.

Sterk, W., & Hermwille, L. (2013). Does the Climate Regime Need New Types of Mitigation Commitments? *Carbon and Climate Law Review*, *7*(4), 270–282.

Sterner, T., & Coria, J. (2013). *Policy instruments for environmental and natural resource management* (2nd ed.). New York: RFF Press. https://doi.org/10.4324/9781315780894

Stiehler, A. (2017). Longer Term Investments: Waste Management and Recycling. No Place: UBS Switzerland AG.

Stokke, O. S. (2012). *Disaggregating International Regimes. A New Approach to Evaluation and Comparison*. Cambridge, MA: MIT Press.

Stumpf, R. (2017, July). U.K. to Ban Internal Combustion Engine Vehicles by 2040. Is the ICE age beginning to thaw in Europe? *The Drive*. Retrieved from http://www.thedrive.com/news/12859/u-k-to-ban-internal-combustion-engines-by-2040

Tagliapietra, S. (2017). The Political Economy of Middle East and North Africa Oil Exporters in Times of Global Decarbonisation. Brussels: Breugel.

TCFD. (2016). Phase I Report of the Task Force on Climate-Related Financial Disclosures. No Place: Task Force on Climate-Related Financial Disclosures. Retrieved from https://www.fsb-tcfd.org/wp-content/uploads/2016/03/Phase_I_Report_v15.pdf

TCFD. (2017). Recommendations of the Task Force on Climate-Related Financial Disclosures. No Place: Task Force on Climate-Related Financial Disclosures. Retrieved from https://www.fsb-tcfd.org/wp-content/uploads/2017/06/FINAL-TCFD-Report-062817.pdf

TEAP. (2016). Report of the Technology and Economic Assessment Panel, Volume I, Decision XXVII/4, Task Force Update Report, Further Information on Alternatives to Ozone-Depleting Substances. Nairobi, Kenya: United Nations Environment Programme (UNEP). Retrieved from http://conf.montreal-protocol.org/meeting/mop/mop-28/presession/Background Documents are available in English only/TEAP_TFXXVII-4_Report_September2016.pdf

The Economist. (2013). The Global Cement Industry - Ready-Mixed Fortunes. Retrieved from http://www.economist.com/news/business/21579844-worlds-cement-giants-look-setrecoverybut-will-it-be-durable-ready-mixed-fortunes

The Guardian. (2017, February 1). Deutsche Bank pulls out of coal projects to meet Paris climate pledge. Retrieved from https://www.theguardian.com/business/2017/feb/01/deutsche-bank-pulls-out-of-coal-projects-to-meet-paris-climate-pledge

The Storting. (2015). The Storting has made the unanimous decision to pull the Government Pension Fund Global (GPFG) out of coal. Retrieved from https://www.stortinget.no/en/In-English/About-the-Storting/News-archive/Front-page-news/2014-2015/hj9/

The World Bank. (2016). $81 Billion Mobilized in 2015 to Tackle Climate Change – Joint MDB Report. Retrieved from http://www.worldbank.org/en/news/press-release/2016/08/09/81-billion-mobilized-in-2015-to-tackle-climate-change---joint-mdb-report

The World Counts. (2014). Deforestation Facts and Statistics. Retrieved from http://www.theworldcounts.com/stories/deforestation-facts-and-statistics

Thema, J., Thomas, S., Kopatz, M., Spitzner, M., & Ekardt, F. (2017). Energiesuffizienzpolitik mit Schwerpunkt auf dem Stromverbrauch der Haushalte. Wuppertal: Wuppertal Institut fur Klima,

Umwelt, Energie. Retrieved from https://epub.wupperinst.org/frontdoor/index/index/docId/6670

Tickell, O. (2008). *Kyoto 2: How to Manage the Global Greenhouse*. London and New York: Zed Books.

Treves, T., Pineschi, L., Tanzi, A., Pitea, C., Chiara Ragni, & Jacur, F. R. (2009). *Non-Compliance Procedures and Mechanisms and the Effectiveness of International Environmental Agreements*. The Hague: T.M.C. Asser Press.

Tullo, A. (2016). C&EN's Global, Sales are Down in the Low Oil Price Environment, But Profits are Soaring. *Chemical and Engineering News*, *94*(30), 32–37. Retrieved from http://cen.acs.org/articles/94/i30/CENs-Global-Top-50.html

Tyabji, N., & Nelson, W. (2012). Mitigating Emissions from Aluminium. The GNCS Factsheets. Columbia Climate Centre.

U.S. Geological Survey. (2015). Mineral Commodity Summaries 2015: U.S. Geological Survey. Retrieved from http://dx.doi.org/10.3133/70140094

UK Department of Energy and Climate Change. (2012). Land Use, Land Use Change and Forestry (LULUCF): GHG Inventory summary Factsheet. London: UK Department of Energy and Climate Change. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48417/1222-ghg-inventory-summary-factsheet-lulucf.PDF

UK Department of Energy and Climate Change. (2013). Initial Agreement Reached on New Nuclear Power Station at Hinkley. London: UK Department of Energy and Climate Change. Retrieved from https://www.gov.uk/government/news/initial-agreement-reached-on-new-nuclear-power-station-at-hinkley

UN Climate Summit 2014. (2014). Investors commit to decarbonize $100 billion in investments. Retrieved from http://www.un.org/climatechange/summit/2014/09/investors-commit-decarbonize-100-billion-investments/

UNDESA. (2015). *World Population Projected to Reach 9.7 Billion by 2050*. New York. Retrieved from http://www.un.org/en/development/desa/news/population/2015-report.html

UNEP. (2002). Production and Consumption of Ozone Depleting Substances under the Montreal Protocol, 1986-2000. Nairobi: Ozone Secretariat, UNEP. Retrieved from http://ozone.unep.org/pdfs/15-year-data-report.pdf

UNEP. (2010). Waste and Climate Change: Global Trends and Strategy Framework. Osaka/Shiga: United Nations Environmental Programme Division of Technology, Industry and Economics International Environmental Technology Centre. Retrieved from http://www.unep.or.jp/ietc/Publications/spc/Waste&ClimateChange/Waste&ClimateChange.pdf

UNEP. (2015). *Global Waste Management Outlook Summary for Decision-Makers*. Vienna. Retrieved from https://www.iswa.org/fileadmin/galleries/Publications/ISWA_Reports/GWMO_summary_web.pdf

UNEP. (2016). En.lighten: Efficient lighting for developing and emerging countries. Paris: United Nations Environment Programme. Retrieved from http://www.enlighten-initiative.org/.

UNFCCC. (2007). *Investment and Financial Flows to Address Climate Change* (1st ed.). Bonn: United Nations Framework Convention on Climate Change.

UNFCCC. (2013). Time Series - GHG data from UNFCCC Annex I. No Place: United Nations Framework Convention on Climate Change. Retrieved from http://unfccc.int/ghg_data/ghg_data_unfccc/items/4146.php

UNFCCC. (2016). Summary and recommendations by the Standing Committee on Finance on the 2016 biennial assessment and overview of finance flows. Bonn: United Nations Framework Convention on Climate Change. Retrieved from http://unfccc.int/files/cooperation_and_support/financial_mechanism/standing_committee/application/pdf/2016_ba_summary_and_recommendations.pdf

UNFCCC. (2017). Land Use, Land-Use Change and Forestry (LULUCF). Retrieved from https://unfccc.int/land_use_and_climate_change/lulucf/items/1084.php

United Nations. (2014). *World urbanization prospects: the 2014 revision*. New York: UN Department of Economic and Social Affairs, Population Division.

United Nations Human Settlements Programme. (2013). Planning and Design for Sustainable Urban Mobility. Global Report on Human Settlements 2013. New York: United Nations Human Settlements Programme.

Unruh, G. C. (2000). Understanding Carbon Lock-In. *Energy Policy*, *28*(12), 817–830.

Urge-Vorsatz, D., Cabeza, L. F., Serrano, S., Barreneche, C., & Petrichenko, K. (2015). Heating and Cooling Energy Trends and Drivers in Buildings. *Renewable and Sustainable Energy Reviews*, *41*, 85–98. Retrieved from http://www.sciencedirect.com/science/article/pii/S1364032114007151

Urge-Vorsatz, D., Eyre, N., Graham, P., Harvey, D., Hertwich, E., Jiang, Y., … Novikova, A. (2012). Chapter 10 - Energy End-Use: Building. In *Global Energy Assessment - Toward a Sustainable Future* (pp. 649–760). Cambridge, New York : Cambridge University Press. Retrieved from http://www.iiasa.ac.at/web/home/research/Flagship-Projects/Global-Energy-Assessment/GEA_Chapter10_buildings_hires.pdf

US Department of Commerce. (2016). Global Steel Report July 2016. Washington DC: U.S. Department of Commerce, International Trade Administration. Retrieved from http://trade.gov/steel/pdfs/07192016global-monitor-report.pdf

Van Asselt, H., & Kulovesi, K. (2017). Seizing the Opportunity: Tackling Fossil Fuel Subsidies under the UNFCCC. *International Environmental Agreements: Politics, Law and Economics*, *17*(3), 357–370. https://doi.org/https://doi.org/10.1007/s10784-017-9357-x

Velders, G. J. M., Fahey, D. W., Daniel, J. S., Andersen, S. O., & McFarland, M. (2015). Future atmospheric abundances and climate forcings from scenarios of global and regional HFCs emissions. *Atmospheric Environment*, *123*(Part A), 200–209. Retrieved from http://www.sciencedirect.com/science/journal/13522310?sdc=1

Vidal, J. (2016, October 19). Shipping “progressives” call for industry carbon emission cuts. *The Guardian*. Retrieved from https://www.theguardian.com/environment/2016/oct/19/shipping-progressives-call-for-industry-carbon-emission-cuts

von Germis, C. (2017, September 11). Das sind die E-Auto-Pläne von VW. *Frankfurter Allegmeine*. No Place. Retrieved from http://www.faz.net/aktuell/wirtschaft/unternehmen/ziele-von-matthias-mueller-selbstkritische-worte-von-vw-chef-zum-beginn-der-iaa-15193863.html

Walsh, C., Mander, S., & Larkin, A. (2017). Charting a Low Carbon Future for Shipping: A UK Perspective. *Marine Policy*, *82*, 32–40.

WBCSD. (2010). Vision 2050. The New Agenda for Business. Geneva: WBCSD.

WBGU. (2016). Humanity on the Move. Unlocking the Transformative Power of Cities. Berlin: WBGU.

Weber, C., & Matthews, H. (2008). Food-Miles and the Relative Climate Impacts of Food Choices in the United States. *Environmental Science & Technology*, *42*(10), 3508–3513.

WEF. (2011). A Profitable and Resource Efficient Future: Catalysing Retrofit Finance and Investing in Commercial Real Estate. Geneva: World Economic Forum. Retrieved from http://www3.weforum.org/docs/WEF_IU_CatalysingRetrofitFinanceInvestingCommercialRealEs

tate_Report_2011.pdf

WEF. (2016). Towards the Circular Economy: Accelerating the Scale-up Across Global Supply Chains. Geneva: World Economic Forum. Retrieved from http://www3.weforum.org/docs/WEF_ENV_TowardsCircularEconomy_Report_2014.pdf

Whitley, S., & van der Burg, L. (2015). Fossil Fuel Subsidy Reform: From Rhetoric to Reality. London, Washington, DC: The Global Commission on the Economy and Climate. Retrieved from http://newclimateeconomy.report/misc/working-papers

WHO. (2008). Global and Regional Food Consumption Patterns and Trends. Retrieved from http://www.who.int/nutrition/topics/3_foodconsumption/en/index4.html

Widerberg, O., & Stripple, J. (2016). The expanding field of cooperative initiatives for decarbonization: a review of five databases. *Wiley Interdisciplinary Reviews: Climate Change*, *7*(4), 486–500. https://doi.org/10.1002/wcc.396

WIEGO. (2013). Waste Pickers: The Right to be Recognised as Workers. No Place: Women in Informal Employment: Globalizing and Organizing (WIEGO). Retrieved from http://www.wiego.org/sites/wiego.org/files/resources/files/WIEGO-Waste-Pickers-Position-Paper.pdf

Wollenberg, E., Richards, M., Smith, P., Havlik, P., Obersteiner, M., Tubiello, F., … Campbell, B. (2016). Reducing Emissions from Agriculture to Meet the 2°C Target. *Global Change Biology*, *22*(12), 3859–3864.

World Bank. (2015). *HFO IPR – Challenges and Opportunities, presentation by the World Bank Montreal Protocol Operations, The 27th Meeting of the Parties to the Montreal Protocol*. Dubai. Retrieved from http://conf.montreal-protocol.org/meeting/mop/mop-27/pubs/Observer Publications/WB IP Side Event - Landscape of HFO Patents WB final.pdf

World Bank & Ecofys. (2017). Carbon Pricing Watch. No Place: World Bank & Ecofys. Retrieved from https://www.ecofys.com/files/files/world-bank-ecofys-carbon-pricing-watch-2017.pdf

World Energy Council. (2016). World Energy Resources: Waste to Energy. No Place: World Energy Council. Retrieved from https://www.worldenergy.org/wp-content/uploads/2017/03/WEResources_Waste_to_Energy_2016.pdf

World Steel Association. (2016). World Steel in Figures 2016. Brussels, Beijing: World Steel Association.

World Steel Association. (2017). Press Release: World Crude Steel Output Increases by 0.8% in 2016. No Place: World Steel Association. Retrieved from https://www.worldsteel.org/en/dam/jcr:81295079-b8c8-4933-b426-0ce3a31b2cad/2016+World+Crude+Steel+Production+Press+Release.pdf

WRI. (2012). CAIT Climate Data Explorer, Historical Emissions from Waste. Retrieved September 21, 2017, from http://cait.wri.org/historical/Country GHG Emissions?indicator[]=Waste&year[]=2012&sortDir=desc&chartType=bars

WTO. (2017a). International Trade Statistics 2015. Retrieved from https://www.wto.org/english/res_e/statis_e/wts2016_e/wts16_chap9_e.htm

WTO. (2017b). International Trade Statistics 2015 - Merchandise Trade. Retrieved from https://www.wto.org/english/res_e/statis_e/its2015_e/its15_merch_trade_product_e.htm

Wurzel, R., Zito, A., & Jordan, A. J. (2013). *Environmental Governance in Europe: A Comparative Analysis of the Use of New Environmental Policy Instruments*. Cheltenham: Edward Elgar. https://doi.org/10.1108/meq.2013.08324eaa.009

Young, O. R. (1980). International Regimes: Problems of Concept Formation. *World Politics*, *323*, 331–356.

Young, O. R. (1982). *Resource regimes : Natural resources and social institutions*. Berkeley: University

of California Press.

Young, O. R. (1986). International Regimes: Towards a New Theory of Institutions. *World Politics*, *39*, 104–122.

Young, O. R. (1989). The power of institutions: why international regimes matter. In O. R. Young (Ed.), *International cooperation: Building regimes for natural resources and the environment* (pp. 58–80). Ithaca, NY: Cornell University Press.

Young, O. R. (Ed.). (1999). *The effectiveness of international environmental regimes: Causal connections and behavioral mechanisms*. Cambridge, MA: MIT Press.

Young, O. R., & Levy, M. A. (1999). The Effectiveness of International Environmental Regimes. In O. R. Young (Ed.), *The Effectiveness of International Environmental Regimes: Causal Connections and Behavioural Mechanisms* (pp. 1–32). Cambridge, MA: MIT Press.

Zhang, D., Huang, G., Xu, Y., & Gong, Q. (2015). Waste-to-energy in China: Key challenges and opportunities. *Energies*, *8*(12), 14182–14196. https://doi.org/10.3390/en81212422

Zheng, L., Song, J., Li, C., Gao, Y., Geng, P., Qu, B., & Lin, L. (2014). Preferential Policies Promote Municipal Solid Waste (MSW) to Energy in China: Current Status and Prospects. *Renewable and Sustainable Energy Review*, *36*, 135–148.