WG III contribution to the Sixth Assessment Report

List of corrigenda to be implemented

The corrigenda listed below will be implemented in the Chapter during copy-editing.

CHAPTER 17

Document (Chapter, Annex, Supp. Material)	Page (Based on the final pdf FGD version)	Line	Detailed information on correction to make
Chapter 17	24	51-53	Coal has hitherto been the dominant energy source in China and has accounted for more than 70% of its total energy consumption for the past twenty years, falling to 64% in 2015 (The National BIM Report 2018). In the 13th Five Year Plan (2016-2020), for the first time China included the target of a national coal consumption cap of 4.1 billion tons for 2020, as well as a goal of reducing the primary energy share of coal to 58% by 2020 from the level of 64% in 2015 (The National People's Congress of the People's Republic of China 2016). Delete paragraph
Chapter 17	55	7-9	Replace: For example, the case of coal-fired power in China (section 17.3) shows that a transition to a lower carbon system is unlikely to happen even if models find it technically feasible and cost-effective. With "A transition to a lower carbon system is unlikely to happen even if models find it technically feasible and cost-effective."

Chapter 17: Accelerating the transition in the context of sustainable development

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Executive summary

Accelerating climate actions and progress towards a just transition is essential to reducing climate risks and addressing sustainable development priorities, including water, food and human security *(robust evidence, high agreement)*. Accelerating action in the context of sustainable development involves not only expediting the pace of change (speed) but also addressing the underlying drivers of vulnerability and high emissions (quality and depth of change) and enabling diverse communities, sectors, stakeholders, regions and cultures (scale and breadth of change) to participate in just, equitable and inclusive processes that improve the health and well-being of people and the planet. Looking at climate change from a justice perspective means placing the emphasis on a) the protection of vulnerable populations and low income countries from the impacts of climate change, b) mitigating the effects of the transformations, and c) ensuring an equitable decarbonized world {17.1.1}.

While transition pathways will vary across countries, they are likely to be challenging in many contexts. (*robust evidence, high agreement*). Climate change is the result of decades of unsustainable production and consumption patterns (for example energy production and land-use), as well as governance arrangements and political economic institutions that lock in resource-intensive development patterns (*robust evidence, high agreement*). Reframing development objectives and shifting development pathways towards sustainability can help transform these patterns and practices, allowing space for transitions to transform unsustainable systems (*medium evidence, high agreement*). {17.1.1.2}.

Sustainable development can enhance sectoral integration and social inclusion (*robust evidence, high agreement*). Inclusion merits attention because equity within and across countries is critical to transitions that are not simply rapid but also sustainable and just. Resource shortages, social divisions, inequitable distributions of wealth, poor infrastructure and limited access to advanced technologies can constrain the options and capacities for developing countries to achieve sustainable and just transitions (*medium evidence, high agreement*) {17.1.1.2}.

Concrete actions aligning sustainable development and climate mitigation and partnerships can support transitions. Strengthening different stakeholders' "response capacities" to mitigate and adapt to a changing climate will be critical for a sustainable transition (*robust evidence, high agreement*). Response capacities can be increased by means of alignment across multiple stakeholders at different levels of decision-making. This alignment will also help achieve synergies and manage trade-offs between climate and sectoral policies by breaking down sectoral silos and overcoming the multiple barriers that prevent transitions from gaining traction and gathering momentum (*medium evidence, high agreement)* {17.1.1.1}.

Economics, psychology, governance and systems research have pointed to a range of factors that influence the speed, scale and quality of transitions (*robust evidence, high agreement*). Views nonetheless differ on how much market-correcting policies, shift preferences (economics) and shifts in individual and collective mindsets (psychology) and multi-level governance arrangements and inclusive political institutions (governance) contribute to system transitions (*medium evidence, high agreement*) {17.2}.

While economics, psychology, governance and systems thinking emphasize different enablers of transitions, they often share a view that strengthening synergies and avoiding trade-offs between climate and sustainable development priorities can overcome barriers to transitions (*medium evidence, high agreement*). A growing body of research and evidence can show which factors in the views from economics, psychology, governance and systems affect how interrelationships are managed between climate, mitigation policies and sustainable development. Greater integration between studies based on different methodological approaches can show how to construct an enabling environment that increases the feasibility and sustainability of transitions {17.2, 17.3 and 17.4}.

Short- and long-term studies of transformations using macroeconomic models and integrated assessment models (IAMs) have identified synergies and trade-offs of mitigation options in the context of development pathways that align sustainable development and climate change (*robust evidence, high agreement*). IAMs often look at climate change mitigation and SDGs in an aggregate manner: supplementing this aggregate view with detail-rich studies involving SDGs can build support for transitions within and across countries (*medium evidence, medium agreement*). {17.3.2}.

The impacts of climate-change mitigation and adaptation responses, are highly context-specific and scale-dependent. There are synergies and trade-offs between adaptation and mitigation as well as synergies and trade-offs with sustainable development(*robust evidence, high agreement*). A strong link exists between sustainable development, vulnerability and climate risks, as limited economic, social and institutional resources often result in low adaptive capacities and high vulnerability, especially in developing countries. Resource limitations in these countries can similarly weaken the capacity for climate mitigation and adaptation. The move towards climate-resilient societies requires transformational or deep systemic change. This has important implications countries' sustainable development pathways *(medium evidence, high agreement)* {17.3.3.6}.

Sectoral mitigation options present synergies with the SDGs, but there are also trade-offs, which can become barriers to implementation. Such trade-offs are particularly identified in relation to the use of land for bioenergy crops, water and food access, and competition for land between forest or food production (*robust evidence, high agreement*). Many industrial mitigation options, like efficiency improvements, waste management and the circular economy, have synergies with the SDGs relating to access to food, water and energy (*robust evidence, high agreement*). The promotion of renewable energy in some industrial sectors, can imply stranded energy supply investments, which need to be taken into consideration *(medium evidence, medium agreement)*. The Agriculture, Forestry, and Other Land Uses (AFOLU) sector offers many low-cost mitigation options, but actions aimed at producing bioenergy, extending food access and protecting biodiversity can also create trade-offs between different land-uses (*robust evidence, high agreement*). Some options can help to minimize these trade-offs, for example, integrated land management, cross-sectoral policies and efficiency improvements. Lifestyle changes, including dietary changes and reduced food waste, have several synergies with climate mitigation and the SDGs (*medium evidence, medium agreement*). Cross-sectoral policies are important in avoiding trade-offs, to ensure that synergies between mitigation and SDGs are captured, and to ensure local people are involved in the development of new products, as well as production and consumption practices. There can be many synergies in urban areas between mitigation policies and the SDGs, but capturing these depends on the overall planning of urban structures and on local integrated policies, where, for example, affordable housing and spatial planning as a climate mitigation measure are combined with walkable urban areas, green electrification and clean renewable energy. Such integrated options can also reduce the pressures on agricultural land by reducing urban growth, thus improving food security. Access to green electricity can also support quality education *(medium evidence, medium agreement).* {17.3.3, 17.3.3.1, 17.3.3.3}.

Digitalization could facilitate a fast transition to sustainable development and low-emission pathways by contributing to efficiency improvements, cross-sectoral coordination and a circular economy with new IT services and decreasing resource use (*low evidence, medium agreement*)**.** Several synergies with SDGs could emerge in terms of energy, food and water access, health and education, as well as trade-offs, for example, in relation to reduced employment, increasing energy demand and increasing demand for services, all implying increased GHG emissions. However, developing countries with limited internet access and poor infrastructure could be excluded from the benefits of digitalization *(medium evidence, medium agreement).* {17.3.3}.

Actions aligning sustainable development and climate mitigation and partnerships can support transitions. Strengthening different stakeholders' "response capacities" to mitigate and adapt to a changing climate will be critical for a sustainable transition (*robust evidence, high agreement*). Response capacities can be increased by means of alignment across multiple stakeholders at different levels of decision-making. This alignment will also help achieve synergies and manage trade-offs between climate and sectoral policies by breaking down sectoral silos and overcoming the multiple barriers that prevent transitions from gaining traction and gathering momentum (*medium evidence, high agreement)* {17.1.1.1}.

The landscape of transitions to sustainable development is changing rapidly, with multiple transitions already underway. This creates the room to manage these transitions in ways that prioritise the needs for workers in vulnerable sectors (land, energy) to secure their jobs and maintain secure and healthy lifestyles, especially as the risks multiply for those exposed to heavy industrial jobs and associated outcomes (*medium evidence, high agreement*). {17.3.2.3}. A just transition incorporates key principles, such as respect and dignity for vulnerable groups, the creation of decent jobs, social protection, employment rights, fairness in energy access and use, and social dialogue and democratic consultation with the relevant stakeholders, while coping with the effects of asset-stranding and the transition to green and clean economies *(medium evidence, medium agreement).* The economic implications of the transition will be felt especially strongly by developing countries, with high dependence on hydrocarbon products for revenue streams, as they will be exposed to reduced fiscal incomes given a low demand for oil and consequent fall in oil prices *(limited evidence, medium agreement).* {17.3.2}.

Countries with assets that are at risk becoming stranded may lack the relevant resources, knowledge, autonomy or agency to reorientate, or to decide on the speed, scale and quality of the transition (*limited evidence, medium agreement*). The urgency of mitigation might overshadow some of the other priorities related to the transition, like climate change adaptation and its inherent vulnerabilities. Consequently, the transition imperative could reduce the scope and autonomy for local priority-setting and could ignore the additional risks in countries with a low capacity to adapt. A just transition will depend on local contexts, regional priorities, the starting points of different countries in the transition and the speed at which they want to travel. Both mitigation and adaptation warrant urgent and prompt action given current and continuing greenhouse gas emissions and associated negative impacts on humanity and ecosystems. *(limited evidence, medium agreement).* {17.3.2}.

A wide range of factors have been found to enable sustainability transitions, ranging from technological innovations to shifts in markets, and from policies and governance arrangements to shifts in belief systems and market forces (*robust evidence, high agreement*). Many of these factors come together in a co-evolutionary process that has unfolded globally, internationally and locally over several decades (*low evidence, high agreement*). Those same conditions that may serve to impede the transition (i.e., organizational structure, behaviour, technological lock-in) can also 'flip' to enable both it and the framing of sustainable development policies to create a stronger basis and policy support (*robust evidence, high agreement*). It is important to note that strong shocks to these systems, including accelerating climate change impacts, economic crises and political changes, may provide crucial openings for accelerated transitions to sustainable systems. For example, re-building more sustainably after an extreme event, or renewed public debate about the drivers of social and economic vulnerability to multiple stressors *(medium evidence, medium agreement)* {17.4}.

Sustainable development and deep decarbonization will involve people and communities being connected through various means, including globally via the internet and digital technologies, in ways that prompt shifts in thinking and behaviour consistent with climate change goals (*medium evidence, medium agreement*). Individuals and organizations like institutional entrepreneurs can function to build transformative capacity through collective action (*robust evidence, high agreement)*, but private-sector entrepreneurs can also play an important role in fostering and accelerating the transitions to sustainable development (*robust evidence, medium agreement*). Ultimately, the adoption of coordinated, multi-sectoral policies targeting new and rapid innovation can help national economies take advantage of widespread decarbonization. Green industrial policies that focus on building domestic supply chains and capacities can help states prepare for the influx of renewable, CDR-methods, or mechanisms for carbon capture and storage (*medium evidence, medium agreement*){17.4.2}.

Accelerating the transition to sustainability will be enabled by explicit consideration being given to the principles of justice, equality and fairness. Interventions to promote sustainability transitions that account for local context (including unequal access to resources, capacity and technology) in the development process are necessary but not sufficient in creating a just transition (*low evidence, high agreement)*. {17.4.6}

17.1 Introduction

This chapter focuses on the opportunities and challenges for "accelerating the transition in the context of sustainable development." The chapter suggests that accelerating transitions in the context of sustainable development requires more than concentrating on speed. Rather, it involves expediting the pace of change (speed) while also removing the underlying drivers of vulnerability and high emissions (quality and depth) and aligning the interests of different communities, regions, sectors, stakeholders and cultures (scale and breadth). One key to enabling deep and broad transitions is integrating the views of different government agencies, businesses and non-governmental organizations (NGOs) in transition processes. Another critical driver of deep and broad transitions is engaging and empowering workers, youth, women, the poor, minorities and marginalized stakeholders in just, equitable and inclusive processes. The result of such processes will be the transformation of large-scale socioeconomic systems to restore the health and well-being of the planet and the people on it.

Section 17.1 begins by reviewing how climate and sustainability issues have been discussed in the Intergovernmental Process on Climate Change (IPCC), as well as international climate change and sustainable development processes at different levels. It further introduces key themes addressed in the chapter's remaining subsections. Section 17.2 provides an overview of how key theories understand transitions and transformation, and notes a shared concern over leveraging synergies and managing trade-offs between climate change and sustainable development across different disciplines. Section 17.3 provides an assessment of the mitigation options that can help achieve these synergies and avoid trade-offs. 17.4 pulls together the theoretical and empirical aspects by detailing the essential elements of an enabling environment that helps drive forward transitions that are quick, deep, broad and, ultimately, sustainable.

17.1.1 Integrating Climate Change and Sustainable Development in International Assessments

Climate change not only poses a profound challenge to sustainable development, it is inexorably linked to it. From the early stages of the IPCC assessment process, this challenge and the inherent link between climate change and sustainable development have been well recognized. For example, the First Assessment Report (FAR) highlighted the relevance of sustainable development for climate policy. The Second Assessment Report (SAR) went further to include equity issues in its presentation of sustainable development. The Third Assessment Report (TAR) (Banuri et al. 2001) made the link even stronger, noting that "parties have a right to and should promote sustainable development" (as stated in the text of the UNFCCC 2015 (Article 3.4)), and offering an early review of studies integrating sustainable development and climate change. The Fourth Assessment Report (AR4) (Sathaye et al. 2007) added an additional perspective to these interconnections, acknowledging the existence of a two-way relationship between sustainable development and climate change.

The Fifth Assessment Report (AR5) (Denton et al. 2014; Fleurbaey et al. 2014) and the Special Report on Global Warming of 1.5°C (IPCC 2018; Roy et al. 2018a) have arguably made the strongest links between climate and sustainable development to date. One of the key messages of AR5 was that the implementation of climate mitigation and adaptation actions could help promote sustainable development, and it emphasized the need for transformational changes in this regard. AR5 also concluded that the link between climate change and sustainable development is cross-cutting and complex, and that thus the impacts of climate change are threatening the efforts being made to achieve sustainable development. The IPCC special report on Global Warming of 1.5°C helped systematize these links by mapping the synergies and trade-offs between selected SDG indicators and climate mitigation (IPCC 2018; Roy et al. 2018b) (see also sect. 17.3).

Despite the clear links between sustainable development and climate change being recognised from the early stages of the IPCC, climate change has often been portrayed as an environmental problem to be addressed chiefly by environmental ministries (Brown et al. 2007; Munasinghe 2007; Swart and Raes 2007). However, this perception has evolved over time. It is now increasingly common to see governments and other actors understand the wider ramifications of a changing climate for sustainable development. In a growing number of studies, work on climate policies and just transitions towards sustainable development are framed as going hand in hand (Fuso Nerini et al. 2019; Dugarova and Gülasan 2017; Sanchez Rodriguez et al. 2018; Schramade 2017; Zhenmin and Espinosa 2019).

17.1.2 Integrating Climate Change and Sustainable Development in International Policymaking Processes

Among the reasons for the growing realization of these interdependencies are milestones in international climate and sustainable development processes. As outlined in Chapter 14, the year 2015 was a turning point due to two agreements: 1) the Paris Agreement; and 2) the 2030 Agenda on Sustainable Development and its seventeen Sustainable Development Goals (SDGs) (Farzaneh et al. 2021).

Following a long history of references to sustainable development in the UNFCCC and related agreements, the Paris Agreement helped to strengthen the links between climate and sustainable development by emphasizing that sustainability is related to its objectives (Sindico 2016; UNFCCC 2016). One of the ways that it helped tighten this link is by institutionalizing bottom-up pledges and the review architecture. Toward this end, the Paris Agreement instituted nationally determined contributions (NDCs) as vehicles through which countries make pledges and demonstrate their commitment to climate action. Although there was no clear guidance on what should be included in the NDCs, some of the requirements were elaborated in the Paris Rule Book (see above, Chapter 14). Some of the submitted NDCs included only mitigation efforts, but others set out mitigation and adaptation goals aligning NDC commitments to national planning processes, while yet others mentioned links with the SDGs.

Another way that the Paris Agreement and the NDCs could strengthen their links to sustainable development is to update country-specific climate pledges. Countries are free to choose their targets and the means and instruments with which to implement them. A core feature of the NDCs was that countries submit NDCs every five years, giving them an opportunity to assess themselves relative to other countries, raise their ambitions and learn from their peers. Moreover, it was emphasized that countries should not "backslide" in subsequent NDCs, thus ensuring that countries should always be forward-looking in respect of increasing their ambitions to deliver the Paris Goals. Höhne et al. (2017) found that, in developing countries especially, the NDC preparation process has improved national climate policy-making.

Despite some favourable reviews, several assessments of specific countries' NDCs (Andries et al. 2017; Rogelj et al. 2016; Vandyck et al. 2016) have assessed that those submitted for 2020-2030 are insufficient for delivering on the Paris goals. Updated and/or new NDCs were therefore submitted by end of 2020. However, an assessment of those NDCs revealed that the level of ambition was significantly lower than the goals of the Paris Agreement (UNFCCO 2020; see also this Chapter). One of the urgent calls in Paris was to assess the impacts and efforts that need to be undertaken to keep global warming well below 2°C in relation to pre-industrial levels and evaluate related global greenhouse-gas emission pathways (UNFCCC 2015). Although the initial NDCs fell short of these goals, the idea was that NDCs would be living documents that could ratchet up climate action and ambition.

Countries have also started to take actions on the SDGs themselves (Antwi-Agyei et al. 2018a; UNDESA 2016, 2017, 2018). The SDGs were perceived as a novel approach to development and as establishing a universal agenda for the transformation of development patterns and socioeconomic systems. At their core, the SDGs hold that building an integrated framework for action necessitates addressing the economic, social and environmental dimensions of sustainable development in an integrated manner (Biermann et al. 2017; Kanie and Biermann 2017). The SDGs take multiple elements of development into account in aiming to offer coherent, well-integrated, overarching approaches to a range of sustainability challenges, including climate change.

One way a link is made between climate and the SDGs is through Voluntary National Reviews (VNRs). Paralleling the bottom-up orientation of the Paris Agreement and the NDCs, every year approximately forty countries voluntarily share their VNRs with the international community at the High-Level Political Forum (HLPF). Even more flexible than the NDCs, the VNRs can include content such as a summary of key policies and measures that are intended to achieve the SDGs, a list of the means of implementation that support the SDGs, and related challenges and needs. The VNRs also often cover SDG 13 (on climate change) as well as many other issues connected with climate change. Even with these links, implementation of the SDGs should be mentioned as part of national development processes reflecting different countries' different priorities, visions and plans (Hanson and Puplampu 2018; Marcotullio et al. 2018; OECD 2016; Puplampu et al. 2017; Srikanth 2018).

Yet another way that the 2030 Agenda for Sustainable Development underlines the importance of capturing synergies is its calls for policy coherence (goals 17 and 14). Policy coherence and integration between sectors are two of the most critical factors in breaking down the silo mode of working of different sectors. Working across climate and other sustainability agendas is essential to coherence.

A final way that the sustainability and climate agendas have been linked is through vertical integration. Following a similar trend that appeared with Agenda 21, for which many cities adopted local plans, a growing number of cities have introduced Voluntary Local Reviews. The VLRs resemble the VNRs, but place the emphasis on local actions and needs regarding the SDGs (and some links to climate change) (Ortíz-Moya et al. 2021). The 2019 SDG Report shows that 150 countries have developed national urban plans, almost half of them also being in the implementation phase (United Nations General Assembly 2019).

17.1.3 Integrating Climate Change and Sustainable Development in Other Policymaking Processes

Other non-UN-led initiatives involving international organizations or clusters of countries have also helped to raise the issue of sustainable development as a framework for mitigation. The OECD, for instance, assesses different types of investments and economic activities with reference to their significance for environmental sustainability (OECD 2020), while G20 countries have drawn up action agendas with sustainable development at the (UToronto 2016). Meanwhile, the Petersberg Climate Dialogue, a political movement convened by major country-group representatives launched in 2010 by the German government, has also called for sustainability to be an intrinsic part of the transition (UNFCCO 2020; BMU 2018).

Due in part to the shifting orientation of these international processes, there is growing evidence of action on climate change and sustainable development at other levels of decision-making. National policies often aim to implement climate change policies in the context of sustainable development (Chimhowu et al. 2019; Chirambo 2018; ECLAC 2017; Fuseini and Kemp 2015; Galli et al. 2018; Haywood et al. 2019; Ministry of Environment of Jordan 2016; McKenzie and Abdulkadri 2018; UNDESA 2016, 2017, 2018; UN Women 2017). Some countries are adjusting their existing policies to build on themes familiar to sustainable development (Lucas et al. 2016), including renewable energy and energy efficiency (Fastenrath and Braun 2018; Kousksou et al. 2015), urban planning (Gorissen et al. 2018; Loorbach et al. 2016; Mendizabal et al. 2018), health systems (Pencheon 2018; Roschnik et al. 2017) and agricultural systems (Lipper and Zilberman 2018; Shaw and Roberts 2017). Cross-cutting and integrated approaches, such as the circular economy, have also been gaining traction in some European countries (EESC 2015) and G20 countries (Noura et al. 2020). Many of these efforts have also extended up to the regional and down to the local level (Gorissen et al. 2018; Hess 2014; Shaw and Roberts 2017).

There has also been a shift to actors outside government aligning climate with sustainable development. An assessment by Hoyer (2020) found that collective action against climate change by businesses, governments and civil society, reinforced through partnerships and coalitions across departments, industries and supply chains, can deliver significant development impacts. In order for this diverse collection of stakeholders to take action, a fundamental paradigm shift is needed from a linear model of knowledge-generation to an interdisciplinary model that co-produces knowledge (Liu et al. 2019). In fact, some have argued that accelerating just transitions for purposes of sustainable development requires the involvement of several actors, institutions and disciplines (Delina and Sovacool 2018). Not only do these roles need to be discussed more thoroughly (Kern and Rogge 2016; den Elzen et al. 2019), but it is also important to survey different views on transitions and transformations. A variety of theories that are useful for explaining the causes and constraints regarding transitions are examined in Section 17.2.

17.2 Accelerating Transitions in the Context of Sustainable Development: Definitions and Theories

This section focuses on how different theoretical frameworks can help us understand and explain what is meant by accelerating transitions in the context of sustainable development. As suggested in sect. 17.1, the reference to "*in the context of sustainable development*" suggests that sustainable transitions require more than speed, also necessitating removing the underlying drivers of vulnerability and high emissions (quality and depth of transitions) while also aligning the interests of different individuals, communities, sectors, stakeholders and cultures (scale and breadth of transitions).

The outcome of sustainable transitions is a sustainable *transformation*. While transitions involve *processes that shift development pathways and reorient energy, transport, urban and other subsystems* (Loorbach et al. 2017; Chapter 16)*,* transformation is the resulting *fundamental reorganization of large-scale socioeconomic systems* (Hölscher et al. 2018). Such a fundamental reorganization often requires dynamic multi-stage transition processes that change everything from public policies and prevailing technologies to individual lifestyles, and social norms to governance arrangements and institutions of political economy. This set of factors can lock in development pathways and prevent transitions from gathering the momentum needed for transformations. Chapter 16 (above) provides an overview of the multistage transition dynamics involved in moving from experimentation to commercialization to integration to stabilization. That overview describes how transitions can break through lock-ins and result in a transformation.

While there may be a relatively consistent set of transition dynamics for all countries, pathways are likely to vary across and even within countries. This variation is due to different development levels, starting points, capacities, agencies, geographies, power dynamics, political economies, ecosystems and other contextual factors. Given the diversity of contributing factors, a sustainable transition is likely to be a complex and multi-faceted process which cannot be reduced to a single dimension (Köhler et al. 2019). Even with this multi-dimensionality, transition processes are likely to gain speed and become more sustainable as decision-makers adopt targeted policies and other interventions. Many disciplines have reflected on the roles of and relative influence on the policies and interventions that can drive transitions. The following discussion describes this diversity of views with a survey of how prominent lines of economic, psychological, institutional and systems thinking explain transitions. Though these disciplines differ greatly, they often stress that leveraging synergies and managing trade-offs between climate change and sustainable development can help advance a transition.

17.2.1 Economics

This section concentrates on economic explanations for transitions. At the core of many of these explanations is the assumption that economic development can deliver multiple economic, social and environmental benefits. Many modern economic systems may nonetheless struggle to deliver these benefits due to major disruptions and shocks such as climate change (Heal 2020). One way to limit disruptions to free markets are targeted interventions in free markets such as taxes or regulation. These targeted interventions motivate firms and other entities to internalize GHGs and other pollutants, potentially paving the way for a sustainable transition (Arrow et al. 2004; Chichilnisky and Heal 1998).

A related line of thought common to economic explanations involves the principles of "weak sustainability". These principles suggest that the substitution of exhaustible resources is, to some extent, feasible (Arrow et al. 2004). One way to capitalize on this substitution is to target investments at technological change, green growth, and research and development. Targeted investments in the form of subsidies can encourage the substitution of exhaustible by non-exhaustible resources. To illustrate with a concrete example, investments in renewable energy can not only mitigate climate change but also offset the use of exhaustible fossil fuels and boost energy security (Heal 2020). It is nonetheless important to note that the principles of "weak sustainability" contrasts with "strong sustainability" or "integrated sustainability" principles. These stronger principles suggest that constraints on resources restrict such substitutions (Rockström et al. 2009). These constraints merit attention because some scarce non-substitutable forms of natural capital can be exhausted (Bateman and Mace 2020). There is hence a need to capitalize on possible synergies such as those with other development priorities and trade-offs, for example, the exhaustion of non-substitutable resources. Capturing these synergies and managing these trade-offs is consistent with sustainable development, a state where the needs of the present generation do not compromise the ability of future generations to meet their own needs (Bruntland, WCED 1987).

As suggested above, aligning climate investments with other sustainable development objectives is critical to a transition. In order to support better investments in sustainable development, financing schemes, including environmental, social and governance (ESG) disclosure schemes and the Task Force on Climate-Related Financial Disclosures (TCFD), can play important roles (Executive Summary in Chapter 15). After COVID-19, economic recovery packages have increased government-led investments (Section 1.3.3 in Chapter 1), which could potentially be aligned with sustainable development. Technological change and innovation are considered key drivers of economic growth and of many aspects of social progress (Section 16.1 in Chapter 16), but if technological innovation policies are coordinated with the shift to sustainable development pathways, then the economic benefits of technological change could come at the cost of increasing climate risks (Chapter 16, Gossart 2015) Chapter 16, 16:1; Alarcón and Vos 2015). The environmental impacts of social and economic activities, including emissions of GHGs, are greatly influenced by the rate and direction of technological changes. Innovation and technological transformations present trade-offs that create externalities and rebound effects. This suggests that a sustainable future for people and nature requires rapid, radical and transformative societal change by integrating the technical, governance, financial and societal aspects (Chapter 16, 16.1; Pörtner et al. 2021).

One area that is pertinent to transitions and has received considerable attention in economic modelling involving climate change is innovation. In particular, some studies have shown how low-cost innovations and improvements in end-use technologies have significant potential for emissions reductions as well as sustainable development (Wilson et al. 2019). Currently information technologies are improving rapidly, and IoT, AI and Big Data can all contribute to other development needs. This is often the case in end-use sectors, as the benefits accrue directly to the individuals who use the new innovations. The achievement and widespread deployment of fully autonomous cars, for example, will bring about broader car- and ride-sharing with negative or low additional costs compared to more conventional approaches to car ownership, with their typically very low load factors. (Grubler et al. 2018) estimate that the low energy demand (LED) scenario which assumes information technology innovations and induced social changes, including a sharing economy, have considerable potential for harmonizing the multiple achievements of SDGs with low marginal abatement costs compared with other scenarios (IPCC 2018).

It is nonetheless important to highlight a caveat to the above logic on innovation. Whether a technological innovation is wholly sustainable or not becomes less clear when considering its effects on the wider economy. To illustrate, some models predict that CO_2 marginal abatement costs in the power sector will be 240 and 565 USD/tCO_2 for the 2 degree and below 2 degree goals respectively (IEA 2017).

In theory, if marginal abatement costs meet marginal climate damage, mitigation measures are economically optimal in the long run. Yet marginal damage from climate change is notoriously uncertain, and economic theories do not always reflect climate-related damage. On the other hand, marginal abatement mitigation costs impose additional costs in the short term. These added costs can cause productivity in capital to decline through increases in the prices of energy and products in which the energies are embodied. These increased costs can restrict the ability to invest in and achieve the sustainable development priorities. However, precisely the opposite can occur when innovation reduces additional costs or achieves negative costs. If technological innovation leads to the accumulation of capital and productivity increases due to the substitution of energy, material and labour, these are likely to deliver sustainable development and climate mitigation benefits.

17.2.2 Institutions, Governance, and Political Economy

This subsection focuses on institutions, governance and the political economy. Institutional and governance arrangements can influence which actors possess authority, as well as how motivated they are to cooperate in transition processes that are directed at finding solutions to climate change and other sustainability challenges. Often cooperation is enabled when policy frameworks or institutions align climate change with the political and economic interests of national governments, cities or businesses, and when institutional and governance arguments that support that alignment expand the scale of the transitions. However, there may also be political and economic interests and structures that can lock in unsustainable development patterns, frustrate this alignment and slow down transitions (Haas 2021; Mattioli et al. 2020; Newell and Mulvaney 2013; Power 2016).

An extensive literature has examined how the international climate agreements and architecture influence collaboration across countries regarding climate and sustainable development to support a transition (Bradley 2005). For example, international institutions offer opportunities for governments and other actors to share new perspectives on integrated solutions (Cole 2015). For some observers, however, decades of difficulties in crafting a comprehensive climate-change agreement and the resulting fragmented climate-policy landscape have been inimical to the collaboration needed for a transition (Chapter 1 and 13; Nasiritousi and Bäckstrand 2019; van Asselt 2014). Yet others see the potential for more incremental cooperation across countries, even without a single, integrated forms of climate governance (Keohane and Victor 2016).

A related argument suggests that fragmentation at the global level provides opportunities for cooperation at the national level (Kanie and Biermann 2017). For example, in contrast to the relatively top-down Kyoto Protocol, the bottom-up pledge and review architecture of the Paris Agreement has prompted national governments to integrate climate change with other sustainable development priorities (Nachmany and Setzer 2018; Townshend et al. 2013). Concrete examples included incorporating the SDGs into the NDCs as an international response to climate change (The Energy and Resources Institute 2017) or bringing climate into sustainable development strategies and so-called voluntary national reviews (VNRs) as part of the SDG and 2030 Agenda process (Elder and King 2018; Elder and Bartalini 2019).

Another branch of institutional research is concerned with the interactions between multiple levels of governance. In this multi-level governance perspective, cities and other subnational governments often lead transitions by devising innovative solutions to challenged to climate and local energy, transport, the environment, resilience and other forms of sustainability (Bellinson and Chu 2019; Doll and Puppim De Oliveira 2017; Geels 2011; Koehn 2008; Rabe 2007; van der Heijden et al. 2019). A complementary perspective suggests that national governments can help scale up transitions by allocating resources and can provide the technical support that can spread innovative solutions (Bowman et al. 2017; Corfee-Morlot et al. 2009; Gordon 2015). Such support has become increasingly important during the pandemic, as national government transfer funds for investments in climate-friendly infrastructure, transport systems and energy systems. This line of thinking is supported by calls to strengthen vertical and horizontal integration within and across government agencies and stakeholders in ways that can enhance policy coherence (Amanuma et al. 2018; OECD 2018, 2019). The incoherence or misalignment between national and local fiscal institutions and policies can restrict the ability of local governments to secure resources for climate-friendly investments. Such investments are particularly likely to flow, as more local governments have adopted net zero targets, climate emergency declarations and action plans that can stimulate innovations (Davidson et al. 2020). Others have seen greater potential for collaboration and innovation, with more multi-centred or polycentric forms of governance that lead to the formulation and dissemination of transformative solutions to climate and other environmental challenges (Ostrom 2008). Though much of the above governance research has focused on western countries, there are some applications in other regions and countries such as China (Gu et al. 2020).

Yet another set of channels facilitating integration between climate and other concerns are networks of like-minded actors working across administrative borders and physical boundaries. For instance, city networks such as the Global Covenant of Mayors for Climate and Energy (Covenant of Mayors 2019), the World Mayors Council on Climate Change (ICLEI 2019; C40 Cities 2019) and UN- UNDRR (2019) have agreed to share decision-making tools and good practices, and to sponsor ambition-raising campaigns that help align climate and sustainable development concerns within and across cities (Betsill and Bulkeley 2006) (see Chapter 8 and Section 17.3.3.5). This can be particularly important for less capable "following" and "laggard" cities needing greater financing and other forms of support to move a transition forward (Fuhr et al. 2018).

Furthermore, sub-national governments may often work together with civil-society groups to create new networked forms of governance (Biermann et al. 2012). Other forms of multi-stakeholder partnerships focusing on issues with strong climate synergies, such as forms of air pollution known as short-lived climate pollutants (Climate and Clean Air Coalition (CCAC)) or transport (Sustainable Low Carbon Transport Partnership (SLoCaT)), take their cue from global scientific communities or civic-minded advocacy groups that transmit knowledge across boundaries (Keck and Sikkink 1999). There is also scope for suggesting that the international climate regime serves a Global Framework for Climate Action (GFCA) in helping orchestrate the multilateral climate regime and non-state and subnational initiatives (Chan and Pauw 2014), though questions remain about its actual impacts on mitigation (Michaelowa and Michaelowa 2017).

Policymaking institutions and networks are themselves policies. A significant literature has looked at integrated policy frameworks and efforts across sectors, including climate adaptation and mitigation, as drivers of transitions (Landauer et al. 2015; Favretto et al. 2018; Obersteiner et al. 2016; Steen and Weaver 2017; Thornton and Comberti 2017). Policy coherence between climate and other development objectives is often considered essential to sustainable development (Sovacool 2018). A similar discussion about synergies and conflicts has been raised on the relationship between resilience and sustainability (Marchese et al. 2018). To help achieve coherence, there have been some efforts to develop suitable tools and decision-making frameworks (Scobie 2016).

A related line of reasoning has suggested that sustainable development often requires not one but a mix of policy instruments to bring about the multiple policy effects needed for social and technological change (Edmondson et al. 2019; Rogge and Johnstone 2017). Following these calls, some governments have aimed to address climate change and sustainability jointly with coherent and integrated approaches to achieving these agendas (Chimhowu et al. 2019), although for some countries (SIDS) this has proven more challenging (Scobie 2016).

Though the above work tends to downplay politics and business, others suggest that political economy should feature prominently in transitions. Some branches of political-economy research underline how resource-intensive and fossil-fuel industries leverage their resources and positions to undermine transitions (Chapter 1; Geels 2014; Jones, C.A. and Levy 2009; Moe 2014; Newell and Paterson 2010; Zhao et al. 2013). These vested interests can lock in status quo policies in countries where political systems offer interest groups more opportunities to veto or overturn climate- or eco-friendly proposals (Madden 2014). Companies with a strong interest in earning profits and building competitiveness from conventional fossil fuel-based energy systems have particularly strong incentives to capture politicians and agencies (Meckling and Nahm 2018). Such strategies can be particularly powerful when combined with concerns over job losses and dislocation, preventing transitions from gaining traction (Haas 2021; Mattioli et al. 2020; Newell and Mulvaney 2013; Power 2016).

This suggests that politics can be an impediment to change: other studies argue instead that politics can be harnessed to drive transitions forward. For example, some observers contend that building coalitions around green industrial policies and sequencing reforms to reward industries in such coalitions can align otherwise divergent interests and inject momentum into transitions (Meckling et al. 2015). Others see the effects of political economy varying over time depending upon external market conditions. To illustrate, renewable feed-in tariffs in Europe persisted for over two decades and were crucial in wind and solar power technologies making the breakthrough. But once competition from China led to the demise of European technology providers, and once European populations started to oppose surcharges on their electricity bills, feed-in tariffs were abolished by politicians in the purely national interest (Michaelowa and Michaelowa 2017).

17.2.3 Psychology, Individual Beliefs and Social Change

This subsection draws on value- and action-oriented research that employs inter- or transdisciplinary methods such as transactional psychology, transformative science and similarly focused disciplines (Wamsler et al. 2021). These approaches frequently encourage researchers to participate in transitions that induce changes in the researcher's own beliefs while triggering wider shifts in social norms (including human stewardship for the natural environment) (Adger et al. 2013; Hulme 2009; Ives et al. 2019; O'Brien 2018). This research also emphasizes how changes in individual beliefs could lead to climate actions that contribute to more sustainable, equitable and just societies (see e.g. "the mind- & paradigm shifts" (Göpel et al. 2016; Meadows 2008). They further suggest the potential for virtuous cycles of individual-level and wider social changes that ultimately benefit the climate (Banks 2007; Day et al. 2014; Lockhart 2011; Montuori and Donnelly 2018; Power 2016).

The starting point for this virtuous circle are inner transitions. Inner transitions occur within individuals, organizations and even larger jurisdictions that alter beliefs and actions involving climate change (Woiwode et al. 2021). An inner transition within an individual (see e.g., Parodi and Tamm 2018) typically involves a person gaining a deepening sense of peace and a willingness to help others, as well as protecting the climate and the planet (see e.g., Banks 2007; Power 2016). Inner transition can imply that individuals become sympathetic to concerns that include climate issues and values connected to nature. For instance, they may include a desire to become a steward of nature (Buijs et al. 2018), "live according to the principles of integrated sustainability" (Schweizer-Ries 2018), "achieve the good life" (see Section 1.6.2 in Chapter 1; Asara et al. 2015; Escobar 2015; Kallis 2017; Latouche 2018; Chapter 5) or protect the well-being of other living creatures (Section 1.6.3.1 in Chapter 1 and Chapter 5).

Examples have also been seen in relation to a similar set of inner transitions to individuals, organizations and societies, which involves embracing post-development, de-growth, or non-material values that challenge carbon-intensive lifestyles and development models (Kothari 2019; Neuteleers and Engelen 2015; Paech 2017; Sklair 2016). These shifts in values can occur when humans reconnect with nature, deepen their consciousness and take responsibility for protecting the planet and its climate (Cross et al. 2019; Martinez-Juarez et al. 2015; Speldewinde et al. 2015). Changes in both values and beliefs may also emerge through consciousness-raising processes where people cooperate in ways that would protect the climate (see Section 1.6.4 in Chapter 1; Banks 2007; Hedlund-de Witt et al. 2014; Woiwode and Woiwode 2019).

Many of the above-mentioned beliefs and values that support climate actions have spread through expanding interests in conservationist world views, indigenous cultures (see e.g., Lockhart 2011) and branches of neuroscience and psychology that suggest different notions of the self (Hüther 2018; Lewis 2016; Seligman and Csikszentmihalyi 2014). These beliefs and values can also be spread through meditation, yoga or other social practices that encourage lower carbon lifestyles (Woiwode and Woiwode 2019). Another channel for spreading climate concerns is sustainability culture, which is premised on connecting people and communities, and has also benefited from the internet and digital technologies that support these connections (see e.g., Bradbury 2015; Scharmer 2018). The spread of this culture, in turn, has led to the creation of social fields that allow changes to happen ((see e.g., Gillard et al. 2016) or has promoted low-carbon thinking and related behavioural changes (O'Brien 2018; Veciana and Ottmar 2018). Studies of social contagions may also offer insights into the mechanisms that lead to the adoption of new values and related climate actions (see e.g., Iacopini et al. 2019). It is nonetheless worth highlighting that communication networks and other mechanisms promoting the spread of interpersonal communication that can spread pro-climate views may also lead to the proliferation of climate scepticism and denial (Leombruni 2015). At the same time, some studies suggest that such scepticism can be countered by the generation of more credible information on climate change (Samantray and Pin 2019).

One of the more direct channels through which transitions spread are climate change education and action-oriented research (Fazey et al. 2018; Ives et al. 2019; Scharmer 2018; Schäpke et al. 2018; Schneidewind et al. 2016). For instance, research using "social experiments" or "real world labs" has helped give rise to shifts in mindsets on energy, food, transport and other systems that can benefit the climate (Bernstein and Hoffmann 2018; Berkhout et al. 2010; Bulkeley et al. 2015; Hoffmann 2010). In much the same way, the acquisition of transformational knowledge and transformative learning (Lange 2018; O'Neil and Boyce 2018; Pomeroy and Oliver 2018; Walsh et al. 2020; Williams 2013) contributes to thinking and acting that open climate-friendly development pathways (Berkhout et al. 2010; Lo and Castán Broto 2019; Roberts et al. 2018; Turnheim and Nykvist 2019; Section 1.7.2 in Chapter 1). First-person and action research can also facilitate similar changes that bring about climate actions (see e.g. Bradbury et al. 2019; Dick 2007; Hutchison and Walton 2015; Streck 2007).

17.2.4 System Level Explanations

Systems explanations help explain the dynamics of transitions toward sustainable development while explicitly uncovering links between the human and natural worlds, the socio-cultural embeddedness of technology, and the inertia behind high-carbon development pathways. This line of thinking often envisages transitions emerging from complex systems in which many different elements interact at small scales and spontaneously self-organize to produce behaviour that is unexpected, unmanaged and fundamentally different from the sum of the system's constituent parts.

Social-ecological systems theory describes the processes of exchange and interaction between human and ecological systems, investigating in particular non-linear feedback occurring across different scales (Folke 2006; Holling 2001). This approach has informed subsequent theoretical and empirical developments, including the 'planetary boundaries' approach (Rockström et al. 2009), conceptualizations of vulnerability and adaptive capacity (Hinkel 2011; Pelling 2010) and more recent explorations of urban resilience (Romero-Lankao et al. 2016) and regenerative sustainability (Clayton and Radcliffe 2018; Robinson and Cole 2015). Employing a systems lens to address the 'root causes' of unsustainable development pathways (such as dysfunctional social or economic arrangements) rather than the 'symptoms' (dwelling quality, vehicle efficiency, etc.) can trigger the non-linear change needed for a transformation to take place (Pelling et al. 2015). Exploring synergies between climate-change adaptation, mitigation and other sustainability priorities (such as biodiversity and social equity, for instance) (Beg 2002; Burch et al. 2014; Shaw et al. 2014) may help to yield these transformative outcomes, though data regarding the specific nature of these synergies is still emerging.

Socio-technical transition theory, on the other hand, explores the ways in which technologies such as low-carbon vehicles or regenerative buildings are bound up in a web of social practices, physical infrastructure, market rules, regulations, norms and habits (see, for example, Loorbach et al. 2017). Radical social and technical innovations can emerge that ultimately challenge destabilized or increasingly ineffective and undesirable incumbents, but path dependencies often stymie these transition processes, suggesting an important role for governance actors (Burch 2017; Frantzeskaki et al. 2012; Holscher et al. 2019).

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This also reveals the large-scale macro-economic, political and cultural trends (or contexts) that may reinforce or call into question the usefulness of current systems of production and consumption. One branch of this theory, transition management (Kern and Smith 2008; Loorbach 2010), explores ways of guiding a socio-technical system from one path to another. In particular, it highlights interactions between actors, technologies and institutions, and the complex governance mechanisms that facilitate them (Smith et al. 2005). The challenge, in part, becomes linking radical short-term innovations with longer-term visions of sustainability (Loorbach and Rotmans 2010) and creating opportunities for collaborative course-correction in light of new information or unexpected outcomes (Burch 2017).

17.2.5 Conclusions

This section has surveyed several explanations for interventions that can give rise to transitions. The review suggests that there are several differences between these various perspectives. Whether individuals, organisations, markets or sociotechnical systems drive or undermine transitions is a key distinction. These differences have implications for the evidence these claims draw on in support of their arguments. For instance, some of the explanations tend to employ qualitative evidence to explain changes in attitudes at the individual or community levels as paving the way for broader changes to cultures and belief systems. Others assess how institutional arrangements can be reformed in order to align climate with the sustainable development agenda to enable a transition.

While there are indeed significant differences between explanations, there are also important parallels. Such parallels begin with a shared emphasis on synergies and trade-offs between climate and sustainable development. Most explanations tend to underline the importance of synergies in aligning the climate with broader sustainability agendas. Most importantly, many of the explanations are complementary with the systems-level discussion in that they offer a broad framework, while economic, psychological and governance theories offer more specific insights. Moving a transition forward will often require drawing upon insights from multiple schools of thought. Though is unlikely that a one-size-fits-all set of factors will drive a transition, there is a growing body of empirical evidence shedding light on the factors that can strengthen synergies between climate and the broader sustainable development agenda.

17.3. Assessment of the results of studies where decarbonisation transitions are framed within the context of sustainable development

17.3.1 Introduction

This section assesses studies based on the links between sustainable development and climate change mitigation in order to facilitate robust conclusions on synergies and trade-offs between different policy objectives across methodologies, scenarios and sectors. Conclusions are drawn based on national and sub-national, sectoral and cross-sectoral, short- and long-term transition studies presented in this and other sections of the report as a basis for establishing an overall picture of how sustainable development and climate change policies can be linked as a basis for accelerated transitions

This section focuses initially on issues related to short- and long-term transitions to meet climate change and sustainable development goals in the context of the UNFCCC and the UN 2030 Agenda for Sustainable Development. Global-modelling results and economy-wide studies are then assessed, followed by a discussion of specific challenges in relation to renewable energy penetration and phasing out fossil fuels, stranded assets and just transitions. Key synergies and trade-offs between meeting the UN 2030 sustainable development goals (SDGs) and mitigation are then illustrated by means of cross-sectoral examples. Finally, an overview of the assessment of SDG synergies and trade-offs based on all sectoral chapters in this report for a range of key mitigation options is then presented.

17.3.2 Short-term and long-term transitions

It is increasingly being recognised that sustainable-development policy goals and meeting short- and long-terms climate policy goals are closely linked (IPCC 2018). It is also being realised that, under the Paris Agreement, climate change policies should be integrated into sustainable development agendas, while the UN 2030 Agenda as well includes SDG 13 on climate actions. In this way, both UN agreements provide joint opportunities for systematic transitions in support of both climate change and sustainable development. Achievement of the Paris Agreement's goals will require a rapid and deep worldwide transition in all GHG emissions sectors, including land-use, energy, industry, buildings, transport and cities, as well as in consumption and behaviour (United Nations Environment Programme 2019). Meeting the goals of such a transformation requires that the long-term targets and pathways to fulfil the stabilization scenarios play an important role in guiding the direction and pathways of short-term transitions. There is therefore a need for long- and short-term policies and investment decisions to be closely coordinated.

In the context of the Paris Agreement, countries have submitted their initial plans for the decarbonization of their economies to the UNFCCC in the form of their so-called national determined contributions (NDCs). The ambitions of the NDCs are closely related to the ongoing UNFCCC negotiations over the financial measures and forms of compensation. Although the Paris Agreement emphasizes the links between climate policies and sustainable development, the UN's 2030 Agenda and the SDGs are not very well represented at present in the NDCs, according to Fuso Nerini et al. (2019). Very few of the NDCs include any reference to the SDGs, which Fuso Nerini et al. (2019) highlight as a barrier to the successful implementation of the Paris Agreement, which induces them to call for a more holistic policy approach. Campagnolo and Davide (2019) have assessed the impacts of the submitted NDCs on poverty eradication and inequalities of income based on empirical research and a global CGE model. One conclusion is that the NDCs of less developed countries would tend to reduce poverty alleviation, but this can be offset if international financial support is provided for the mitigation actions.

The alignment of climate-policy targets in the NDCs with sustainable development has been assessed by means of integrated assessment models (IAMs), macroeconomic and sectoral modelling. Iyer et al. (2018) based on IAM-based studies, the implications of framing NDCs being placed more narrowly on mitigation targets rather than on a framing in which the impacts on sustainable development were explicitly taken into consideration. It was thus concluded that some SDGs would be directly supported as a side benefit of the climate policy targets included in the NDCs, while other SDGs needed a special policy design going beyond narrow climate policy objectives. Iyer et al. (2018) also assessed the regional distribution of efforts in terms of domestic mitigation costs and SDG impacts and concluded that the geographical distribution of mitigation costs and SDG benefits were not similar, so a special effort would be needed to match climate policies and policies to meet the SDGs. Accordingly, a national decision-making perspective suggests that SDGs should be integrated into national climate policies.

The NDCs submitted to the Paris Agreement have demonstrated a lack of progress in meeting the long-term temperature goals. In the context of the UN's 2030 Agenda, the UN Sustainable Development Report 2019 (Sachs et al. 2019) also concluded that there is a particular lack of progress in achieving SDG 13 (Climate action), SDG 14 (Life below water) and SDG 15 (Life on land). Given the close link between the SDGs and climate-change policies, the current obstacles in meeting the former could also be a barrier to realizing transitions to low-carbon societies. Conversely, opportunities to leverage the SDGs could in many cases involve climate actions, since policies enabling climate adaptation and mitigation could also support food and energy security and water conservation if they were well designed (see the detailed discussion in the section on synergies and trade-offs between climate policies and meeting the SDGs in section 17.3.3.7, Chapter 3 and IPCC 2018).These findings point to a specific need to align economic and social development perspectives, climate change and natural systems. While all countries share the totality of the SDGs, development priorities differ across countries and over time. These priorities are strongly linked to local contexts and depend on which dimension of the improvement in the well-being of people is considered to be the most urgent. Eradicating poverty and reducing inequality are key development priorities for many low- and middle-income countries. (Section 4.3.2.1 in Chapter 4).

A key barrier to the development of national plans and policies to meet the UN 2030 SDG goals is the lack of finance. Sachs et al. (2019) conclude that meeting the SDGs to achieve social transformations worldwide would require 2-3% of global GDP and that it would be a huge challenge to ensure that finance is targeted to the world's poorest countries and people. The UN Secretary General has called for the allocation of finance to meet the UN's 2030 Agenda with a strong emphasis on the private sector, but to date no governance frameworks or associated financial modalities have been established in the UN or the UNFCCC context for the formal alignment of sustainable development and transitions to take place in accordance with the low global temperature-stabilization targets in the Paris Agreement. Accelerating investments particularly in low-income countries will be required to meet both the Paris goals and the SDGs (Section 15.6.7 in Chapter 15). The mismatch between capital and investment needs, home bias considerations and differences in risk perceptions between rich and poor represent major challenges for private finance. Green bond markets and markets for sustainable financal products have increased significantly, and the landscape has continued to evolve since AR5 (Executive Summary in Chapter 15). Special efforts and activities are particularly required for raising finance in developing countries.

Based on the Paris Agreement, the UNFCCC has invited countries to communicate their mid-century and long-term low greenhouse-gas emission-development strategies by 2020 (UNFCCC 2019). National long-term low-emission development strategies and their global stocktake in the UNFCCC context provide a platform for informing the long-term strategic thinking on transitions towards low-carbon societies. One specific value of these plans is that they reflect how specific transition pathways, policies and measures can work in different parts of the world in a very context-specific way, that is, by taking context-specific issues and stakeholder perspectives into consideration. Many nations have submitted national long-term strategies to the UNFCCC, including sustainable development perspectives (See Section 4.2.4, 'Mid-century low-emission strategies at the national level' in Chapter 4 for a review of the plans and scientific assessments).

17.3.2.1 Model assessments on the sustainable development pathways for decarbonization

This section assesses the model evaluations of the sustainable development pathways for decarbonization, including the co-benefits and trade-offs involving explorations of alternative future development pathways as a basis for clarifying societal objectives and understanding the restrictions. Shifting development pathways to increased sustainability involves a number of complex issues, which are difficult to integrate into models. For a more detailed discussion about this, see Section 4.4.1 in Chapter 4 and the Cross-Chapter Box 5 in Chapter 4.

Development pathways that focus narrowly on climate mitigation or economic growth will not lead to the SDGs and long-term climate-stabilization objectives being achieved. The best chances of doing this lie in development pathways that can maximize the synergies between climate mitigation and sustainable development more broadly (Section 1.3.2 in Chapter 1). Areas of focal modelling include green investments, technological change, employment generation and the performance of policy instruments, such as green taxes, subsidies, emission permits, investments and finance. Short- and long-term macroeconomic models have been used to assess the impacts of such policy instruments. Jaumotte et al. (2021) analyse the economic impacts on net zero emissions by 2050 with a focus on short-term economic policies and the integration of climate policies such as CO_2 taxes with green reform policies. This may imply the co-creation of benefits between climate policy objectives, and macroeconomic policy goals such as employment creation.

There is an emerging modelling literature focusing on the synergies and trade-offs between low-carbon development pathways and various aspects of sustainable development. The early literature, including that on IAMs, and macroeconomic and sectoral models mainly focused on the co-benefits of mitigation policies in terms of reduced air pollution, energy security and to some extent employment generation security (IPCC 2014, 2018c; WGIII AR6 Chapter 6). Some models have been developed further with assessments of a broader range of the joint benefits of mitigation, health, water, land-use and food security (Clarke et al. 2014; IPCC 2014, 2018; Kolstad et al. 2014). According to WGIII AR6 Chapter 1, there is a need to incorporate issues and enablers further, including a wide range of non-climate risks, varying forms of innovation, possibilities for behavioural and social change, feasible policies and equity issues (Executive Summary in Chapter 1).

IAMs and macroeconomic models typically calculate mitigation costs based on the assumption that markets internalise externalities like GHG emissions through carbon prices (Barker et al. 2016; IEA 2017, 2019). Yet, there are legitimate questions to be asked about whether carbon-pricing will be efficient if markets are inefficient (World Bank 2019). However, market inefficiencies are difficult to integrate into the models. How GHG emissions taxes would actually work is thus quite uncertain based on the modelling studies (Barker et al. 2016; Fontana and Sawyer 2016; Meyer et al. 2018). Despite these limitations, the use of GHG emission taxes as an effective instrument based on modelling results in practice has implications for public policies and private-sector investments.

Despite the shortcomings of conventional economic thought and models, already pointed out, improved models have demonstrated new perspectives on how mitigation costs can be assessed in macroeconomic models. For instance, while a conventional perspective might suggest that climate-change mitigation costs can limit investments in sustainability because they reduce the productivity of capital by increasing energy prices and the products in which energies are embodied, another perspective is that innovation can imply increases in efficiency and that the substitution of energy, material and labour can lead to the accumulation of capital and productivity gains. This appears to occur with innovations in end-use energy applications generating emissions reductions and delivering on other sustainable development benefits (Wilson et al. 2019). Similarly, IAM models have been applied to model the potential for low energy demand scenarios associated with demand-side innovations in the service sector. Grubler et al. (2018) have developed a climate-friendly, low-energy demand (LED) scenario which assumes information technology innovations such as the internet of things (IoT) and induced social changes such as the sharing economy. Nonetheless there are still very important limits on the degree to which highly aggregated IAM models and macroeconomic models can integrate ethics, equity and several other key policy-relevant aspects of sustainable development (Easterlin et al. 2010; Koch 2020). A key limitation in this context is that, while all countries share the totality of the SDGs, development priorities differ across countries and over time. Moreover, these priorities are strongly linked to local contexts, and this can only be reflected directly in national models (Section 4.3.2 in Chapter 4).

An example of a project that assesses the economy-wide impacts of linking sustainable development with deep decarbonization is the deep decarbonization project or DDPP (Bataille et al. 2016), which is undertaking a comparative assessment of studies of sixteen countries representing more than 74% of global energy-related emissions for the pathway to two-degree stabilization scenarios. The DDDP's methodology is to combine scenario analysis in different national contexts using macroeconomic models and sectoral models and to facilitate a consistent cross-country analysis using a set of common assumptions.

The key conclusions of the DDPP team on the economy-wide impacts are that country studies like South Africa's demonstrate that it is possible to improve income distribution, alleviate poverty and reduce unemployment while simultaneously transitioning to a low-carbon economy (Altieri et al. 2016). The DDPP in Japan explores whether energy security can be enhanced through increases in renewable energy (Oshiro et al. 2016). The reduction of uncontrolled fossil-fuel emissions has significant public-health benefits according to the Chinese and Indian DDPPs, as fossil-fuel combustion is the major source of air pollution.

For example, in the Chinese DDDP, deep decarbonization scenarios have resulted in reductions of 42–79% in primary air pollutants (e.g., SO_2, NO_x, particulate matter (PM2.5), volatile organic compounds (VOCs), and NH3), thus meeting air-quality standards in major cities. The deep decarbonization scenarios include the large and fast energy-efficient improvements required to improve energy access and affordability. The DDPP studies are thus an example of an approach in which national deep-carbonization scenarios are linked to the development goals of income generation, energy access and affordability, employment, health and environmental policy.

Sustainable development scenarios have also been developed by the Low-Carbon Society's (LCS) assessments (Kainuma et al. 2012), in which multiple sustainable development and climate change mitigation goals were assessed jointly. The scenario analysis was conducted for Asian countries such as South Korea, Japan, India, China and Nepal with a soft linked IAM using economy-wide and sectoral models and linked to very active stakeholder engagement in order to reflect national policy perspectives and priorities. Some of the models are economy-wide global IAMs, while others are national partial equilibrium models.

The LCS scenarios also include a specific attempt to include ongoing dialogues with policy-makers and stakeholders in order to reflect governance and enabling factors and to enable the modelling processes to reflect political realism as far as possible. Diverse stakeholders who acted as validators of the scientific process were included, stakeholder preferences were revealed, and recipients and users of the LCS outputs were included in ongoing dialogues on outputs and in interpreting the results. The aim of the stakeholder interactions was thus to fill the gap between typical laboratory-style integrated modelling assessments and down-scaled but unaligned practical assessments performed at disaggregated geographical and sector-specific scales.

Energy scenarios for sustainable development were included in The World Energy Outlook of the IEA (IEA 2019, 2020) in terms of a Sustainable Development Scenario (SDS), which assessed not only SDG 13 (climate change) but also SDG 7 (energy access) and SDG 3.9 (air pollution). This scenario takes as its starting point the policy goal of meeting these SDGs and then assesses the costs of meeting an emissions reduction target of 70% of CO_2 from the energy system by 2030. The scenario concludes that retrofitting coal-fired power plants with pollution controls is the cheapest option for dealing with local pollution in the short term, but that this is not consistent with meeting the long-term emissions goals of the Paris Agreement. The SDS scenario combines the goal of reducing the amount of CO_2 in the energy system by 70%, with large decreases in energy-related emissions of NO_X, SO_2 and PM2.5, leading to a fall of 40–60% by 2030, and to 2.5 million fewer premature deaths from air pollution in 2030 than in the Stated Policies Scenario (STEPS), which represent a continuation of current trends in the energy system (IEA 2020).

The costs of energy-system transitions have been assessed by several energy-system studies. The economic costs of meeting the different goals depend on the stringency of the mitigation target, as well as economic (fuel prices etc.) and technological developments (technology availability, capital costs etc.). In addition, changes in infrastructure and behavioural patterns and lifestyles matter. Model-based assessments vary, depending on these assumptions and differences in modelling approaches (Krey et al. 2019; Section 6.7.7 in Chapter 6). Country characteristics determine the social, economic and technical priorities for low-emission pathways. Domestic policy circumstances impact on pathways and costs, e.g. when affordability and energy-security concerns are emphasized (Oshiro et al. 2016).

Mitigation policies can have important distributive effects between and within countries, and may affect impact on the poorest through their effects on energy and food prices (Section 3.6.4 in Chapter 3; Hasegawa et al. 2018; Fujimori et al. 2019), while higher levels of warming are projected to generate higher inequality between countries as well as within them (Chapter 16). Mitigation thus can reduce economic inequalities and poverty by avoiding such impacts (Section 3.6.4 in Chapter 3).

Improved air quality and the associated health effects are the co-benefit category dominating model-based assessments of co-benefits, but a few studies have also covered other aspects, such as the health effects of dietary change and biodiversity impacts (Section 3.6.3 in Chapter 3 and Section 17.3 of this chapter). Mitigation has implications for global economic inequalities through different channels and can compound or lessen inequalities, avoid impacts and create co-benefits that reduce inequalities (Section 3.6.4 in Chapter 3). There are, however, several challenges involved in balancing the dilemmas associated with meeting the SDGs, such as, for example, energy access, equity and sustainability. Fossil fuel-dependent developing countries cannot transit to low-carbon economics without considering the wider impacts on development by doing so (Section 3.7.3 in Chapter 3).

Climate change has negative impacts on agricultural productivity in general, including unequal geographical distribution (Chapter 3). On top of that, there is also a risk that climate-change mitigation aimed at achieving stringent climate goals could negatively affect food access and food security (Akimoto et al. 2012; Fujimori et al. 2019; Hasegawa et al. 2018). If not managed properly, the risk of hunger due to climate policies such as large-scale bioenergy production increases remarkably if the 2 °C and 1.5 °C targets are implemented (Section 3.7.1 in Chapter 3). Taking the highest median values from different IAMs for given classes of scenarios, up to 14.9 $GtCO_2$ yr^{-1} carbon dioxide removal (CDR) from BECCS is required in 2100, and 2.4 $GtCO_2$ yr^{-1} for afforestation. Across the different scenarios, median changes in global forest area throughout the 21st century reach the required 7.2 Mkm^2 increases between 2010 and 2100, and agricultural land used for second-generation bioenergy crop production may require up to 6.6 Mkm^2 in 2100, increasing the competition for land and potentially affecting sustainable development (AR6 scenarios database).

Reducing climate change can reduce the share of the global population exposed to increased stress from reductions in water resources (Arnell and Lloyd-Hughes 2014) and therefore to water scarcity as defined by a cumulative abstraction-to-demand ratio (Hanasaki et al. 2013). Byers et al. (2018), show that 8–14% of the population will be exposed to severe reductions in water supply if average temperatures increase between 1.5 and 2.0 °C (also see Section 3.7.2 in Chapter 3). Hayashi et al. (2018) assess the water availability for different emission pathways, including the 2°C and 1.5°C targets, in light of the various factors governing availability. There are very different impacts among nations. In Afghanistan, Pakistan and South Africa, water stress is estimated to increase by 2050 mainly due to increases in irrigation water associated with the rising demand for food, and climate change will already increase water stress within the next decades. Other factors, such as changes in the demand for municipal water, water for electricity generation, other industrial water and water for livestock due to climate change mitigation, are of limited importance.

Vandyck et al. (2018) estimate that the 2°C pathway would reduce air pollution and avoid 0.7–1.5 million premature deaths in 2050 compared to current levels. It is generally agreed that in both developed and developing countries there are additional benefits of climate change mitigation in terms of improved air quality (Section 3.7.4 in Chapter 3). Markandya et al. (2018) assessed the health co-benefits of air pollution reductions and the mitigation costs of the Paris Agreement using global scenarios for up to 2050. They concluded that the health co-benefits substantially outweighed the policy costs of achieving the NDC targets and either 2°C or 1.5°C stabilization. The ratio of health co-benefits to the mitigation costs ranged from 1.4 to 2.45, depending on the scenario. The extra effort of trying to pursue the 1.5°C target instead of the 2°C target would generate a substantial net benefit in some areas.

In India, the co-health benefits were valued at USD3.28–8.4 trillion and those in China at USD0.27–2.31 trillion. Gi et al. (2019) also show that developing countries such as India have a huge potential to produce co-benefits. In addition, this implies that while the cost advantages of simultaneously achieving reductions of CO_2 emissions and of PM2.5 are clear, the advantages for integrated measures could be limited, as the costs greatly depend on the CO_2 emissions reduction target.

Grubler et al. (2018) models a pathway leading to global temperature change of less than 1.5°C without CCS, taking end-use changes into account, including innovations in information technologies and changes to consumer behaviour apart from passive consumption. The pathway estimates global final-energy demand of 245 EJ/yr in 2050, which is much lower than in existing studies (also see Section 5.3.3 in Chapter 5). It also shows the possibilities of creating synergies between multiple SDGs, including hunger, health, energy access and land-use. Integrated technological and social innovations will increase the opportunity to achieve sustainable development. Millward-Hopkins et al. (2020) estimates global final energy at 149 EJ/yr in 2050 as required to provide decent material living standards, which is much lower than the 1.5 °C scenario ranges (330–480 EJ/yr in 2050) of IAMs (IPCC 2018) and the 390 EJ/yr in the IEA SDS (IEA 2019), and also lower than Grubler et al. (2018). The conclusion is that, although providing material living standards does not guarantee that every person will live a good life, there are large potentials in achieving low energy demand with sustainable development.

An overview of the co-benefits and trade-offs of several SDGs based on modelling results is provided in Figure 3.39 (Section 3.7 in Chapter 3). Selected mitigation co-benefits and trade-offs are provided in relation to meeting the 1.5 degree temperature goal based on a subset of models and scenarios, despite many IAMs so far not having comprehensive coverage of the sustainable development goals (Rao et al. 2017; van Soest et al. 2019). There are several co-benefits of mitigation policies, including increased forest cover (SDG 15) and reduced mortality from ambient PM2.5 pollution (SDG 3) compared to reference scenarios. However, mitigation policies can also cause higher food prices and thus increase the share of the global population at risk from hunger (SDG 2), while also relying on solid fuels (SDGs 7 & 3) as side effects. It is then concluded in Section 3.7 of Chapter 3, that these trade-offs can be balanced through targeted support measures and/or additional SD policies (Bertram et al. 2018; Cameron et al. 2016; Fujimori et al. 2019).

The World in 2050 Initiative (TWI) includes a comprehensive assessment of technologies, economies and societies embodied in the SDGs (IIASA 2018). The assessment addresses social dynamics, governance and sustainable development pathways within the areas of human capacity and demography, consumption and production, decarbonization and energy, food, the biosphere and water, smart cities and digitalization. The report concludes that the 17 SDGs are integrated and complementary and need to be addressed in unison. Studies using global IAMs that were presented in the GEO6 report (United Nations Environment Programme 2019, Chapter 22) concluded that transitions to low-carbon pathways will require a broad portfolio of measures, including a mixture of technological improvements, lifestyle changes and localized solutions. The many different challenges require dedicated measures to improve access to, for example, food, water and energy, while at the same time reducing the pressure on environmental resources and ecosystems. A key contribution may be a redistribution of access to resources, where both physical access and affordability play a role. The IAMs cover large countries and regions, and localized solutions are not properly addressed in the modelling results. This implies that, for example, trade-offs between energy access and affordability are not fully represented in aggregate modelling results.

There are also several country-level studies for deep emissions reductions (see Chapter 4 for an overview of the results). The studies find significant impacts of mitigation policies at the sectoral level, reflecting the fact that the sectoral scope does not allow for as much flexibility in mitigation measures the despite macroeconomic impacts being assessed to be small (Executive Summary in Chapter 4). Another key lesson is that the detailed design of mitigation policies is critical for the distributional impacts (Executive Summary in Chapter 4). The potential mitigation measures, the potential economic growth, the political priorities and so forth are different among nations, and there may be several emissions reduction transition pathways to long-term goals among nations (Figure 4.2 in Chapter 4).

17.3.2.2 Renewable energy penetration and fossil-fuel phase-out

As pointed out in Chapter 6, the achievement of long-term temperature goals in line with the Paris Agreement requires the rapid penetration of renewable energy and a timely phasing out of fossil fuels, especially coal, from the global energy system. Limiting warming to 1.5°C with no or limited overshoot means that global CO_2 emissions must reach "net zero" in 2050/2060 (IPCC 2018). Net zero emissions imply that fossil fuel use is minimised and replaced by renewables and other low-carbon primary forms of energy, or that the residual emissions from fossil fuels are offset by carbon dioxide removal. The 1.5°C scenario requires a 2-3% annual improvement rate in carbon intensities till 2050. The historical record only shows a slight improvement in the carbon intensity rate of global energy supplies, far from what is required to limit likely global warming to 2°C, or limit warming to 1.5°C with no or limited overshoot.

The role of coal in the global energy system is changing fast. Given the global temperature goals of the Paris Agreement, the global coal sector needs a transition to near zero by 2050 – earlier in some regions (Bauer et al. 2018; IEA 2017; IPCC 2018). Other global trends, including air quality, water shortages, the improved cost efficiencies of renewables, the technical availability of energy storage and the economic rebalancing of emerging countries, are also driving global coal consumption t to a plateau followed by a reverse (Sator 2018; Spencer et al. 2018). The world should be prepared for a managed transition away from coal and should identify appropriate transition options for the future of coal, which can include both the penetration of renewable energy and improvements in energy efficiency (Shah et al. 2015).

Phasing out fossil fuels from energy systems is technically possible and is estimated to be relatively low in cost (Chapter 6). The cost of low-carbon alternatives, including onshore and offshore wind, solar PV and electric vehicles, has been reduced substantially in recent years and has become competitive with fossil fuels (Shen et al. 2020). However, studies show that replacing fossil fuels with renewables can have major synergies and trade-offs with a broader agenda of sustainable development (Swain and Karimu 2020), including land use and food security (McCollum et al. 2018), decent jobs and economic growth (Swain and Karimu 2020). Clarke et al. (2014:Table 6.7) provides detailed mapping of the sectoral co-benefits and adverse side-impacts of and links to transformation pathways. In Section 17.3.3.7 in this chapter, this is supplemented with a mapping of the synergies and trade-offs between the deployment of renewable energy and the SDGs.

The general conclusion is that the potential co-benefits of renewable energy end-use measures outweigh the adverse impacts in most sectors and in relation to the SDGs, though this is not the case for the AFOLU (Agriculture, Forestry and Other Land Uses) sectors. Some locally negative economic impacts can result in increased energy costs and competition over land areas and water resources. Some sectors may also experience increasing unemployment as a consequence of the transition process. Although the deployment of renewable energy will generate a new industry and associated jobs and benefits in some areas and economies, these impacts will often not directly replace or offset activities in areas that have been heavily dependent on the fossil-fuel industry.

The transition to low emission pathways will require policy efforts that also address the emissions that are locked into existing infrastructure like power plants, factories, cargo ships and other infrastructure already in use: for example, today coal-fired power plants account for 30% of all energy-related emissions (IEA 2019). Over the past twenty years, Asia has accounted for 90% of all coal-fired capacity built worldwide, and these plants have potentially long operational lifetimes ahead of them. In developing economies in Asia, existing coal-fired plants are just twelve years old on average. There are three options for bringing down emissions from the existing stock of plants: to retrofit them with carbon capture, utilisation and storage (CCUS) or biomass co-firing equipment; to repurpose them to focus on providing system adequacy and flexibility while reducing operations; and to retire them early. In the

IEA Sustainable Development Scenario, most of the 2080 GW of existing coal-fired capacity would be affected by one of these three options.

Even though the transition away from fossil fuels is desirable and technically feasible, it is still largely constrained by existing fossil fuel-based infrastructure and stranded investments. The "committed" emissions from existing fossil-fuel infrastructure may consume all the remaining carbon budget in the 1.5°C scenario, or two thirds of the carbon budget in the 2°C scenario (Tong et al. 2019). Kefford et al. (2018) assess the early retirement of fossil-fuel power plants in the US, EU, China and India based on the IEA 2°C scenario and conclude that a massive early retirement of coal-fired power plants is needed, and that two to three standard 500 MW generators will need to come offline every week for fifteen years. This high rate is the result of a very large deployment of coal-fired power plants from 2004 to 2012. The early phasing out of this infrastructure will result in a significant share of stranded assets (Ansari and Holz 2020) with an impact on workers, local communities, companies and governments (van der Ploeg and Rezai 2020). The challenge is thus to manage a transition which delivers the rapid phasing out of existing fossil fuel-based infrastructure while also developing a new energy system based on low-carbon alternatives within a very short window of opportunity.

Chapter 6 similarly concludes that the transition towards a high penetration of renewable systems faces various challenges in the technical, environmental and socio-economic fields. The integration of renewables into the grid requires not only sufficient flexibility in power grids and intensive coordination with other sources of generation, but also a fundamental change in long-term planning and grid operation (see Chapter 6 for more details on these issues).

Examples from various countries show that, compared with top-down decision-making, bottom-up policy-making involving local stakeholders could enable regions to benefit and reduce their resistance to transitions. Kainuma et al. (2012) conclude that social dialogue is a critical condition for engaging local workers and communities in managing the transitions with the necessary support from transition assistance. They also point out that macro-level policies, training programmes, participatory processes and specific programmes to support employment creation for workers in fossil fuel-dependent industries are needed.

Examples of challenges in transitions away from using coal are given in Box 17.1.

START BOX 17.1 HERE

Box 17.1 Case study: coal transitions

The coal transition will pose challenges not only to the power sector, but even more importantly to coal-mining. A less diversified local economy, low labour mobility and heavy dependence on coal revenues will make closing down coal production particularly challenging from a political economy perspective. Policy is needed to support and invest in impacted areas to smooth the transition, absorb the impact and incentivize new opportunities. A supportive policy for the transition could include both short-term support and long-term investment. Short-term compensation could be helpful for local workers, communities, companies and governments to manage the consequences of coal closures. Earlier involvement with local stakeholders using a structured approach is crucial and will make the transition policy more targeted and better administered. The long-term policy should target support to the local economy and workers to move beyond coal, including a strategic plan to transform the impacted area, investment in local infrastructure and education, and preference policies to incentivize emerging businesses. Most importantly, ex-ante policy implementation is far better than ex-post compensation. Even without the climate imperative, historical evidence shows that coal closures can happen surprisingly fast.

Coal has hitherto been the dominant energy source in China and has accounted for more than 70% of its total energy consumption for the past twenty years, falling to 64% in 2015 (The National BIM Report 2018). In the 13th Five Year Plan (2016-2020), for the first time China included the target of a national coal consumption cap of 4.1 billion tons for 2020, as well as a goal of reducing the primary energy share of coal to 58% by 2020 from the level of 64% in 2015 (The National People's Congress of the People's Republic of China 2016). The main driving forces of the coal transition in China are increasing domestic environmental concerns and the pressure to reduce greenhouse gas emissions. Coal combustion contributes about 90% of total SO2 emissions, 70% of NOx emissions and 54% of primary PM2.5 emissions in China (Yang and Teng 2018). The early phasing out of coal also delivers a co-benefit in terms of reductions of air pollutants that are consistent with China's goal to improve air quality (Zhang et al. 2019), as well as the reduction of methane (Teng et al. 2019) and black carbon (Zhang et al. 2019). The coal transition in China will change the future value of coal-related assets, and both coal power generators in China and coal producers outside China need to identify appropriate responses to avoid and manage the potentially substantial stranding of fossil-fuel assets. A rapid transition away from coal is critical for China to reach the peak in its emissions (Cui et al. 2019). Despite the deployment of CCS and extending the use of coal, retrofitting CCS plant may be more expensive than deploying renewables (IEA 2019).

Presently, coal-fired power plants play a key role in the German energy system, providing almost 46% of the electricity consumed in Germany. These coal power plants play a crucial role in balancing fluctuations in producing electricity form renewables (Parra et al. 2019). Political and economic considerations, at least regionally, are also of great importance in the coal sector due to the approximately 35,000 people employed within it (including coal-mining and the power stations themselves). For a long time, coal-fired power plants were able to protect their position in Germany, but against the background of decreasing public acceptance, economic problems resulting from the growing use of renewables and ambitious GHG reduction targets, the sector cannot resist the political pressures against them any longer. The governing parties have agreed to establish a commission called "Growth, structural change and employment" to develop a strategy for phasing out coal-fired power plants (E3G Annual Review 2018). This Commission consists of experts and stakeholders from industry, associations, unions, the scientific community, pressure groups and politicians. Its establishment shows that the phasing-out process deserves close attention and that management policies must be implemented to ensure a soft landing for the electricity sector.

END BOX 17.1 HERE

The transition towards a high-penetration renewable system also raises concerns over the availability of rare metals for batteries like lithium and cobalt. While metal reserves are unlikely to limit the growth rate or total amount of solar and wind energy, used battery technologies and the known reserves currently being exploited are not compatible with the transition scenario due to insufficient cobalt and lithium reserves (Månberger and Stenqvist 2018). Global lithium production rose by roughly 13 percent from 2016 to 2017 to 43,000 MT in 2018 (Golberg 2021). Africa has rich reserves of lithium and is expected to produce 15% of the world's supply soon (Rosenberg et al. 2019). Such reserves are found in Zimbabwe, Botswana, Mozambique, Namibia, South Africa (Steenkamp 2017) and the Democratic Republic of Congo (Roker 2018).

The demand for these resources as ingredients in rechargeable batteries is growing rapidly, with global demand for cobalt set to quadruple to over 190,000tn by 2026. The DRC is a mineral-rich country (Smith et al. 2019a) with rich reserves of fossil fuels (coal and oil) (Buzananakova 2015). The extraction of lithium and cobalt can be environmentally and socially damaging, though its use as a principal component in most rechargeable batteries for electric vehicles and electronic smart grids affords it high sustainability value. Chapter 10 includes a more detailed assessment of the issues with mining these rare metals, as well as the associated social problems, including exploitative working conditions and child labour, the latter a major issue that needs to be taken into consideration in transitions. Recycling batteries is also highlighted as a major supplementary policy if negative environmental side impacts are to be avoided (Rosendahl and Rubiano 2019). In the future, more attention should be paid to reducing vulnerability through subsidizing R&D in rare metals recycling, establishing systems to incentivize the collection of rare-metal waste and promoting technological progress using abundant metals as a replacement for rare metals (Rosendahl and Rubiano 2019).

Chapter 10 also provides a more detailed assessment of the issues involved in mining these rare metals, as well as the associated social problems, including exploitative working conditions and child labour, the latter a major issue that needs to be taken into consideration in transitions. Recycling batteries is also highlighted as a major supplementary policy if negative environmental side impacts are to be avoided (Rosendahl and Rubiano 2019).

17.3.2.3 Stranded assets, inequality and just transitions

As the momentum towards achieving carbon neutrality grows, the risk of certain assets becoming stranded is on the increase. International policies and the push for low-carbon technologies in the context of climate change are reducing the demand for and value of fossil-fuel products. Stranded assets become devalued before the end of their economic life or can no longer be monetised due to changes in policies and regulatory frameworks, technological change, security, or environmental disruption. In short, stranded assets are "assets that have suffered from unanticipated or premature write-down, devaluations or conversions to liabilities" (Caldecott et al. 2013).

Stranded assets are likely to "lose economic value ahead of their anticipated useful life" (Bos and Gupta 2019). They are often described as creative when they become stranded because of innovation, competition or economic growth (Gupta et al. 2020). Divestment refers to "the action or process of selling off subsidiary business interests or investments.'' This often occurs due to changing social norms and perceptions of climate change.

Indeed, pressure is mounting on fossil-fuel industries to remove their capital from heavy carbon industries. As the former Governor of the Bank of England, Mark Carney, remarked, a wholesale reassessment of prospects, especially if it were to occur suddenly, could potentially destabilise markets, sparking a pro-cyclical crystallisation of losses and a persistent tightening of financial conditions. In other words, an abrupt resolution to the tragedy of horizons itself poses a risk to financial stability (OECD 2015). The divestment narrative is also based on the view that a shift away from intensive carbon resources will be significant, as the "less value will be destroyed, […] the more can be re-invested in low carbon infrastructure'(OECD 2015). Social movements are critical to triggering rapid transformational change and moving away from dangerous levels of climate change (Mckibben 2012). Although divestment is hailed as a necessary action to decouple fossil fuel from growth and force carbon-intensive industries to go out of business, there is the sense that there is no shortage of investors who are willing to buy shares, so that such resources are not stranded, but simply relocated. Criticism has been levelled at the divestment movement for not having a significant impact on funding fossil fuels and not being sufficiently in tune with other wide-ranging complexities that go beyond the moral dimensions (Bergman 2018). Despite being labelled a 'moral entrepreneur', the divestment movement has the potential to disrupt current practices in the fossil-fuel industry, shape a 'disruptive innovation' and contribute to a strategy for decarbonising economies globally (Bergman 2018). Divestment is contributing to the political situation that is 'weakening the political and economic stronghold of the fossil fuel industry' (Grady-Benson and Sarathy 2016).

The risks attached to the stranding of fossil-fuel assets have increased with the recent and sustained plunge in oil prices because of the global health pandemic (COVID-19) and the concomitant economic downturn, forcing demand to plummet to unprecedentedly low levels. (Oil prices have recently increased). Many economies in transition and countries dependent on fossil fuels are going through turbulent times where asset and transition management will be critical (UNEP/SEI 2020). However, COVID-19 provides a foretaste of what a low-carbon transition could look like, especially if assets become stranded in an effort to respond to the call for action in 'building back better' and putting clean energy jobs and the just transition at the heart of the post-COVID-19 recovery (IEA 2020; United Nations General Assembly 2021). COVID-19 provides a useful proxy for issuing two alerts. First, it is a reminder of the urgency of addressing climate change, given that delaying the move away from stranded assets will further worsen climate change. Second, failure to recognize the threat from stranded assets will result in new assets becoming stranded (Rempel and Gupta 2021). Hence, the momentum towards a transformational push is resting on a new opportunity ushered in by COVID-19 to emphasize the urgency for a new departure towards rapid emissions reductions (Cronin et al. 2021).

The stranded assets narrative has focused overwhelmingly on consumption by companies: not much emphasis has been placed on the commercialisation- and investment-related aspects. In addition, other carbon-intensive activities can also run the risk of being stranded, such as cement, petrochemicals, steel and aviation (Baron and David 2015). This is why stranded assets are often referred to as having a cascading impact on several other sectors.

Transitions are broad-based and complex, involving governance structures, institutions and climate vulnerabilities, and there is need to include historical responsibility, resource intensity and capacity differentials, thus relegating the debate across simplistic binary lines of developed versus developing countries (Carney 2016). Hence, transition processes will have to respond to several preconditions and structural inequalities related to climate finance, energy poverty, vulnerabilities and the broader macro-economic implications associated with managing the debt burden, fiscal deficits and uneven terms of development in developing countries. In addition to structural inequalities, the COVID-19 pandemic has severely disrupted energy and food systems to and reduced the speed at which developing countries can procure new low-carbon technologies and decouple economic growth from fossil fuels (Winkler 2020). For instance, global supply-chain transition costs might be lower when compared to in-country supply chains, as became evident when COVID-19 created further disruption to renewable energy projects (Cronin et al. 2021). Moreover, developing countries can experience difficulties in phasing out old technologies, especially if the latter has a cost disadvantage, has not benefitted from an established track record and its performance is uncertain (Bos and Gupta 2019). There is the risk of lock-in effects related to grandfathering when emitters comply with less stringent standards.

Despite their efforts in deploying renewable energies, many developing countries are still contending with problems related to the immaturity of the current technologies and the challenges of battery storage. In short, the transition to a low carbon development must consider the challenges of renewable energy penetration and existing energy-related vulnerabilities and inequalities. There are power asymmetries between first-comers and latecomers, especially in cases where mature technologies can be located in countries with less stringent laws and standards. Carbon leakage has implications for just transitions, as carbon-intensive industries can move their dirty industries to developing countries as a way of outsourcing the production of carbon (Bos and Gupta 2019; UNU-INRA 2020, Denton et al, 2021). When the challenge of climate mitigation is transferred to developing countries in the form of carbon leakage, the risks of carbon lock-in for developing countries are heightened (Bos and Gupta 2019).

Overcoming the carbon lock-in is not simply a matter of the right policies or switching to low-carbon technologies. Indeed, it would mean a radical change in the existing power relations between fossil-fuel industries and their governments and social structural behaviour (Seto et al. 2016). Some actions to fix the climate change problem can themselves create injustices, thereby challenging sustainable development (Cronin et al. 2021). Not paying sufficient attention to perceptions of injustice related to the rights to development, energy and resource sovereignty can further create resistance to climate action (Cronin et al. 2021).

The shrinking carbon budget has raised questions over whether to meet our commitment to 2 degrees Celsius if fossil-fuel resources were to be mined or left stranded, as McGlade and Ekins argue: '… [a] large portion of the reserve base and an even more significant proportion of the resource base should not be produced if the temperature rise is to remain below 2 degrees C' (McGlade and Ekins 2015). This logic means that developing countries that rely on fossil-fuel extraction will need to replace their hydrocarbon revenues with other income-generating activities. Stranded assets remind most oil-producing governments that fossil-fuel assets do not have a durable value and are vulnerable to politico-economic forces and fluctuations. The goal of staying within the 1.5°C temperature goal, in line with the Paris Agreement, is already part of the policy vision and planning of large fossil fuel-consuming economies. For early fossil-fuel producers, however, the reality that their resources may not yield the desired returns is often perceived as bad news, particularly in the context of the increasing depreciation of fossil-fuel products.

Stranded assets raise fundamental questions related to issues of equity and just transitions:

- Who decides which resources should be stranded?
- Who shoulders the burden of the transition and losses incurred from moving away from heavy industries with associated compensation?
- How should the advantages of short-term fossil-fuel exploitation be shared based on the principle of distributive justice?

The transition to a low-carbon development is wired in issues of justice and equity: how do you align carbon reductions to meet the needs of humanity? Distributive justice calls for a fairer sharing of the benefits and burdens of the transition process, while procedural justice is essentially about ensuring that the demands of vulnerable groups are not ignored in the pull to the transition. The impacts of climate change and the mitigation burdens are experienced differently by different social actors, with indigenous communities facing multiple threats and being subjected to unequal power dynamics (Sovacool 2021).

Nonetheless, the production of fossil fuels is central to many economies with numerous development implications related to rents associated with export revenues, energy security and poverty alleviation (Lazarus and van Asselt 2018). The central question is who decides which types of carbon should be burnable or non-burnable. Hence, social equality is at the heart of the transition process, but it falls short of a response on how to chart a new road map towards carbon neutrality, especially given that fossil-fuel producers and investors tend to belong to large, powerful companies and wield a great deal of influence and power, especially when their entrenched interests are at stake (Lazarus and van Asselt 2018). The question of whether developing countries should be compensated for foregoing their resources in light of their current development needs has not yielded many results and had only limited success in mobilising international finance, as demonstrated by the case of Yasuni-ITT in Ecuador (Sovacool and Scarpaci 2016). According to Sovacool et al. (2021), affected communities and their views may be discounted and excluded from planning, which can neglect important matters such as rights, recognition and representation (Sovacool 2021).

Fossil fuel-dependent countries are doubly exposed to the vulnerability related to climate-change impacts and are being targeted in the global effort to address the problem (Peszko et al. 2020). Countries that are heavily reliant on oil, coal and gas are also those most at risk from a low-carbon transition that may curtail the activities of their fossil-fuel industries and render the value chains and economies associated with the exploitation of fossil fuels unviable (Peszko et al. 2020).

Developing countries in Latin America and Africa that are reliant on revenue streams from fossil fuels may not see these returns converted into much needed infrastructure and other social and economic amenities that can reduce poverty. However, given the falling prices of renewables, developing countries do not have to face the burden of retrofitting their infrastructure to align with new low-carbon industries, since they can leapfrog technologies and shape a sustainable trajectory that is more resilient and fit for the future.

However, the transition towards a carbon-neutral world is complex and non-linear, and it will likely result in some disruptions, with manifest equality implications, given the scale of the transformation envisaged. There are parallel movements that can be observed. On the one hand, divestment initiatives are underway to move away from carbon-intensive investments. On the other hand, hydrocarbon-rich countries in some parts of the developing world are identifying new opportunities to reduce the fiscal loss associated with the loss of fossil-fuel revenues. Indeed, with global investment in energy expected to shrink by 20% this year, this has created fiscal challenges for countries that are heavily reliant on fossil-fuel products as their main source of revenue.

Other disruptions are linked to redundant contracts and postponed or cancelled explorations, as many oil companies are diversifying their production in the wake of the pandemic and are cutting back on planned hydrocarbon investments (Denton et al, 2021). These failed concessions and disruptions have implications for the just transition, especially in developing countries without the financial ability to pull out of fossil fuels and to diversify with the same urgency as the industrialized nations (Peszko et al. 2020). For instance, in South Africa, which is seeking to divest away from coal and decarbonize its energy sector, if the transition is not properly managed, this could lead to a loss in revenue of R1.8 trillion (USD125 billion), thus compromising the government's ability to support social spending (Huxham et al. 2019). Emerging oil producers like Uganda are having to postpone the start of production. Eni and Total, two of the largest international oil and gas majors in Africa, have already signalled they are making 25% cuts to their investment in exploration and production projects in 2020, representing a €4bn reduction in foreign direct investment for Total and a USD2bn reduction for Eni (Le Bec 2020).

A poorly managed transition will reproduce inequalities, thus contradicting the very essence of a just, sustainable, inclusive transition. Revenues from oil and gas have been ploughed into social safety nets and are supporting free senior high-school education in countries such as Ghana, thus enabling the realisation of SDG 4 on quality education (UNU-INRA 2020). The move from fossil fuels towards a low-carbon economy has economic implications for lower income countries that are dependent on hydrocarbon resources, are endowed with significant untapped oil and gas reserves, and may not have the transitional tools to move towards low-carbon technologies or economies (Peszko et al. 2020).

The energy transition landscape is changing rapidly, and we are witnessing multiple transitions. This creates room to manage the transition in ways that will prioritise the need for workers in vulnerable sectors (land, energy) to secure their jobs and to maintain a secure and healthy lifestyle, especially as the risks multiply for those who are exposed to heavy industrial jobs and all the associated outcomes. The shift to carbon neutrality is being driven by convergent factors related to energy security and the benefits of climate mitigation, including the health impacts of air pollution and consumer demand (Svobodova et al. 2020).

Climate change is high on the global agenda, as is energy's role in decarbonizing the economy, giving rise to a number of equality issues. Oswald et al. (2020) have shown that economic inequality translates into inequality in energy consumption, as well as emissions. This is largely because people with different levels of purchasing power make use of different goods and services, which are sustained by different energy quantities and carriers (Oswald et al. 2020; Poblete-Cazenave et al. 2021)

A study by Bai et al. (2020) shows that an increase in income inequality in China hinders the carbon abatement effect of innovations in renewable energy technologies, possibly even leading to an increase in carbon emissions, while a decrease in inequality of incomes is conducive to giving play to the role of this carbon abatement effect, thereby indicating that there is an important correlation between the goals of "sustainable social development" and "sustainable ecological development".

India is home to one sixth of world's population but accounts for only 6.8% of global energy use and consumes only 5.25% of electricity produced globally. During the period 1990–1991 to 2014–2015, overall energy intensity in India declined from 0.007 Mtoe per billion INR of GDP to 0.004 Mtoe per billion INR of GDP, an annual average decline of 2%. The industrial sector is making the highest contribution CO_2 mitigation by reducing its energy intensity (Roy et al. 2021).

Household carbon emissions are mainly affected by incomes and other key demographic factors. Understanding the contribution of these factors can inform climate responsibilities and potential demand-side climate-mitigation strategies. A study by Feng et al. (2021) on inequalities in household carbon the in USA shows that the per-capita carbon footprint (CF) of the highest income group (>200 thousand USD per year) with 32.3 tons is about 2.6 times the per-capita CF of the lowest income group (<15 thousand USD) with 12.3 tons. Most contributors of high carbon footprints across income groups in the US are heating, cooling and private transport, which reflects US settlement structures and lifestyles, heavily reliant as they are on cars and living in large houses.

Studies by Jaccard et al. (2021) on energy in Europe shown a top-to-bottom decile ratio (90:10) of 7.2 for expenditure, 3.1 for net energy and 2.6 for carbon. Given such inequalities, these two targets can only be met through the use of carbon capture and storage (CCS), large efficiency improvements and an extremely low minimum final energy use of 28 GJ per adult equivalent. Assuming a more realistic minimum energy use of about 55 GJ ae^{-1} and no CCS deployment, the 1.5◦C target can only be achieved at near full equality. The authors conclude that achieving both stated goals is an immense and widely underestimated challenge, the successful management of which requires far greater room for manoeuvre in monetary and fiscal terms than is reflected in the current European political discourse.

The 'Just Transition' concept has evolved over the years (Sweeney and Treat 2018) and is still undergoing further evolution. It emphasizes the key principles of respect and dignity for vulnerable groups, the creation of decent jobs, social protection, employment rights, fairness in energy access and use, and social dialogue and democratic consultation with relevant stakeholders, whilst coping with the effects of asset-stranding or the transition to green and clean economies. The concept has come under increased scrutiny, with its protagonists emphasizing the need to focus on the equality of the transition, not simply on its speed (Forsyth 2014). The emphasis on justice is also gaining in momentum, with a growing recognition that the sustainability transition is about justice in the transition and not simply about economics (Newell and Mulvaney 2013; Swilling, M. Annecke 2010; Williams and Doyon 2020). Scholars are increasingly of the view that a transition involving low-carbon development should not replace old forms of injustice with new ones (Setyowati 2021).

The economic implications of the transition will be felt by developing countries with high degrees of dependence on hydrocarbon products as a revenue stream, as they are exposed to reduced fiscal incomes, given the low demand for oil and low oil prices and the associated economic fallout of the pandemic. This link with stranded assets is important, but it may be overlooked, as countries whose assets are becoming stranded may not have the relevant resources, knowledge, autonomy or agency to design a fresh orientation or decide on the transition. In addition, some developing countries are dependent not only on fossil-fuel revenues, but also on foreign exchange earnings from exports. This dependence comes into sharp focus when one considers that 30% of the Malaysian government's revenues are linked to petroleum products, and that Mozambique, by exploiting its newly discovered natural-gas reserves, can earn seven times the country's current GDP over a period of 25 years (Cronin et al. 2021). Thus, any attempt to accelerate the transition to low-carbon development must take into account foreign exchange, domestic revenue and employment generation, which are precisely what ensure the attractiveness of fossil-fuel industries (Addison and Roe 2018).

Energy use and its deployment are sovereign matters. State responsibilities over the control and use of natural resources concern both current and future generations (Carney 2016). Climate-change impacts will disable the food, water and energy systems of the most vulnerable. Therefore, the resources required to enable a just transition are predicated on good leadership and governance institutions that will support quality and justice-based transitions. Beyond energy systems, changes to land systems can benefit from sustainable land management in ways that will reduce the pressure on land for food and at the same time support carbon storage. With land coming under increased pressure, land and forest management are critical for carbon sequestration, as well as other ecosystem benefits. Extractive processes have impacts on land, and often there are few if any redistributive benefits for communities in regions where extraction takes place. In addition, extraction of strategic minerals such as cobalt, copper and lithium have been linked to violence, human rights abuses and conflict (Cronin et al. 2021).

However, in the race to achieve carbon neutrality by 2050, some of the other priorities of the transition, like climate-change adaptation and its inherent vulnerabilities, might become muted, given the urgency to mitigate at all costs. Consequently, the transition imperative reduces the scope for local priority-setting and ignores the additional risks faced by countries with the least capacity to adapt. Equally, the 'just transition' is often seen through the prism of job losses and the attendant retooling and reskilling imperatives necessary to re-dynamize local businesses, especially those that may fail as a result of mine closures. It is equally important to consider current disparities in knowledge and capacity which could maintain the existing inequalities in the global regional distribution of costs and benefits. One striking example is the manufacturing of PV in India when compared to manufacturing PV in China. In China, manufacturing costs are lower than in India, as are import tariffs (Behuria 2020). Similarly, a solar industry might have greater development prospects in one region than another given existing regional disparities in human capital, infrastructure, finance and technological development (Cronin et al. 2021).

Low-carbon transitions and equality implications will depend on local contexts, regional priorities, the points of departure of different countries in the transition and the speed at which they will want to travel. Hence, timing and scope are important elements that are associated more with a quality transition than a race to the bottom. To date the debate has had some obvious blind spots, not least considerations of power, politics and political economy (Denton et al, 2021). Certainly, the transition will create winners and losers, as well as stakeholders that can frame their economic interests so as to determine the orientation, pace, timing and scope of the transition.

The determination of a just transition is complex and not simply dependent on the allocation of perceived risks or solutions, but rather on how risks and solutions are defined (Forsyth 2014). Acting urgently to achieve environmental solutions or meet transition imperatives has certain risks given the need to go beyond commonplace definitions of the just transition by emphasizing the distributive or procedural aspects. The framing of policies to align with fast and low-cost mitigation without paying sufficient attention to social and economic resilience creates its own potential risks and can enhance social vulnerability rather than address it. The need to distribute climate-change solutions must not delegitimise appropriate economic growth strategies, nor indeed create the additional risks of policy imposition. Perceptions of justice with regard to environmental problems and solutions matter equally. Hence, the types of transition pathway that are chosen may have equality implications. Mitigation at all costs, if done "cheaply and crudely", can create additional problems for social justice and inclusive development (Forsyth 2014).

The assumption that the benefits of mitigation are enough to offset trade-offs with other policy objectives can be questioned. If one accepts the argument that not all adaptation addresses vulnerability concerns (Kjellén 2006), and that some adaptation strategies can heighten vulnerabilities if there are flaws in their design and implementation, then the same logic applies, namely that not all mitigation is necessarily beneficial. Hence the emphasis on the transition resulting from mitigation should be placed not only on speed or cost effectiveness, but also on legitimacy of the actions, and whether the transition is well designed or not. In short, justice is not always a shorthand for acting ethically, but rather a point of reasoning on what is considered legitimate. Planning for the transition often discounts human rights and social inclusivity that can occur as the result of a rapid transition. The emphasis should be placed on the management of the transition rather than the speed – for instance, if in the rush to build new hydropower energy sources implies that populations are displaced, then this constitutes a human rights violation (Castro et al. 2016; Piggot et al. 2019).

Ambitious climate goals can increase the urgency of mitigation and accelerate the speed at which carbon neutrality is achieved. However, if the transition is done with speed, then this will leave diversification efforts stymied, particularly in developing countries that are highly dependent on fossil-fuel revenue streams (UNEP/SEI 2020). Transition decisions and policies may also have far-reaching gendered implications, as the closure of mines is often linked to several ancillary businesses impacts where men are laid off and women may have to take on multiple jobs to compensate for the reduction in the household's income (Piggot et al. 2019; UNU-INRA 2020).

A just transition holds out the prospects for alternative high-quality jobs, public-health improvements and an opportunity to focus on well-being and prosperity, with spill-over benefits to urban areas and economic systems. Nonetheless, countries that transition from fossil fuels experience different challenges, different levels of dependence and have different capacities to transition. There will be countries with lower capacity and higher dependence, and vice versa (UNEP/SEI 2020).

Deciding on matters of justice is essential to the transition, and there are several inherent questions to consider when thinking through the allocation of costs and benefits, as is the case with distributive justice. How matters are defined and who defines matters such as the timing of phasing out, prioritising which energy sources need to be phased out and who might be affected are all political economy questions (Piggot et al. 2019).

Similarly, when considering issues of procedural justice, there are matters related to interests, participation and power dynamics that are essential to the process, but that might also subvert the process, depending on whose rights, whose participation and whose power are being put in jeopardy.(Forsyth 2014; Piggot et al. 2019). Hence, both distribution and procedure matter, as do inter-generational and intra-generational equity in planning transitions. Six critical variables can shape or inhibit the transition process. These are dependence, timing, capacity, agency, scope and inclusion (Denton et al, 2021).

Dependence, or the extent to which a country may depend on revenue streams from fossil fuels, will determine their ability to manage the transition from fossil fuels. Countries who rely on the proceeds from hydrocarbon resources as economic rents to support fiscal income and spending on public service-related needs such as education, health and infrastructure, export earnings and foreign exchange reserves will have greater difficulties in foregoing their fossil-fuel resources.

Timing: the transition pathway has to be aligned with a timetable which is anchored in national development priorities. For example, South Africa's Integrated Resource Planning indicates that the transition away from coal, if not aligned with national development priorities, will reproduce new forms of inequality. In addition, if the transition is imposed and its timing is not organic, then this might also produce social inequalities.

Capacity: Transitions need to reflect spaces and planning. If knowledge about the transition pathway is not adequately mastered or in place, this can disable the process or steer it in the wrong direction. Capacity also relates to several attributes, including technical, governance, institutional, technologies, economic resources to manage the transition. Poorer countries will have difficulties in managing all these resources, as well as absorbing the costs associated with the transition (UNEP/SEI 2020).

Agency: transitions are inherently about the sovereign right to determine one's orientation towards low-carbon development. However, given the urgency to stick to the Paris Agreement and the new conditionalities related to post-COVID stimulus packages, the absence of agency to deal with the transition might jeopardize its flow, orientation and pace (Newell and Mulvaney 2013).

Scope: the extent to which the transition is rolled out and its potential impacts. If transition policies are ambitious in making commensurate diversification investments, this may enable job creation, but it may also affect employees who are insufficiently prepared to undertake new jobs and skills.

Inclusion. Who is considered in the transition process and how their interests and risks are assessed are important aspects of transition pathways. Stakeholders with strong vested interests may resist the transition, especially as it moves towards diversification activities and policies.

17.3.3 Cross-sectoral transitions

Transitions will involve multiple sectoral- and cross-sectoral policies. Section 17.3.3 presents a range of studies and conclusions on the relationship between climate-change mitigation goals and meeting the SDGs in order to identify major synergies and trade-offs. The interactions are manifold and complex (Section 4.3.1.2 in Section 4; Nilsson et al. 2016; Pradhan et al. 2017). Here we draw on conclusions from sectoral chapters and add additional studies as a basis for drawing more general conclusions about agriculture, food and land-use, the water-energy-food nexus, industry, cities, infrastructure and transportation, cross-sectoral digitalization, and mitigation and adaptation relations.

17.3.3.1 Agriculture, Forestry and Other Land Uses (AFOLU)

Sustainable development and mitigation policies are closely linked in the agriculture, food and land-use sectors. We assess synergies and trade-offs between meeting the SDGs and reducing GHG emissions within the sectors based on modelling studies and case studies illustrating how trade-offs between SDG 2 (zero hunger, biomass for energy) and SDG 15 (life on land) can be addressed by cross-sectoral mitigation options.

Chapter 7 emphasizes the high expectations on land to deliver mitigation, yet the pressures on land have grown with population, dietary changes, the impacts of climate change and the conversion of uncultivated land to agriculture and other land uses. Agriculture, Forestry and Other Land Uses (AFOLU) are expected to play a vital role in the portfolio of mitigation options across all sectors. The AFOLU sector is also the only one in which it is currently feasible to achieve carbon dioxide removal (CDR) from the atmosphere, including A/R, improved forest management and soil carbon sequestration (see Chapters 7 and 12). The AFOLU sector has a significant mitigation potential, with many scenarios showing a shift to net negative CO_2 emissions during the 21st century. Total cumulative AFOLU CO_2 sequestration varies widely across scenarios, with as much as 415 $GtCO_2$ being sequestered between 2010 and 2100 in the most stringent mitigation scenarios. The largest share of net GHG emissions reductions from AFOLU in both the 1.5°C and 2°C scenarios is from forestry-related measures, such as afforestation, reforestation and reduced deforestation. Afforestation, reforestation and forest management result in substantial carbon dioxide removal in many scenarios. CO_2 and CH_4 show larger and more rapid declines than N_2O, an indication of the difficulties of reducing N_2O emissions in agriculture (Chapter 3).

The Global Assessment on Biodiversity and Ecosystem Services Report (IPBES 2019, Chapter 5) assessed the relationship between meeting the goals of the Paris Agreement and SDGs 2 (zero hunger), 7 (affordable and clean energy) and 15 (life on land). It concluded that a large expansion of the amount of land used for bioenergy production would not be compatible with these SDGs. However, combining bioenergy options with other mitigation options, like more efficient land management and the restoration of nature, could contribute to welfare improvements and to accessing food and water. Demand-side climate-mitigation measures, like energy-efficiency improvements, reduced meat consumption and reduced food waste, were considered to be the most economically attractive and efficient options in order to support low GHG emissions, food security and biodiversity objectives. Implementing such options, however, can involve challenges in terms of lifestyle changes (IPBES 2019).

The potential joint contribution of food and land-use systems to sustainable development and climate change has also been addressed in policy programmes by the UN, local governments and the private sector. These programmes address options for pursuing sustainable development and climate change jointly, such as agroforestry, agricultural intensification, better agriculture practices and avoided deforestation. Griggs and Stafford-Smith (2013) assess production- and consumption-based methods of achieving joint sustainability and climate-change mitigation in food systems, concluding that efficiency improvements in agricultural production systems can provide large benefits. Given the expectations of high levels of population growth and the strong increase in the demand for meat and dairy products, there is also a need for the careful management of dietary changes, as well for those areas which could be used most effectively for livestock and plant production.

Loss of biodiversity has been highlighted in several studies as a major trade-off of the low stabilization scenarios (Prudhomme et al. 2020). A wide range of mitigation and adaptation responses – for example, preserving natural ecosystems such as peatland, coastal lands and forests, reducing the competition for land, fire management, soil management and most risk management options – have the potential to make positive contributions to sustainable development, ecosystems services and other social goals

(McElwee et al. 2020). Smith et al. (2019a) also stressed that agricultural practices (e.g. improving yields, agroforestry), forest conservation (e.g. afforestation, reforestation), soil carbon sequestration (e.g. biochar addition to soils) and the removal of carbon dioxide (e.g. BECCS) could contribute to climate-change mitigation (Smith et al. 2019a). However, there are also options that could improve biodiversity if they were implemented jointly with climate-change mitigation in AFOLOU. In their study, (Leclère et al. 2020) show that increasing conservation management, restoring degraded land and generalized landscape-level conservation planning could be positive for biodiversity. In general, the ambitious conservation efforts and transformations of food systems are central to an effective post-2020 biodiversity strategy.

The IPCC Special Report on Climate Change and Land (IPCC 2019) emphasizes the need for governance in order to avoid conflict between sustainable development and land-use management. It states: "Measuring progress towards goals is important in decision-making and adaptive governance to create common understanding and advance policy effectiveness". The report concludes that measurable indicators are very useful in linking land-use policies, the NDCs and the SDGs.

One example of an area where special governance efforts have been called for is the protection of forestry, ecosystem services and local livelihoods in a context of the large-scale deployment of high-value crops like palm oil, short-term, high income-generating activities and sustainable development. Serious challenges are already being seen within these areas according to (IPBES 2019).

Palm-oil is one example of a product with potentially major trade-offs between meeting the SDGs and climate-change mitigation in the agriculture, forest and other land uses (AFOLU) sector. Currently the area under oil palms is showing a tremendous increase, mostly in forest conversions to oil-palm plantations (Austin et al. 2019; Gaveau et al. 2016; Schoneveld et al. 2019). The conversion of peat swamp forest and mineral forest to oil palms will yield different amounts of CO_2. A study by Novita et al. (2020) shows that the carbon stock of primary peat-swamp forest was 1,770 Mg C/ha compared to a carbon stock of oil palm of 759 Mg C/ha. The study conducted by Guillaume et al. shows that the carbon stock in mineral soils was 284 Mg C/ha compared to that in rain forest, which was 110.76 Mg C/ha (Guillaume et al. 2018).

Restoring peatlands is one of the most promising strategies for achieving nature-based CDR (Girardin et al. 2021; Seddon et al. 2021). A study by Novita et al. (2021) shows that significantly different CO_2 emissions for different land-use categories are influenced more by the water table depth and latitude position for those locations relative to other observed parameters, such as bulk density, air temperature and rainfall.

Given that the frequent peat-land fires in Indonesia were caused by land clearances in the replanting season, multi-stakeholder collaboration between oil-palm plantations, local communities and local governments over practices such zero burning when clearing land might be one of the most effective ways to reduce the deforestation impact of oil palm (Jupesta et al. 2020). Behavioural changes as a mitigation option have been suggested as a major factor in aligning sustainable development, climate change and land management. In the absence of the policy intervention, the expansion of oil-palm plantations has provided limited benefits to indigenous and Afro-descended communities. Even when oil-palm expansion improves rural livelihoods, the benefits are unevenly distributed across the rural population (Andrianto et al. 2019; Castellanos-Navarrete et al. 2021). In any case, while oil-palm production can improve smallholders' livelihoods in certain circumstances, this sector offers limited opportunities for agricultural labourers, especially woman (Castellanos-Navarrete et al. 2019).

Economy-wide mitigation costs can be effectively limited by lifestyle, technology and policy choices, as well as benefit from synergies with the SDGs. Synergies come from the consumption side *by* managing demand. For example, reducing food waste leads to resources being saved because water, land-use, energy consumption and greenhouse gas emissions are all reduced (Chapter 3).

IPCC 6th AR Chapter 12 emphasized that diets high in plant protein and low in meat, in particular red meat, are associated with lower GHG emissions. Emerging food-chain technologies such as microbial, plant, or insect-based protein promise substantial reductions in direct GHG emissions from food production. The full mitigation potential of such technologies can only be realised in low-GHG energy systems.

Springmann et al. (2018) conclude that reductions in food waste could be a very important option for reducing agricultural GHG emissions, the demand for agricultural land and water, and nitrogen and phosphorous applications. In addition to the possibility to reduce food waste, their study analysed several other options for reducing the environmental effects of the food system, including dietary changes in the direction of healthier, more plant-based diets and improvements in technologies and management. It was concluded that, relative to a baseline scenario for 2050, dietary changes in the direction of healthier diets could reduce GHG emissions by 29% and 5–9% respectively in a dietary-guideline scenario, and by 56% and 6–22% respectively in a more plant-based diet scenario. Demand-side, service-oriented solutions vary between and within countries and regions, according to living conditions and context. Avoiding food waste reduces GHG emissions substantially. Dietary shifts to plant-based nutrition leads to healthier lives and reduce GHG emissions (Chapter 5.3).

A similar study also found a positive impact form zero food waste. The 'no food waste' scenario could decrease global average food calorie availability by 120 kcal person^{-1} d^{-1} and protein availability by 4.6 g protein person−1 d^{-1} relative to their baseline levels, thus reducing required crop and livestock production by 490 and 190 Mt respectively. This lower level of production reduces agricultural land use by 57 Mha and thus mitigates the associated side effects on the environment. The lower levels of production also reduce the requirements for fertilizers and water by 10 Mt and 110 km^3 respectively, and GHG emissions are reduced by 410 $MtCO_2e$ yr^{-1} relative to the 2030 baseline. Reducing food waste can contribute to lessening the demand for food, feed and other resources such as water and nitrogen, reducing the pressure on land and the environment while ending hunger (Hasegawa et al. 2019).

In 2007, Britain launched a nationwide initiative to reduce household food waste, which achieved a 21 percent reduction within five years (FAO 2019). The basis of this initiative was the "Love Food, Hate Waste" radio, TV, print and online media campaign run by a non-profit organization, the Waste and Resources Action Programme (WRAP). The campaign raised awareness among consumers about how much food they waste, how it affects their household budgets and what they can do about it. This initiative collaborated with food manufacturers and retailers to stimulate innovation, such as re-sealable packaging, shared meal-planning and food-storage tips. The total implementation costs during the five-year period were estimated at GBP 26 million, from which it was households that derived the most benefit, estimated to be worth GBP 6.5 billion. Local authorities also realized a substantial GBP 86 million worth of savings in food-waste disposal costs. As for the private sector, the benefits took the form of increased product shelf lives and reduced product loss. While households started to consume more efficiently and companies may have experienced a decline in food sales, the latter also stated that the non-financial benefits, such as strengthened consumer relationships, had offset the costs.

The Asia Pacific Economic Cooperation (APEC) group of countries has also created several types of public–private partnership to tackle food waste and reduce losses. Most of these partnerships are focused on food-waste recycling in both developed and developing countries (Rogelj et al. 2018). APEC members stated that knowledge-sharing and improved policy and project management were the most important advantages of public–private partnerships.

The inextricably intertwined factors in decision-making are influenced by the characteristics of the person, in interaction with the characteristics of more sustainable practices and products, which interact with a particular context that includes the immediate environment (e.g., household, farm), the indirect environment (e.g., community) and macro-environmental factors (e.g., the political, financial and economic contexts) (Hoek et al. 2021). Hence, to influence people to make decisions in favour of sustainable food production or consumption, a wider perspective is needed on decision-making processes and behavioural change, in which individuals are not targeted in isolation, but in interaction with this wider systemic environment.

In conclusion, the AFOLU sector offers many low-cost mitigation options, which, however, can also create trade-offs between land-use for food, energy, forest and biodiversity. Some options can help to mitigate such trade-offs, like agricultural practices (e.g., improved yields, agroforestry), forest conservation (e.g. afforestation, reforestation), soil carbon sequestration (e.g. biochar addition to soils) and the removal of carbon dioxide (e.g. BECCS), which could contribute to climate change mitigation. Lifestyle changes, including dietary changes and reduced food waste, are tightly embedded in modes of behaviour that are influenced by the immediate environment (e.g., household, farm), the indirect environment (e.g., community) and macro-environmental factors (e.g., political, financial and economic contexts). Achieving zero-food waste could reduce the demands for land (SDG 15), water use (SDG 6) and chemical fertilizers (SDG 9), leading to GHG emissions reductions (SDG 13) by encouraging sustainable consumption and production practices (SDG 12).

17.3.3.2 Water-Energy-Food-Nexus

This section addresses the links between water, energy and food in the context of sustainable development and the associated synergies and trade-offs, with links to related chapters. The focus outline includes scoping and the relationship with the SDGs, general climate-change impacts on global water resources, energy-system impacts and the relationship to renewables, enabling strategies, trade-offs and cross-sectoral implications (see also Chapter 12), nexus-management tools and strategies, and a box with examples from India and South Africa.

The continually increasing pressures on natural resources, such as land and water, due to the rising demands from increases in population and living standards, which also require more energy, emphasises the need to integrate sustainable planning and exploitation (Bleischwitz et al. 2018).

The water-energy-food nexus is at the epicentre of these challenges, which are of global relevance and are the focus of policies and planning at all levels and sectors of the global society. The nexus between water, energy and food (WEFN) (Zhang et al. 2018b) is tight and complex, and needs careful attention and deciphering across spatio-temporal scales, sectors and interests to balance proper management and trade-offs and to pursue sustainable development (Biggs et al. 2015; Dai et al. 2018; Hamiche et al. 2016). The WEFN touches upon the majority of the UN's SDGs, such as 2, 6-7 and 11-15 (Bleischwitz et al. 2018), and deals with basic commodities, thus guaranteeing the basic livelihoods of the global population.

The task of gaining an improved understanding of WEFN processes across disciplines such as the natural sciences, economics, the social sciences and politics has been further exacerbated by climate change, population growth and resource depletion. In light of the system of interlinkages involved, the WEFN concept essentially also covers land (Ringler et al. 2013) and climate (Brouwer et al. 2018; Sušnik et al. 2018) and can be further assessed in light of the relevant economic, ecological, social and SDG aspects (Fan et al. 2019a). Fan et al. (2019b) specifically, SDGs 2 (food), 6 (water), (7) energy, 11 (cities) and 12 (production and consumption) are considered essential to the WEFN (Bleischwitz et al. 2018). The nexus approach was introduced in the early 2010s, when it was argued that advantages could be gained by adopting a nexus approach with regard to cross-sectoral and human–nature dependencies and by taking externalities into account (Hoffmann 2011). Hence, within the nexus, obvious trade-offs exist with competing interests, such as water availability versus food production.

Climate change is projected to impact on the distribution, magnitude and variability of global water resources. A yearly increase in precipitation of 7% globally is expected by 2100 in a high-emissions scenario (RCP 8.5), although with significant inter-model, inter-regional and inter-temporal differences (Giorgi et al. 2019). Similarly, extreme events related to the water balance, such as droughts and extreme precipitation, are projected to shift in the future (RCP4.5) towards 2100: for example, the number of consecutive dry days is projected to increase in the Mediterranean region, southern Africa, Australia and the Amazon (Chen et al. 2014). In impact terms, an increase of 20-30% in global water-use is expected by 2050 due to the industrial and domestic demand for water. Already four billion people experience severe water scarcity for at least one month per year (WWAP-UNESCO 2019).

Globally, climate change has been shown to cause increases of 4%, 8% and 10% in the share of population being exposed to water scarcities under the 1.5°C, 2°C and 3°C scenarios for global warming respectively (RCP8.5) (Koutroulis et al. 2019). At the same time, climate change is projected to cause a general increase in extreme events and climate variability, placing a substantial burden on society and the economy (Hall et al. 2014). Other than the human influence on the global hydro-climate, human activities have been shown to surpass even the impact of climate change in low to moderate emission scenarios of the water balance (Haddeland et al. 2014). Similar conclusions have been found by (Destouni et al. 2013; Koutroulis et al. 2019).

An obvious consequence of the impact of climate change on future hydro-climatic patterns is the fact that the energy system is projected to experience vast impacts through climate change (Fricko et al. 2016; Van Vliet et al. 2016a; van Vliet et al. 2016; Chapter 6). In the short run, where fossil-fuel sources make up a significant share of the global energy grid, climate impacts related to water availability and water temperatures will affect thermoelectric power generation, which relies mainly on water cooling (Larsen and Drews 2019; Pan et al. 2018); water is also used for pollution and dust control, cleaning etc. (Larsen et al. 2019). Currently, 98% of electricity generation relies on thermoelectric power (81%) and hydropower (17%) (van Vliet et al. 2016).

Of these thermoelectric sources, the vast majority employ substantial amounts of water for cooling purposes, although there is a trend currently towards implementing more hybrid or drier forms of cooling (Larsen et al. 2019).

The renewable energy conversion technologies that are currently dominant globally and are projected to remain so are less vulnerable to water deficiencies than fossil-based technologies, since no cooling is used. These renewable energy conversion sources include, e.g., wind, solar PV and wave energy. The implementation of such sources will, in the longer run, have the potential to reduce water usage by the energy sector substantially (Lohrmann et al. 2019). Also, an increasing share of renewables within desalination, as well as improved irrigation efficiencies, have been shown to potentially improve the inter-sectorial WEFN water balance (Lohrmann et al. 2019). Also, an increasing share of renewables on connection with desalination, as well as improved irrigation efficiencies, have been shown to potentially improve the inter-sectorial WEFN water balance (Caldera and Breyer 2020). Some less dominant renewable-energy technologies do use water for cooling, such as geothermal energy and solar CSP, if wet cooling is employed. Despite the general detachment from water resources, wind and solar PV, for example, are highly dependent on climate-change patterns, including variability depending on future energy-storage capacities and on-/off-grid solutions (Schlott et al. 2018). Furthermore, regardless of whether or not they are based on renewables, climate change will affect energy usage across sectors, such as heating and cooling in the building stock. The energy systems in question need to be able to handle variations and extremes in demand (Larsen et al. 2020).

For the 2080s compared to 1971-2000, an increase of 2.4% to 6.3% in the global gross hydropower potential, from the hydrological side alone, is seen across all scenarios (van Vliet et al. 2016 and Chapter 6). Alongside the global increase in hydropower potential, the global mean water-discharge cooling capacity, which also relates to water temperatures, experiences a decrease of 4.5% to 15% across the scenarios. In very general and global terms, when combined, these changes support the shift towards sources of renewable energy, including hydropower, in the energy mix. When it comes to ensuring stability in the management of the electricity grid, hydro-climatological extremes have the potential to pose vast difficulties in certain regions and/or seasons depending on the nature of the energy mix (Van Vliet et al. 2016b). Van Vliet et al. (2016a) showed significant reductions in both thermoelectric and hydropower electricity capacities, exemplified by the 2003 European drought, which resulted in reductions of 4.7% and 6.6% respectively.

The energy sector is vulnerable to production losses caused mainly by heatwaves and droughts, whereas coastal and fluvial floods are also responsible for a large relative share of the energy sector's vulnerability, as assessed by (Forzieri et al. 2018) for Europe in 2100. In total, heatwaves and droughts will be responsible for 94% of the damage costs to the European energy system compared to 40% today. Similarly, (Craig et al. 2018) show that, despite potentially minor spatiotemporally aggregated differences for various energy-system components, such as demand, thermoelectric power, wind etc., the aggregated impact of climate change across these components will cause a significant impact on the energy system, as currently exemplified by the USA. In terms of investments and management, it is important to unravel these cross-component relations in light of the projected nature of the future climate.

In the ongoing transition towards renewable sources of energy (see also Chapters 3, 4 and 6), the impact of the hydro-climate on energy production continues to be highly relevant (Jones and Warner 2016). As the shares of thermoelectric energy production in the energy grid go down along with the introduction of thermoelectric cooling technologies using smaller amounts of water, new energy sources and technologies are being introduced, and existing sources scaled up. Of these, hydropower, wind and solar energy are the key energy sources currently and will be in the near future, making up 2.5% and 1.8% of the total global primary energy supply in 2017 respectively (IEA 2019). Wind and solar energy are directly independent of water in themselves, but are dependent on atmospheric conditions related to processes that also drive the water balance and circulation. Hydropower, on the other hand, is directly influenced by and dependent on the supply of water, while at the same time being an essential counter-component to seasonality and climatological variation, as well as to current and future demand curves and diurnal variations, as against wind and solar energy (De Barbosa et al. 2017).

Furthermore, policy instruments in power-system management, here exemplified by hydropower in a climate-change scenario, have been shown to enhance energy production during droughts (Gjorgiev and Sansavini 2018). The significant influence of variation in the planning of renewable energy for the 21st century has also been highlighted by (Bloomfield et al. 2016). At the same time, the integration of renewables must account for lower thermoelectric efficiencies and capacities due to increases in temperature (van Vliet et al. 2016), power-plant closures during extreme weather events due to a lack of cooling capacity (Forzieri et al. 2018) and further efficiency reductions and penalties following the implementation of CCS technologies in the effort to reach the GHG mitigation targets (Byers et al. 2015). However, more recent studies find more promising amounts of water being used for energy conversion (IEAGHG 2020; Magneschi et al. 2017).

The extraction, distribution and wastewater processes of anthropogenic water-management systems similarly use vast amounts of energy, making the proper management of water essential to reduce energy usage and GHG emissions (Nair et al. 2014 and Chapter 11). One study reports that the water sector accounts for 5% of total US GHG emissions (Rothausen and Conway 2011). Within the WEFN, there is an obvious trade-off between water availability and food production, competing demands that pose a risk to the supply of the basic commodities of food, energy and water in line with the SDGs (Bleischwitz et al. 2018; Gao et al. 2019), all of which has the potential for inter-sectorial or inter-regional conflicts (Froese and Schilling 2019). Currently, 24% of the global population live in regions with constant water-scarce food production, and 19% experience occasional water scarcities (Kummu et al. 2014). To counterbalance the demand for food and comestibles in regions that experience constant or intermittent supplies, transportation is needed, which in itself requires suitable infrastructure, energy supplies, a well-functioning trading environment and support policies. Of the 2.6 billion people who experience constant or occasional water scarcities in food production, 55% rely on international trade, 21% on domestic trade and the remainder on water stocks (Kummu et al. 2014).

The relations between the influence of hydro-climatic variability, socio-economic conditions and patterns of water scarcity have been addressed by (Veldkamp et al. 2015). A key finding of this study was the ability of the hydro-climate and the socio-economy to interact, enforcing or attenuating each other, though with the former acting as the key immediate driver, and the influence of the latter emerging after six to ten years.

The trade-offs between competing demands have been investigated on a continental scale in the US Great Plains, highlighting the influence of irrigation in mitigating reductions in crop yields (Zhang et al. 2018b). Despite crop-yield reductions of 50% in dry years compared to wet years, a key conclusion was that the irrigation should be counterbalanced against general water and energy savings within the context of trade-offs. In East Asia, the WEFN has been quantified, highlighting obvious trade-offs between economic growth, environmental issues and food security (White et al. 2018). This same study also highlights the concept of a virtual WEFN that includes water embodied within products that are traded and shipped. (Liu et al. 2019) find an urgent need for proper assessment methods, including of trade within the WEFN, due to the significant resource allocations.

Within the WEFN, the implementation of policies to achieve low stabilisation targets is strongly linked to sustainable development within the water sector with regard to water management and water conservation, indicating that additional coherence in policies affecting the water, energy and food sectors (among others) will be critical in achieving the SDGs see also Chapter 7). Subsidized fertilizers, energy and crops can drive unsustainable levels of water usage and pollution in agriculture. More than half the world's population, roughly 4.3 billion people in 2016, live in areas where the demand for water resources outstrips sustainable supplies for at least part of the year. Irrigated agriculture is already using around 70% of the available freshwater, and the large seasonal variations in water supply and the needs of different crops can create conflicts between water needs across sectors at different time scales (Wada et al. 2016). However, as there is little potential for increasing irrigation or expanding cropland (Steffen et al. 2015), gaps in food production gaps must be closed by increasing productivity and cropping densities on currently harvested land by increasing either rain-fed yields or water-use efficiency (Alexandratos and Bruinsma 2012).

It has been argued that applying an integrated approach to water-energy-climate-food resource management and policy-making is highly beneficial in properly addressing the co-benefits and trade-offs (Brouwer et al. 2018; Howells et al. 2013), accommodating the SDGs (Rasul 2016) and in general assessing enabling strategies to improve resource efficiency (Dai et al. 2018). For an integrated approach to analysing the WEFN, a number of modelling approaches, tools and frameworks have been proposed (Brouwer et al. 2018; de Strasser et al. 2016; Gao et al. 2019; Larsen et al. 2019; Smajgl et al. 2016), often involving multi-objective calibration. Such tools enable decision-makers to evaluate the optimal water-allocation and energy-saving solutions for the specific geography in question. As an example, (Scott 2011) found the higher transportability of electricity, compared to water, pivotal in water-energy adaptation solutions in the USA, while arguing for the additional coordination of water and energy policies as a key instrument in balancing the trade-offs.

Common to all these integrated efforts is the challenge involved in making comparisons across studies due to the combined complexities of assumptions, model codes, regions, variables, forcings etc. To accommodate these challenges, (Larsen et al. 2019) suggest employing shared criteria and forcing data to enable cross-model comparisons and uncertainty estimates, as also highlighted by (Brouwer et al. 2018). Other limitations in current WEFN research are partial system descriptions, the failure to address uncertainties, system boundaries, and evaluation methods and metrics (Zhang et al. 2018b). The lack of proper access to WEFN data and data quality has been highlighted by (D'Odorico et al. 2018; Larsen et al. 2019). Furthermore, gaps have been identified between theory and end-user applications in the lack of any focus on food nutritional values as opposed to calories alone, in the understanding of water availability in relation to management practices, in integrating new energy technologies and in the resulting environmental issues (D'Odorico et al. 2018).

Therefore, looking ahead, future fields of WEFN research should provide greater insights into all these aspects. Holistic frameworks have been put forward to facilitate methods of WEFN management by focusing on, for example, the geographical complexities with regard to transboundary challenges within hydrological catchments (de Strasser et al. 2016), aligning policy incentives (Rasul 2016) and making synergies and trade-offs in relation to WEFN SDG targets (Fader et al. 2018) etc. The roles of all levels of government in optimal WEFN management are also highlighted in (Kurian 2017), especially with regard to shaping the behaviour of individuals. Furthermore, (Kurian 2017) highlights the challenges involved in science and policy communicating with one another and in the provision of optimal instruments and guidelines. Engaging non-experts and end-users in scientific processes is seen as essential to capturing previous failures and successes and to ensure that understanding the challenges is updated to help shape the research questions.

Coordination of water use across different sectors and deltas is an important factor in sustainable water management. Examples of instruments and policies that support this from India and Sub-Saharan Africa in relation to the groundwater crisis are given below. India is the world's largest user of groundwater for irrigation, which covers more than half of the country's total irrigated agricultural area, is responsible for 70% of food production and supports more than 50% of the population (700 million people) (see also Chapter 7). However, excessive extraction of groundwater is depleting aquifers across the country, and falls in the water table have become pervasive. Improved water-use efficiency in irrigated agriculture is being considered, both globally and in India, as a way of meeting future food requirements with increasingly scarce water resources (Fishman et al. 2015).

The entirety of Sub-Saharan Africa has an undeveloped potential for groundwater exploitation, despite the general perception of a global groundwater crisis, this being due to the absence of services to support groundwater development (Cobbing 2020). It is estimated that most Sub-Saharan countries in Africa utilize less than 5% of their national sustainable yields (Cobbing and Hiller 2019). The initial tool for driving sustainable groundwater exploitation is a change in the narrative of a lack of resources in order to stimulate increased agricultural production and increased fulfilment of the SDGs (Cobbing 2020). Quantitative measures of actual groundwater vulnerability based on multiple indicators have been calculated by, for example, (van Rooyen et al. 2020), showing that 20.4% of South Africa's current water resources are highly vulnerable and are projected to worsen fifty years into the future.

Despite the positive perspectives regarding Sub-Saharan groundwater resources, the 2015-2017 water crisis in South Africa, including in Cape Town, clearly predicts vulnerability to climate variability (Carvalho Resende et al. 2019), which is predicted to increase. Serving as inspiration for the future mitigation of water depletion, (Olivier and Xu 2019) suggest certain governance tools to improve the diversification of water sources and the management of existing supplies.

17.3.3.3 Industry

Industrial transformation is a core component in achieving sustainable development. Across all industrial sectors, the development and deployment of innovative technologies, business models and policy approaches at scale will be essential in accelerating progress both with meeting the economic and social development goals and with achieving low emissions. In this section, we assess the synergies and trade-offs between mitigation options and the SDGs, with a specific focus on asking whether economic growth and employment creation can work jointly with climate actions and other SDGs in least developed and developing countries. Examples of synergies and trade-offs are provided based on the conclusions of Chapter 9 on the building sector and Chapter 11 on industry. The potential for greening industry is discussed in relation to eco-industrial parks, with examples from Ethiopia, China, South Africa and Ghana.

Chapter 11 concludes that achieving net zero emissions from the industrial sector are possible. This will require the provision of electricity free from greenhouse gas (GHG) emissions, including from other energy carriers, increased electrification, low carbon feedstocks, and a combination of energy efficiency, reduced demand for materials, a more circular economy, electrification and carbon capture, use and storage (CCUS).

The potential co-benefits of mitigation options in industry has been mapped out in Chapter 11 in relation to five categories of mitigation options: material efficiency and reductions in the demand for materials, the circular economy and industrial waste, carbon capture utilization and storage, energy efficiency, and electrification and fuel switching (Figure 11.15 in Chapter 11). In particular, the first two categories of options are assessed as having several co-benefits for the SDGs, including SDGs 3, 5, 7, 8, 9 11, 12, and 15. Some studies also point out the potential trade-offs in respect of employment and the costs of cleaner production. The other options primarily impact on climate actions, decent work and employment, and industry as such.

Okereke et al. (2019) offer important generic conclusions on green industrialisation and the transition based on a study of socio-technical transition in Ethiopia. The importance of drivers for changes in terms of clear policy goals and government support for green growth and climate policies, as well as support from a strong culture of innovation, is emphasized. The study also identifies key barriers in relation to stakeholder interactions, the availability of resources and the ongoing tensions between ambitions for high economic growth and climate change. Green innovation in industry critically depends on regulations. Gramkow and Anger-Kraavi (2018) have assessed the role of fiscal policies in greening Brazilian industry based on an econometric analysis of 24 manufacturing sectors. They conclude that instruments like low-cost finance for innovation and support to sustainable practices effectively promote green innovation.

Luken (2019) have assessed the drivers, barriers and enablers for green industry in Sub-Saharan Africa, concluding that major barriers exist related to material and input costs, as well as product requirements in foreign markets, and that as a result there are trade-offs between economic and environmental performance. Studies of ten countries are reviewed, and although they suffer from limited information, they conclude similarly that further progress is being hindered by poor access to finance and weak government regulation. (Greenberg and Rogerson 2014) They similarly conclude that the greening of industry in South Africa is lagging behind due to economic barriers and weak governance, despite its high priority in government planning and among international partners.

Ghana has launched a "One District One Factory" (1D1F) initiative, aimed at establishing at least one factory or enterprise in each of Ghana's 216 districts as a means of creating economic growth poles to accelerate the development of these areas and create jobs for the country's increasingly youthful population. The policy aims to transform the structure of the economy from one dependent on the production and export of raw materials to a value-added industrialized economy driven primarily by the private sector (Yaw 2018). As has been pointed out by (Mensah et al. 2021), in its initial design the programme did not take environmental quality into consideration. Although it was successful in creating economic growth, exports and employment, the environmental impacts have been negative. It has therefore been recommended that environmental regulations be imposed on foreign investments. Similar conclusions have been drawn by (Solarin et al. 2017).

Chapter 11 concludes that eco-industrial parks, in which businesses cooperate with each other in order to avoid environmental pressure and support sustainable development, have delivered several benefits in relation to overall reductions in both virgin materials and final wastes, implying significant reductions in industrial GHG emissions. Due to these advantages, eco-industrial parks have been actively promoted, especially in East Asian countries such as China, Japan and South Korea, where national indicators and governance exist (Geng et al. 2019; Geng and Hengxin 2009).

Zeng et al. (2020) have assessed the role of eco-industrial parks in China's green transformation for 33 development zones in relation to contributions to GDP, industrial value added, exports, water and energy consumption, CO_2 levels and sulphur emissions. They concluded that industrial parks have played a very important role in China's industrialisation, and that this structure has supported the decoupling of economic growth and energy and water consumption from the environmental impacts. However, improved environmental performance would require better access to finance and a higher priority by management.

Eco-industrial parks have been promoted in Ethiopia by the government and UNIDO, based on the expectation that they could help to boost the economy (UNIDO 2018, Oqubay et al 2021). One of the success stories is an industrial park in Hawassa, a nation-level textile and garment industrial park with a "zero emissions commitment" based on renewable energy and energy-efficient technologies. However, the concept of the industrial park, including feasible policies and institutional arrangements, is new to Ethiopia's regulatory processes, and this has created problems for management, knowledge and governance, hindering their fast implementation.

A number of business associations have developed strategies for sustainable development and climate change, including cooperate social responsibility (CSR). International initiatives have included the promotion of CSR initiatives by international investors in low-income countries to support a broad range of development priorities, including social working conditions, eliminating child labour and climate change (Lamb et al. 2017). Leventon et al. (2015) evaluated the role of mining industries in Zambia in supporting climate-compatible development and concluded that, although the industry has played a positive role in avoiding migration and pressure on forest resources, there is a lack of coordination between government and industry initiatives.

It can be concluded that most of the mitigation options in industry considered in this section could have synergies with the SDGs, but also that some of the renewable-energy options could indicate some trade-offs in relation to land use, with implications for food- and water security and costs. Carbon capture and storage could play an enabling role in the provision of reliable, sustainable and modern energy and could support decarbonisation, but it can also be costly (IEAGHG 2020; Mikunda et al. 2021). The provision of water for CCS can include both synergies and trade-offs with the SDGs due to recent progress in water-management technologies (Giannaris et al. 2020; IEAGHG 2020; Mikunda et al. 2021)

17.3.3.4 Cities, Infrastructure and Transportation

With 80% of the global population expected to be urban by 2050, cities will shape development paths for the foreseeable future (United Nation 2018). The challenge for many policymakers is to construct development paths that make cities clean, prosperous and liveable while mitigating climate change and building resilience to heatwaves, flooding and other climate risks. The IPCC 1.5 report sees achieving these objectives as feasible: cities could potentially realize significant climate and sustainable-development benefits from shifting development paths (Wiktorowicz et al. 2018). The section assesses the synergies and trade-offs between meeting the SDGs and climate-change mitigation, as well as providing a general overview of mitigation options in cities and of enabling factors, including city networks and plans for jointly addressing the SDGs and climate-change mitigation.

Chapter 8 concludes that urban areas potentially offer several joint benefits between mitigation and the SDGs, and that since AR5, evidence of the co-benefits of urban mitigation continues to grow. In developing countries, a co-benefits approach that frames climate objectives alongside other development benefits arise increasingly being seen as an important concept justifying and driving climate-change actions in developing countries (Sethi and Puppum De Oliveria 2018; Seto et al. 2016).

Evidence of the co-benefits of urban mitigation measures on human health has increased significantly since the IPCC AR5, especially through the use of health-impact assessments in cities like Geneva, where energy savings and cleaner energy-supply structures based on measures for urban planning, heating and transport have reduced CO_2, NOx and PM10 emissions and increased the opportunities for physical activity for the prevention of cardiovascular diseases (Diallo et al. 2016).

There is increasing evidence that climate-mitigation measures can lower health risks that are related to energy poverty, especially in vulnerable groups, such as the elderly (Monforti-Ferrario et al. 2019). Moreover, the use of urban forestry and green infrastructure as both a climate mitigation and an adaptation measure can reduce heat stress (Kim and Coseo 2019; Privitera and La Rosa 2017) while removing air pollutants to improve air quality (Scholz et al. 2018; De la Sota et al. 2019) and enhancing well-being, including contributions to local development and possible reductions of inequalities (Lwasa et al. 2015). Other studies evidence the potential to reduce premature mortality by up to 7,000 in 53 towns and cities and to create 93,000 net new jobs and lower global climate costs, as well as reduce personal energy costs based on road maps for renewable energy transformations (Jacobson et al. 2018).

The co-benefits of energy-saving measures described by 146 signatories to a city climate network due to improved air quality have been quantified as 6,596 avoided premature deaths (with a 95% confidence interval of 4,356 to 8,572 avoided premature deaths) and 68,476 years of life saved (with a 95% confidence interval of 45,403 and 89,358 years of life saved) (Monforti-Ferrario et al. 2019). Better air quality further reinforces the health co-benefits of climate-mitigation measures based on walking and bicycling, since the evidence suggests that increased physical activity in urban outdoor settings with low levels of black carbon improves lung function (Laeremans et al. 2018). Chapter 9 shows that mitigation actions in buildings have multiple co-benefits resulting in substantial social and economic value beyond their direct impacts on reducing energy consumption and GHG emissions, thus contributing to the achievement of almost all the United Nation's SDGs. Most studies agree that the value of these multiple benefits is greater than the value of the energy savings, while their quantification and inclusion in decision-making processes will strengthen the adoption of ambitious reduction targets and improve coordination across policy areas.

There are several examples of cities that have developed plans for meeting both the SDGs and mitigation, which demonstrates the feasibility of meeting these objectives jointly. Quito, Ecuador, a city with large carbon footprints (Global Opportunity Explorer 2019) and climate vulnerabilities, has adopted low-carbon plans that aim to achieve the climate goals while introducing net zero energy buildings and reducing water stress (Ordoñez et al. 2019; Marcotullio et al. 2018). Several cities in China, Indonesia and Japan have invested in green city initiatives by means of green infrastructural investments, which is claimed to be a form of smart investment. Through this type of investment, economic growth and greenhouse gas (GHG) emissions reductions can be achieved in cities (Jupesta et al. 2016). Multi-level governance arrangements, public-private cooperation and robust urban-data platforms are among the factors enabling the pursuit of these objectives within countries (Corfee-Morlot et al. 2009; Gordon 2015; Creutzig et al. 2019; Yarime 2017).

In addition to the mostly domestic enablers listed previously, some cities have also benefited from working with international networks. The Global Covenant of Mayors for Climate and Energy (Covenant of Mayors 2019), the World Mayors Council on Climate Change, ECLEI, C40, and UNDRR (ECLEI 2019; C40 Cities 2019; UN- UNDRR 2019) have provided targeted support, disseminated information and tools, and sponsored campaigns (Race to Zero) to motivate cities to embrace climate and sustainability objectives. Despite this support, it should be stressed that most cities are in the early stages of climate planning (Climate-Adapt 2019; Eisenack and Reckien 2013; Reckien et al. 2018). Furthermore, in some cases city policymakers may fail to highlight the synergies and trade-offs between climate and sustainable development or rebrand GHG-intensive practices as 'sustainable' in relevant plans (Tozer 2018).

With regard to city networks, Chapter 8, Section 8.5 concluded that the importance of urban-scale policies for sustainability has increasingly been recognized by international organizations and national and regional governments. For example, in 2015, more than 150 national leaders adopted the UN's 2030 Sustainable Development Agenda, including stand-alone SDG 11, "make cities and human settlements inclusive, safe, resilient and sustainable" (United Nations 2015 p. 14). The following year, 170 countries agreed to the UN New Urban Agenda (NUA), a central part of which is recognizing the importance of national urban policies (NUPs) as a key to achieving national economic, social and environmental goals (United Nations 2015a, 2017). Similarly, the Sendai Framework for Disaster Risk Reduction identifies the need to focus on unplanned and rapid urbanization to reduce exposure and vulnerability to the risks of disasters (United Nations 2015b).

For many cities, a key to reorienting development paths will be investing in sustainable, low-carbon infrastructure. Because infrastructure has a long lifetime and influences everything from lifestyle choices to consumption patterns, decisions over an estimated USD90 trillion of infrastructure investment (from now to 2030) will be critical in order to avoid becoming locked into unsustainable paths (WRI 2016). This is particularly true in developing countries, where demands for new buildings, roads, energy and waste-management systems are already surging. To some extent, policies that accelerate building renovation rates, including voluntary programmes (Van der Heijden 2018), can support transitions down more sustainable paths (Kuramochi et al. 2018). Factoring climate and sustainable development considerations into policy tools that facilitate quantitative emission performance standard (EPS) and the inclusion of climate and sustainable development benefits and risks in infrastructure assessments or risk-adjusted returns on investments in development banks could also prove useful (Rydge et al. 2015). Strong policy signals from the UNFCCC and from national climate policies and strategies (including NDCs) could facilitate uptake of the relevant policies and the use of these tools.

Infrastructural investments will also have wide-ranging implications for sustainable, low-carbon urban development, namely transport and mobility. To some extent, decision-making frameworks such as Avoid-Shift-Improve could help make these patterns low carbon and sustainable (Dalkmann and Brannigan 2007; Wittneben et al. 2009). Mixed land-use planning and compact cities can not only help avoid emissions or shift travellers into cleaner modes (Cervero 2009),), they can also improve air quality, reduce commuting times, enhance energy security and improve connectivity (Pathak and Shukla 2016; Zusman et al. 2011)

17.3.3.5 Mitigation-adaptation relations

The section will consider the links between mitigation and adaptation options in the context of sustainable development and the associated synergies and trade-offs. Cross-cutting conclusions will be drawn based on Chapter 3 and the sectoral chapters of AR6 WGIII and Chapter 18 of AR6 WGII. The focus will be on the following sectors: agriculture, food and land use; water-energy-food; industry and the circular economy; and urban areas.

IPCC, WG II, concludes that coherent and integrated policy-planning is needed in order to support integrated climate change adaptation and mitigation policies and that this is a key component of climate-resilient development pathways. Section 4.5.2 in Chapter 4 assesses development pathways and the specific links between mitigation and adaptation, concluding that there can be co-benefits, and trade-offs, where mitigation implies maladaptation. However, adaptation can also be a prerequisite for mitigation. It is therefore concluded that making development pathways more sustainable can build the capacity for both mitigation and adaptation.

Climate actions, including climate-change mitigation and adaptation, are highly scale-dependent, and solutions are very context-specific. Especially in developing countries, a strong link exists between sustainable development, vulnerability and climate risks, as limited economic, social and institutional resources often result in low adaptive capacities and high vulnerability. Similarly, the limitations in resources also constitute key elements weakening the capacity for climate-change mitigation (Jakob et al. 2014). The change to climate-resilient societies requires transformational or systemic changes, which also have important implications for the suite of available sustainable-development pathways (Kates et al. 2012; Lemos et al. 2013). Thornton and Comberti (2017) point to the need for social-ecological transformations to take place if synergies between mitigation and adaptation are to be captured, based on the argument that incremental adaptation will not be sufficient when climate-change impacts can be extreme or rapid and when deep decarbonization simultaneously involves social change (Chapter 18 in AR6 WG II).

As discussed in AR6 WG II, Section 18.4 in Chapter 18, there are synergies and trade-offs between adaptation and sustainable development, as well as between mitigation and sustainable development, which is supported by comprehensive assessments such as that by (Dovie 2019; Sharifi 2020). Links between mitigation and adaptation options are identified in Chapter 18 in AR6 WG II, such as expected changes in energy demand due to climate change interacting with energy-system development and mitigation options, changes to agricultural production practices to manage the risks of potential changes in weather patterns affecting land-based emissions and mitigation strategies, or mitigation strategies that place additional demands on resources and markets. This increases the pressures on and costs of adaptation or ecosystem restoration linked to carbon sequestration and the benefits in terms of the resilience of natural and managed ecosystems, but it also could restrict mitigation options and increase costs. Chapter 3 of AR6 WG III similarly concludes that the connectedness and coherence of actions to mitigate climate change could support the conservation and adaptation of ecosystems and meet the sustainable development goals more widely.

Options to reduce agricultural demand (e.g., dietary change, reducing food waste) can have co-benefits for adaptation through reductions in the demand for land and water (Smith et al. 2019b). For example, Grubler et al. (2018) show that stringent climate-mitigation pathways without reliance on BECCS can be achieved through efficiency improvements and reduced energy service and consumptions levels in high-income countries.

Agriculture, food and land-use is the sector where most climate policy options can simultaneously generate impacts on mitigation, adaptation and the SDGs (Locatelli et al. 2015; Kongsager et al. 2016). Bryan et al. (2013) identified a range of synergies and trade-offs across adaptation, mitigation and the SDGs in Kenya, given the diversity of its climatic and ecological conditions. Improved management of soil fertility and improved livestock-feeding practices could provide benefits to both climate-change mitigation and adaptation, as well as increase income generation from farming. However, other improvements to agricultural management in Kenya, for example, soil water conservation, could only provide benefits across all three domains in some specific sub-regions.

Conservation agriculture can yield mitigation co-benefits through improved fertiliser use or the efficient use of machinery and fossil fuels (Cui et al. 2019; Harvey et al. 2014; Pradhan et al. 2018). Climate-smart agriculture (CSA) ties mitigation to adaptation through its three pillars of increased productivity, mitigation and adaptation (Lipper et al. 2014), although managing trade-offs among the three pillars requires care (Kongsager et al. 2016; Thornton and Comberti 2017; Soussana et al. 2019). Sustainable intensification also complements CSA (Campbell et al. 2014). Enhanced sustainable adaption can lead to effective emission-reduction benefits, such as climate-smart agricultural technologies (Nefzaoui et al. 2012; Poudel 2014) and ecosystem-based adaptation. Berry, P et al. (2015); Geneletti and Zardo (2016); and Warmenbol and Smith (2018) have shown how increases in livelihoods can contribute to climate change mitigation in Europe.

Agroforestry can sustain or increase food production in some systems and increase farmers' resilience to climate change (Jones et al. 2013). Some sustainable agricultural practices have trade-offs, and their implementation can have negative effects on adaptation or other ecosystem services. Agricultural practices can aid both mitigation and adaptation on the ground, but yields may be lower, so there may be a trade-off between resilience to climate change and efficiency. Interconnections within the global agricultural system may also lead to deforestation elsewhere (Erb et al. 2016). Implementation of sustainable agriculture can increase or decrease yields, depending on context (Pretty et al. 2006) (Chapter 4).

Land-based mitigation and adaptation will not only help reduce greenhouse gas emissions in the AFOLU sector, but also help augment the sector's role as a carbon sink by increasing forest and tree cover through afforestation and agroforestry activities and other eco-system-based approaches. Some of these options, however, can also have negative impacts on GHG emissions in the form of indirect impacts on land use (for a more detailed discussion, see Chapter 7). If managed and regulated appropriately, the land use, land-use change and forestry (LULUCF) sector could play a key role in mitigation and be a key sector for emissions reductions beyond 2025 instead of contributing substantially to emissions reductions beyond 2025 (Keramidas et al. 2018). However, the large-scale deployment of intensive bioenergy plantations, including monocultures, replacing natural forests and subsistence farmlands are likely to have negative impacts on biodiversity and can threaten food and water security, as well as local livelihoods, partly by intensifying social conflicts, partly by reducing resilience (Díaz et al. 2019). Expansion on to abandoned or unused croplands and pastures nonetheless present significant global potential, and will avoid the sustainability risks of expanding agriculture into natural vegetation (Næss et al. 2021).

Based on a literature review, Berry et al. (2015) identified water-saving and irrigation techniques in agriculture as attractive adaptation options that have positive synergies with mitigation in increasing soil carbon, reducing energy consumption and reducing CH_4 emissions from intermittent rice-paddy irrigation. These measures could, however, reduce water flows in rivers and adversely affect wetlands and biodiversity. The study also concluded that afforestation could reduce peak water flows and increase carbon sequestration, but trade-offs could emerge in relation to the increased demand for water.

Fast-growing tree monocultures or biofuel crops may enhance carbon stocks but reduce downstream water availability and the availability of agricultural land (Harvey et al. 2014). Similarly, in some dry environments, agroforestry can increase competition with crops and pastureland, decreasing productivity and reducing the yields of catchment water (Schrobback et al. 2011; Chapter 7).

Hydro-power dams are among the low-cost mitigation options, provided the cost of constructing the plant is taken into account, but they could have serious trade-offs in relation to key sustainable-development aspects, since in respect of water and land availability dams can have negative effects on ecosystems and livelihoods, thereby implying increased vulnerabilities. Section 17.3.3.2 on the water-energy-food nexus includes examples of trade-offs between the benefits of producing electricity from hydro-power dams and the trade-offs with ecosystem services and using land for agriculture and livelihoods.

There are several potentially strong links between climate-change adaptation in industry and climate-change mitigation. Various supply chains can be affected by climate change, energy supply and water supply, and other resources can be disrupted by climate events. Adaptation measures can influence GHG emissions in their turn and thus mitigation because of the demand for basic materials, for example, as well as by influencing outdoor environments and labour productivity (Chapter 11.1.4).

Implementing adaptation options in industry can also imply increasing the demand for packaging materials such as plastics and for access to refrigeration. These are among the adaptation options that are dependent on temperature and storage possibilities, as well as being major sources of GHG emissions.

An increasing number of cities are becoming involved in voluntary actions and networks aimed at drawing up integrated plans for sustainable development and climate-change mitigation and adaptation, including cities in both high- and low-income countries around the world. Grafakos et al. (2019); Sanchez Rodriguez et al. (2018) concluded that cities are an obvious place for the development of plans that can capture several synergies between sustainable development and climate-resilient pathways. Kim and Grafakos (2019); and Landauer et al. (2019) similarly concluded that cities are an obvious platform for the development of integrated planning efforts because of the scale of policies and actions, which could potentially match the different policy domains. Kim and Grafakos (2019) assessed the level of integration of mitigation and adaptation in urban climate-change plans across 44 major Latin American cities, concluding that the integration of climate-change mitigation and adaption plans was very weak in about half the cities and that limited donor finance was a main barrier. The authors also mention barriers in relation to governance and the weakness or lack of legal frameworks. The integration of SDGs with adaptation could help increase the willingness of politicians to implement climate actions, as well as provide stronger arguments for investing the required resources (Sanchez Rodriguez et al. 2018).

The local integration of planning and policy implementation practices was also examined by Newell et al. (2018) in a study of eleven Canadian communities. It was concluded that, in order to put plans into practice, a deeper understanding needs to be established of the potential synergies and trade-offs between sustainable development and climate-change mitigation and adaptation. A model was applied to the evaluation of key impacts, including energy innovation, transportation, the greening of cities and city life. The impact assessment came to the conclusion that multiple benefits, costs and conflicting areas could be involved, and that bringing a broad range of stakeholders into policy implementation was therefore to be recommended.

There are several links between mitigation and adaptation options in the building sector, as pointed out in Chapter 9. Adaptation can increase energy consumption and associated GHG emissions (Kalvelage et al. 2013; Campagnolo and Davide 2019), for example, in relation to the demand for energy to meet indoor thermal comfort requirements in a future warmer climate (de Wilde and Coley 2012; Li and Yao 2012; Clarke et al. 2018). Mitigation alternatives using passive approaches may increase resilience to the impacts of climate change on thermal comfort and could reduce cooling needs (Wan et al. 2012; Andrić et al. 2019). However, climate change may reduce their effectiveness (Ürge-Vorsatz et al. 2014).

Mitigation and the co-benefits of adaptation in urban areas in relation to air quality, health, green jobs and equality issues are dealt with in Section 8.2 in Chapter 8, where it is concluded that most mitigation options will have positive impacts on adaptation, with the exception of compact cities, with trade-offs between mitigation and adaptation. This is because decreasing urban sprawl can increase the risks of flooding and heat stress. Detailed mapping between mitigation and adaptation in urban areas shows that there are many, very close interactions between the two policy domains and that coordinated governance across sectors is therefore called for.

Rebuilding and refurbishment after climate hazards can increase energy consumption and GHG emissions in the construction and building materials sectors, as it could making the existing building stock more climate-resilient (Hallegatte 2009; de Wilde and Coley 2012; Pyke et al. 2012) and thus also support implementation of the Sendai framework on disaster risk reduction (United Nations 2015b). Climate change in the form of extremely high temperatures, intense rainfall leading to flooding, more intense winds and/or storms and sea level rises (SLRs) can seriously impact transport infrastructure, including the operations and mobility of road, rail, shipping and aviation; Chapter 10 assesses the impacts on subsectors within transportation. At the same time, these sectors are major targets for GHG mitigation options, and many countries are currently examining what to do in terms of combined mitigation-adaptation efforts, using the need to mitigate climate change through transport-related GHG emissions reductions and pollutants as the basis for adaptation action (Thornbush et al. 2013; Wang and Chen 2019). For example, urban sprawl indirectly affects climate processes, increasing emissions and vulnerability, which worsens the ability to adapt (Congedo and Munafò 2014). Hence greater use of rail by passengers and freight will reduce the pressures on the roads, while having less urban sprawl will reduce the impacts on new infrastructure, often in more vulnerable areas (IPCC 2019; Newman et al. 2017).

Despite many links between mitigation and adaptation options, including synergies and trade-offs, Chapter 13 concludes that there are few frameworks for integrated policy implementation. One review of climate legislation in Europe found a lack of coordination between mitigation and adaptation, their implementation varying according to different national circumstances (Nachmany et al. 2015).

In developing and least developed countries, there are many examples of climate policies in the NDCs that have been drawn up in the context of sustainable development and that cover both mitigation and adaptation (Chapter 13; Beg 2002; and Duguma et al. 2014). However, there are many barriers to joint policy implementation. Despite the emphasis on both mitigation and adaptation policies, there is very limited literature on how to design and implement integrated policies (Di Gregorio et al. 2017; Shaw et al. 2014). For example, the links within the water, energy and food nexus require coordination among sectoral institutions and capacity-building in innovative frameworks linking science, practice and policy at multiple levels (Cook and Chu 2018; Nakano 2017; Shaw et al. 2014).

Another challenge is the shortage of financial, technical and human resources for implementing joint adaptation and mitigation policies (Antwi-Agyei et al. 2018b; Chu 2018; David and Venkatachalam 2019; Kedia 2016; Satterthwaite 2017). Several studies have stressed that the lack of finance for integrating policy implementation between sustainable development and climate-change mitigation and adaptation may constitute barriers to the implementation of adaptation projects to protect least-developed countries with many vulnerabilities.

Locatelli et al. (2016) come to similar conclusions regarding finance based on interviews with multilateral development banks, green funds and government organizations in respect of the agricultural and forestry sectors. International climate finance has been totally dominated by mitigation projects.

Those who were interviewed were asked about their willingness to change this balance and to commit more resources to projects that address both climate-change mitigation and adaptation. More than two-thirds of those interviewed, however, raised concerns that integrated projects could be too complicated and that a greater alignment of financial models across different policy domains could entail greater financial risks. Another barrier mentioned in respect of finance was that mitigation projects were primarily aimed at GHG emissions reductions, while adaptation projects had more national benefits and were also more suitable for community development and promoting equality and fairness. In an assessment of 201 projects in the forestry and agricultural sectors in the tropics Kongsager et al. (2016), found that a majority of the projects contributed to both adaptation and mitigation or at least had the potential to do so, despite the separation between these two objectives by international and national institutions.

17.3.3.6 Cross-sectoral digitalization

In this section, the potential role of digitalization as a facilitator of a fast transition to sustainable development and low emission pathways is assessed based on sectoral examples. The contributions of digital technology could contribute to efficiency improvements, cross-sectoral coordination, including new IT services, and decreasing resource use, implying several synergies with the SDGs, as well as trade-offs, for example, in relation to reduced employment, increasing energy demand and the increasing demand for services, possibly increasing GHG emissions.

The COVID-19 pandemic caused radical temporary breaks with past energy use trends. How post-pandemic recovery will impact on the longer-term energy transition is unclear. Recovering from the pandemic with energy-efficient practices embedded in new patterns of travel, work, consumption and production reduces climate mitigation challenges (Kikstra et al. 2021). The potential of digital contact-tracing to slow the spread of a virus had been quietly explored for over a decade before the COVID-19 pandemic thrust the technology into the spotlight (Cebrian 2021). The COVID-19 crisis is among the most disruptive events in recent decades and has had consequences for consumer behaviour. During the lockdowns in most countries, consumers have turned to online shopping for food products, personal hygiene and disinfection (Cruz-Cárdenas et al. 2021), making society more digitally literate.

The cost of new services provided by digitalization can be high, and this could imply barriers for low-income countries in joining new global information sharing systems and markets. Altogether this implies that any assessment of the contribution of digitalization to support the SDGs and low-carbon pathways will only be able to provide very context-specific results. Digital technologies could potentially disrupt production processes in nearly every sector of the economy. However, as an emerging area experiencing the rapid penetration of many sectors, there could be a window of opportunity for integrating sustainable development and low emission pathways. IIASA (2020) concludes that the digital revolution is characterised by many innovative technologies, which can create both synergies and trade-offs with the SDGs (IIASA 2020).

Digital technologies could potentially disrupt production processes in nearly every sector of the economy. However, as an emerging area experiencing the rapid penetration of many sectors, there could be a window of opportunity for integrating sustainable development and low emission pathways. TWI2050 (2020) concludes that the digital revolution is characterised by many innovative technologies, which can create both synergies and trade-offs with the SDG's (IIASA 2020).

WBSD (2019) has assessed the potential of communication technologies (ICT) to contribute to the transition to a global low-carbon economy in the energy, transportation, building, industry, and other sectors. The potential is estimated to be around 15% CO_2-equivalent emissions reductions in 2020 compared with a business as usual scenario. A range of ICT solutions have been highlighted, including smart motors and industrial process-management in industry, traffic-flow management, efficient engines for transport, smart logistics and smart energy systems.

The TWI2050 2019 report (IIASA 2019) assessed both the positive and negative impacts of digitalization in the context of sustainable development. It found that efficiency improvements, reduced resource-consumption and new services can support the SDGs, but also that there were challenges, including in relation to equality, facing the least developed and developing countries because of their low level of access to technologies. The necessary preconditions for successful digital transformation include prosperity, social inclusion, environmental sustainability, protection of jobs and good governance of sustainability transitions. One negative impact of digitalisation could be the rebound effects, where easier access to services could increase demand and with it GHG emissions. Digitalization in the manufacturing sector could also provide a comparative advantage to developed countries due to the falling importance of labour costs, while the barriers to emerging economies seeking to enter global markets could accordingly be increased.

In respect of governance, Krishnan et al. (2020) point out that the creation of synergies between sustainable development and low-emission urbanization based on digitalization could face barriers in the form of inadequate knowledge of structures and value creation through ecosystems that would need to be addressed by means of smart digitalizing, requiring organizational measures to support transformation processes.

Urban areas are one of the main arenas for new digital solutions due to rapid urbanization rates and high concentrations of settlements, businesses and supply systems, which offer great potential for large-scale digital systems. The emergence of smart cities has supported the uptake of smart integrated energy, transportation, water and waste-management systems, while synergies have been created in terms of more flexible and efficient systems. In its 2018 Policy and Action document, the Japanese Business Federation (Keidanren) launched Society 5.0, which include plans for smart city development (Carraz and Yuko 2019; Narvaez Rojas et al. 2021). To achieve smart cities, Society 5.0 aimed to facilitate diverse lifestyles and business success, while the quality of life offered by these options will be enhanced. It also aims to offer high-standard medical and educational services. Autonomous vehicles will be available and integrated with smart grid systems in order to facilitate mobility and flexibility in energy supply with a high share of renewable energy. The energy system will include microgrids, renewable with demand-side controls aligned with local conditions.

Chapter 6 of this report on "Energy Systems" points out that there are many smart energy options with the potential to support sustainable development by facilitating the integration of high shares of fluctuating renewable energy in electricity systems, potentially storing energy in EV batteries or fuel cells, and applying load shifting by varying prices over time. It is concluded that very large efficiency gains are expected to emerge from digitalization in the energy sector (Figure 6.18 in Chapter 6).

Section 9.9.2 in Chapter 9 concludes that the improved energy efficiency and falling costs in the building sector that could result from digitalization could have rebound effects in increasing both energy consumption and comfort levels. Increasing GHG emissions could be the result, but if low-income consumers are given faster access to affordable energy, this could agree with the SDGs, making it desirable to integrate policies targeting mitigation.

Section 10.1.2 in Chapter 10 discusses how the sharing economy, which, for example, could be facilitated by ICT platforms, could influence both mitigation and the SDGs. On the one hand, sharing has the potential to save transport emissions, especially if EVs are supplied with decarbonised grid electricity. However, an increase in transport emissions could result from this if increasing demand and higher comfort levels are facilitated, for example, by making access to EVs relatively easy compared with mass transit. Another possible trade-off is that the supply of public transport services would be limited to the elderly and other user groups.

Green innovation in agriculture is another emerging area in which digitalization is making huge progress. From the perspective of water provision, weather data can be used to predict rain amounts so that farmers can better manage the application of farm chemicals to minimize polluting aquifers and surface water systems used for drinking water. Meanwhile, smart meters, onsite and remote sensors and satellite data connected to mobile devices allow real-time monitoring of crop-water and optimal irrigation requirements. On the supply side, remote tele-control systems and efficient irrigation technologies enable farmers to control and optimize the quantity and timing of water applications, while minimizing the energy-consumption trade-offs of pressurized irrigation in both rural and urban agricultural contexts (Germer et al. 2011; Ruiz-Garcia et al. 2009).

Technology-driven precision agriculture, which combines geomorphology, satellite imagery, global positioning and smart sensors, enables enormous increases in efficiency and productivity. Taken together, these technologies provide farmers with a decision-support system in real time for the whole farm. Arguably, the world could feed the projected rise in population without radical changes to current agricultural practices if food waste can be minimized or eliminated. Digital technologies will contribute to minimizing these losses through increased efficiencies in supply chains, better shipping and transit systems, and improved refrigeration.

In conclusion, in most cases digitalization options may have both positive synergistic impacts on mitigation and the SDGs and some negative trade-offs. Energy-sector options are assessed primarily as having synergies, while some digitalisation options in transport could increase the demand for emission-intensive modes of transport. Digital platforms for the sharing economy could have both positive and negative impacts depending on the goods and services that are actually exchanged (see Cross Chapter Box 6 in Chapter 7). Options related to agriculture and the energy-water-food nexus could help manage resources more efficiently across sectors, which could create synergies. Digitalization can also raise a number of ethical challenges according to (Clark et al. 2019). Wider public discussion of internet-based activities was accordingly recommended, including topics such as the negotiation of online consent and the use of data for which consent has not been obtained.

17.3.3.7 Cross-sectoral overview of synergies and trade-offs between climate change mitigation and the SDGs

Based on a qualitative assessment in the sectoral chapters 6, 7, 8, 9, 10, and 11, Figure 17.1 below provides an overview of the most likely links between sectoral mitigation options and SDGs in terms of synergies and trade-offs. The general overview provided in the figure is supplemented by specific sector by sector comments on how the synergies and trade-offs mapped depend on the scale of implementation and the overall development context of places where the mitigation options are implemented. For some mitigation options these scaling and context-specific issues imply that there can be both synergies and trade-offs in relation to specific SDGs. In addition to the information provided in Figure 17.1, supplementary material (Supplementary Material Table 17.1) includes the detailed background material provided by the sectoral chapters in terms of qualitative information for each of the synergies and trade-offs mapped.

The assessment of synergies and trade-offs presented in Figure 17.1 depends on the underlying literature assessed by the sectoral chapters. In cases where no information about the links between specific mitigation options and SDGs are indicated, this does not imply that there are no links, but rather that the links have not been assessed by the literature.

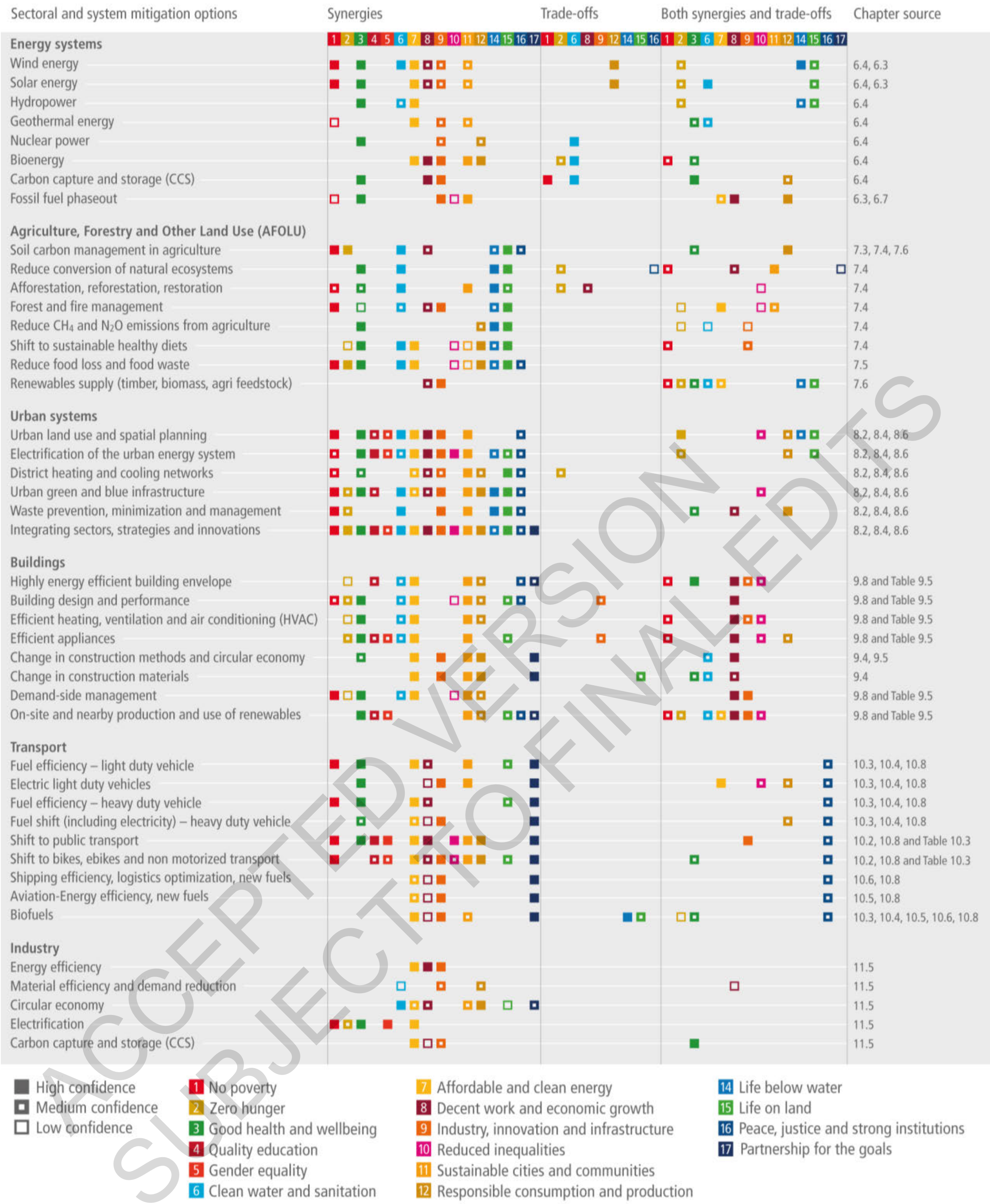

Figure 17.1 Trade-offs and synergies between sectoral mitigation options and the SDGs

Most of the energy sector options are assessed as having synergies with several SDGs, but there could be mixed synergies and trade-offs between SDG 2 'zero hunger' for wind and solar energy, and for hydropower due to land-use conflicts and fishery damage. Offshore wind could also have both synergies and trade-offs with SDG 14 'life below water' dependent on scale and implementation site, and it is emphasized that land-use should be coordinated with biodiversity concerns. Both wind and solar energy are assessed as having trade-offs with SDG 12 'responsible production and consumption' due to significant material consumption and disposal needs.

Geothermal energy is assessed as having synergies with SDG 1 'zero poverty' due to energy access and mixed synergies and trade-offs in relation to SDG 3 'good health and well-being' due to reduced air pollution, but with some risks in relation to water pollution, and in relation to SDG 'clean water and sanitation', if it is not well managed. Nuclear power is assessed as having synergies with SDG 3 'good health and well-being' due to reduced air pollution, but potential trade-offs in relation to SDG 6 'clean water and sanitation' due to high water consumption, and water consumption issues are also possible in relation to many of the other mitigation options in the energy sector. Synergies are identified in relation to SDG 12 'responsible production and consumption' for nuclear power due to low material consumption. CCUS has been assessed as having trade-offs in relation SDG 1 'end poverty' due to high costs and SDG 6 'clean water and sanitation' due to high water consumption. Synergies are related to SDG3 'improved health and well-being', and to SDG 9 'industry, innovation and infrastructure' due to the facilitation of decarbonisation of industrial processes. Both synergies and trade-offs could arrive in relation to SDG 12 'responsible production and consumption', since some rare chemicals and other inputs could in some cases be used with large-scale applications.

Bioenergy use as a fuel is assessed as one of the energy-sector mitigation options with most synergies and trade-offs with the SDGs. There could be synergies with SDG 1 'no poverty', with SDG 8 'decent work and economic growth' and SDG 9 'industry, innovation and infrastructure', This option, however, if combined with CCS, can be expensive and can compromise SDG1 'end poverty' due to the high costs involved.

Agriculture, forestry and other land-use mitigation options are very closely linked to the SDGs and offer both synergies and trade-offs, which in many cases are highly dependent on the scale of implementation. All the mitigation options included in Figure 17.1 are assessed as potentially having synergies with SDG 1 'end poverty', but trade-offs could also happen if large areas are used for biocrops and taken away from other activities, thus causing poverty, as well as in relation to food costs if healthier diets are made more expensive. In relation to SDG 2 'zero hunger', most of the mitigation options are assessed as being associated with both synergies and trade-offs. Trade-offs are particularly a risk with large-scale applications of afforestation projects, bioenergy crops and other land-hungry activities, which can crowd out food production.

SDG 'good health and well-being' can be supported by many mitigation options in the agriculture, forestry and food sectors, primarily due to the reduced environmental impacts, and the same is the case with SDG 14 'life below water' due to decreased nutrient loads, and SDG 15 'life on land' due to increased biodiversity, with the caveat however, that SDGs 14 and 15 could have both synergies and trade-offs dependent on land use. It is considered that there could be both synergies and trade-offs in relation to SDG 8 'decent work and economic growth' due to competition over land use related to the mitigation options reducing deforestation and reforestation and restoration, and the same is the case in relation to SDG 7 'affordable and clean energy' depending on the economic outcome of the mitigation options. Similarly the mitigation option of reduced CH_4 and N_2O emissions from agriculture are assessed as having mixed impacts on SDG 8 'decent work and economic growth', and SDG 9 'industry, innovation and infrastructure' depending on innovative food production. The mitigation options of reforestation and forest management are assessed as having mixed impacts on SDG 10 'reduced inequalities' depending on the involvement of local communities in projects. The assessment emphasises that the synergies and trade-offs of the mitigation options with the SDGs in this sector are very context- and scale-dependent, depending on how measures are carried out, for example, in relation to the enhanced production of renewables needed to replace fossil fuel-based products. If done on a massive scale and not adapted to local circumstances, there are adverse implications for food security, livelihoods and biodiversity.

All the urban mitigation options that have been assessed are considered to have synergies with the SDGs, and in a few cases both synergies and trade-offs are identified. In general, many links between mitigation options in the urban area and the SDGs have been identified in the literature. Urban land-use and spatial planning, for example, can support SDG1 'end poverty', and can also reduce vulnerability to climate change if integrated planning is undertaken, while access to food (SDG 2 'zero hunger'), and water (SDG 6) can also be achieved if supported by integrated planning. Electrification, district heating, and green and blue infrastructure in urban areas are expected to have synergies with all the SDGs addressed by the reviewed studies.

Mitigation options like waste prevention minimization and management are also assessed as having many synergies with the SDGs, but trade-offs could depend on the application of air-pollution control technologies, and on the character of informal waste-recycling activities. The impacts of the possible synergies and/or trade-offs with the SDGs will change according to the specific urban context. Synergies and/or trade-offs may be more significant in certain contexts than others. Regarding the SDGs, urban mitigation can support shifting pathways of urbanization towards sustainability. The feasibility of urban mitigation options is also malleable and can increase with more enablers. Strengthened institutional capacity that also supports the scale and coordination of the mitigation options can increase the synergies between urban mitigation options and the SDGs.

As for the urban mitigation options, the reviewed buildings sector studies reveal a lot of links between mitigation and the SDGs. Highly efficient building envelopes are expected to have synergies with the SDGs in all cases except those with potential trade-offs in relation to SDG 10 'reduced inequalities in relation to incomes'. Many SDG synergies are also identified for the building design and performance, heating, ventilation and air conditioning, and efficient appliances mitigation options. However, some trade-offs could appear in relation to SDG 8 'decent work and economic growth' due to macroeconomic impacts of reduced energy consumption, decreasing prices and stranded investments. Similar issues related to the economic impacts of reduced energy demand are also highlighted for all the other mitigation options, included for the building sector. In relation to construction materials and the circular economy, some trade-offs have been identified in relation to SDG 6 'clean water and sanitation' and SDG 15 'life on land' related to the use of biobased materials.

Consideration of the building sector highlights important context-specific issues related to synergies and trade-offs between mitigation options and SDGs such as the economic impacts (synergies and trade-offs) associated with reduced energy demand, resulting in lower energy prices, energy efficiency investments, the fostering of innovation and improvements in labour productivity. Furthermore, the distributional costs of some mitigation policies may hinder the implementation of these measures. In this case, appropriate access policies should be designed to shield poor households efficiently from the burden of carbon taxation. Under real-world conditions, improved cookstoves have shown smaller, and in many cases limited, long-term health and environmental impacts than expected, as the households use these stoves irregularly and inappropriately, and fail to maintain them, so that their usage declines over time. Specific distributional issues are highlighted in relation to various cookstove programs.

The mitigation options in the transportation sector are assessed as having synergies with SDG 1 'no poverty' and SDG 3 'good health and well-being' due to reduced environmental pollution, with exceptions in relation to pollution from biofuels and the risks of traffic accidents. Trade-offs are also mentioned in relation SDG 2 'zero hunger' where the production of biofuels takes land away from food production. Synergies are assessed in relation to SDG 7 'affordable and clean energy', SDG 8 'decent work and economic growth' and SDG 9 'industry, innovation and infrastructure'. It is emphasized that some mitigation options, like the increased penetration of electric vehicles, require innovative business models, and that digitalization and automatic vehicles will support the socio-economic structures that impede adoption of EV's and the urban structures that enable reduced car dependence. In conclusion, there is a need for investments in infrastructure that can support alternative fuels for LDVs. The large-scale electrification of LDVs requires the expansion of low-carbon power systems, while charging or battery-swapping infrastructure is needed for some segments.

The mitigation options in the industrial sector have been assessed primarily as having synergies with meeting the SDGs. Several options, including energy efficiency, material recycling and electrification, are assessed has being able to create increased employment and business opportunities related to SDG 8 'decent work and economic growth', but material efficiency improvements could reduce tax revenues. Electrification is assessed as having many synergies with SDGs, such as supporting SDG 1 'end poverty', SDG 2 'zero hunger', and SDG 3 'good health and well-being'. CCS applied in industry is assessed as having synergies in terms of the control of non-CO_2 pollutants (such as sulphur dioxide), but increases in non-CO_2 pollutants (such as particulate matter, nitrogen oxide and ammonia). The conclusion is that 15-25% additional energy will be required by CCS technologies compared with conventional plants, implying that production costs could increase significantly. For the industrial sector in general, it is concluded that the balance between synergies and trade-offs between mitigation options and SDGs in industry depends on technology and the scale of the sharing of co-benefits across regions, as well as on the sharing of benefits in business models over whole value chains.

Thus a number of cross-sectoral conclusions on synergies and trade-offs between mitigation options and the SDGs appear from the overview provided in Figure 17.1. There are many synergies in all sectors between mitigation options and the SDGs, and in a few cases there are also significant trade-offs that it is very important to address, since they can compromise major SDGs including SDG1 'no poverty', SDG 2 'zero hunger', and in some cases SDG 14 and SDG 15 'life below water' and 'life on land'. In particular, mitigation options in relation to land-use, such as afforestation and reforestation and bioenergy crops, can in some cases imply trade-offs with access to food and local sharing of benefits, but synergies can also exist if proper land management and cross-sectoral policies take sustainable land-use into account. The impacts and trade-offs for this sector are highly scale- and context-dependent, so the final outcome of mitigation policies should be considered in detail.

The urban systems and transportation could potentially achieve many synergies between mitigation policies and the SDGs, but integrated planning and infrastructure management are critical to avoiding trade-offs. Similarly, the buildings sector and industry have identified many potential synergies between mitigation options and the SDGs, but that raises issues related to the costs of new technologies, and in relation to households and buildings important equity issues are emerging in relation to the ability of low-income groups to afford the introduction of new technologies. Altogether these cross-sectoral conclusions call for a need to support policies that aid coordination between different sectoral domains and that include context-specific assessments of the sharing of benefits and costs related to the implementation of mitigation options.

17.4 Key barriers and enablers of the transition: synthesizing results

This section provides a deep and broad synthesis of theory (section 17.2) and evidence (section 17.3) in order to identify the conditions that either enable or inhibit transitions to sustainable low-carbon futures. Following the literature on sustainability transitions (see Cross-chapter Box 12 on Transition Dynamics), the section finds that there is rarely any one single factor promoting or preventing such transitions. Rather, marked departures from business as usual typically involve several factors, including technological innovations, shifts in markets, concerted efforts by scientists and civil-society organizations to raise awareness of the costs of continued emissions, social movements, policies and governance arrangements, and changes in belief systems and values.

All of this comes together in a co-evolutionary process that has unfolded globally, internationally and locally over several decades (Hansen and Nygaard 2014; Rogge et al. 2017; Sorman et al. 2020), and that may be guided or facilitated by interventions that target leverage points in the underlying development path (Burch and Di Bella 2021; Leventon et al. 2021). While transitions necessarily follow context-specific trajectories, more general lessons can be drawn by comparing the empirical details with both system-level and narrower explanations of change.

Sections 17.2 and 17.3 show that transitions often face multiple barriers, including infrastructure lock-in, behavioural, cultural and institutional inertia (Markard et al. 2020), trade-offs between transitions and other social or political priorities (Chu 2016), cost and a reliable (and growing) supply of renewable energy technologies and constituent materials (García-Olivares et al. 2018). Transitions away from fossil fuels and toward renewable energy-based systems, for instance, will require significant land-use decisions to avoid negative trade-offs with biodiversity and food security (Capellán-Pérez et al. 2017). Previous sections underline a related need to move beyond focusing on "rational" assessments of the costs and benefits of policies and technologies to involve people at all levels in order to overcome these multiple barriers. For example, the case of coal-fired power in China (section 17.3) shows that a transition to a lower carbon system is unlikely to happen even if models find it technically feasible and cost-effective. Rather, achieving a transition requires breaking locked-in high-carbon technological trajectories, path dependencies and resistance to change from the industries and actors that are benefiting from the current system (Rogge et al. 2017). Lock-in effects may be weaker in sectors and policy areas where fewer technologies exist, potentially opening the door to innovations that embed the climate in broader sustainability objectives (e.g., technologies and innovations that support the integration of food, water and energy goals). Such effects may still happen when there are significant information asymmetries and high-cost barriers to action, as can occur when working across multiple climate and development-related sectors (Kemp and Never 2017).

However, the same conditions that may serve to impede a transition (i.e., organizational structure, behaviour, technological lock-in) can also be 'flipped' to enable it (Burch 2010; Lee et al. 2017), while the framing of policies that are relevant to the sustainable development agenda can also create a stronger basis and stronger policy support. The technological developments and broader cultural changes that may generate new social demands on infrastructure to contribute to sustainable development will involve a process of social learning and awareness building (Naber et al. 2017; Sengers et al. 2019). However, it is also important to note that strong shocks to these systems, including accelerated climate-change impacts, economic crises and political changes, may provide crucial openings for accelerated transitions to sustainable systems through fundamental institutional changes (Broto et al. 2014). The global COVID-19 pandemic is one such shock that has sparked widespread conversations about recovery that is fundamentally more sustainable, equitable and resilient (McNeely and Munasinghe 2021). Key enabling conditions appear to be individual and collective actions, including leadership and education; financial, material, social and technical drivers that foster innovation; robust national and regional innovation systems that enhance technological diffusion (Wieczorek 2018); supportive policy and governance dynamics at multiple levels that permit both agility and coherence (see e.g. Göpel et al. 2016); measures to recognize and address the challenges to equality inherent in the transition; and long-range, holistic planning that explicitly seeks synergies between climate change and sustainable development while avoiding trade-offs. The sections that follow seek to assess and integrate these key categories of the barriers to and enablers of an accelerated transition to sustainable development pathways.

17.4.1 Behavioural and lifestyle changes

Transitions toward more sustainable development pathways are both an individual and a collective challenge, requiring an examination of the role of values, attitudes, beliefs and structures that shape behaviour, and of the dynamics of social movements and education at the local community, regional and global levels. Labelling the carbon included in products, for example, could help the decision-making process and increase awareness and knowledge. Individual action suggests aggregated but uncoordinated actions taken by individuals, whereas collective sustainability actions involve coordination, a process of participation and governance that may ensure more efficient, equitable and effective outcomes. There is evidence that the behaviour of individuals and households are part of a more encompassing collective action (see also Chapter 5.4.1).

Indeed, individual actions are necessary but insufficient to deliver transformative mitigation, and it is suggested that this be coupled with collective actions to accelerate the transition to sustainable development (Dugast et al. 2019). Actors with conflicting interests will compete to frame mitigation technologies that either "build or erode" the legitimacy of the technology, contested framing sites that can occur between incumbent and emerging actors or between actors in new but competing spaces

(Rosenbloom et al. 2016). How narratives are built around desired development pathways and specific emerging technologies, as well as how local values are integrated into visions of the future, have relevance for how these experiments are managed and enabled to expand (Horcea-Milcu et al. 2020; Lam et al. 2020).

17.4.1.1 Social movements and education

Sustainable development and deep decarbonization will involve people and communities being connected locally through various means – including globally via the internet and digital technologies (Bradbury 2015; Scharmer 2018; Scharmer, C, Kaufer 2015) –in ways that form social fields that allow sustainability to unfold (see also Gillard et al. 2016) and that prompt other shifts in thinking and behaviour that are consistent with the 1.5°C goal (O'Brien 2018; Veciana and Ottmar 2018). Indeed, social movements serve to develop collective identities, foster collective learning and accelerate collective action ranging from energy justice (see Section 17.4.5) (Campos and Marín-González 2020) to restricting fossil-fuel extraction and supply (Piggot 2018). This does not apply only to adults: as seen in the "Fridays for Future" marches, the young are also involving themselves politically (Peterson et al. 2019). Many initiatives have started with these marches, including "science for future" and new forms of sustainability science (Shrivastava et al. 2020).

It was Theory-U (Scharmer 2018, building on the work of scholars like Schein, Lewin or Senge) that inspired a so-called "massive open online course" (MOOC) jointly initiated by the Bhutan Happiness Institute and German Technical Assistance (GIZ) in 2015, since when it has been developed further and adapted to transform business, society and self as one example of how social movements can go together with science and education. It brings together people from different professions, cultures and continents in shared discussions and practices of sustainability. It also included marginalised communities and is shifting towards more sustainable lifestyles in all sectors (Nikas et al. 2020), including climate action.

Moreover, approaches like the "Art of Hosting" (Sandfort and Quick 2015) and qualitative research methods like storytelling and first-person research, as well as second-person inquiries, for example (Scharmer, C, Kaufer 2015; Trullen and Torbert 2004; Varela 1999), have been employed to bridge differences in cultures and sciences, as well as to forge connections between those working on climate change and sustainable development. Likewise, experiential tools, simulations and role-playing games have been shown to increase knowledge of the causes and consequences of climate change, the sense of urgency around action and the desire to pursue further learning (Ahamer 2013; Eisenack and Reckien 2013; Hallinger et al. 2020; Rooney-Varga et al. 2020).

The results from these research communities reveal how experiential learning takes place and how it encourages bonding between people, society and nature. This can be achieved by going jointly and consciously into nature (Gioacchino 2019), by creating spaces for intensive dialogue sessions with colleagues (Goldman-Schuyler et al. 2017) and forming, for example, a very practical u.lab hub, which involves following the MIT-u.lab course with a local community and is accompanied scientifically (Pomeroy and Oliver 2018). Others have pointed to social networks such as the "transition initiative" (Hopkins 2010), eco-village networks (see e.g., Barani et al. 2018), civil-society movements (Seyfang and Smith 2007) and intentional communities (see e.g., Grinde et al. 2018; Veciana and Ottmar 2018) as ways of generating the shared understandings that are central to inner and outer transitions, as well as the broader development of social movements. In some cases, these networks build on principles like permaculture to encourage people to "observe and interact," "produce no waste" and "design from patterns to details", not only in agriculture and gardening, but also in sustainable businesses and technologies to reduce CO_2 emissions (see e.g., Ferguson and Lovell 2014; Lessem 2018).

A related line of inquiry involves education for sustainable development (ESD). This builds on the UNESCO programme, 'ESD for 2030', and involves core values like peace culture, valuing cultural diversity and living global citizenship. One of the core insights from research on ESC is lifelong education continuing outside the classroom, a lifelong learning process that involves sustained actions by all ages and social segments (see e.g., Hume and Barry 2015) and achieving collaboration (Munger and Riemer 2012). Some authors have pointed to good levels of communication either directly or through the internet as the key to facilitating this learning (Sandfort and Quick 2015). Others have noted that transformative learning – that is, deepening the learning process – is critical because it helps to induce both shared awareness and collective actions (see e.g., Brundiers et al. 2010; Singleton 2015; Wamsler and Brink 2018).

A final area of work points to the importance of moving toward the knowledge production that underpins awareness-raising (Pelling et al. 2015). The accumulation of applied knowledge is leading increasingly to the co-design of participatory research with local stakeholders who are investigating and transforming their own situations in line with climate action and sustainable development (see e.g., Abson et al. 2017; Fazey et al. 2018; Wiek et al. 2012).

17.4.1.2 Habits, values and awareness

Many of the cases that explore transitions to sustainable development point to engrained habits, values and awareness levels as the most persistent yet least visible barriers to a transition. For example, in the transport sector, individuals can quickly become accustomed to personal vehicles, making it difficult for them to transition to sustainable, low-carbon modes of public transport. Demand for high-carbon transportation may also be locked in, and habits reinforced, if low-cost housing (for instance) is not sufficiently served by more sustainable (i.e. mass transit, safe cycling and walking infrastructure) transportation options (Mattioli et al. 2020).

This is made all the more challenging because car-manufacturing "incumbents" utilize information campaigns directed at the public, pursue lobbying and consulting with policy-makers, and set technical standards that privilege the status quo and prevent the entry of more sustainable innovations (Smink et al. 2015; Turnheim and Nykvist 2019). Tools such as congestion pricing, however, have been shown to be effective in motivating the switch from single-occupancy vehicle use to public transit, thus improving air quality and reducing traffic delays in dense city centres (Baghestani et al. 2020).

Complicating the problem further is that even well-intentioned top-down programmes initiated by an external actor may in some cases ultimately hinder transformative change (Breukers et al. 2017). For instance, in Delhi, India, attempts to introduce ostensibly more sustainable bus rapid transit (BRT) systems failed in part due to an arguably top-down approach that had limited public support. It may nonetheless be difficult to win public support (Bachus and Vanswijgenhoven 2018), and even grassroots initiatives may themselves be contested and dynamic, making it difficult to generate the collective push to drive a bottom-up transition forward (Hakansson 2018).

However, dominant, top-down approaches and local, grassroots "alternative" approaches and values do overlap and interact. For example, in Manchester, UK, dominant and alternative discourses interact with each other to create sustainable transformations through re-scaling (decentralizing) energy generation, creating local engagement with sustainability, supporting green infrastructure to reduce costs, re-claiming local land, transforming industrial infrastructure and creating examples of sustainable living (Hodson et al. 2017).

Embedding local values in higher-level policy frameworks is also significant for forest communities in Nepal and Uganda. Even so, policy intermediaries are not confident that these values will be advanced due largely to an emphasis on carbon accounting and the distribution of benefits (Reckien et al. 2018). In this case, however, norm entrepreneurs were able to promote the importance of local values through the formation of grassroots associations, media campaigns and international support networks (Reckien et al. 2018).

17.4.2 Technological and social innovation

Individuals and organizations, like institutional entrepreneurs, can function to build transformative capacity through collective action (Brodnik and Brown 2018). The transition from a traditional water-management system to the Water Sensitive Urban Design (WSUD) model in Melbourne offers an illustration of how whole systems can be changed in an urban system.

Private-sector entrepreneurs also play an important role in fostering and accelerating transitions to sustainable development (Burch et al. 2016; Ehnert et al. 2018a; Dale et al. 2017). Sustainable entrepreneurs (SEs), for instance, are described as those who participate in the development of an innovation while simultaneously being rooted in the incumbent energy-intensive system. SE actors who have developed longer term relationships, both formal and informal, with the public authorities can have considerable influence on developing novel renewable-energy technologies (Gasbarro et al. 2017). Institutions and policies that nurture the activities of sustainable entrepreneurs, in particular small- and medium-sized enterprises (Burch et al. 2016), can facilitate and strengthen transitions toward more sustainable development pathways, as can more fundamental adjustments to underlying business models, rather than relying only on incremental adjustments in the efficiency with which resources are used (Burch and Di Bella 2021).

The creation and growth of sustainable energy and clean-tech clusters enable economic development and transformation on regional scales. Such clusters can put pressure on incumbent technologies and rules to accelerate energy transitions. Successful clusters are nurtured by multi-institutional and multi-stakeholder actors building institutional support networks, facilitating collaboration between sectors and actors, and promoting learning and social change. Notably, regional economic clusters generate a buzz, which can have a strong influence on public acceptance, support and enthusiasm for sociotechnical transitions (McCauley and Stephens 2012).

In Norway, many incumbent energy firms have already expanded their operations into the alternative energy sector as both producers and suppliers (who often follow the lead of producers). Producers are responding to perceptions of larger-scale changes in the energy landscape (e.g., the green shift), along with uncertainties in their own sectors, and innovation can spill across actors in multiple sectors (Koasidis et al. 2020). While these firms are expanding out of self-interest, the expansion provides more legitimacy to new forms of technology and enables transfers of knowledge and resources to be introduced within this developing niche (Steen and Weaver 2017). Many large, well-established firms are pursuing sustainability agendas and opting for transparency with regard to their greenhouse gas emissions (Guenther et al. 2016; Kolk et al. 2008), supply chain management (Formentini and Taticchi 2016) and sustainable technology or service development (Dangelico et al. 2016).

Experiments with the transition open up pathways that can lead to energy transitions on broader scales. Experiments can build capacity by developing networks and building bridges between diverse actors, leveraging capital from government funds, de-risking private- and public-sector investment, and acting as hubs for public education and engagement (Rosenbloom et al. 2018).

Material barriers and spatial dynamics (Coenen et al. 2012; Hansen and Coenen 2015) are other critical obstacles to innovation: often, infrastructure and built environments change more slowly than policies and institutions due to the inherently long lifespans of fixed assets (Turnheim and Nykvist 2019). The example of transport infrastructure in Ontario, Canada, illustrates the need to integrate climate change into these infrastructural decisions in the very short term to combat the risk of being left with unsustainable planning features long into the future, especially combustion engines, significant road networks and suburbanization (Birch 2016).

17.4.3 Financial systems and economic instruments

Market-oriented policies, such as carbon taxes and green finance, can promote low-carbon technology and encourage both private and public investment in enabling transitions. Policies that are currently being tested include loan guarantees for renewable energy investments in Mali, policy insurance to reduce credit defaults within the feed-in tariff regime in Germany, or pledged funding to fully finance or partner private firms in order to advance renewable energy projects (Roy et al. 2018a). However, there may be some limitations in using carbon-pricing alone (rather than in combination with flexible regulations and incentives) where market failures hinder low-carbon investments (Campiglio 2016; World Bank 2019) and high political costs are incurred (Van Der Ploeg 2011).

Many forms of transformational change to energy systems are not possible when financial systems still privilege investing in unsustainable, carbon-intensive sectors. One of the root causes of the failure of traditional financial systems is the undervaluation of natural capital and unsettled property right issues that are associated with it. The exclusion of proper rents for scarcities or for global and local externalities, including climate change, can undermine larger-scale changes to energy systems (Clark et al. 2018). But even smaller-scale low-carbon energy and infrastructure projects can fail to get off the ground if uncertainty and investment risk discourage project planning and bank-lending programmes (Bolton et al. 2016). The EU's previous actions regarding the "shareholder maximisation norm" and non-binding measures have created path dependencies, limiting its flexibility in creating sustainable financial legislation. However, the Sustainable Finance Initiative and the Single Market may prove to be "policy hotspots" in encouraging sustainable finance (Ahlström 2019).Taking advantage of these hotspots may be crucial in overcoming path dependencies and setting new ones in motion.

One possible positive turn in this regard is the acceleration in investing in the environment (impact and ESG) globally: for instance, there is evidence that some institutional investors are divesting from coal, potentially auguring well for the future (Richardson 2017). The encouragement of governance and policy reforms that could facilitate similar expansions of investment in sustainable firms and sectors (Clark et al. 2018; Owen et al. 2018) could contribute to the dynamic feedback that gives a transition lift and injects momentum into it. Also, the degrowth movement, with its focus on sustainability over profitability, has the potential to speed up transformations using alternative practices like fostering the exchange of non-monetary goods and services if large numbers of stakeholders want to invest in these areas (Chiengkul 2017).

17.4.4 Institutional capacities and multi-level governance

Capable institutions and multi-level governance often support the inter-agency coordination and stakeholder coalitions that drive sustainable transitions. Such institutions and governance arrangements are frequently required to formulate and implement the multi-sectoral policies that spur the adoption and scaling of innovative solutions to climate change and other sustainable development challenges. For example, such institutional and governance conditions have helped support the industrial policies that will be needed to spread renewables through the creation of domestic supply chains (Zenghelis 2020) or to pilot CDR methods (Quarton and Samsatli 2020).

However, government agencies with climate and other remits do not always work well together: the absence of coordination and consensus building mechanisms can further deepen inter-agency conflicts that stall a transition. These challenges appear not only within but also between levels of decision-making. Studies of developing megacities, for instance, have found the lack of mechanisms promoting vertical cross-level integration to be a sizable constraint on decarbonisation (Canitez 2019). Differences in perspectives across non-state actors can similarly frustrate transitions in areas such as green buildings (Song et al. 2020).

Here coordination complicates matters: coalition-building may require mutually reinforcing changes to institutions and policies. For example, decentralized renewable energy has made progress in Argentina, but consumer electricity subsidies give agencies and firms supporting conventional energy an advantage over those promoting renewable energy. Similarly, the lack of concrete guidance in green finance policies can deprive government agencies and other stakeholders of the information needed to balance ecological and financial goals (Wang and Zhi 2016). Many of these challenges can be particularly formidable in developing countries, where agencies lack sufficient financial and other capacities. A lack of government funds to cover ongoing maintenance costs along with resource shortages in rural locations can pose constraints on sustainable energy (Schaube et al. 2018).

Building inter-agency or multiple stakeholders is frequently challenging because of the mutually reinforcing interactions between institutions and ideas. The imperceptible embedding of long-standing development paradigms (such as ‘grow now, clean up later’) in agency rules and standard operating procedures can make changes to governance arrangements challenging. This is partly because these rules and procedures can also shape the interests of key decision-makers (e.g., the head of an environmental agency). For some, this suggests a need to look not just at changing prevailing ideas and interests, but also at broader institutional and governance arrangements (Kern 2011).

However, institutional and governance reforms can be more than a technical exercise. Political, economic and other power relations can lock in dominant institutional and economic structures, making the integration of climate and sustainable development agendas exceedingly difficult. For example, though there have been recent reforms, the initial lack of early progress in Australia's energy transition is partly attributable to institutions of political economy being oriented to providing steady supplies of affordable fossil fuels (Warren et al. 2016).

This suggests that it is important to look closely at the pre-existing political economic system as well as the institutional context and capacities in assessing the prospects for transitions to sustainability. Furthermore, this is how existing institutions interact with ideas that often strengthen lock-ins. To illustrate, studies have shown that the status-quo orientations of leaders (including decision-makers' disciplinary backgrounds, world views and perceptions of risk) (Willis 2018), as well as the organizational culture and management paradigms within which they operate, affect the speed and ambitions of climate policies (Rickards et al., 2014).

Some studies have focused on factors that can break institutional and ideational lock-ins (Arranz 2017), while others have found that intentional higher-level (or, in the language of socio-technical transitions, "landscape") pressures can be the destabilizing force needed to move transitions forward (Falcone and Sica 2015). Often the state or national government (as the sovereign that determines how resources are used and allocated) can play a key role in destabilizing incumbent energy regimes, a role that is significantly strengthened by public support (Arranz 2017; Avelino et al. 2016). However, this role is not limited to government insiders. In some contexts, regime outsiders have also played a pivotal role in destabilizing regimes by combining persuasive narratives that gain market influence (Arranz 2017). Carbon-intensive luxury goods and services for wealthy consumers, for instance, especially if applied at the "acceleration" phase of a transition, can help transform long-term social practices and behaviour and dissolve the "structural imperative for growth" (Wiedmann et al. 2020). In a similar fashion, environmental taxes can remove "locked-in" technology and place pressure on dominant regimes to become more sustainable (Bachus and Vanswijgenhoven 2018).

In many contexts, it is not multiple institutional and policy variables that come together to break unsustainable inertias. In South Korea, where the state was an initiator and enabler of change, the clean-energy transition took much longer than anticipated due to private-sector resistance. However, when policy-makers focused on incorporating adaptive learning and flexibility into their decision-making, public- and private-sector interests gradually converged and joined with top-down policy-making to drive the transition forward (Lee et al. 2019). Thus, a political strategy can help align the interests and institutions needed to break lock-ins.

This becomes clear in studies that show that political coalitions can affect the speed of transitions (Hess 2014). These same studies show that incumbent industry coalitions are now competing with 'green' coalitions in terms of campaign spending over environmentally-friendly ballot proposals (Hess 2014). Another way of shifting political-economic incentives is by offering a realistic exit strategy for incumbents, like interventions that provide long-term incentives for renewable energy firms (de Gooyert et al. 2016; Hamman 2019).

Overall, the previous subsection suggests that complementary policies and institutions that simultaneously integrate across multiple sectors and scales and also alter political economic structures that lock in carbon-intensive energy system are more likely to move a sustainable transition forward (Burch 2010). Yet, despite a trend in climate governance towards greater integration and inclusivity and certain other novel governance approaches, traditional approaches to governance and a tendency to incrementalism remain dominant (Holscher et al. 2019). Building the governance arrangements and capacities that prioritize climate change across all sectors and scales while destabilizing entrenched interests and putting pressure on existing norms, rules and practices is still needed in many contexts (Holscher et al. 2019).

At least three themes require further research in the scholarship on governance of transitions: 1) the role of coalitions in supporting and hindering acceleration; 2) the role of feedback, through which policies may shape actor preferences, which in turn create stronger policies; and 3) the role of broader contexts (political economies, institutions, cultural norms, and technical systems) in creating conditions for acceleration (Roberts et al. 2018). Importantly, these themes may serve as both barriers to and opportunities for transitions (ibid.).

17.4.5 Equity in a just transition

Energy justice, although increasingly being emphasized (Pellegrini-Masini et al. 2020), has been under-represented in the literature on sustainability and in debates on energy transitions, and it remains a contested term with multiple meanings (Green and Gambhir 2020). Energy justice includes affordability, sustainability, equality (accessibility for current and future households) and respect (ensuring that innovations do not impose further burdens on particular groups) (Fuso Nerini et al. 2019). Furthermore, it suggests that a just transition is a shared responsibility among countries that are making more rapid progress towards net negative emissions and those economies that are focused on pressing development priorities related to improved health, well-being and prosperity (van den Berg et al. 2020).

Looking at climate change from a justice perspective means placing the emphasis on a) the protection of vulnerable populations from the impacts of climate change; b) mitigating the effects of the transformations themselves, including easing the transition for those whose livelihoods currently rely on fossil fuel-based sectors; and c) envisaging an equitable decarbonized world. Neglecting issues of justice risks a backlash against climate action generally, particularly from those who stand to lose from such actions (Patterson et al. 2018), and it will also have implications for the pace, scale and quality of the transition. Explicit interventions to promote sustainability transitions that integrate local spaces into the whole development process are necessary but not sufficient in creating a just transition (Breukers et al. 2017; Ehnert et al. 2018b).

Renewable energy transitions in rural, impoverished locations can simultaneously reinforce and disrupt local power structures and inequalities. Policy interventions to help the most impoverished individuals in a community gain access to the new energy infrastructure are critical in ensuring that existing inequalities are not reinforced. Individuals who are empowered by energy development projects can influence the onward extension of sustainable energy to other communities (Ahlborg 2017). In Denmark in the 1970s, for example, grassroots windmill cooperatives opened a pathway to the creation of one of the world's largest wind-energy markets. The unique dynamics of grassroots-led changes mean that new technologies and low-carbon initiatives develop strong foundations by being designed, tested and improved in the early stages with reference to the socio-political contexts in which they will grow later (Ornetzeder and Rohracher 2013).

Intersectional theory can shine a light on the hidden costs of resource extraction, as well as renewable energy development (see, for instance, (Chatalova and Balmann 2017), which go beyond environmental or health risks to include the socio-cultural impacts on both communities adjacent to these sites and those who work in them (Daum 2018). Indeed, development decisions often do not properly integrate the burdens and risks placed on marginalized groups, like indigenous peoples, while risk assessments tend to reinforce existing power imbalances by failing to differentiate between how benefits and risks might impact on certain groups (Healy et al. 2019; Kojola 2019). In some cases, such as the deployment of small-scale solar power in Tanzania by a non-profit organization, an explicit gender lens on the impacts of energy poverty revealed the significant socio-economic benefits of improving access to renewable energy (Gray et al. 2019).

17.4.6 Holistic planning and the nexus approach

Poor sectoral coordination and institutional fragmentation have triggered a wide range of unsustainable uses of resources and threatened the long-term sustainability of food, water and energy security (Rasul 2016). Greater policy coherence among the three sectors is critical to moving to a sustainable and efficient use of resources (United Nations 2019), given that political ambition, values, the energy mix, infrastructure and innovation capacities collectively shape transition outcomes (Neofytou et al. 2020). Capacity- and coalition-building, particularly among sub-national and non-state actors (e.g. non-governmental organizations) is a particularly important enabler of greater coherence (Bernstein and Hoffmann 2018). The nexus approach, a systems-based methodology that focuses attention on the many ways in which natural resources are deeply interwoven and mutually interdependent, can strengthen coordination and help to avoid maladaptive pathways (Cremades et al. 2016).

A major shift is required in the decision-making process in the direction of taking a holistic view, developing institutional mechanisms to coordinate the actions of diverse actors and strengthening complementarities and synergies (Nikas et al. 2020; Rasul 2016). Currently, nexus approaches have moved from purely conceptual arguments to application and implementation. (Liu et al. 2018) suggest the need for a systematic procedure and provide perspectives on future directions. These include expanding nexus frameworks that take into account interaction linkages with the SDGs, incorporating overlooked drivers and regions, diversifying nexus toolboxes and making these strategies central to policy-making and governance in integrating and implementing the SDGs.

In respect of processes, (Seyfang and Haxeltine 2012) found a lack of realistic and achievable expectations among both members (internally) and the wider public (externally), which hampers the acceleration of transitions. This movement could concentrate strategically on developing and promoting short-term steps towards shared long-term visions, including clearly identifiable goals and end-points. Sustainability science must link research on problem structures with a solutions-oriented approach that seeks to understand, conceptualize and foster experiments in how socio-technical innovations for sustainability develop, are diffused and are scaled up (Miller et al. 2014).

Various strategies and processes have been explored that might facilitate the translation of barriers into enablers, thus accelerating transitions to sustainable development. Common themes include frequent monitoring and system evaluation to reveal the barriers in the first place, the collaborative co-creation and envisioning of pathways toward sustainable development, ambitious goal-setting, the strategic tackling of sources of path dependence or inertia, iterative evaluations of progress and risk management, adaptive management and building in opportunities for agile course-correction at multiple levels of governance (Burch et al. 2014; Halbe et al. 2015). Given the political infeasibility of stable, long-term climate policies, the better choice may be to embrace uncertainty in specific policies but entrench the low-carbon transition as the overarching goal. Framing climate policy too narrowly, rather than taking a more holistic, sustainable development-oriented approach, may tie success to single policies, rather than allowing for system-wide change.

Decarbonisation may be encouraged by embedding the transition in a broader socio-economic agenda, focusing on constructing social legitimacy to justify the transformation, encouraging municipalities with a material interest in the transition and reforming institutions to support the long-term transition goals (Rosenbloom et al. 2019). In jurisdictions where climate and energy policy have been integrated and harmonized, such as the UK, progress has been made in transitioning to sustainable energy (Warren et al. 2016).

Developing countries that are rich in fossil fuels now have an opportunity to reset their development trajectories by focusing on those opportunities that will offer resilient development in land-use change, low-carbon energy generation and not least more efficient resource-planning (UN- UNDRR 2019). Resource-rich developing countries can choose an alternative pathway by deciding to monetize carbon capital and diversifying away from the high-carbon aspects of risk. Countries rich in hydrocarbons can diversify their energy mix and maximize their renewable energy potential. For instance, Namibia, a net importer of electricity, is seeking to reduce its current dependence on hydrocarbons by promoting solar energy. The government has issued permits allowing independent power producers (IPPs) to sell directly to consumers, thus ending the monopoly hitherto enjoyed by the state utility company NamPower (Kruger et al. 2019).

Cities are important spaces where the momentum to achieve low-carbon transitions can be built (Burch 2010; Holscher et al. 2019; Shaw et al. 2014), especially where centralized energy structures and national governance and politics are posing deep-rooted challenges to change (Dowling et al. 2018; Meadowcroft 2011). Cities can enter networks and partnerships with other cities and multilevel actors, spaces that are important for capacity-building and accelerating change (Dale et al. 2020; Heikkinen et al. 2019; Westman et al. 2021).

Addressing the uncertainties and complexities associated with locally, regionally and nationally sustainable development pathways requires creative methods and participatory processes. These may include powerful visualizations that make the implications of climate change (and decarbonization) clear locally (Shaw et al. 2014; Sheppard et al. 2011), other visual aids or "progress wheels" that effectively communicate the relevant contexts (Glaas et al. 2019), storytelling and mapping, and both analogue and digital games (Mangnus et al. 2019).

17.5 Conclusions

This chapter has been concerned to assess the opportunities and challenges for acceleration *in the context of sustainable development*. As such, many of the claims reviewed involve not only increasing the speed of the transition but also ensuring that it is just, equitable and delivers a wider range of environmental and social benefits. A sustainability transition requires removing the underlying drivers of vulnerability and high emissions (quality and depth) while aligning the interests of different communities, regions, sectors, stakeholders and cultures (scale and breadth).

Interest in a sustainability transition has grown steadily over the history of the IPCC and of climate and related policy processes. That interest hit a high point in 2015 with the Paris Agreement and the 2030 Agenda for Sustainable Development and its 17 SDGs. It has continued to remain high as countries have issued NDCs on climate change, VNRs on the SDGs and, in some instances, integrated climate and SDG plans (or similarly themed integrated actions, e.g. circular economy plans). Interest has also gained momentum as local governments, businesses and other stakeholders have followed suit with climate change- or SDG-related plans.

Implementing many of the recent pledges, however, has proved challenging. Part of the challenge is a need to address everything from public policies and prevailing technologies to individual lifestyles and social norms to governance arrangements and institutions with associated political economy implications. These factors can lock in development pathways and prevent transitions from gathering the momentum needed for large-scale transformations of socioeconomic systems. Another consideration is that transition pathways are likely to vary across and within countries due to different development levels, starting points, differential vulnerabilities, capacities, agencies, geographies, power dynamics, political economies, ecosystems and other contextual factors.

Even with this diversity, prominent lines of economic, institutional, psychological and systems thinking have reflected on interventions that can enable transitions. Because these disciplines often focus on different levels of analysis and draw upon diverse analytical methods and empirical evidence, the recommended interventions also tend to vary. For instance, economic arguments often point to the need for targeted regulation or investments, institutional claims centre on multilevel governance reforms, and psychology encourages participation to change mind sets and social norms. Systems-level perspectives offer a useful frame for bringing together these views, but may not capture the richness and details of them treated separately. Greater inter- and transdisciplinary research is needed to integrate the more focused interventions and show how they work together in a system. Such research will be particularly important for working on the concern running through these studies: strengthening synergies between climate and the broader sustainable development agenda.

National and sub-national, sectoral and cross-sectoral, short- and long-term transition studies have assessed the links between sustainable development and mitigation policies and synergies and the trade-offs between the different policy domains. Some general conclusions can be drawn on synergies and trade-offs, despite the actual impacts of policy implementation depending on scale, context and the development starting point.

From a cross-sectoral perspective, it can be concluded that the AFOLU sector offers many low-cost mitigation options with synergetic SDG impacts, which, however, can also create trade-offs between land-use for food, energy, forest and biodiversity. Some options can help to mitigate such trade-offs, like agricultural practices, forest conservation and soil carbon sequestration. Lifestyle changes, including dietary changes and reduced food waste, could jointly support the SDGs and mitigation. Industry also offers several mitigation options with SDG synergies, for example, related to energy efficiency and the circular economy. Some of the renewable-energy options in industry could indicate some trade-offs in relation to land use, with implications for food- and water security and costs. Cities provide a promising basis for implementing mitigation with SDG synergies, particularly if urban planning, transportation, infrastructure and settlements are coordinated jointly. Similarly, studies of the building sector have identified many synergies between the SDGs and mitigation, but there are issues related to the costs of new technologies. Also, in relation to households and buildings, important equity issues emerge due to the ability of low-income groups to afford the introduction of new technologies. Altogether these cross-sectoral conclusions create a need for policies to address both synergies and trade-offs, as well as for coordination between different sectoral domains. Context-specific assessments of synergies and trade-offs are here important, as is sharing the benefits and costs associated with mitigation policies.

Several opportunities for creating SDG synergies and avoiding trade-offs have also been identified in relation to integrated adaptation and mitigation policies. The AFOLU sector has a large potential for integrating adaptation and mitigation policies related to agriculture, bioenergy crops, forestry and water use. As was concluded for mitigation options, integrated adaptation and mitigation policies also entail the risks of creating trade-offs in relation to food, water, energy access and biodiversity. There are several potentially strong links between climate-change adaptation in industry and climate-change adaptation more generally. Various supply chains can be affected by climate change, and mitigation options related to energy and water supply can be disrupted by climate events, implying that great benefits may come from integrating adaptation in industrial planning efforts. Adaptation options in industry can imply increasing the demand for packaging materials such as plastics and for access to refrigeration, which are also major sources of GHG emissions, which then would require further mitigation options. Mitigation and the co-benefits of adaptation in urban areas in relation to air quality, health, green jobs and equality issues can in most cases to be synergetic and can also support the SDGs. One exception are compact cities, with their trade-offs between mitigation and adaptation because decreasing urban sprawl can increase the risks of flooding and heat stress. Detailed mapping of mitigation and adaptation in urban areas shows that there are many, very close interactions between the two policy domains and that coordinated governance across sectors is therefore called for.

Meeting the ambitions of the Paris Agreement will require phasing out fossil fuels from energy systems, which is technically possible and is estimated to be relatively low in cost. However, studies also show that replacing fossil fuels with renewables can have major synergies and trade-offs with a broader agenda of sustainable development if a balance is established in relation to land use, food security and job creation (McCollum et al. 2018). Furthermore, the transition to low-emission pathways will require policy efforts that also address the emissions locked into existing infrastructure, like power plants, factories, cargo ships and other infrastructure already in use: for example, today coal-fired power plants account for 30% of all energy-related emissions. Thus, even though the transition away from fossil fuels is desirable and technically feasible, it is still largely constrained by existing fossil fuel-based infrastructure and the existence of stranded investments. The “committed” emissions from existing fossil-fuel infrastructure may consume all the remaining carbon budget in the 1.5°C scenario or two thirds of the carbon budget in the 2°C scenario.

Stranded hydrocarbon assets, including hydrocarbon resources and the infrastructure from which they are produced, and investments made in exploration and production activities, are likely to become unusable, lose value, or may end up as liabilities before the end of the anticipated economic lifetime. This phenomenon is rapidly becoming a global reality as social norms change and the pressure to reduce emissions mounts. Energy and other forms of structural inequities are likely to make the transition planning more challenging, especially given stranded assets.

Countries dependent on fossil fuel income will need to forego these revenues to keep well within the Paris agreement requirements and align with the rapidly growing divestment movement. Climate injustice, energy poverty, and COVID 19 have reduced the space and maneuverability for developing countries to innovate and use surplus funds to procure new and clean technologies. A rising debt burden already hamstrings many. Decisions on how to spend the remaining carbon budget and who has the right to decide on what to do with existing fossil fuels reflect the complexity of the transition and its non-linearity character. Given the asymmetrical dimension of energy production, distribution, and use, it is likely that stranded assets will have implications for oil-producing countries, especially for early producers who perceive that newfound oil and gas will open doors to new forms of prosperity.

While the transitional drivers are not in place in some developing countries, i.e., technology, infrastructure, knowledge, and finance, among others, investing in new forms of renewable energy for land, energy, or water sectors will see the emergence of a more diversified economy and one less vulnerable to carbon and other exogenous risks. The transition away from fossil fuels will come with hard choices. Still, these choices can enable a sustainable development world and reduce the many asymmetries and injustices inherent in the current system, not least the gaping energy disparities that divide the developed and the developing world.

Equality and justice are central dimensions of transitions in the context of sustainable development. Viewing climate change through the lens of justice requires a focus on the protection of vulnerable populations from the impacts of climate change, addressing the unequal distribution of the costs and consequences of the transitions themselves, including for those whose livelihoods are rooted in fossil fuel-based sectors, and developing more creative and participatory processes for envisioning an equitable decarbonized world. Neglecting issues of justice will have implications for the pace, scale and quality of the transition.

Ultimately, the evidence demonstrates that there is rarely any one single factor promoting or preventing transitions. A constellation of elements come into play, including technological innovations, shifts in markets, social and behavioural dynamics, and governance arrangements. Indeed, transitions require an examination of the role of values, attitudes, beliefs and the structures that shape behaviour, as well as the dynamics of social movements and education at multiple levels. Likewise, technological and social innovation both play an important role in enabling transitions, highlighting the importance of multi-institutional and multi-stakeholder actors building institutional support networks, facilitating collaboration between sectors and actors, and promoting learning and social change. Financial tools and economic instruments are crucial enablers, since many forms of transformational change to energy systems are not possible when financial systems still privilege investing in unsustainable, carbon-intensive sectors. These instruments are deployed within the context of the multi-level governance of climate change, which suggests the importance of complementary policies and institutions that simultaneously integrate across multiple sectors and scales to address the multiple sources of lock-in that are shaping the current carbon-intensive energy system. Systems-oriented approaches, which holistically address the intersections among climate, water and energy (for instance), have significant potential to reveal and help avoid trade-offs, foster experimentation, and deliver a range of co-benefits on the path towards sustainable development.

Frequently Asked Questions (FAQs)

FAQ 17.1 Will decarbonisation efforts slow or accelerate sustainable development transitions?

Sustainable development offers a comprehensive pathway to achieving ambitious climate change mitigation goals. Sustainable development requires the pursuit of synergies and the avoidance of trade-offs between the economic, social and environmental dimensions of development. It can thus provide pathways that accelerate progress towards ambitious climate change mitigation goals. Factoring in equality and distributional effects will be particularly important in the pursuit of sustainable policies and partnerships, and in accelerating the transition to sustainable development. Using climate change as a key conduit can only work if synergies across sectors are exploited and if policy implementation is supported by national and international partnerships.

The speed, quality, depth and scale of the transition will depend on the developmental starting point, that is, on explicit goals as well as the enabling environment consisting of individual behaviour, mindsets, beliefs and actions, social cohesion, governance, policies, institutions, social and technological innovations etc. The integration of both climate change mitigation and adaptation policies in sustainable development is also essential in the establishment of fair and robust transformation pathways.

FAQ 17.2 What role do considerations of justice and inclusivity play in the transition towards sustainable development?

Negative economic and social impacts in some regions could emerge as a consequence of ambitious climate change mitigation policies if these are not aligned with key sustainable development aspirations such as those represented by the SDGs on ‘no poverty, energy-, water- and food access’ etc., which could in turn slow down the transition process. Nonetheless, many climate change mitigation policies could generate incomes, new jobs and other benefits. Capturing these benefits could require specific policies and investments to be targeted directly towards including all parts of society in the new activities and industries created by the climate change mitigation policies, and that activities that are reduced in the context of transitions to a low carbon future, including industries and geographical areas, are seeing new opportunities. Poor understanding of how governance at multiple levels can meet these challenges to the transition may fail to make significant progress in relation to national policies and a global climate agreement. It may therefore either support or weaken the climate architecture, thus constituting a limiting factor.

FAQ 17.3 How critical are the roles of institutions in accelerating the transition and what can governance enable?

Institutions are critical in accelerating the transition towards sustainable development: they can help to shape climate change response strategies in terms of both adaptation and mitigation. Local institutions are the custodians of critical adaptation services, ranging from the mobilisation of resources, skills development and capacity-building to the dissemination of critical strategies. Transitions towards sustainable development are mediated by actors within particular institutions, the governance mechanisms they use as implementing tools and the political coalitions they form to enable action. Patterns of production and consumption have implications for a low-carbon development, and many of these patterns can act as barriers or opportunities towards sustainable development. Trade policies, international economic issues and international financial flows can positively support the speed and scale of the transition; alternatively, they can have negative impacts on policies that may inhibit the process. Nonetheless, contextual factors are a fundamental part of the change process, and institutions and their governance systems provide pathways that can influence contextual realities on the ground. For instance, politically vested interests may lead powerful lobby groups or coalition networks to influence the direction of the transition, or they could put pressure on a given political elite through the imposition of regulatory standards, taxation, incentives and policies that may speed or delay the transition process. Civil society institutions, such as NGOs or research centres, can act as effective governance 'watch dogs' in the transition process, particularly when they exercise a challenge function and question government actions in respect of transitions related to sustainable development.

References

Abson, D. J. et al., 2017: Leverage points for sustainability transformation. *Ambio*, **46**(1), 30–39, doi:10.1007/s13280-016-0800-y.

Addison, T., and A. R. Roe, 2018: *Extractive Industries*. 1st ed. Oxford University Press, 766 pp.

Adger, W. N., J. Barnett, K. Brown, N. Marshall, and K. O'Brien, 2013: Cultural dimensions of climate change impacts and adaptation. *Nat. Clim. Chang.*, **3**(2), doi:10.1038/nclimate1666.

Ahamer, G., 2013: Game, Not Fight: Change Climate Change! *Simul. Gaming*, **44**(2–3), 272–301, doi:10.1177/1046878112470541.

Ahlborg, H., 2017: Towards a conceptualization of power in energy transitions. *Environ. Innov. Soc. TRANSITIONS*, **25**, 122–141, doi:10.1016/j.eist.2017.01.004.

Ahlström, H., 2019: Policy hotspots for sustainability: Changes in the EU regulation of sustainable business and finance. *Sustain.*, , doi:10.3390/su11020499.

Akimoto, K. et al., 2012: Consistent assessments of pathways toward sustainable development and climate stabilization. *Nat. Resour. Forum*, **36**(4), doi:10.1111/j.1477-8947.2012.01460.x.

Alarcón, D., and R. Vos, 2015: Introduction: The Imperative of Sustainable Development. In: *Technology and Innovation for Sustainable Development* [Vos, R. and D. Alarcón, (eds.)], *The United Nations Series on Development*, Bloomsbury Academic, London, pp. 1–14.

Alexandratos, N., and J. Bruinsma, 2012: *World agriculture towards 2030/2050.* , Rome, 1–154 pp.

Altieri, K. E. et al., 2016: Achieving development and mitigation objectives through a decarbonization development pathway in South Africa. *Clim. Policy*, **16**(1), 78–91, doi:10.1080/14693062.2016.1150250.

Amanuma, N. et al., 2018: *Governance for Integrated Solutions to Sustainable Development and Climate Change: From Linking Issues to Aligning Interests*. [ZUSMAN, E. and N. AMANUMA, (eds.)]. IGES, Hayama, Japan,.

Andrianto, A., H. Komarudin, and P. Pacheco, 2019: Expansion of oil palm plantations in Indonesia's frontier: Problems of Externalities and the Future of Local and Indigenous Communities. *Land*, **8**(4), 16, doi:10.3390/land8040056.

Andrić, I., M. Koc, and S. G. Al-Ghamdi, 2019: A review of climate change implications for built environment: Impacts, mitigation measures and associated challenges in developed and developing countries. *J. Clean. Prod.*, **211**, 83–102, doi:10.1016/j.jclepro.2018.11.128.

Andries, H. F. et al., 2017: Global and regional abatement costs of Nationally Determined Contributions (NDCs) and of enhanced action to levels well below 2°C and 1.5°C. *Environ. Sci. Policy*, **71**, 30–40, doi:https://doi.org/10.1016/j.envsci.2017.02.008.

Ansari, D., and F. Holz, 2020: Between stranded assets and green transformation: Fossil-fuel-producing developing countries towards 2055. *World Dev.*, **130**, 18, doi:10.1016/j.worlddev.2020.104947.

Antwi-Agyei, P., A. J. Dougill, T. P. Agyekum, and L. C. Stringer, 2018a: Alignment between nationally determined contributions and the sustainable development goals for West Africa. *Clim. Policy*, **18**(10), 1296–1312, doi:10.1080/14693062.2018.1431199.

Antwi-Agyei, P., A. J. Dougill, L. C. Stringer, and S. N. A. Codjoe, 2018b: Adaptation opportunities and maladaptive outcomes in climate vulnerability hotspots of northern Ghana. *Clim. Risk Manag.*, **19**, 83–93, doi:https://doi.org/10.1016/j.crm.2017.11.003.

Arnell, N. W., and B. Lloyd-Hughes, 2014: The global-scale impacts of climate change on water resources and flooding under new climate and socio-economic scenarios. *Clim. Change*, **122**(1–2), 127–140, doi:10.1007/s10584-013-0948-4.

Arranz, A. M., 2017: Lessons from the past for sustainability transitions? A meta-analysis of socio-technical studies. *Glob. Environ. Chang. POLICY Dimens.*, **44**, 125–143, doi:10.1016/j.gloenvcha.2017.03.007.

Arrow, K. et al., 2004: Are we consuming too much? *J. Econ. Perspect.*, **18**(3), 147–172, doi:10.1257/0895330042162377.

Asara, V., I. Otero, F. Demaria, and E. Corbera, 2015: Socially sustainable degrowth as a social–ecological transformation: repoliticizing sustainability. *Sustain. Sci.*, **10**(3), 375–384, doi:10.1007/s11625-015-0321-9.

Austin, K. G., A. Schwantes, Y. Gu, and P. S. Kasibhatla, 2019: What causes deforestation in Indonesia?

Environ. Res. Lett., **14**, 10, doi:10.1088/1748-9326/aaf6db.
Avelino, F., J. Grin, B. Pel, and S. Jhagroe, 2016: The politics of sustainability transitions. *J. Environ. POLICY Plan.*, **18**(5), 557–567, doi:10.1080/1523908X.2016.1216782.
Bachus, K., and F. Vanswijgenhoven, 2018: The use of regulatory taxation as a policy instrument for sustainability transitions: old wine in new bottles or unexplored potential? *J. Environ. Plan. Manag.*, **61**(9), 1469–1486, doi:10.1080/09640568.2017.1358155.
Baghestani, A., M. Tayarani, M. Allahviranloo, and H. O. Gao, 2020: Evaluating the Traffic and Emissions Impacts of Congestion Pricing in New York City. *Sustainability*, **12**(9), 3655, doi:10.3390/su12093655.
Bai, C. et al., 2020: Will income inequality influence the abatement effect of renewable energy technological innovation on carbon dioxide emissions? *J. Environ. Manage.*, **264**(15), 110482, doi:10.1016/J.JENVMAN.2020.110482.
Banks, S., 2007: The Heart and Soul of Transition—Creating a Low Carbon Future with Psychological and Spiritual Awareness. *Self Soc.*, **35**(2), 5–14, doi:10.1080/03060497.2007.11083972.
Banuri, T. et al., 2001: Setting the Stage: Climate Change and Sustainable Development. In: *Summary for PolicyMakers Climate Change 2001: Mitigation . A Report of Working Group III of the Intergovernmental Panel on Climate Change* [Banuri, T. et al., (eds.)], pp. 47–114.
Barani, S., A. H. Alibeygi, and A. Papzan, 2018: A framework to identify and develop potential ecovillages: Meta-analysis from the studies of world's ecovillages. *Sustain. Cities Soc.*, **43**, 275–289, doi:10.1016/j.scs.2018.08.036.
Barker, T., E. Alexandri, J. F. Mercure, Y. Ogawa, and H. Pollitt, 2016: GDP and employment effects of policies to close the 2020 emissions gap. *Clim. Policy*, **16**(4), 393–414, doi:10.1080/14693062.2014.1003774.
Baron, R., and F. David, 2015: *Divestment and Stranded Assets in the Low-carbon Transition*. , Paris, 26 pp. https://www.oecd.org/sd-roundtable/papersandpublications/Divestment and Stranded Assets in the Low-carbon Economy 32nd OECD RTSD.pdf.
Bataille, C. et al., 2016: The need for national deep decarbonization pathways for effective climate policy. *Clim. Policy*, **16**(No. S1), S7–S26, doi:10.1080/14693062.2016.1173005.
Bateman, I. J., and G. M. Mace, 2020: The natural capital framework for sustainably efficient and equitable decision making. *Nat. Sustain.*, **3**(10), 776–783, doi:10.1038/s41893-020-0552-3.
Bauer, N., C. McGlade, J. Hilaire, and P. Ekins, 2018: Divestment prevails over the green paradox when anticipating strong future climate policies. *Nat. Clim. Chang.*, **8**(2), 130–134, doi:10.1038/s41558-017-0053-1.
Beg, N., 2002: Linkages between climate change and sustainable development. *Clim. Policy*, **2**(2–3), 129–144, doi:10.1016/s1469-3062(02)00028-1.
Behuria, P., 2020: The politics of late late development in renewable energy sectors: Dependency and contradictory tensions in India's National Solar Mission. *World Dev.*, **126**, 104726, doi:https://doi.org/10.1016/j.worlddev.2019.104726.
Bellinson, R., and E. Chu, 2019: Learning pathways and the governance of innovations in urban climate change resilience and adaptation. *Environ. Policy Plan*, **21**(1), 76–89, doi:https://doi.org/10.1080/1523908X.2018.1493916.
Bergman, N., 2018: Impacts of the Fossil Fuel Divestment Movement: Effects on Finance, Policy and Public Discourse. *Sustainability*, **10**(7), 2529, doi:10.3390/su10072529.
Berkhout, F. et al., 2010: Sustainability experiments in Asia: Innovations shaping alternative development pathways? *Environ. Sci. Policy*, **13**(4), 261–271, doi:10.1016/j.envsci.2010.03.010.
Bernstein, S., and M. Hoffmann, 2018: The politics of decarbonization and the catalytic impact of subnational climate experiments. *Policy Sci.*, **51**(2), 189–211, doi:10.1007/s11077-018-9314-8.
Berry, P et al., 2015: Cross-sectoral interactions of adaptation and mitigation measures. *Clim. Chang.*, **128–393**, 381-, doi:https://doi.org/10.1007/s10584-014-1214-0.
Bertram, C. et al., 2018: Targeted policies can compensate most of the increased sustainability risks in 1.5{\hspace{0.167em}}{\textdegree}C mitigation scenarios. **13**(6), 64038, doi:10.1088/1748-9326/aac3ec.
Betsill, M. M., and H. Bulkeley, 2006: Cities and the multilevel governance of global climate change. *Glob. Gov.*, **12**(2), 141–159, doi:10.1163/19426720-01202004.
Biermann, F. et al., 2012: Transforming governance and institutions for global sustainability: Key

insights from the Earth System Governance Project. *Curr. Opin. Environ. Sustain.*, **4**(1), 51–60, doi:10.1016/j.cosust.2012.01.014.
Biermann, F., N. Kanie, and R. E. Kim, 2017: Global governance by goal-setting: the novel approach of the UN Sustainable Development Goals. *Curr. Opin. Environ. Sustain.*, **26–27**, 26–31, doi:10.1016/j.cosust.2017.01.010.
Biggs, E. M. et al., 2015: Sustainable development and the water–energy–food nexus: A perspective on livelihoods. *Environ. Sci. Policy*, **54**, 389–397, doi:10.1016/j.envsci.2015.08.002.
Birch, K., 2016: Materiality and sustainability transitions: integrating climate change in transport infrastructure in Ontario, Canada. *PROMETHEUS*, **34**(3–4), 191–206, doi:10.1080/08109028.2017.1331612.
Bleischwitz, R. et al., 2018: Resource nexus perspectives towards the United Nations Sustainable Development Goals. *Nat. Sustain.*, **1**, 737–743, doi:10.1038/s41893-018-0173-2.
Bloomfield, H. C., D. J. Brayshaw, L. C. Shaffrey, P. J. Coker, and H. E. Thornton, 2016: Quantifying the increasing sensitivity of power systems to climate variability. *Environ. Res. Lett.*, **11**(124025), 1–12, doi:10.1088/1748-9326/11/12/124025.
BMU, 2018: *Conclusions of the Petersberg Climate Dialogue IX - BMU.* , Berlin, 5 pp. https://www.bmu.de/en/topics-1/climate-energy/climate/international-climate-policy/12th-petersberg-climate-dialogue-pcd-xii/petersberg-climate-dialogue-ix.
Bos, K., and J. Gupta, 2019: Stranded assets and stranded resources: Implications for climate change mitigation and global sustainable development. *Energy Res. Soc. Sci.*, **56**, 101215, doi:https://doi.org/10.1016/j.erss.2019.05.025.
Bolton, R., T. J. Foxon, and S. Hall, 2016: Energy transitions and uncertainty: Creating low carbon investment opportunities in the UK electricity sector. *Environ. Plan. C-GOVERNMENT POLICY*, **34**(8), 1387–1403, doi:10.1177/0263774X15619628.
Bowman, A., O. Portney, and J. Berry, 2017: Multilevel Governance and City Sustainability Policies: Does It Exist? Does it Matter? *Paper delivered at the Local Governance and Sustainability Conference within Conference*, New Orleans, 1–118 https://localgov.fsu.edu/sites/g/files/upcbnu1196/files/Bowman Portney and Berry SPSA 2017.final.pdf.
Bradbury, D., 2015: Internet of things How can privacy survive in the era of the internet of things? *Guard.*,. https://www.theguardian.com/technology/2015/apr/07/how-can-privacy-survive-the-internet-of-things (Accessed August 10, 2021).
Bradbury, H. et al., 2019: A call to Action Research for Transformations: The times demand it. *Action Res.*, **17**(1), 8, doi:10.1177/1476750319829633.
Bradley, H., 2005: Class, Self and Culture. *Br. J. Sociol.*, **56**(4), 677–678, doi:https://doi.org/10.1111/j.1468-4446.2005.00088_13.x.
Breukers, S., R. M. Mourik, L. F. M. van Summeren, and G. P. J. Verbong, 2017: Institutional 'lock-out' towards local self-governance? Environmental justice and sustainable transformations in Dutch social housing neighbourhoods. *Energy Res. Soc. Sci.*, **23**, 148–158, doi:10.1016/j.erss.2016.10.007.
Brodnik, C., and R. Brown, 2018: Strategies for developing transformative capacity in urban water management sectors: The case of Melbourne, Australia. *Technol. Forecast. Soc. Change*, **137**, 147–159, doi:10.1016/j.techfore.2018.07.037.
Broto, V. C., S. Glendinning, E. Dewberry, C. Walsh, and M. Powell, 2014: What can we learn about transitions for sustainability from infrastructure shocks? *Technol. Forecast. Soc. Change*, **84**, 186–196, doi:10.1016/j.techfore.2013.08.002.
Brouwer, F. et al., 2018: Energy modelling and the Nexus concept. *Energy Strateg. Rev.*, **19**, 1–6, doi:10.1016/j.esr.2017.10.005.
Brown, O., A. Hammill, and R. McLeman, 2007: Climate change as the "new" security threat: Implications for Africa. *Int. Aff.*, **83**(6), 1141–1154, doi:10.1111/j.1468-2346.2007.00678.x.
Brundiers, K., A. Wiek, and C. L. Redman, 2010: Real-world learning opportunities in sustainability: from classroom into the real world. *Int. J. Sustain. High. Educ.*, **11**(4), 308–324, doi:10.1108/14676371011077540.
Bryan, E. et al., 2013: Can agriculture support climate change adaptation, greenhouse gas mitigation

and rural livelihoods? insights from Kenya. *Clim. Chang.*, **118**, 151–165, doi:https://doi.org/10.1007/s10584-012-0640-0.

Buijs, A., A. Fishcher, and A. Muhar, 2018: From urban gardening to planetary stewardship: human–nature relationships and their implications for environmental management. *J. Environ. Plan. Manag.*, **61**(5–6), 10, doi:https://doi.org/10.1080/09640568.2018.1429255.

Bulkeley, H., V. Castán Broto, and G. A. S. Edwards, 2015: *An Urban Politics of Climate Change: Experimentation and the Governing of Socio-Technical Transitions*. Routledge, 282 pp.

Burch, S., 2010: Transforming barriers into enablers of action on climate change: Insights from three municipal case studies in British Columbia, Canada. *Glob. Environ. Chang.*, **20**(2), 287–297, doi:10.1016/j.gloenvcha.2009.11.009.

Burch, S., 2017: The governance of transformative change: Tracing the pathway of the sustainability transition in Vancouver, Canada. *Urban Sustain. Transitions*, , 50–64, doi:10.4324/9781315228389.

Burch, S., and J. Di Bella, 2021: Business models for the Anthropocene: accelerating sustainability transformations in the private sector. *Sustain. Sci.*, **16**(6), 1963–1976, doi:10.1007/s11625-021-01037-3.

Burch, S., A. Shaw, A. Dale, and J. Robinson, 2014: Triggering transformative change: A development path approach to climate change response in communities. *Clim. Policy*, **14**(4), 467–487, doi:10.1080/14693062.2014.876342.

Burch, S. et al., 2016: Governing and accelerating transformative entrepreneurship: exploring the potential for small business innovation on urban sustainability transitions. *Curr. Opin. Environ. Sustain.*, **22**, 26–32, doi:10.1016/j.cosust.2017.04.002.

Buzananakova, A., 2015: *Democratic Republic of the Congo Coal Reserves*. , Democratic Republic of the Congo, 3 pp. https://drcongo.opendataforafrica.org/gkocbhe/democratic-republic-of-the-congo-coal-reserves?lang=en.

Byers, E. et al., 2018: Global exposure and vulnerability to multi-sector development and climate change hotspots. *Environ. Res. Lett.*, **13**(5), 55012, doi:10.1088/1748-9326/aabf45.

Byers, E. A. et al., 2015: Cooling water for Britain's future electricity supply. *Proc. Inst. Civ. Eng. Energy*, **168**(3), 188–204, doi:10.1680/ener.14.00028.

C40 Cities, 2019: C40 Cities. *Around world, C40 cities are Tak. bold Clim. action, Lead. W. Towar. a Heal. more Sustain. Futur.*,. https://www.c40.org/ (Accessed August 16, 2021).

Caldecott, B., N. Howarth, and P. McSharry, 2013: *Stranded Assets in Agriculture: Protecting Value from Environment-Related Risks*. , Oxford, 109 pp. https://www.smithschool.ox.ac.uk/publications/reports/stranded-assets-agriculture-report-final.pdf.

Caldera, U., and C. Breyer, 2020: Strengthening the global water supply through a decarbonised global desalination sector and improved irrigation systems. *Energy*, **200**, 117507, doi:https://doi.org/10.1016/j.energy.2020.117507.

Cameron, C. et al., 2016: Policy trade-offs between climate mitigation and clean cook-stove access in South Asia. *Nat. Energy*, **1**(1), 15010, doi:10.1038/nenergy.2015.10.

Campagnolo, L., and M. Davide, 2019: Can the Paris deal boost SDGs achievement? An assessment of climate mitigation co-benefits or side-effects on poverty and inequality. *World Dev.*, **122**, 96–109, doi:10.1016/j.worlddev.2019.05.015.

Campiglio, E., 2016: Beyond carbon pricing: The role of banking and monetary policy in financing the transition to a low-carbon economy. *Ecol. Econ.*, **121**, 220–230, doi:10.1016/j.ecolecon.2015.03.020.

Campos, I., and E. Marín-González, 2020: People in transitions: Energy citizenship, prosumerism and social movements in Europe. *Energy Res. Soc. Sci.*, **69**, 101718, doi:https://doi.org/10.1016/j.erss.2020.101718.

Campbell, B. M., P. Thornton, R. Zougmoré, P. van Asten, and L. Lipper, 2014: Sustainable intensification: What is its role in climate smart agriculture? *Curr. Opin. Environ. Sustain.*, **8**, 5, doi:10.1016/j.cosust.2014.07.002.

Canitez, F., 2019: Pathways to sustainable urban mobility in developing megacities: A socio-technical transition perspective. *Technol. Forecast. Soc. Change*, **141**, 319–329, doi:10.1016/j.techfore.2019.01.008.

Capellán-Pérez, I., C. de Castro, and I. Arto, 2017: Assessing vulnerabilities and limits in the transition to renewable energies: Land requirements under 100% solar energy scenarios. *Renew. Sustain. Energy Rev.*, **77**, 760–782, doi:10.1016/j.rser.2017.03.137.

Carney, M., 2016: Resolving the climate paradox. , 13. https://www.bis.org/review/r160926h.pdf (Accessed August 9, 2021).

Carraz, R., and H. Yuko, 2019: Japan's Innovation Systems at the Crossroads: Society 5.0. *Panor. Insights into Asian Eur. Aff.*, **3**, 33–45.

Carvalho Resende, T. et al., 2019: Assessment of the impacts of climate variability on total water storage across Africa: implications for groundwater resources management. *Hydrogeol. J.*, **27**(2), 493–512, doi:10.1007/s10040-018-1864-5.

Castellanos-Navarrete, A., W. V. Tobar-Tomás, and C. E. López-Monzón, 2019: Development without change: Oil palm labour regimes, development narratives, and disputed moral economies in Mesoamerica. *J. Rural Stud.*, **71**, 169–180, doi:10.1016/J.JRURSTUD.2018.08.011.

Castellanos-Navarrete, A., F. de Castro, and P. Pacheco, 2021: The impact of oil palm on rural livelihoods and tropical forest landscapes in Latin America. *J. Rural Stud.*, **81**, 294–304, doi:10.1016/J.JRURSTUD.2020.10.047.

Castro, M. C. et al., 2016: Examples of coupled human and environmental systems from the extractive industry and hydropower sector interfaces. *Proc. Natl. Acad. Sci.*, **113**(51), 14528–14535, doi:10.1073/pnas.1605678113.

Cebrian, M., 2021: The past, present and future of digital contact tracing. *Nat. Electron.*, **4**(1), 2–4, doi:10.1038/s41928-020-00535-z.

Cervero, R., 2009: Public transport and sustainable urbanism: Global lessons. *Transit Oriented Dev. Mak. it Happen*, , 43–56.

Chan, S., and P. Pauw, 2014: A global framework for climate action: orchestrating non-state and subnational initiatives for more effective global climate governance, Discussion Paper. *Ger. Dev. Inst.*, (34), 54.

Chatalova, L., and A. Balmann, 2017: The hidden costs of renewables promotion: The case of crop-based biogas. *J. Clean. Prod.*, **168**, 893–903, doi:10.1016/j.jclepro.2017.09.031.

Chen, H., J. Sun, and X. Chen, 2014: Projection and uncertainty analysis of global precipitation-related extremes using CMIP5 models. *Int. J. Climatol.*, **34**, 2730–2748, doi:10.1002/joc.3871.

Chichilnisky, G., and G. Heal, 1998: Economic returns from the biosphere. *Nature*, , 629–630, doi:10.1038/35481.

Chiengkul, P., 2017: *The political economy of the agri-food system in Thailand hegemony, counter-hegemony, and co- optation of oppositions*. 8th ed. Routledge, London, 228 pp.

Chimhowu, A. O., D. Hulme, and L. T. Munro, 2019: The 'New' national development planning and global development goals: Processes and partnerships. *World Dev.*, **120**, 76–89, doi:https://doi.org/10.1016/j.worlddev.2019.03.013.

Chirambo, D., 2018: Towards the achievement of SDG 7 in sub-Saharan Africa: Creating synergies between Power Africa, Sustainable Energy for All and climate finance in-order to achieve universal energy access before 2030. *Renew. Sustain. Energy Rev.*, **94**, 600–608, doi:https://doi.org/10.1016/j.rser.2018.06.025.

Chu, E., 2016: The political economy of urban climate adaptation and development planning in Surat, India. *Environ. Plan. C Gov. Policy*, **34**(2), 281–298, doi:10.1177/0263774X15614174.

Chu, E. K., 2018: Urban climate adaptation and the reshaping of state–society relations: The politics of community knowledge and mobilisation in Indore, India. *Urban Stud.*, **55**(8), 1766–1782, doi:10.1177/0042098016686509.

Clark, K. et al., 2019: Advancing the ethical use of digital data in human research: challenges and strategies to promote ethical practice. *Ethics Inf. Technol.*, **21**(1), 59–73, doi:10.1007/s10676-018-9490-4.

Clark, R., J. Reed, and T. Sunderland, 2018: Bridging funding gaps for climate and sustainable development: Pitfalls, progress and potential of private finance. *Land use policy*, **71**, 335–346, doi:10.1016/j.landusepol.2017.12.013.

Clarke, L. et al., 2014: Assessing Transformation Pathways. 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. et al., (eds.)], Cambridge University Press, Cambridge/New York, p. pp. 98.

Clarke, L. et al., 2018: Effects of long-term climate change on global building energy expenditures. *Energy Econ.*, **72**, 667–677, doi:https://doi.org/10.1016/j.eneco.2018.01.003.

Clayton, T., and N. Radcliffe, 2018: *Sustainability: A Systems Approach*. 1st ed. Routledge, Edinburgh, 253 pp.

Climate-Adapt, 2019: Climate-Adapt - City Profiles. *Cities and towns*,. https://climate-adapt.eea.europa.eu/countries-regions/cities (Accessed August 2, 2021).

Cobbing, J., 2020: Groundwater and the discourse of shortage in Sub-Saharan Africa. *Hydrogeol. J.*, **28**(4), 1143–1154, doi:10.1007/s10040-020-02147-5.

Cobbing, J., and B. Hiller, 2019: Waking a sleeping giant: Realizing the potential of groundwater in Sub-Saharan Africa. *World Dev.*, **122**, 597–613, doi:10.1016/j.worlddev.2019.06.024.

Coenen, L., P. Benneworth, and B. Truffer, 2012: Toward a spatial perspective on sustainability transitions. *Res. Policy*, **41**(6), 968–979, doi:https://doi.org/10.1016/j.respol.2012.02.014.

Congedo, L., and M. Munafò, 2014: Urban Sprawl as a Factor of Vulnerability to Climate Change: Monitoring Land Cover Change in Dar es Salaam. In: *Climate Change Vulnerability in Southern African Cities* [Macchi, S. and M. Tiepolo, (eds.)], Springer, Cham, Cham, pp. 73–88.

Cook, M. ., and E. Chu, 2018: Between Policies, Programs, and Projects: How Local Actors Steer Domestic Urban Climate Adaptation Finance in India. In: *Climate Change in Cities. The Urban Book Series* [Hughes, S. and M. Chu, (eds.)], Springer, Cham, Cham, pp. 255–277.

Córdova, R., N. J. Hogarth, and M. Kanninen, 2019: Mountain Farming Systems' Exposure and Sensitivity to Climate Change and Variability: Agroforestry and Conventional Agriculture Systems Compared in Ecuador's Indigenous Territory of Kayambi People. *Sustainability*, **11**(9), doi:10.3390/su11092623.

Corfee-Morlot, J. et al., 2009: *Cities, Climate Change and Multilevel Governance*. , Paris, 125 pp. http://www.oecd.org/dataoecd/10/1/44242293.pdf.

Covenant of Mayors, 2019: Covenant of Mayors for Climate Energy. https://iclei.org/en/GCoM.html?gclid=CjwKCAjwx8iIBhBwEiwA2quaqy1lUqrcbjvH4tTdiFiUM7W-bOsP77Tbn2KyicroS-uOaaeMLzJHRBoCmqwQAvD_BwE.

Craig, M. T. et al., 2018: A review of the potential impacts of climate change on bulk power system planning and operations in the United States. *Renew. Sustain. Energy Rev.*, **98**, 255–267, doi:10.1016/j.rser.2018.09.022.

Cremades, R. et al., 2016: Co-benefits and trade-offs in the water–energy nexus of irrigation modernization in China. *Enviromental Res. Lett.*, **11**(2), 054007, doi:https://doi.org/10.1088/1748-9326/11/5/054007.

Creutzig, F. et al., 2019: Upscaling urban data science for global climate solutions. *Glob. Sustain.*, **2**(2), 1–25, doi:10.1017/sus.2018.16.

Cronin, J. et al., 2021: Embedding justice in the 1.5°C transition: A transdisciplinary research agenda. *Renew. Sustain. Energy Transit.*, **1**, 100001, doi:https://doi.org/10.1016/j.rset.2021.100001.

Cross, A. T., P. G. Nevill, K. W. Dixon, and J. Aronson, 2019: Time for a paradigm shift toward a restorative culture. *Restor. Ecol.*, **27**(5), 924–928, doi:10.1111/rec.12984.

Cruz-Cárdenas, J., E. Zabelina, J. Guadalupe-Lanas, A. Palacio-Fierro, and C. Ramos-Galarza, 2021: COVID-19, consumer behavior, technology, and society: A literature review and bibliometric analysis. *Technol. Forecast. Soc. Change*, **173**, 121179, doi:https://doi.org/10.1016/j.techfore.2021.121179.

Cui, R. Y. et al., 2019: Quantifying operational lifetimes for coal power plants under the Paris goals. *Nat. Commun.*, **10**(1), 9, doi:10.1038/s41467-019-12618-3.

D'Odorico, P. et al., 2018: The Global Food-Energy-Water Nexus. *Rev. Geophys.*, (56), 456–531, doi:10.1029/2017RG000591.

Dai, J. et al., 2018: Water-energy nexus: A review of methods and tools for macro-assessment. *Appl. Energy*, **210**, 393–408, doi:10.1016/j.apenergy.2017.08.243.

Dale, A., S. Burch, and J. Robinson, 2017: Multilevel Governance of Sustainability Transitions in Canada: Policy Alignment, Innovation, and Evaluation. In: *Climate Change and Cities* [Chu, E., S. Manson, and S. Higues, (eds.)], Springer, Cham, Cham, pp. 343–358.

Dale, A. et al., 2020: Meeting the climate change challenge: local government climate action in British

Columbia, Canada. *Clim. Policy*, **20**(7), 866–880, doi:10.1080/14693062.2019.1651244.
Dalkmann, H., and C. Brannigan, 2007: *Urban Transport and Climate Change: Module 5e Sustainable Transport*. First. GIZ, Eschborn, 1–87 pp.
Dangelico, R. M., D. Pujari, and P. Pontrandolfo, 2016: Green product innovation in manufacturing firms: A sustainability-oriented dynamic capability perspective. *Bus. Strateg. Environ.*, **26**(4), 490–506.
Daum, T., 2018: We need more than apps. , 1. https://www.rural21.com/english/home.html?no_cache=1 (Accessed October 5, 2020).
David, D., and A. Venkatachalam, 2019: A Comparative Study on the Role of Public--Private Partnerships and Green Investment Banks in Boosting Low-Carbon Investments. In: *Handbook of Green Finance: Energy Security and Sustainable Development* [Sachs, J.D., W.T. Woo, N. Yoshino, and F. Taghizadeh-Hesary, (eds.)], Springer Singapore, Singapore, pp. 261–287.
Davidson, K. et al., 2020: The making of a climate emergency response: Examining the attributes of climate emergency plans. *Urban Clim.*, **33**, 100666, doi:https://doi.org/10.1016/j.uclim.2020.100666.
Day, D. V., J. W. Fleenor, L. E. Atwater, R. E. Sturm, and R. A. McKee, 2014: Advances in leader and leadership development: A review of 25 years of research and theory. *Leadersh. Q.*, , 1–182, doi:10.1016/j.leaqua.2013.11.004.
De Barbosa, L. S. N. S., D. Bogdanov, P. Vainikka, and C. Breyer, 2017: Hydro, wind and solar power as a base for a 100% renewable energy supply for South and Central America. *PLoS One*, **12**(3), 1–28, doi:10.1371/journal.pone.0173820.
de Gooyert, V., E. Rouwette, H. van Kranenburg, E. Freeman, and H. van Breen, 2016: Sustainability transition dynamics: Towards overcoming policy resistance. *Technol. Forecast. Soc. Change*, **111**, 135–145, doi:10.1016/j.techfore.2016.06.019.
De la Sota, C., V. J. Ruffato-Ferreira, L. Ruiz-García, and S. Alvarez, 2019: Urban green infrastructure as a strategy of climate change mitigation. A case study in northern Spain. *Urban For. Urban Green.*, **40**, 145–151, doi:10.1016/j.ufug.2018.09.004.
de Strasser, L., A. Lipponen, M. Howells, S. Stec, and C. Bréthaut, 2016: A Methodology to Assess the Water Energy Food Ecosystems Nexus in Transboundary River Basins. *Water*, **8**(2), 59, doi:https://doi.org/10.3390/w8020059.
de Wilde, P., and D. Coley, 2012: The implications of a changing climate for buildings. *Build. Environ.*, **55**, 1–7, doi:10.1016/j.buildenv.2012.03.014.
Delina, L. L., and B. K. Sovacool, 2018: Of temporality and plurality: an epistemic and governance agenda for accelerating just transitions for energy access and sustainable development. *Curr. Opin. Environ. Sustain.*, **34**, 1–6, doi:10.1016/j.cosust.2018.05.016.
den Elzen, M. et al., 2019: Are the G20 economies making enough progress to meet their NDC targets? *Energy Policy*, **126**(November 2018), 238–250, doi:10.1016/j.enpol.2018.11.027.
Denton, F. et al., 2014: Climate-resilient pathways: adaptation, mitigation, and sustainable development. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1101–1131.
Denton, F, T. et al.: 2021 G. 'Blind Alleys and Bright Prospects: Africa Navigating Stranded Assets and Just Transitions, UNU Publications.
Destouni, G., F. Jaramillo, and C. Prieto, 2013: Hydroclimatic shifts driven by human water use for food and energy production. *Nat. Clim. Chang.*, (3), 213–217, doi:10.1038/nclimate1719.
Di Gregorio, M. et al., 2017: Climate policy integration in the land use sector: Mitigation, adaptation and sustainable development linkages. *Environ. Sci. Policy*, **67**, 35–43, doi:10.1016/j.envsci.2016.11.004.
Diallo, I. et al., 2016: Projected changes of summer monsoon extremes and hydroclimatic regimes over West Africa for the twenty-first century. *Clim. Dyn.*, **47**(12), 3931–3954, doi:10.1007/s00382-016-3052-4.
Díaz, S. et al., 2019: Pervasive human-driven decline of life on Earth points to the need for transformative change. *Science (80-.).*, **366**(6471), eaax3100,

doi:10.1126/science.aax3100.

Dick, B., 2007: Action Research as an Enhancement of Natural Problem Solving. *Int. J. Action Res.*, **3**(1/2), 149–167, doi:10.1177/1541344613490997.

Doll, C. N. H., and J. A. Puppim De Oliveira, 2017: *Urbanization and climate co-benefits: Implementation of win-win interventions in cities*. Taylor and Francis, 1–324 pp.

Dovie, D. B. K., 2019: Case for equity between Paris Climate agreement's Co-benefits and adaptation. *Sci. Total Environ.*, **656**, 732–739, doi:10.1016/j.scitotenv.2018.11.333.

Dowling, R., P. McGuirk, and S. Maalsen, 2018: Multiscalar governance of urban energy transitions in Australia: The cases of Sydney and Melbourne. *Energy Res. Soc. Sci.*, **44**, 260–267, doi:10.1016/j.erss.2018.05.027.

Dugarova, E., and N. Gülasan, 2017: *GLOBAL TRENDS Challenges and Opportunities in the Implementation of the Sustainable Development Goals*. , New York, 101 pp. https://www.undp.org/publications/global-trends-challenges-and-opportunities-implementation-sdgs#modal-publication-download.

Dugast, J., S. Uslu, and P.-O. Weill, 2019: *A Theory of Participation in OTC and Centralized Markets*. , Cambridge, 1–45 pp.

Duguma, L. A., P. A. Minang, and M. van Noordwijk, 2014: Climate Change Mitigation and Adaptation in the Land Use Sector: From Complementarity to Synergy. *Environ. Manage.*, **54**(3), 420–432, doi:10.1007/s00267-014-0331-x.

E3G Annual Review, 2018: E3G Annual Review 2018. https://www.e3g.org/library_asset/e3g-annual-review-2018/ (Accessed August 26, 2021).

Easterlin, R. A., L. A. McVey, M. Switek, O. Sawangfa, and J. S. Zweig, 2010: The happiness - Income paradox revisited. *Proc. Natl. Acad. Sci. U. S. A.*, **107**(52), 1–6, doi:10.1073/pnas.1015962107.

ECLAC, 2017: *Annual report on regional progress and challenges in relation to the 2030 Agenda for Sustainable Development in Latin America and the Caribbean*. 114 pp.

ECLEI, 2019: Cities and towns gathered around one shared ambition. https://iclei.org/en/GCoM.html?gclid=CjwKCAjwx8iIBhBwEiwA2quaqy1lUqrcbjvH4tTdiFiUM7W-bOsP77Tbn2KyicroS-uOaaeMLzJHRBoCmqwQAvD_BwE (Accessed August 15, 2021).

Edmondson, D. L., F. Kern, and K. S. Rogge, 2019: The co-evolution of policy mixes and socio-technical systems: Towards a conceptual framework of policy mix feedback in sustainability transitions. *Res. Policy*, **48**(10), 14, doi:10.1016/j.respol.2018.03.010.

EESC, 2015: *Building the Europe We Want: Models for civil society involvement in the implementation of the Post-2015 agenda at the EU level*. 54 pp.

Ehnert, F. et al., 2018a: The Acceleration of Urban Sustainability Transitions: A Comparison of Brighton, Budapest, Dresden, Genk, and Stockholm. *Sustainability*, **10**(3), 612, doi:10.3390/su10030612.

Ehnert, F. et al., 2018b: Urban sustainability transitions in a context of multi-level governance: A comparison of four European states. *Environ. Innov. Soc. Transitions*, **26**, 101–116, doi:10.1016/j.eist.2017.05.002.

Eisenack, K., and D. Reckien, 2013: Climate Change and Simulation/Gaming. *Simul. Gaming*, **44**(2–3), 245–252, doi:10.1177/1046878113490568.

Elder, M., and P. King, 2018: *Realising the Transformative Potential of the SDGs*. , Hayama, Japan, 188 pp. https://www.iges.or.jp/jp/pub/realising-transformative-potential-sdgs/en.

Elder, M., and A. Bartalini, 2019: *Assessment of the G20 Countries' Concrete SDG Implementation Efforts: Policies and Budgets Reported in Their 2016-2018 Voluntary National Reviews*. , Hayama, Japon, 92 pp.

Erb, K.-H. et al., 2016: Exploring the biophysical option space for feeding the world without deforestation. *Nat. Commun.*, **7**(1), 11382, doi:10.1038/ncomms11382.

Escobar, A., 2015: Degrowth, postdevelopment, and transitions: a preliminary conversation. *Sustain. Sci.*, **10**(3), 451–462, doi:10.1007/s11625-015-0297-5.

Fader, M., C. Cranmer, R. Lawford, and J. Engel-Cox, 2018: Toward an understanding of synergies and trade-offs between water, energy, and food SDG targets. *Front. Environ. Sci.*, **6**, 112, doi:10.3389/fenvs.2018.00112.

Falcone, P. M., and E. Sica, 2015: How much does economic crisis affect sustainability transitions? A social network analysis of the italian biofuel sector. *Econ. Reg.*, **1**(1), 10, doi:10.17059/2015-1-23.

Fan, J.-L., L.-S. Kong, X. Zhang, and J.-D. Wang, 2019a: Energy-water nexus embodied in the supply chain of China: Direct and indirect perspectives. *Energy Convers. Manag.*, **183**, 126–136, doi:https://doi.org/10.1016/j.enconman.2018.12.095.

Fan, J. L., L. S. Kong, H. Wang, and X. Zhang, 2019b: A water-energy nexus review from the perspective of urban metabolism. *Ecol. Modell.*, **392**, 128–136, doi:10.1016/j.ecolmodel.2018.11.019.

FAO, 2019: *The State of Food and Agriculture: Moving forward on food loss and waste reduction.* 182 pp.

Farzaneh, H., E. Zusman, and Y. Chae, 2021: *Aligning Climate Change and Sustainable Development Policies in Asia*. 1st ed. [Farzaneh, H., E. Zusman, and Y. Chae, (eds.)]. Springer, Singapore, 185 pp.

Fastenrath, S., and B. Braun, 2018: Sustainability transition pathways in the building sector: Energy-efficient building in Freiburg (Germany). *Appl. Geogr.*, **90**, 339–349, doi:10.1016/j.apgeog.2016.09.004.

Favretto, N., A. J. Dougill, L. C. Stringer, S. Afionis, and C. H. Quinn, 2018: Links between climate change mitigation, adaptation and development in land policy and ecosystem restoration projects: lessons from South Africa. *Sustainability*, **10**(3), 19.

Fazey, I. et al., 2018: Community resilience for a 1.5°C world. *Curr. Opin. Environ. Sustain.*, **31**, 30–40, doi:https://doi.org/10.1016/j.cosust.2017.12.006.

Feng, K., K. Hubacek, and K. Song, 2021: Household carbon inequality in the U.S. *J. Clean. Prod.*, **278**, 123994, doi:10.1016/j.jclepro.2020.123994.

Ferguson, R. S., and S. T. Lovell, 2014: Permaculture for agroecology: Design, movement, practice, and worldview. A review. *Agron. Sustain. Dev.*, **34**, 251–274, doi:10.1007/s13593-013-0181-6.

Fishman, R., N. Devineni, and S. Raman, 2015: Can improved agricultural water use efficiency save India's groundwater? *Environ. Res. Lett.*, (10), 10, doi:10.1088/1748-9326/10/8/084022.

Fleurbaey, M. et al., 2014: Sustainable Development and Equity. 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*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA., Cambrige and New York, pp. 283–350.

Folke, C., 2006: Resilience: The emergence of a perspective for social-ecological systems analyses. *Glob. Environ. Chang.*, **16**(3), 253–267, doi:10.1016/j.gloenvcha.2006.04.002.

Fontana, G., and M. Sawyer, 2016: Towards post-Keynesian ecological macroeconomics. *Ecol. Econ.*, **121**, 186–195, doi:10.1016/j.ecolecon.2015.03.017.

Formentini, M., and P. Taticchi, 2016: Corporate sustainability approaches and governance mechanisms in sustainable supply chain management. *J. Clean. Prod.*, **112**, 1920–1933.

Forsyth, T., 2014: Climate justice is not justice. *Geoforum*, **54**, 230–232, doi:10.1016/j.geoforum.2012.12.008.

Forzieri, G. et al., 2018: Escalating impacts of climate extremes on critical infrastructures in Europe. *Glob. Environ. Chang.*, **48**, 97–107, doi:10.1016/j.gloenvcha.2017.11.007.

Frantzeskaki, N., D. Loorbach, and J. Meadowcroft, 2012: Governing societal transitions to sustainability. *Int. J. Sustain. Dev.*, **15**(1), doi:10.1504/IJSD.2012.044032.

Fricko, O. et al., 2016: Energy sector water use implications of a 2°C climate policy. *Environ. Res. Lett.*, **11**(034011), 1–11, doi:10.1088/1748-9326/11/3/034011.

Froese, R., and J. Schilling, 2019: The Nexus of Climate Change, Land Use, and Conflicts. *Curr. Clim. Chang. Reports*, **5**(1), 24–35, doi:10.1007/s40641-019-00122-1.

Fuhr, H., T. Hickmann, and K. Kern, 2018: The role of cities in multi-level climate governance: local climate policies and the 1.5 °C target. *Curr. Opin. Environ. Sustain.*, , doi:10.1016/j.cosust.2017.10.006.

Fujimori, S. et al., 2019: A multi-model assessment of food security implications of climate change mitigation. *Nat. Sustain.*, **2**(5), 386–396, doi:10.1038/s41893-019-0286-2.

Fuseini, I., and J. Kemp, 2015: A review of spatial planning in Ghana's socio-economic development trajectory: A sustainable development perspective. *Land use policy*, **47**, 309–320, doi:https://doi.org/10.1016/j.landusepol.2015.04.020.

Fuso Nerini, F. et al., 2019: Connecting climate action with other Sustainable Development Goals. *Nat. Sustain.*, **2**(8), 674–680, doi:10.1038/s41893-019-0334-y.

Galli, A., G. Đurović, L. Hanscom, and J. Knežević, 2018: Think globally, act locally: Implementing the sustainable development goals in Montenegro. *Environ. Sci. Policy*, **84**, 159–169, doi:https://doi.org/10.1016/j.envsci.2018.03.012.

Gao, J. et al., 2019: Insights into water-energy cobenefits and trade-offs in water resource management. *J. Clean. Prod.*, **213**, 1–22, doi:10.1016/j.jclepro.2018.12.126.

García-Olivares, A., J. Solé, and O. Osychenko, 2018: Transportation in a 100% renewable energy system. *Energy Convers. Manag.*, **158**, 266–285, doi:https://doi.org/10.1016/j.enconman.2017.12.053.

Gasbarro, F., F. Iraldo, and T. Daddi, 2017: The drivers of multinational enterprises' climate change strategies: A quantitative study on climate-related risks and opportunities. *J. Clean. Prod.*, **160**, 8–26, doi:https://doi.org/10.1016/j.jclepro.2017.03.018.

Gaveau, D. L. A. et al., 2016: Rapid conversions and avoided deforestation: Examining four decades of industrial plantation expansion in Borneo. *Sci. Rep.*, **6**, 32017, doi:10.1038/srep32017.

Geels, F. W., 2011: The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environ. Innov. Soc. Transitions*, **1**(1), 24–40, doi:https://doi.org/10.1016/j.eist.2011.02.002.

Geels, F. W., 2014: Regime Resistance against Low-Carbon Transitions: Introducing Politics and Power into the Multi-Level Perspective. *Theory, Cult. Soc.*, **31**(5), doi:10.1177/0263276414531627.

Geneletti, D., and L. Zardo, 2016: Ecosystem-based adaptation in cities: An analysis of European urban climate adaptation plans. *Land use policy*, **50**, 38–47, doi:https://doi.org/10.1016/j.landusepol.2015.09.003.

Geng, Y., and Z. Hengxin, 2009: Industrial park management in the Chinese environment. *J. Clean. Prod.*, **17**(14), 1289–1294, doi:10.1016/j.jclepro.2009.03.009.

Geng, Y., J. Sarkis, and R. Bleischwitz, 2019: How to globalize the circular economy. *Nature*, **565**(7738), 153–155, doi:10.1038/d41586-019-00017-z.

Germer, J. et al., 2011: Skyfarming an ecological innovation to enhance global food security. *J. fur Verbraucherschutz und Leb.*, **6**(2), doi:10.1007/s00003-011-0691-6.

Gi, K., F. Sano, A. Hayashi, and K. Akimoto, 2019: A model-based analysis on energy systems transition for climate change mitigation and ambient particulate matter 2.5 concentration reduction. *Mitig. Adapt. Strateg. Glob. Chang.*, **24**(2), 181–204, doi:10.1007/s11027-018-9806-z.

Giannaris, S., C. Bruce, B. Jacobs, W. Srisang, and Janowczyk, 2020: Implementing a second generation CCS facility on a coal fired power station – results of a feasibility study to retrofit SaskPower's Shand power station with CCS. *Green Gases Sci. ans Technol.*, **10**, 506–518, doi:https://doi.org/10.1002/ghg.1989.

Gillard, R., A. Gouldson, J. Paavola, and J. Van Alstine, 2016: Transformational responses to climate change: Beyond a systems perspective of social change in mitigation and adaptation. *Wiley Interdiscip. Rev. Clim. Chang.*, **7**(2), 251–265, doi:10.1002/wcc.384.

Gioacchino, G., 2019: You defend what you feel: 'Presencing' nature as 'experiential knowing.' *Action Res.*, **1**(1), 108–129, doi:10.1177/1476750319829208.

Giorgi, F., F. Raffaele, and E. Coppola, 2019: The response of precipitation characteristics to global warming from climate projections. *Earth Syst. Dyn.*, **10**(1), 73–89, doi:10.5194/esd-10-73-2019.

Girardin, C. A. J. et al., 2021: Nature-based solutions can help cool the planet - if we act now. *Nature*, **593**(7858), 191–194, doi:10.1038/d41586-021-01241-2.

Gjorgiev, B., and G. Sansavini, 2018: Electrical power generation under policy constrained water-energy nexus. *Appl. Energy*, **210**, 568–579, doi:10.1016/j.apenergy.2017.09.011.

Glaas, E. et al., 2019: Developing transformative capacity through systematic assessments and visualization of urban climate transitions. *Ambio*, **48**(5), 515–528, doi:10.1007/s13280-018-1109-9.

Global Opportunity Explorer, 2019: Quito: Planning For Smaller CO2 And Water Footprints. *Quito Plan. Smaller CO2 Water Footprints*,. https://goexplorer.org/quito-planning-for-smaller-co2-and-water-footprints/ (Accessed August 20, 2021).

Golberg, S., 2021: Lithium Mining: Dirty Investment or Sustainable Business? *Investopedia*,.

https://www.investopedia.com/investing/lithium-mining-dirty-investment-or-sustainable-business/.
Goldman-Schuyler, K., S. Skjei, J. Sanzgiri, and V. Koskela, 2017: "Moments of Waking Up": A Doorway to Mindfulness and Presence. *J. Manag. Inq.*, **26**(1), 86–100, doi:10.1177/1056492616665171.
Göpel, M., V. Hermelingmeier, K. Kehl, D. Vallentin, and T. Wehnert, 2016: *System Innovation Lab.* , Berlin, 1–41 pp. https://epub.wupperinst.org/frontdoor/deliver/index/docId/6538/file/6538_System_Innovation_Lab.pdf.
Gordon, D. J., 2015: An uneasy equilibrium: The coordination of climate governance in federated systems. *Glob. Environ. Polit.*, **15**(2), 121–141, doi:10.1162/GLEP_a_00301.
Gorissen, L., F. Spira, E. Meynaerts, P. Valkering, and N. Frantzeskaki, 2018: Moving towards systemic change? Investigating acceleration dynamics of urban sustainability transitions in the Belgian City of Genk. *J. Clean. Prod.*, **173**, 171–185, doi:https://doi.org/10.1016/j.jclepro.2016.12.052.
Gossart, C., 2015: ICT Innovations for Sustainability. In: *ICT Innovations for Sustainability* [Hilty, L. and B. Aebischer, (eds.)], Springer Link, Zurich, pp. 435–448.
Grady-Benson, J., and B. Sarathy, 2016: Fossil fuel divestment in US higher education: student-led organising for climate justice. *Local Environ.*, **21**(6), 661–681, doi:10.1080/13549839.2015.1009825.
Grafakos, S., K. Trigg, M. Landauer, L. Chelleri, and S. Dhakal, 2019: Analytical framework to evaluate the level of integration of climate adaptation and mitigation in cities. *Clim. Change*, **154**(1–2), 87–106, doi:10.1007/s10584-019-02394-w.
Gramkow, C., and A. Anger-Kraavi, 2018: Could fiscal policies induce green innovation in developing countries? The case of Brazilian manufacturing sectors. *Clim. Policy*, **18**(2), 246–257, doi:10.1080/14693062.2016.1277683.
Gray, L., A. Boyle, E. Francks, and V. Yu, 2019: The power of small-scale solar: gender, energy poverty, and entrepreneurship in Tanzania. *Dev. Pract.*, **29**(1), 26–39, doi:10.1080/09614524.2018.1526257.
Green, F., and A. Gambhir, 2020: Transitional assistance policies for just, equitable and smooth low-carbon transitions: who, what and how? *Clim. Policy*, **20**(8), 902–921, doi:10.1080/14693062.2019.1657379.
Greenberg, D. A., and J. M. Rogerson, 2014: The greening of industrial property developments in South Africa. *Urbani Izziv*, **25**(Special Issue), 122–133, doi:10.5379/urbani-izziv-en-2014-25-supplement-009.
Griggs, D., and Stafford-Smith, 2013: Sustainable development goals for people and planet. *Nature*, **495**(21 March), 305–307, doi:doi:10.1038/495305a.
Grinde, B., R. B. Nes, I. F. MacDonald, and D. S. Wilson, 2018: Quality of Life in Intentional Communities. *Soc. Indic. Res.*, **137**, 625–640, doi:10.1007/s11205-017-1615-3.
Grubler, A. et al., 2018: A low energy demand scenario for meeting the 1.5 °c target and sustainable development goals without negative emission technologies. *Nat. Energy*, **3**, 515–527, doi:10.1038/s41560-018-0172-6.
Gu, Y., Y. Wu, J. Liu, M. Xu, and T. Zuo, 2020: Ecological civilization and government administrative system reform in China. *Resour. Conserv. Recycl.*, **155**, 104654, doi:https://doi.org/10.1016/j.resconrec.2019.104654.
Guillaume, T., M. Kotowska, and D. Hertel, 2018: Carbon costs and benefits of Indonesian rainforest conversion to plantations. *Nat Commun*, **9**, 2388, doi:https://doi.org/10.1038/s41467-018-04755-y.
Gupta, J., A. Rempel, and H. Verrest, 2020: Access and allocation: the role of large shareholders and investors in leaving fossil fuels underground. *Int. Environ. Agreements Polit. Law Econ.*, **20**(2), 303–322, doi:10.1007/s10784-020-09478-4.
Guenther, E., T. Guenther, F. Schiemann, and G. Weber, 2016: Stakeholder Relevance for Reporting: Explanatory Factors of Carbon Disclosure. *Bus. Soc.*, **5**(3), 361–397, doi:10.1177/0007650315575119.

Haas, T., 2021: From Green Energy to the Green Car State? The Political Economy of Ecological Modernisation in Germany. *New Polit. Econ.*, **26**(4), 660–673, doi:10.1080/13563467.2020.1816949.

Haddeland, I. et al., 2014: Global water resources affected by human interventions and climate change. *Proc. Natl. Acad. Sci.*, **111**(9), 3251–3256, doi:10.1073/pnas.1222475110.

Hakansson, I., 2018: The socio-spatial politics of urban sustainability transitions: Grassroots initiatives in gentrifying Peckham. *Environ. Innov. Soc. TRANSITIONS*, **29**, 34–46, doi:10.1016/j.eist.2017.10.003.

Halbe, J., C. Pahl-Wostl, M. A. Lange, and C. Velonis, 2015: Governance of transitions towards sustainable development – the water–energy–food nexus in Cyprus. *Water Int.*, **40**(5–6), doi:10.1080/02508060.2015.1070328.

Hall, J. W. et al., 2014: Coping with the curse of freshwater variability: Institutions, infrastructure, and information for adaptation. *Science* , **346**(6208), 429–430, doi:10.1126/science.1257890.

Hallegatte, S., 2009: Strategies to adapt to an uncertain climate change. *Glob. Environ. Chang.*, **19**(2), 240–247, doi:https://doi.org/10.1016/j.gloenvcha.2008.12.003.

Hallinger, P., R. Wang, C. Chatpinyakoop, V. T. Nguyen, and U. P. Nguyen, 2020: A bibliometric review of research on simulations and serious games used in educating for sustainability, 1997–2019. *J. Clean. Prod.*, **256**, doi:10.1016/j.jclepro.2020.120358.

Hamiche, A. M., A. B. Stambouli, and S. Flazi, 2016: A review of the water-energy nexus. *Renew. Sustain. Energy Rev.*, , 319–331, doi:10.1016/j.rser.2016.07.020.

Hamman, P., 2019: Local governance of energy transition: sustainability, transactions and social ties. A case study in Northeast France. *Int. J. Sustain. Dev. World Ecol.*, **26**(1), 1–10, doi:10.1080/13504509.2018.1471012.

Hanasaki, N. et al., 2013: A global water scarcity assessment under Shared Socio-economic Pathways - Part 2: Water availability and scarcity. *Hydrol. Earth Syst. Sci.*, **17**(7), 2393–2413, doi:10.5194/hess-17-2393-2013.

Hansen, T., and L. Coenen, 2015: The geography of sustainability transitions: Review, synthesis and reflections on an emergent research field. *Environ. Innov. Soc. Transitions*, **17**, 92–109, doi:https://doi.org/10.1016/j.eist.2014.11.001.

Hansen, U. E., and I. Nygaard, 2014: Sustainable energy transitions in emerging economies: The formation of a palm oil biomass waste-to-energy niche in Malaysia 1990-2011. *Energy Policy*, **66**, 666–676, doi:10.1016/j.enpol.2013.11.028.

Hanson, K. T., and T. M. S. Korbla P. Puplampu, 2018: *From Millennium Development Goals to Sustainable Development Goals Rethinking African Development*. Routledge 2 Park Square, Milton Park, Abingdon, Oxon OX14 4RN, 180 pp.

Harvey, C. A. et al., 2014: Climate-Smart Landscapes: Opportunities and Challenges for Integrating Adaptation and Mitigation in Tropical Agriculture. *Conserv. Lett.*, **7**(2), 14, doi:10.1111/conl.12066.

Hasegawa, T. et al., 2018: Risk of increased food insecurity under stringent global climate change mitigation policy. *Nat. Clim. Chang.*, **8**(8), 699–703, doi:10.1038/s41558-018-0230-x.

Hasegawa, T., P. Havlík, S. Frank, A. Palazzo, and H. Valin, 2019: Tackling food consumption inequality to fight hunger without pressuring the environment. *Nat. Sustain.*, **2**(12), 826–833, doi:10.1038/s41893-019-0439-3.

Hayashi, A., F. Sano, Y. Nakagami, and K. Akimoto, 2018: Changes in terrestrial water stress and contributions of major factors under temperature rise constraint scenarios. *Mitig. Adapt. Strateg. Glob. Chang.*, **23**(8), 1179–1205, doi:10.1007/s11027-018-9780-5.

Haywood, L. K., N. Funke, M. Audouin, C. Musvoto, and A. Nahman, 2019: The Sustainable Development Goals in South Africa: Investigating the need for multi-stakeholder partnerships. *Dev. South. Afr.*, **36**(5), 555–569, doi:10.1080/0376835X.2018.1461611.

Heal, G., 2020: *Economis aspects of the energy transitions*. , New York, 22 pp.

Healy, N., J. C. Stephens, and S. A. Malin, 2019: Embodied energy injustices: Unveiling and politicizing the transboundary harms of fossil fuel extractivism and fossil fuel supply chains. *Energy Res. Soc. Sci.*, **48**, 219–234, doi:10.1016/j.erss.2018.09.016.

Hedlund-de Witt, A., J. de Boer, and J. J. Boersema, 2014: Exploring inner and outer worlds: A quantitative study of worldviews, environmental attitudes, and sustainable lifestyles. *J. Environ. Psychol.*, **37**, 40–54, doi:10.1016/j.jenvp.2013.11.005.
Heikkinen, M., T. Ylä-Anttila, and S. Juhola, 2019: Incremental, reformistic or transformational: what kind of change do C40 cities advocate to deal with climate change? *J. Environ. Policy \& Plan.*, **21**(1), 90–103, doi:10.1080/1523908X.2018.1473151.
Hess, D. J., 2014: Sustainability transitions: A political coalition perspective. *Res. Policy*, **43**(2), 278–283, doi:10.1016/j.respol.2013.10.008.
Hinkel, J., 2011: Indicators of vulnerability and adaptive capacity: towards a clarification of the science-policy interface. *Glob. Environ. Chang.*, **21**(1), 198–208, doi:https://doi.org/10.1016/j.gloenvcha.2010.08.002.
Hodson, G., C. MacInnis, and M. Busseri, 2017: Bowing and kicking: Rediscovering the fundamental link between generalized authoritarianism and generalized prejudice. Personality and Individual Differences. **104**, 104–243, doi:https://doi.org/10.1016/j.paid.2016.08.018.
Hoek, A., M. Shirin, Rob Raven, Eli Court, and Emily Byrne, 2021: Towards environmentally sustainable food systems: decision-making factors in sustainable food production and consumption. *Sci. Direct*, , 610–626.
Hoffmann, I., 2010: Climate Change in Context: Implications for Livestock Production and Diversity. In: *Sustainable improvement of animal production and health* [Odongo, N.E., M. Garcia, and G.J. Viljoen, (eds.)], FAO-IAEA, Rome, pp. 33–44.
Hoffmann, M. J., 2011: *Climate Governance at the Crossroads: Experimenting with a Global Response after Kyoto*. Oxford University Press, New York, 240 pp.
Höhne, N. et al., 2017: The Paris Agreement: resolving the inconsistency between global goals and national contributions. *Clim. Policy*, **17**(1), 16–32, doi:10.1080/14693062.2016.1218320.
Holling, C. S., 2001: Understanding the complexity of economic, ecological and social systems. *Ecosystems*, **4**(5), 390–405, doi:https://doi.org/10.1007/s10021-001-0101-5.
Holscher, K., N. Frantzeskaki, T. McPhearson, and D. Loorbach, 2019: Tales of transforming cities: Transformative climate governance capacities in New York City, US and Rotterdam, Netherlands. *J. Environ. Manage.*, **231**(1), 843–857, doi:10.1016/j.jenvman.2018.10.043.
Hölscher, K., J. M. Wittmayer, and D. Loorbach, 2018: Transition versus transformation: What's the difference? *Environ. Innov. Soc. Transitions*, **27**, 1–3, doi:10.1016/j.eist.2017.10.007.
Hopkins, R., 2010: What can communities do? *post carbon reader. Manag. 21st century Sustain. Cris.*, , 442–454.
Horcea-Milcu, A. I., B. Martín-López, D. P. M. Lam, and D. J. Lang, 2020: Research pathways to foster transformation: Linking sustainability science and social-ecological systems research. *Ecol. Soc.*, **25**(1), 13, doi:10.5751/ES-11332-250113.
Howells, M. et al., 2013: Integrated analysis of climate change, land-use, energy and water strategies. *Nat. Clim. Chang.*, **3**, 621–626, doi:10.1038/NCLIMATE1789.
Hoyer, C., 2020: Accelerating Climate Action Beyond Company Gates. In: *Handbook of Climate Change Management: Research, Leadership, Transformation* [Leal Filho, W., J. Luetz, and D. Ayal, (eds.)], Springer International Publishing, Cham, pp. 1–22.
Hulme, M., 2009: *Why We Disagree About Climate Change: Understanding Controversy, Inaction and Opportunity . Cambridge, UK: Cambridge University Press.* Cambridge University, 436 pp.
Hume, T., and J. Barry, 2015: Environmental Education and Education for Sustainable Development. In: *International Encyclopedia of the Social & Behavioral Sciences*, Elsevier, Sligo, pp. 733–739.
Hutchison, S., and J. Walton, 2015: An inquiry into the significance of first-person research for the creation of knowledge to reduce suffering and enhance human flourishing. In: Action Learning and Action Research Association (ALARA) World Congress. , 9.
Hüther, G., 2018: *Co-creativity and Community*. First edit. Vandenhoeck & Ruprecht, 184 pp.
Huxham, M., M. Anwar, and D. Nelson, 2019: *Understanding the impact of a low carbon transition on South Africa*. , South Africa, 114 pp.
Iacopini, I., G. Petri, A. Barrat, and V. Latora, 2019: Simplicial models of social contagion. *Nat. Commun.*, **10**(1), 2485, doi:10.1038/s41467-019-10431-6.
ICLEI, 2019: Local Governments for Sustainability. *Local Gov. Sustain.*, , 1. https://www.iclei.org/ (Accessed September 20, 2021).

IEA, 2017: *World Energy Outlook 2017.* , IEA, Paris, 782 pp. https://www.iea.org/reports/world-energy-outlook-2017.

IEA, 2019: *World Energy Outlook 2020 - Event - IEA*. 810 pp. https://www.iea.org/reports/world-energy-outlook-2019.

IEA, 2020: *World Energy Outlook 2020. Executive Summary*. 12 pp. https://iea.blob.core.windows.net/assets/80d64d90-dc17-4a52-b41f-b14c9be1b995/WEO2020_ES.PDF.

IEAGHG, 2020: CCS and the Sustainable Development Goals. *Tech. Reports*, , 14. https://ieaghg.org/ (Accessed November 10, 2021).

IIASA, 2018: *Transformations to Achieve the Sustainable Development Goals - Report prepared by The World in 2050 initiative*. , Laxenburg, Austria, 157 pp.

IIASA, 2019: *The Digital Revolution and Sustainable Development: Opportunities and Challenges. Report prepared by the World in 2050 initiative*. , Laxenburg, Austria, 1–100 pp.

IIASA, 2020: *Innovations for Sustainability: Pathways to an efficient and post-pandemic future*. , Laxenburg, Austria, 118 pp. http://www.twi2050.org/.

IPBES, 2019: *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. , Bonn, 1148 pp.

IPCC, 2014: *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. [Core Writing Team, R.K. Pachauri, and L.A. Meyers, (eds.)]. , Geneva, Switzerland, 151 pp.

IPCC, 2018: *Global Warming of 1.5°C.An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change*. [Masson-Delmotte, V. et al., (eds.)]. 630 pp.

IPCC, 2019: *IPCC 2019: Climate Change and Land*. [Shukla, P.R. et al., (eds.)]. 874 pp.

Ives, C. D., R. Freeth, and J. Fischer, 2019: Inside-out sustainability: The neglect of inner worlds. *Ambio*, (49), 208–2017, doi:10.1007/s13280-019-01187-w.

Iyer, G. et al., 2018: Implications of sustainable development considerations for comparability across nationally determined contributions. *Nat. Clim. Chang.*, **8**, 124–129, doi:10.1038/s41558-017-0039-z.

Jaccard, I. S., P. P. Pichler, J. Többen, and H. Weisz, 2021: The energy and carbon inequality corridor for a 1.5 C compatible and just Europe. *Environ. Res. Lett.*, **16**(6), 064082, doi:10.1088/1748-9326/abfb2f.

Jacobson, M. Z. et al., 2018: 100% clean and renewable Wind, Water, and Sunlight (WWS) all-sector energy roadmaps for 53 towns and cities in North America. *Sustain. Cities Soc.*, **42**, 22–37, doi:https://doi.org/10.1016/j.scs.2018.06.031.

Jakob, M. et al., 2014: Feasible mitigation actions in developing countries. *Nat. Clim. Chang.*, **4**, 961–698, doi:https://doi.org/10.1038/nclimate2370.

Jaumotte, F., W. Liu, and W. McKibbin, 2021: *Mitigating Climate Change: Growth-Friendly Policies to Achieve Net Zero Emissions by 2050*. , Australia, 46 pp. https://cama.crawford.anu.edu.au/sites/default/files/publication/cama_crawford_anu_edu_au/2021-09/75_2021_jaumotte_liu_mckibbin00.pdf.

Jones, C.A. and Levy, D. L., 2009: Business strategies and climate change. Changing climates in North American politics. In: *Business strategies and climate change. Changing climates in North American politics* [Pulver, S., Rabe, B.G. and Stoett, P.J., (ed.)], pp. 219–240.

Jones, G. A., and K. J. Warner, 2016: The 21st century population-energy-climate nexus. *Energy Policy*, **93**, 206–212, doi:10.1016/j.enpol.2016.02.044.

Jones, L. et al., 2013: *The political economy of local adaptation planning: Exploring barriers to flexible and forward-looking decision making in three districtis in Ethiopia, Uganda and Mozambique*. 1st ed. Overseas Development Institute Africa Climate Change Resilience Alliance, Accra, 29 pp.

Jupesta, J., T. Wakiyama, and A. Abdullah, 2016: Introduction. In: *Low Carbon Urban Infrastructure Investment in Asian Cities*.

Jupesta, J. et al., 2020: Establishing Multi-Partnerships Environmental Governance in Indonesia: Case of Desa Makmur Perduli Api (Fire Free Village) Program. In: *Food security and land use change*

under conditions of climatic variability: A multidimensional perspective [Squire, V.. and M.K. Gaur, (eds.)], Springer Nature Publisher, pp. 181–196.
Kainuma, M., P. R. Shukla, and K. Jiang, 2012: Framing and modeling of a low carbon society: An overview. *Energy Econ.*, **34**, 316–324, doi:10.1016/j.eneco.2012.07.015.
Kallis, G., 2017: Socialism Without Growth. *Capital. Nat. Social.*, **30**(2), 189–206, doi:10.1080/10455752.2017.1386695.
Kalvelage, T. et al., 2013: Nitrogen cycling driven by organic matter export in the South Pacific oxygen minimum zone. *Nat. Geosci.*, **6**(3), 228–234, doi:10.1038/ngeo1739.
Kanie, N., and F. Biermann, 2017: *Governing through Goals: Sustainable Development Goals as Governance Innovation*. MIT Press, Cambridge, MA, USA, 352 pp.
Kates, R., W. Travis, and T. Wilbanks, 2012: Transformational adaptation when incremental adaptations to climate change are insufficient. *Proc. Natl. Acad. Sci.*, **109**, 7156–7161, doi:https://doi.org/10.1073/pnas.1115521109.
Keck, M. E., and K. Sikkink, 1999: Transnational advocacy networks in international and regional politics. *Int. Soc. Sci. J.*, **51**(159), 89–101, doi:10.1111/1468-2451.00179.
Kedia, S., 2016: Approaches to low carbon development in China and India. *Adv. Clim. Chang. Res.*, , doi:10.1016/j.accre.2016.11.001.
Kefford, B. M., B. Ballinger, D. R. Schmeda-Lopez, C. Greig, and S. Smart, 2018: The early retirement challenge for fossil fuel power plants in deep decarbonisation scenarios. *Energy Policy*, **119**, 294–306, doi:10.1016/j.enpol.2018.04.018.
Kemp, R., and B. Never, 2017: Green transition, industrial policy, and economic development. *Oxford Rev. Econ. Policy*, **33**(1), 66–84, doi:10.1093/oxrep/grw037.
Keohane, R. O., and D. G. Victor, 2016: Cooperation and discord in global climate policy. *Nat. Clim. Chang.*, **6**(6), doi:10.1038/nclimate2937.
Keramidas, K. et al., 2018: *Global Energy and Climate Outlook 2018: Sectoral mitigation options towards a low-emissions economy - Global context to the EU strategy for long-term greenhouse gas emissions reduction*. [Union, P.O. of the E., (ed.)]. Publications Office of the European Union, Luxembourg,.
Kern, F., 2011: Ideas, institutions, and interests: Explaining policy divergence in fostering “system innovations” towards sustainability. *Environ. Plan. C Gov. Policy*, **29**(6), 1116–1134, doi:10.1068/c1142.
Kern, F., and A. Smith, 2008: Restructuring energy systems for sustainability? Energy transition policy in the Netherlands. *Energy Policy*, **36**(11), doi:10.1016/j.enpol.2008.06.018.
Kern, F., and K. S. Rogge, 2016: The pace of governed energy transitions: Agency, international dynamics and the global Paris agreement accelerating decarbonisation processes? *Energy Res. Soc. Sci.*, **22**, 13–17, doi:10.1016/j.erss.2016.08.016.
Kikstra, J. S. et al., 2021: Climate mitigation scenarios with persistent COVID-19-related energy demand changes. *Nat. Energy*, , 1–10, doi:10.1038/s41560-021-00904-8.
Kim, G., and P. Coseo, 2019: Urban Park Systems to Support Sustainability: The Role of Urban Park Systems in Hot Arid Urban Climates. In: *Growth and Ecosystem Services of Urban Trees* [Rotzer, T., (ed.)], MDPI, Basel, pp. 142–163.
Kim, H., and S. Grafakos, 2019: Which are the factors influencing the integration of mitigation and adaptation in climate change plans in Latin American cities? *Environ. Res. Lett.*, **14**(105008), doi:https://doi.org/10.1088/1748-9326/ab2f4c.
Kjellén, M., 2006: From Public Pipes to Private Hands : Water Access and Distribution in Dar es Salaam, Tanzania. https://finna.fi/Record/fikka.2007220 (Accessed February 22, 2021).
Koasidis, K. et al., 2020: Many Miles to Paris: A Sectoral Innovation System Analysis of the Transport Sector in Norway and Canada in Light of the Paris Agreement. *Sustainability*, **12**(14), 5832, doi:10.3390/su12145832.
Koch, M., 2020: The state in the transformation to a sustainable postgrowth economy. *Env. Polit.*, **29**(1), 115–133, doi:10.1080/09644016.2019.1684738.
Koehn, P. H., 2008: Underneath Kyoto: Emerging subnational government initiatives and incipient issue-bundling opportunities in China and the United States. *Glob. Environ. Polit.*, **8**(1), 53–77, doi:10.1162/glep.2008.8.1.53.
Köhler, J. et al., 2019: An agenda for sustainability transitions research: State of the art and future

directions. *Environ. Innov. Soc. Transitions*, **31**, 1–32, doi:https://doi.org/10.1016/j.eist.2019.01.004.

Kojola, E., 2019: Indigeneity, gender and class in decision-making about risks from resource extraction. *Environ. Sociol.*, **5**(2), 130–148, doi:10.1080/23251042.2018.1426090.

Kolstad, C. et al., 2014: Social, Economic, and Ethical Concepts and Methods. In: *Cimate Change 2014 Mitigation of Climate Change Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Edenhofer, O. et al., (eds.)], Cambridge University Press, Cambridge/New York, p. pp. 76.

Kolk, A., D. Levy, and J. Pinkse, 2008: Corporate responses in an emerging climate regime: the institutionalization and commensuration of carbon disclosure. *Eur. Account. Rev.*, **17**(4), 719–745.

Kongsager, R., B. Locatelli, and F. Chazarin, 2016: Addressing Climate Change Mitigation and Adaptation Together: A Global Assessment of Agriculture and Forestry Projects. *Environ. Manage.*, **57**(2), 271–282, doi:10.1007/s00267-015-0605-y.

Kothari, C., 2019: *Research Methodology: Methods and Techniques*. 4th ed. New Age International, New Delhi, 240 pp.

Kousksou, T. et al., 2015: Renewable energy potential and national policy directions for sustainable development in Morocco. *Renew. Sustain. Energy Rev.*, **47**, 46–57, doi:https://doi.org/10.1016/j.rser.2015.02.056.

Koutroulis, A. G. et al., 2019: Global water availability under high-end climate change: A vulnerability based assessment. *Glob. Planet. Change*, **175**, 52–63, doi:10.1016/j.gloplacha.2019.01.013.

Krey, V. et al., 2019: Looking under the hood: A comparison of techno-economic assumptions across national and global integrated assessment models. *Elsevier*, **172**, 1254–1267, doi:10.1016/j.energy.2018.12.131.

Krishnan, B., S. Arumugam, and K. Maddulety, 2020: Critical success factors for the digitalization of smart cities. *Int. J. Technol. Manag. Sustain. Dev.*, **19**, 69–86.

Kruger, W., S. Stritzke, and P. A. Trotter, 2019: De-risking solar auctions in sub-Saharan Africa – A comparison of site selection strategies in South Africa and Zambia. *Renew. Sustain. Energy Rev.*, **104**, 429–438, doi:https://doi.org/10.1016/j.rser.2019.01.041.

Kummu, M., D. Gerten, J. Heinke, M. Konzmann, and O. Varis, 2014: Climate-driven interannual variability of water scarcity in food production potential: A global analysis. *Hydrol. Earth Syst. Sci.*, **18**, 447–461, doi:10.5194/hess-18-447-2014.

Kuramochi, T. et al., 2018: Ten key short-term sectoral benchmarks to limit warming to 1.5°C. *Clim. Policy*, **18**(3), 287–305, doi:10.1080/14693062.2017.1397495.

Kurian, M., 2017: The water-energy-food nexus: Trade-offs, thresholds and transdisciplinary approaches to sustainable development. *Environ. Sci. Policy*, **68**, 97–106, doi:10.1016/j.envsci.2016.11.006.

Laeremans, M. et al., 2018: Short-term effects of physical activity, air pollution and their interaction on the cardiovascular and respiratory system. *Environ. Int.*, **117**, 82–90, doi:10.1016/j.envint.2018.04.040.

Lam, D. et al., 2020: Scaling the impact of sustainability initiatives: a typology of amplification processes. *Urban Transform.*, **2**(3), doi:10.1186/s42854-020-00007-9.

Lamb, S., J. Jennings, and P. Calain, 2017: The evolving role of CSR in international development: Evidence from Canadian extractive companies' involvement in community health initiatives in low-income countries. *Extr. Ind. Soc.*, **4**(3), 614–621, doi:10.1016/j.exis.2017.05.011.

Landauer, M., S. Juhola, and M. Söderholm, 2015: Inter-relationships between adaptation and mitigation: a systematic literature review. *Clim. Change*, **131**(4), 505–517, doi:10.1007/s10584-015-1395-1.

Landauer, M., S. Juhola, and J. Klein, 2019: The role of scale in integrating climate change adaptation and mitigation in cities. In: *Cities. J. Environ. Plan. Manag*, pp. 741–765.

Lange, E. A., 2018: Transforming Transformative Education Through Ontologies of Relationality. *J. Transform. Educ.*, **16**(4), 280–301, doi:10.1177/1541344618786452.

Larsen, M., S. Petrović, A. M. Radoszynski, R. Mckenna, and O. Balyk, 2020: Climate change impacts on trends and extremes in future heating and cooling demands over Europe. *Energy Build.*, **226**, 110397, doi:10.1016/j.enbuild.2020.110397.
Larsen, M. A. D., and M. Drews, 2019: Water use in electricity generation for water-energy nexus analyses: The European case. *Sci. Total Environ.*, **651**, 2044–2058, doi:10.1016/j.scitotenv.2018.10.045.
Larsen, M. A. D. et al., 2019: Challenges of data availability: Analysing the water-energy nexus in electricity generation. *Energy Strateg. Rev.*, **26**, 100426, doi:10.1016/j.esr.2019.100426.
Latouche, S., 2018: The Path to Degrowth for a Sustainable Society. In: *actor X. Eco-Efficiency in Industry and Science,* [Lehmann, H., (ed.)], Springer, Cham, pp. 277–284.
Lazarus, M., and H. van Asselt, 2018: Fossil fuel supply and climate policy: exploring the road less taken. *Clim. Change*, **150**(1), 1–13, doi:10.1007/s10584-018-2266-3.
Le Bec, C., 2020: Pandemic puts strain 30 major African oil and gas projects. *theafricareport*,. https://www.theafricareport.com/27566/coronavirus-pandemic-puts-strain-30-major-african-oil-and-gas-projects/ (Accessed September 22, 2021).
Leclère, D. et al., 2020: Bending the curve of terrestrial biodiversity needs an integrated strategy. *Nature*, **585**(7826), 551–556, doi:10.1038/s41586-020-2705-y.
Lee, H., E. Y. Jung, and J. D. Lee, 2019: Public–private co-evolution and niche development by technology transfer: A case study of state-led electricity system transition in South Korea. *Energy Res. Soc. Sci.*, **49**, 103–113, doi:10.1016/j.erss.2018.11.001.
Lee, S.-Y., E. Zusman, and S. Lee, 2017: Tracing Sustainability Transitions in Seoul Governance: Enabling and Scaling Grassroots Innovations. *URBAN TRANSITIONS CONFERENCE*, [Seto, K and Robinson, D and Virji, H and Kovacs, Z and Zhai, J and Sami, N and Pettit, C and Sridhar, K., (ed.)], Vol. 198 of *Procedia Engineering*, 293–304.
Lemos, M. et al., 2013: Building Adaptive Capacity to Climate Change in Less Developed Countries. In: *Climate Science for Serving Society* [Asrar, G. and J. Hurrell, (eds.)], Springer Netherlands, Dordrecht, Netherlands, pp. 437–457.
Leombruni, L. V, 2015: How you talk about climate change matters: A communication network perspective on epistemic skepticism and belief strength. *Glob. Environ. Chang.*, **35**, 148–161, doi:https://doi.org/10.1016/j.gloenvcha.2015.08.006.
Lessem, R., 2018: *Community Activation for Integral Development*. 1st ed. Routledge, 156 pp.
Leventon, J., J. C. Dyer, and J. D. Van Alstine, 2015: The private sector in climate governance: Opportunities for climate compatible development through multilevel industry-government engagement. *J. Clean. Prod.*, **102**, 316–323, doi:10.1016/j.jclepro.2015.04.125.
Leventon, J., D. J. Abson, and D. J. Lang, 2021: Leverage points for sustainability transformations: nine guiding questions for sustainability science and practice. *Sustain. Sci.*, **16**(3), 721–726, doi:10.1007/s11625-021-00961-8.
Lewis, S., 2016: *Positive Psychology and Change: How Leadership, Collaboration and Appreciative Inquiry Drive Transformational Results*.
Li, B., and R. Yao, 2012: Building energy efficiency for sustainable development in China: challenges and opportunities. *Build. Res. \& Inf.*, **40**(4), 417–431, doi:10.1080/09613218.2012.682419.
Lipper, L., and D. Zilberman, 2018: A Short History of the Evolution of the Climate Smart Agriculture Approach and Its Links to Climate Change and Sustainable Agriculture Debates. In: *Climate Smart Agriculture : Building Resilience to Climate Change* [Lipper, L., N. McCarthy, D. Zilberman, S. Asfaw, and G. Branca, (eds.)], Springer International Publishing, Cham, pp. 13–30.
Lipper, L. et al., 2014: Climate-smart agriculture for food security. *Nat. Clim. Chang.*, **4**(12), 1068–1072, doi:10.1038/nclimate2437.
Liu, J. et al., 2018: Nexus approaches to global sustainable development. *Nat. Sustain.*, **1**, 466–476, doi:https://doi.org/10.1038/s41893-018-0135-8.
Liu, J. et al., 2019: On knowledge generation and use for sustainability. *Nat. Sustain.*, **2**(2), 80–82, doi:10.1038/s41893-019-0229-y.
Lo, K., and V. Castán Broto, 2019: Co-benefits, contradictions, and multi-level governance of low-carbon experimentation: Leveraging solar energy for sustainable development in China. *Glob. Environ. Chang.*, **59**, 18, doi:10.1016/j.gloenvcha.2019.101993.
Locatelli, B., C. Pavageau, E. Pramova, and M. Di Gregorio, 2015: Integrating climate change

mitigation and adaptation in agriculture and forestry: Opportunities and trade-offs. *Wiley Interdiscip. Rev. Clim. Chang.*, **6**(6), 585–598, doi:10.1002/wcc.357.

Locatelli, B., G. Fedele, V. Fayolle, and A. Baglee, 2016: Synergies between adaptation and mitigation in climate change finance. *Clim. Chang. Strateg. Manag*, **8**, 112–128, doi:https://doi.org/10.1108/IJCCSM-07-2014-0088.

Lockhart, H., 2011: Spirituality & Nature in the transformation to a more sustainable world: Perspectives of South African change agents. Stellenbosch University, 502 pp. https://scholar.sun.ac.za/handle/10019.1/18075.

Lohrmann, A., J. Farfan, U. Caldera, C. Lohrmann, and C. Breyer, 2019: Global scenarios for significant water use reduction in thermal power plants based on cooling water demand estimation using satellite imagery. *Nat. Energy*, **4**(12), 1040–1048, doi:10.1038/s41560-019-0501-4.

Loorbach, D., 2010: Transition management for sustainable development: A prescriptive, complexity-based governance framework. *Governance*, **23**(1), 161–183, doi:10.1111/j.1468-0491.2009.01471.x.

Loorbach, D., and J. Rotmans, 2010: The practice of transition management: Examples and lessons from four distinct cases. *Futures*, **42**(3), 237–246, doi:10.1016/j.futures.2009.11.009.

Loorbach, D., H. Shiroyama, J. M. Wittmayer, J. Fujino, and S. Mizuguchi, 2016: *Governance of Urban Sustainability Transitions - European and Asian Experiences*. 202 pp.

Loorbach, D., N. Frantzeskaki, and F. Avelino, 2017: Sustainability Transitions Research: Transforming Science and Practice for Societal Change. In: *ANNUAL REVIEW OF ENVIRONMENT AND RESOURCES, VOL 42* [Gadgil, A and Tomich, T., (ed.)], Vol. 42 of *Annual Review of Environment and Resources*, pp. 599–626.

Lucas, P., K. Ludwig, M. Kok, and S. Kruitwagen, 2016: *Sustainable Development Goals in the Netherlands: Building blocks for environmental policy for 2030*. , Hague, Netherlands., 56 pp.

Luken, T., 2019: Easy does it: an innovative view on developing career identity and self-direction. *Career Dev. Int.*, **25**(2), 120–145, doi:10.1108/CDI-05-2019-0110.

Lwasa, S. et al., 2015: A meta-analysis of urban and peri-urban agriculture and forestry in mediating climate change. *Curr. Opin. Environ. Sustain.*, **13**, 68–73, doi:https://doi.org/10.1016/j.cosust.2015.02.003.

Madden, N. J., 2014: Green means stop: Veto players and their impact on climate-change policy outputs. *Env. Polit.*, **23**(4), doi:10.1080/09644016.2014.884301.

Magneschi, G., T. Zhang, and R. Munson, 2017: The Impact of CO2 Capture on Water Requirements of Power Plants. *Energy Procedia*, **114**, 6337–6347, doi:https://doi.org/10.1016/j.egypro.2017.03.1770.

Månberger, A., and B. Stenqvist, 2018: Global metal flows in the renewable energy transition: Exploring the effects of substitutes, technological mix and development. *Energy Policy*, **119**, 226–241, doi:10.1016/j.enpol.2018.04.056.

Mangnus, A. C. et al., 2019: New pathways for governing food system transformations: A pluralistic practice-based futures approach using visioning, back-casting, and serious gaming. *Ecol. Soc.*, **24**(4), 2, doi:10.5751/ES-11014-240402.

Marchese, D. et al., 2018: Resilience and sustainability: Similarities and differences in environmental management applications. *Sci. Total Environ.*, **613–614**, 1275–1283, doi:10.1016/J.SCITOTENV.2017.09.086.

Marcotullio, P. et al., 2018: Energy transformation in cities. In: *Climate Change and Cities: Second Assessment Report of the Urban Climate Change Research Network. Cambridge University Press* [Rosenzweig, C., W. Solecki, P. Romero-Lankao, S. Mehrotra, S. Dhakal, and A. Ibrahim, (eds.)], Cambridge University Press, New York, pp. 443–490.

Markandya, A. et al., 2018: Health co-benefits from air pollution and mitigation costs of the Paris Agreement: a modelling study. *Lancet Planet. Heal.*, **2**(3), 126–133, doi:10.1016/S2542-5196(18)30029-9.

Markard, J., F. W. Geels, and R. Raven, 2020: Challenges in the acceleration of sustainability transitions. **15**(8), 81001, doi:10.1088/1748-9326/ab9468.

Martinez-Juarez, P., A. Chiabai, T. Taylor, and S. Quiroga Gómez, 2015: The impact of ecosystems on human health and well-being: A critical review. *J. Outdoor Recreat. Tour.*, **10**, 63–69, doi:https://doi.org/10.1016/j.jort.2015.06.008.

Mattioli, G., C. Roberts, J. K. Steinberger, and A. Brown, 2020: The political economy of car dependence: A systems of provision approach. *Energy Res. Soc. Sci.*, **66**, 101486, doi:10.1016/j.erss.2020.101486.

McCauley, S. M., and J. C. Stephens, 2012: Green energy clusters and socio-technical transitions: Analysis of a sustainable energy cluster for regional economic development in Central Massachusetts, USA. *Sustain. Sci.*, **7**(2), 213–225, doi:10.1007/s11625-012-0164-6.

McCollum, D. L. et al., 2018: Energy investment needs for fulfilling the Paris Agreement and achieving the Sustainable Development Goals. *Nat. Energy*, **3**(7), 589–599, doi:10.1038/s41560-018-0179-z.

McElwee, P. et al., 2020: The impact of interventions in the global land and agri-food sectors on Nature's Contributions to People and the UN Sustainable Development Goals. *Glob. Chang. Biol.*, **26**(9), 4691–4721, doi:10.1111/gcb.15219.

McGlade, C., and P. Ekins, 2015: The geographical distribution of fossil fuels unused when limiting global warming to 2°C. *Nature*, **517**, 187–190, doi:10.1038/nature14016.

McKenzie, S., and A. Abdulkadri, 2018: *Mechanisms to accelerate the implementation of the Sustainable Development Goals in the Caribbean*. , Santiago, Chile, 32 pp. https://repositorio.cepal.org/bitstream/handle/11362/43362/1/S1701302_en.pdf.

Mckibben, B., 2012: Global Warming's Terrifying New Math. *Glob. Warm. Terrifying New Math*, , 8. https://www.rollingstone.com/politics/politics-news/global-warmings-terrifying-new-math-188550/ (Accessed August 15, 2021).

McNeely, J. A., and M. Munasinghe, 2021: Early lessons from COVID-19: An overview. *Ambio*, **50**(4), 764–766, doi:10.1007/s13280-021-01541-x.

Meadowcroft, J., 2011: Engaging with the politics of sustainability transitions. *Environ. Innov. Soc. Transitions*, **1**(1), 70–75, doi:10.1016/j.eist.2011.02.003.

Meadows, D., 2008: *Thinking in Systems*. [Wright, D., (ed.)]. Chelsea Green Publishing, 240 pp.

Meckling, J., and J. Nahm, 2018: The power of process: State capacity and climate policy. *Governance*, **31**(4), 741–757, doi:10.1111/gove.12338.

Meckling, J., N. Kelsey, E. Biber, and J. Zysman, 2015: Winning coalitions for climate policy. *Science*, doi:10.1126/science.aab1336.

Mendizabal, M., O. Heidrich, E. Feliu, G. García-Blanco, and A. Mendizabal, 2018: Stimulating urban transition and transformation to achieve sustainable and resilient cities. *Renew. Sustain. Energy Rev.*, **94**, 410–418, doi:https://doi.org/10.1016/j.rser.2018.06.003.

Mensah, C. N., L. Dauda, K. B. Boamah, and M. Salman, 2021: One district one factory policy of Ghana, a transition to a low-carbon habitable economy? *Environ. Dev. Sustain.*, **23**, 703–721, doi:10.1007/s10668-020-00604-5.

Meyer, M., M. Hirschnitz-Garbers, and M. Distelkamp, 2018: Contemporary resource policy and decoupling trends-lessons learnt from integrated model-based assessments. *Sustain.*, **10**(6), doi:10.3390/su10061858.

Michaelowa, K., and A. Michaelowa, 2017: Transnational Climate Governance Initiatives: Designed for Effective Climate Change Mitigation? *Int. Interact.*, **43**(1), 129–155, doi:10.1080/03050629.2017.1256110.

Mikunda, T. et al., 2021: Carbon capture and storage and the sustainable development goals. *Int. J. Greenh. Gas Control*, **108**, 103318, doi:https://doi.org/10.1016/j.ijggc.2021.103318.

Miller, T. et al., 2014: The future of sustainability science: a solutions-oriented research agenda. *Sustain. Sci.*, **9**(2), 239–246, doi:https://doi.org/10.1007/s11625-013-0224-6.

Millward-Hopkins, J., J. K. Steinberger, N. D. Rao, and Y. Oswald, 2020: *Providing decent living with minimum energy: A global scenario*. , Laxemburg, 1–10 pp.

Ministry of Environment of Jordan, 2016: *National Strategy and Action Plan for Sustainable Consumption and Production in Jordan (2016-2025)*. , Jordan, 86 pp. https://www.greengrowthknowledge.org/sites/default/files/downloads/resource/National Strategy and Action Plan for Sustainable Consumption and Production in Jordan %282016-2025%29.pdf.

Moe, E., 2014: Vested Interests, Energy Policy and Renewables in Japan, China, Norway and Denmark. In: *The Political Economy of Renewable Energy and Energy Security*, Palgrave Macmillan UK, pp. 276–317.

Monforti-Ferrario, F., C. Astorga-Llorens, and E. Pisoni, 2019: *Policy pressures on air Anticipating*

unforeseen effects of EU policies on Air Quality. , Ispra, 50 pp. https://op.europa.eu/es/publication-detail/-/publication/de7643dd-0f34-11ea-8c1f-01aa75ed71a1/language-en/format-PDF.
Montuori, A., and G. Donnelly, 2018: Transformative leadership. In: *Handbook of Personal and Organizational Transformation* [Neal, J., (ed.)], Springer International Publishing, p. pp. 1234.
Munasinghe, M., 2007: The importance of social capital: Comparing the impacts of the 2004 Asian Tsunami on Sri Lanka, and Hurricane Katrina 2005 on New Orleans. *Ecol. Econ.*, **64**(1), 9–11, doi:10.1016/j.ecolecon.2007.05.003.
Munger, F., and M. Riemer, 2012: A process model for research collaborations in environmental and sustainability fields. *Umweltpsychologie*, **1**, 112–142.
Naber, R., R. Raven, M. Kouw, and T. Dassen, 2017: Scaling up sustainable energy innovations. *Energy Policy*, **110**, 342–354, doi:https://doi.org/10.1016/j.enpol.2017.07.056.
Nachmany, M., and J. Setzer, 2018: Global trends in climate change legislation and litigation: 2018 snapshot. *Grantham Res. Inst. Clim. Chang.*, , 8.
Nachmany, M. et al., 2015: *The 2015 Global Climate Legislation Study: a review of climate change legislation in 99 countries: summary for policy-makers*. , London, 1–45 pp. http://eprints.lse.ac.uk/65347/.
Næss, J. S., O. Cavalett, and F. Cherubini, 2021: The land–energy–water nexus of global bioenergy potentials from abandoned cropland. *Nat. Sustain.*, **4**(6), 525–536, doi:10.1038/s41893-020-00680-5.
Nair, S., B. George, H. M. Malano, M. Arora, and B. Nawarathna, 2014: Water-energy-greenhouse gas nexus of urban water systems: Review of concepts, state-of-art and methods. *Resour. Conserv. Recycl.*, **89**, 1–10, doi:10.1016/j.resconrec.2014.05.007.
Nakano, K., 2017: Screening of climatic impacts on a country's international supply chains: Japan as a case study. *Mitig. Adapt. Strateg. Glob. Chang.*, **22**(4), 651–667, doi:10.1007/s11027-015-9692-6.
Narvaez Rojas, C., G. A. Alomia Peñafiel, D. F. Loaiza Buitrago, and C. A. Tavera Romero, 2021: Society 5.0: A Japanese Concept for a Superintelligent Society. *Sustainability*, **13**(12), 6566, doi:10.3390/su13126567.
Nasiritousi, N., and K. Bäckstrand, 2019: *International Climate Politics in the Post-Paris Era*. , Stockholm, 1–19 pp. https://nordregio.org/wp-content/uploads/2018/10/International-Climate-Politics-in-the-post-Paris-era_Nasiritousi.pdf.
Nefzaoui, A., H. Ketata, and M. El Mourid, 2012: Agricultural Technological and Institutional Innovations for Enhanced Adaptation to Environmental Change in North Africa.
Neofytou, H., A. Nikas, and H. Doukas, 2020: Sustainable energy transition readiness: A multicriteria assessment index. *Renew. Sustain. Energy Rev.*, **131**, 109988, doi:https://doi.org/10.1016/j.rser.2020.109988.
Neuteleers, S., and B. Engelen, 2015: Talking money: How market-based valuation can undermine environmental protection. *Ecol. Econ.*, **117**, 253–260, doi:10.1016/j.ecolecon.2014.06.022.
Newell, P., and M. Paterson, 2010: *Climate capitalism: Global warming and the transformation of the global economy*. 1st ed. Cambridge University Press, London, 223 pp.
Newell, P., and D. Mulvaney, 2013: The political economy of the 'just transition.' *Geogr. J.*, **179**(2), 132–140, doi:10.1111/geoj.12008.
Newell, R., A. Dale, and M. Roseland, 2018: Climate Action Co-benefits and Integrated Community Planning: Uncovering the Synergies and Trade-Offs. *Clim. Chang. Impacts Responses*, **10**, 1–23, doi:https://doi.org/10.18848/1835-7156/CGP/v10i04/1-23.
Newman, P., T. Beatley, and H. Boyer, 2017: Create Sustainable Mobility Systems. In: *Resilient Cities*, Island Press, Washington, DC, Washington DC, pp. 53–87.
Nikas, A. et al., 2020: The desirability of transitions in demand: Incorporating behavioural and societal transformations into energy modelling. *Energy Res. Soc. Sci.*, **70**, 101780, doi:10.1016/J.ERSS.2020.101780.
Nilsson, M., D. Griggs, and M. Visbeck, 2016: Policy: Map the interactions between Sustainable Development Goals. *Nature*, **534**(7607), 320–322, doi:10.1038/534320a.
Noura, M. et al., 2020: *A carbon management system of innovation: towards a circular carbon economy*. , Saudi Arabia, 26 pp.

https://t20saudiarabia.org.sa/en/briefs/Documents/T20_TF2_PB4.pdf.

Novita, N. et al., 2020: Carbon Stocks from Peat Swamp Forest and Oil Palm Plantation in Central Kalimantan, Indonesia. In: *Climate Change Research, Policy and Actions in Indonesia: Science, Adaptation and Mitigation* [Djalante, R., J. Jupesta, and E. Aldrian, (eds.)], Springer Nature Publisher.

Novita, N. et al., 2021: Geographic Setting and Groundwater Table Control Carbon Emission from Indonesian Peatland: A Meta-Analysis. *Forests*, **12**(7), 832, doi:10.3390/f12070832.

O'Brien, K., 2018: Is the 1.5°C target possible? Exploring the three spheres of transformation. *Curr. Opin. Environ. Sustain.*, **31**, 153–160, doi:10.1016/J.COSUST.2018.04.010.

O'Neil, K., and B. A. Boyce, 2018: Improving Teacher Effectiveness in Physical Education Teacher Education Through Field-Based Supervision. *Phys. Educ.*, **75**(5), 835–849, doi:10.18666/tpe-2018-v75-i5-7739.

Obersteiner, M. et al., 2016: Assessing the land resource food price nexus of the Sustainable Development Goals. *Sci. Adv.*, **2**(9), doi:10.1126/sciadv.1501499.

OECD, 2015: Pathway to a low-carbon economy: Remarks at OECD-University of Cambridge COP21 side event. *Pathw. to a low-carbon Econ. Remarks OECD-University Cambridge COP21 side event*, , 1. https://www.oecd.org/environment/pathway-to-a-low-carbon-economy-remarks-at-oecd-university-of-cambridge-cop21-side-event.htm (Accessed September 17, 2021).

OECD, 2016: *Better Policies for Sustainable Development 2016: A New Framework for Policy Coherence*. OECD Publishing, Paris, 295 pp.

OECD, 2018: *Development Co-operation Report 2018*. 472 pp.

OECD, 2019: *Development Co-operation Report 2019*. 156 pp.

OECD, 2020: Editorial: Turning hope into reality. *OECD*, **2**(2), 3, doi:https://doi.org/10.1787/fb94a4fb-en.

Okereke, C. et al., 2019: Governing green industrialisation in Africa: Assessing key parameters for a sustainable socio-technical transition in the context of Ethiopia. *World Dev.*, **115**, 279–290, doi:10.1016/j.worlddev.2018.11.019.

Olivier, D. W., and Y. Xu, 2019: Making effective use of groundwater to avoid another water supply crisis in Cape Town, South Africa. *Hydrogeol. J.*, **27**(3), 823–826, doi:10.1007/s10040-018-1893-0.

Ordoñez, E., D. Mora, and K. Gaudry, 2019: Roadmap Toward NZEBs in Quito. *IOP Conf. Ser. Mater. Sci. Eng.*, **609**, 072040, doi:10.1088/1757-899X/609/7/072040.

Ornetzeder, M., and H. Rohracher, 2013: Of solar collectors, wind power, and car sharing: Comparing and understanding successful cases of grassroots innovations. *Glob. Environ. Chang.*, **23**(5), 856–867, doi:10.1016/j.gloenvcha.2012.12.007.

Oqubay, A., and J. Yifu Lin, 2020: *The Oxford Handbook of Industrial Hubs and Economic Development*. 1st ed. [Oqubay, A. and J. Yifu Lin, (eds.)]. Oxford University Press, Oxford, 800 pp.

Ortíz-Moya, F., E. Saraff, Y. Kataoka, and J. Fujino, 2021: *State of the Voluntary Local Reviews 2021: From Reporting to Action*. 1st ed. IGES, Kamiyamaguchi, 66 pp.

Oshiro, K., M. Kainuma, and T. Masui, 2016: Assessing decarbonization pathways and their implications for energy security policies in Japan. *Clim. Policy*, **16**(1), 63–77, doi:10.1080/14693062.2016.1155042.

Ostrom, E., 2008: Polycentric Systems as One Approach for Solving Collective-Action Problems. *Clim. Chang. Sustain. Dev. New Challenges Poverty Reduct.*, , doi:10.2139/ssrn.1304697.

Oswald, Y., A. Owen, and J. K. Steinberger, 2020: Publisher Correction: Large inequality in international and intranational energy footprints between income groups and across consumption categories. *Nat. Energy*, **5**, 231–239, doi:10.1038/s41560-020-0606-9.

Owen, R., G. Brennan, and F. Lyon, 2018: Enabling investment for the transition to a low carbon economy: government policy to finance early stage green innovation. *Curr. Opin. Environ. Sustain.*, **31**, 137–145, doi:10.1016/j.cosust.2018.03.004.

P. Puplampu, K., K. Hanson, and T. Shaw, 2017: 'From MDGs to SDGs: African Development Challenges and Prospects.'

Paech, N., 2017: Woher kommt der Wachstumszwang? *GAIA - Ecol. Perspect. Sci. Soc.*, **16**(4), doi:10.14512/gaia.16.4.13.
Pan, S.-Y., S. W. Snyder, A. I. Packman, Y. J. Lin, and P.-C. Chiang, 2018: Cooling water use in thermoelectric power generation and its associated challenges for addressing water-energy nexus. *Water-Energy Nexus*, **1**(1), 26–41, doi:10.1016/j.wen.2018.04.002.
Parodi, O., and K. Tamm, 2018: *Personal Sustainability Exploring the Far Side of Sustainable Development*. 1st ed. [Parodi, O. and K. Tamm, (eds.)]. Routledge, 224 pp.
Parra, D., L. Valverde, F. J. Pino, and M. K. Patel, 2019: A review on the role, cost and value of hydrogen energy systems for deep decarbonisation. *Renew. Sustain. Energy Rev.*, **101**, 279–294, doi:10.1016/j.rser.2018.11.010.
Pathak, M., and P. R. Shukla, 2016: Co-benefits of low carbon passenger transport actions in Indian cities: Case study of Ahmedabad. *Transp. Res. Part D Transp. Environ.*, **44**, 303–316, doi:10.1016/J.TRD.2015.07.013.
Patterson, J. J. et al., 2018: Political feasibility of 1.5°C societal transformations: the role of social justice. *Curr. Opin. Environ. Sustain.*, **31**, 1–9, doi:10.1016/j.cosust.2017.11.002.
Pellegrini-Masini, G., A. Pirni, and S. Maran, 2020: Energy justice revisited: A critical review on the philosophical and political origins of equality. *Energy Res. Soc. Sci.*, **59**, 101310, doi:10.1016/j.erss.2019.101310.
Pelling, B. et al., 2015: From research design to meta analysis guidelines. , 1–39.
Pelling, M., 2010: *Adaptation to climate change: From resilience to transformation*. First. Taylor & Francis e-Library, London, 274 pp.
Pencheon, D., 2018: Developing a sustainable health care system: the United Kingdom experience. *Med. J. Aust.*, **208**(7), 284–285, doi:10.5694/mja17.01134.
Peszko, G., D. Mensbrugghe van der, and A. Golub, 2020: *Diversification and Cooperation Strategies in a Decarbonizing World*. , Washington, DC, 1–36 pp. https://openknowledge.worldbank.org/bitstream/handle/10986/34056/Diversification-and-Cooperation-Strategies-in-a-Decarbonizing-World.pdf?sequence=4&isAllowed=y.
Peterson, M. N., K. T. Stevenson, and D. F. Lawson, 2019: Reviewing how intergenerational learning can help conservation biology face its greatest challenge. *Biol. Conserv.*, , 290–294, doi:10.1016/j.biocon.2019.05.013.
Piggot, G., 2018: The influence of social movements on policies that constrain fossil fuel supply. *Clim. Policy*, **18**(7), 942–954, doi:10.1080/14693062.2017.1394255.
Piggot, G., M. Boyland, A. Down, and A. R. Torre, 2019: Realizing a just and equitable transition away from fossil fuels. *Stock. Environ. Inst.*, (January), 1–12. https://cdn.sei.org/wp-content/uploads/2019/01/realizing-a-just-and-equitable-transition-away-from-fossil-fuels.pdf (Accessed September 22, 2021).
Poblete-Cazenave, M., S. Pachauri, E. Byers, A. Mastrucci, and B. van Ruijven, 2021: Global scenarios of household access to modern energy services under climate mitigation policy. *Nat. Energy*, **6**(8), 824–833, doi:10.1038/s41560-021-00871-0.
Pomeroy, E., and K. Oliver, 2018: Pushing the boundaries of self-directed learning: research findings from a study of u.lab participants in Scotland. *Int. J. Lifelong Educ.*, **37**(6), 719–733, doi:10.1080/02601370.2018.1550447.
Pörtner, H. et al., 2021: *Launch of IPBES-IPCC Co-Sponsored Workshop Report on Biodiversity and Climate Change*. , Bonn, Bremen- Geneva, 256 pp.
Poudel, S., 2014: Climate Smart Agriculture: A Development Alternative. https://sanjokpoudel.wordpress.com/2014/12/21/climate-smart-agriculture-a-development-alternative/ (Accessed September 2, 2021).
Power, C., 2016: The Integrity of Process: Is Inner Transition Sufficient? *J. Soc. Polit. Psychol.*, **4**(1), 347–363, doi:10.5964/jspp.v4i1.538.
Pradhan, B. B., R. M. Shrestha, A. Pandey, and B. Limmeechokchai, 2018: Strategies to Achieve Net Zero Emissions in Nepal. *Carbon Manag.*, **9**(5), 533–548, doi:10.1080/17583004.2018.1536168.
Pradhan, P., L. Costa, D. Rybski, W. Lucht, and J. P. Kropp, 2017: A Systematic Study of Sustainable Development Goal (SDG) Interactions. *Earth's Futur.*, **5**(11), 1169–1179, doi:https://doi.org/10.1002/2017EF000632.
Pretty, J. N. et al., 2006: Resource-conserving agriculture increases yields in developing countries.

Environ. Sci. Technol., **40**(4), 1114–1119, doi:10.1021/es051670d.
Privitera, R., and D. La Rosa, 2017: Enhancing carbon sequestration potential of urban green spaces through transfer of development rights strategy. *Acta Geobalcanica*, **4**(1), 17–23, doi:10.18509/agb.2018.02.
Prudhomme, R. et al., 2020: Combining mitigation strategies to increase co-benefits for biodiversity and food security. *Environ. Res. Lett.*, , 114005, doi:10.1088/1748-9326/abb10a.
Pyke, C. R., S. McMahon, L. Larsen, N. B. Rajkovich, and A. Rohloff, 2012: Development and analysis of Climate Sensitivity and Climate Adaptation opportunities indices for buildings. *Build. Environ.*, **55**, 141–149, doi:https://doi.org/10.1016/j.buildenv.2012.02.020.
Quarton, C. J., and S. Samsatli, 2020: The value of hydrogen and carbon capture, storage and utilisation in decarbonising energy: Insights from integrated value chain optimisation. *Appl. Energy*, **257**, 113936, doi:10.1016/j.apenergy.2019.113936.
Rabe, B. G., 2007: Beyond Kyoto: Climate change policy in multilevel governance systems. *Governance*, **20**(3), 423–444, doi:10.1111/j.1468-0491.2007.00365.x.
Rao, S. et al., 2017: Future air pollution in the Shared Socio-economic Pathways. *Glob. Environ. Chang.*, **42**, 346–358, doi:https://doi.org/10.1016/j.gloenvcha.2016.05.012.
Rasul, G., 2016: Managing the food, water, and energy nexus for achieving the Sustainable Development Goals in South Asia. *Environ. Dev.*, **18**, 14–25, doi:10.1016/j.envdev.2015.12.001.
Reckien, D. et al., 2018: How are cities planning to respond to climate change? Assessment of local climate plans from 885 cities in the EU-28. *J. Clean. Prod.*, **191**, 207–219, doi:10.1016/j.jclepro.2018.03.220.
Rickards, L., J. Wiseman, and Y. Kashima, 2014: Barriers to effective climate change mitigation: The case of senior government and business decision makers. *Wiley Interdiscip. Rev. Clim. Chang.*, **5**(6), 753–773, doi:10.1002/wcc.305.

Rempel, A., and J. Gupta, 2021: Fossil fuels, stranded assets and COVID-19: Imagining an inclusive & transformative recovery. *World Dev.*, **146**, 105608, doi:10.1016/J.WORLDDEV.2021.105608.
Richardson, B., 2017: Divesting from climate change: the road to influence. *Law Policy*, **39**(4), 325–348, doi:http://dx.doi.org/10.1111/lapo.12081.
Ringler, C., A. Bhaduri, and R. Lawford, 2013: The nexus across water, energy, land and food (WELF): Potential for improved resource use efficiency? *Curr. Opin. Environ. Sustain.*, , 617–624, doi:10.1016/j.cosust.2013.11.002.
Roberts, C. et al., 2018: The politics of accelerating low-carbon transitions: Towards a new research agenda. *Energy Res. Soc. Sci.*, **44**, 304–311, doi:https://doi.org/10.1016/j.erss.2018.06.001.
Robinson, J., and R. J. Cole, 2015: Theoretical underpinnings of regenerative sustainability. *Build. Res. Inf.*, **43**(2), 133–143, doi:10.1080/09613218.2014.979082.
Rockström, J. et al., 2009: A safe operating space for humanity. *Nature*, **461**(7263), 472, doi:10.1038/461472a.
Rogelj, J. et al., 2016: Paris Agreement climate proposals need a boost to keep warming well below 2 °C. *Nature*, **534**(7609), 631–639, doi:10.1038/nature18307.
Rogelj, J. et al., 2018: Mitigation pathways compatible with 1.5°C in the context of sustainable development. In: *Global Warming of 1.5 °C an IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change* [Waterfield, (ed.)], pp. 93–174.
Rogge, K. S., and P. Johnstone, 2017: Exploring the role of phase-out policies for low-carbon energy transitions: The case of the German Energiewende. *Energy Res. Soc. Sci.*, **33**, 128–137, doi:10.1016/j.erss.2017.10.004.
Rogge, K. S., F. Kern, and M. Howlett, 2017: Conceptual and empirical advances in analysing policy mixes for energy transitions. *Energy Res. Soc. Sci.*, **33**, 1–10, doi:10.1016/j.erss.2017.09.025.
Roker, S., 2018: Democratic Republic of Congo home to largest hard rock lithium resource. https://www.globalminingreview.com/exploration-development/02082018/democratic-republic-of-congo-home-to-largest-hard-rock-lithium-resource/.
Romero-Lankao, P., D. M. Gnatz, O. Wilhelmi, and M. Hayden, 2016: Urban sustainability and

resilience: From theory to practice. *Sustain.*, **8**(12), 1224, doi:10.3390/su8121224.
Rooney-Varga, J. N. et al., 2020: The Climate Action Simulation. *Simul. Gaming*, **51**(2), doi:10.1177/1046878119890643.
Roschnik, S. et al., 2017: Transitioning to environmentally sustainable health systems: the example of the NHS in England. *Public Heal. Panor.*, **03**(02), 229–236.
Rosenberg, L., J. D. Ouelette, and D. J. Dowgiallo, 2019: Analysis of S-band Passive Bistatic Sea Clutter. *2019 IEEE Radar Conf.*, , 1–6, doi:10.1109/RADAR.2019.8835730.
Rosenbloom, D., H. Berton, and J. Meadowcroft, 2016: Framing the sun: A discursive approach to understanding multi-dimensional interactions within socio-technical transitions through the case of solar electricity in Ontario, Canada. *Res. Policy*, **45**(6), 1275–1290, doi:10.1016/j.respol.2016.03.012.
Rosenbloom, D., J. Meadowcroft, S. Sheppard, S. Burch, and S. Williams, 2018: Transition experiments: Opening up low-carbon transition pathways for Canada through innovation and learning. *Can. Public Policy*, **44**(4), 368–383, doi:10.3138/cpp.2018-020.
Rosenbloom, D., J. Meadowcroft, and B. Cashore, 2019: Stability and climate policy? Harnessing insights on path dependence, policy feedback, and transition pathways. *Energy Res. Soc. Sci.*, **50**, 168–178, doi:10.1016/j.erss.2018.12.009.
Rosendahl, K. E., and D. R. Rubiano, 2019: How Effective is Lithium Recycling as a Remedy for Resource Scarcity? *Environ. Resour. Econ.*, **74**(3), doi:10.1007/s10640-019-00356-5.
Rothausen, S. G. S. A., and D. Conway, 2011: Greenhouse-gas emissions from energy use in the water sector. *Nat. Clim. Chang.*, **1**, 210–219, doi:10.1038/nclimate1147.
Roy, J. et al., 2018a: Sustainable Development , Poverty Eradication and Reducing Inequalities. In: *Global Warming of 1.5 °C an IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change* [Masson-Delmotte, V. et al., (eds.)], pp. 1–94.
Roy, J. et al., 2018b: Where is the hope? Blending modern urban lifestyle with cultural practices in India. *Curr. Opin. Environ. Sustain.*, **31**, 96–103, doi:10.1016/J.COSUST.2018.01.010.
Roy, J., N. Das, S. Some, and H. Mahmud, 2021: Fast-Growing Developing Countries: Dilemma and Way Forward in a Carbon-Constrained World. In: *Sustainable Development Insights from India*, Springer, Kolkata, pp. 23–41.
Ruiz-Garcia, L., L. Lunadei, P. Barreiro, and I. Robla, 2009: A Review of Wireless Sensor Technologies and Applications in Agriculture and Food Industry: State of the Art and Current Trends. *Sensors*, **9**(6), 4728–4750, doi:10.3390/s90604728.
Rydge, J., M. Jacobs, and I. Granoff, 2015: *Ensuring New Infrastructure is Climate-Smart. Contributing paper for Seizing the Global Opportunity: Partnerships for Better Growth and a Better Climate*. , London-Washington, 1–20 pp. https://newclimateeconomy.report/2015/wp-content/uploads/sites/3/2014/08/Ensuring-infrastructure-is-climate-smart.pdf.
Sachs, J., G. Schmidt-Traub, C. Kroll, G. Lafortune, and G. Fuller, 2019: *Sustainable Development Report 2019*. , New York,.
Samantray, A., and P. Pin, 2019: Credibility of climate change denial in social media. *Palgrave Commun.*, **5**(1), 127, doi:10.1057/s41599-019-0344-4.
Sanchez Rodriguez, R., D. Ürge-Vorsatz, and A. Barau, 2018: Sustainable Development Goals and climate change adaptation in cities. *Nat. Clim. Chang.*, **8**, 181–183, doi:https://doi.org/10.1038/s41558-018-0098-9.
Sandfort, J., and K. Quick, 2015: Building deliberative capacity to create public value: the practices and artifacts of the Art of Hosting. In: *Public Administration and Public Value* [Bryson, J., B. L, and B. Crosby, (eds.)], , Washington, DC Georgetown University Press, pp. 39–52.
Sathaye, J. et al., 2007: Sustainable Development and Mitigation. In: *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Metz, B., O.R. Davidson, P. Bosch, R. Dave, and M. L.A., (eds.)], Cambridge University Press, United Kingdom and New York, NY, USA., pp. 1–54.
Sator, O., 2018: *Insights from case studies of major coal-consuming economies*. IDDRI and Climate Strategies, France, 42 pp. https://coaltransitions.files.wordpress.com/2018/09/coal_synthesis_final.pdf.

Satterthwaite, D., 2017: Successful, safe and sustainable cities: towards a New Urban Agenda. *Commonw. J. Local Gov.*, , 3–18, doi:10.5130/cjlg.v0i19.5446.
Schäpke, N., M. Bergmann, F. Stelzer, and D. Lang, 2018: Labs in the Real World: Advancing Transdisciplinary Research and Sustainability Transformation: Mapping the Field and Emerging Lines of Inquiry. *GAIA-Ecological Perspect. Sci. Soc.*, **27**(1), 8–11, doi:https://doi.org/10.14512/gaia.27.S1.4.
Scharmer, C, Kaufer, K., 2015: Awareness-Based Action Research: Catching Social Reality Creation in Flight. In: *The SAGE Handbook of Action Research* [Bradbury, H., (ed.)], SAGE Publications Ltd, London, pp. 199–210.
Scharmer, O., 2018: *The Essentials of Theory U: Core Principles and Applications*. 2nd ed. Berret-Koehler, Oakland, 248 pp.
Schaube, P., W. Ortiz, and M. Recalde, 2018: Status and future dynamics of decentralised renewable energy niche building processes in Argentina. *Energy Res. Soc. Sci.*, **35**, 57–67, doi:10.1016/j.erss.2017.10.037.
Schlott, M., A. Kies, T. Brown, S. Schramm, and M. Greiner, 2018: The impact of climate change on a cost-optimal highly renewable European electricity network. *Appl. Energy*, **230**, 1645–1649, doi:10.1016/j.apenergy.2018.09.084.
Schneidewind, U., M. Singer-Brodowski, K. Augenstein, and F. Stelzer, 2016: *Pledge for a transformative science: A conceptual framework*. Wuppertal Institut für Klima, Umwelt, Energie, Wuppertal, 1–30 pp. http://hdl.handle.net/10419/144815.
Scholz, L., A. Ortiz Perez, B. Bierer, J. Wöllenstein, and S. Palzer, 2018: Gas sensors for climate research. *J. Sensors Sens. Syst.*, **7**(2), 535–541, doi:10.5194/jsss-7-535-2018.
Schoneveld, G. C., D. Ekowati, A. Andrianto, and S. Van Der Haar, 2019: Modeling peat- and forestland conversion by oil palm smallholders in Indonesian Borneo. *Environ. Res. Lett.*, **14**(1), 15, doi:10.1088/1748-9326/aaf044.
Schramade, W., 2017: Investing in the UN Sustainable Development Goals: Opportunities for Companies and Investors. *J. Appl. Corp. Financ.*, **29**(2), 87–99, doi:10.1111/jacf.12236.
Schrobback, P., D. Adamson, and J. Quiggin, 2011: Turning Water into Carbon: Carbon Sequestration and Water Flow in the Murray-Darling Basin. *Environ. Resour. Econ.*, **49**(1), 23–45, doi:10.1007/s10640-010-9422-1.
Schweizer-Ries, P., 2018: Sustainability Science and its contribution to IAPS: seeking for integrated sustainability. *IAPS Bull.*, **40**, 9–12. https://cupdf.com/document/iaps-bulletin-no40.html (Accessed August 13, 2021).
Scobie, M., 2016: Policy coherence in climate governance in Caribbean Small Island Developing States. *Environ. Sci. Policy*, **58**, 16–28, doi:https://doi.org/10.1016/j.envsci.2015.12.008.
Scott, J., 2011: Social network analysis: developments, advances, and prospects. *Soc. Netw. Anal. Min.*, **1**(1), 21–26, doi:10.1007/s13278-010-0012-6.
Seddon, N. et al., 2021: Getting the message right on nature-based solutions to climate change. *Glob. Chang. Biol.*, **27**(8), 1518–1546, doi:10.1111/gcb.15513.
Seligman, M., and M. Csikszentmihalyi, 2014: Positive Psychology: An Introduction. In: *Flow and the Foundations of Positive Psychology* [Csikszentmihalyi, M., (ed.)], Dordrecht: Springer, pp. 279–298.
Sengers, F., A. J. Wieczorek, and R. Raven, 2019: Experimenting for sustainability transitions: A systematic literature review. *Technol. Forecast. Soc. Change*, **145**, 153–164, doi:https://doi.org/10.1016/j.techfore.2016.08.031.
Sethi, M., and J. Puppum De Oliveria, 2018: *Mainstreaming Climate Co-Benefits in Indian Cities*. 1st ed. [Sethi, M. and J. Puppum De Oliveria, (eds.)]. Springer, Singapore, 373 pp.
Seto, K. C. et al., 2016: Carbon Lock-In: Types, Causes, and Policy Implications. *Annu. Rev. Environ. Resour.*, **41**, 425–452, doi:10.1146/annurev-environ-110615-085934.
Setyowati, A. B., 2021: Mitigating inequality with emissions? Exploring energy justice and financing transitions to low carbon energy in Indonesia. *Energy Res. Soc. Sci.*, **71**, 101817, doi:https://doi.org/10.1016/j.erss.2020.101817.
Seyfang, G., and A. Smith, 2007: Grassroots innovations for sustainable development: Towards a new research and policy agenda. *Env. Polit.*, **16**(4), 584–603, doi:10.1080/09644010701419121.
Seyfang, G., and A. Haxeltine, 2012: Growing grassroots innovations: Exploring the role of

community-based initiatives in governing sustainable energy transitions. *Environ. Plan. C Gov. Policy*, **30**(3), 381–400, doi:10.1068/c10222.

Sgouridis, S., M. Carbajales-Dale, D. Csala, M. Chiesa, and U. Bardi, 2019: Comparative net energy analysis of renewable electricity and carbon capture and storage. *Nat. Energy*, **4**(6), 456–465, doi:10.1038/s41560-019-0365-7.

Shah, N., M. Wei, V. E. Letschert, and A. A. Phadke, 2015: *Benefits of Leapfrogging to Superefficiency and Low Global Warming Potential Refrigerants in Room Air Conditioning*. , California, 57 pp. https://www.osti.gov/servlets/purl/1235571.

Sharifi, A., 2020: Co-benefits and synergies between urban climate change mitigation and adaptation measures: A literature review. *Sci. Total Environ.*, **750**, 141642, doi:https://doi.org/10.1016/j.scitotenv.2020.141642.

Shaw, A., S. Burch, F. Kristensen, J. Robinson, and A. Dale, 2014: Accelerating the sustainability transition: Exploring synergies between adaptation and mitigation in British Columbian communities. *Glob. Environ. Chang.*, **25**(1), 41–51, doi:10.1016/j.gloenvcha.2014.01.002.

Shaw, D., and P. Roberts, 2017: *Regional Planning and Development in Europe*. 1st ed. Routledge, London, 314 pp.

Shen, W. et al., 2020: A comprehensive review of variable renewable energy levelized cost of electricity. *Renew. Sustain. Energy Rev.*, **133**, 110301, doi:10.1016/j.rser.2020.110301.

Sheppard, S. R. J. et al., 2011: Future visioning of local climate change: A framework for community engagement and planning with scenarios and visualisation. *Futures*, **43**(4), 400–412, doi:10.1016/j.futures.2011.01.009.

Shrivastava, P., M. Stafford Smith, K. O'Brien, and L. Zsolnai, 2020: Transforming Sustainability Science to Generate Positive Social and Environmental Change Globally. *One Earth*, **2**(4), 329–340, doi:10.1016/J.ONEEAR.2020.04.010.

Sindico, F., 2016: Paris, Climate Change, and Sustainable Developmen, Climate Law. *Clim. Law*, **6**(1–2), 130–141, doi:https://doi.org/10.1163/18786561-00601009.

Singleton, J., 2015: Head, heart and hands model for transformative learning: place as context for changing sustainability values Transforming eco-paradigms for sustainable values. *J. Sustain. Educ.*, **9**(March), 1–16.

Sklair, L., 2016: D'Alisa, G., Demaria, F. and Kallis. G. (eds) Degrowth: A Vocabulary for a New Era 2014 Routledge 220 pp. £24.99 (paperback). *Br. J. Sociol.*, **67**(1), 168–170, doi:10.1111/1468-4446.12181.

Smajgl, A., J. Ward, and L. Pluschke, 2016: The water-food-energy Nexus - Realising a new paradigm. *J. Hydrol.*, **533**, 530–540, doi:10.1016/j.jhydrol.2015.12.033.

Smink, M. M., M. P. Hekkert, and S. O. Negro, 2015: Keeping sustainable innovation on a leash? Exploring incumbents' institutional strategies. *Bus. Strateg. Environ.*, **24**(2), 86–101, doi:10.1002/bse.1808.

Smith, A., A. Stirling, and F. Berkhout, 2005: The governance of sustainable socio-technical transitions. *Res. Policy*, **34**(10), 1491–1510, doi:10.1016/j.respol.2005.07.005.

Smith, P. et al., 2019a: Land-Management Options for Greenhouse Gas Removal and Their Impacts on Ecosystem Services and the Sustainable Development Goals. *Annu. Rev. Environ. Resour.*, **44**(1), 255–286, doi:10.1146/annurev-environ-101718-033129.

Smith, P. et al., 2019b: Interlinkages between desertification, land degradation, food security and greenhouse gas fluxes: Synergies, trade-offs and integrated response options. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [Shukla, P. et al., (eds.)], p. pp. 122.

Solarin, S. A., U. Al-Mulali, I. Musah, and I. Ozturk, 2017: Investigating the pollution haven hypothesis in Ghana: An empirical investigation. *Energy*, **124**, 706–719, doi:10.1016/j.energy.2017.02.089.

Song, L. et al., 2020: Contested energy futures, conflicted rewards? Examining low-carbon transition risks and governance dynamics in China's built environment. *Energy Res. Soc. Sci.*, **59**, 101306, doi:10.1016/J.ERSS.2019.101306.

Sorman, A. H., E. Turhan, and M. Rosas-Casals, 2020: Democratizing Energy, Energizing Democracy: Central Dimensions Surfacing in the Debate. *Front. Energy Res.*, **8**, 279, doi:10.3389/fenrg.2020.499888.

Soussana, J. F. et al., 2019: Matching policy and science: Rationale for the '4 per 1000 - soils for food security and climate' initiative. *Soil Tillage Res.*, **188**, 1–59, doi:10.1016/j.still.2017.12.002.
Sovacool, B. K., 2018: Bamboo Beating Bandits: Conflict, Inequality, and Vulnerability in the Political Ecology of Climate Change Adaptation in Bangladesh. *World Dev.*, **102**, 183–194, doi:https://doi.org/10.1016/j.worlddev.2017.10.014.
Sovacool, B. K., 2021: Who are the victims of low-carbon transitions? Towards a political ecology of climate change mitigation. *Energy Res. Soc. Sci.*, **73**, 101916, doi:https://doi.org/10.1016/j.erss.2021.101916.
Sovacool, B. K., and J. Scarpaci, 2016: Energy justice and the contested petroleum politics of stranded assets: Policy insights from the Yasuní-ITT Initiative in Ecuador. *Energy Policy*, **95**, 158–171, doi:https://doi.org/10.1016/j.enpol.2016.04.045.
Sovacool, B. K., D. J. Hess, and R. Cantoni, 2021: Energy transitions from the cradle to the grave: A meta-theoretical framework integrating responsible innovation, social practices, and energy justice. *Energy Res. Soc. Sci.*, **75**, 102027, doi:https://doi.org/10.1016/j.erss.2021.102027.
Speldewinde, P. C., D. Slaney, and P. Weinstein, 2015: Is restoring an ecosystem good for your health? *Sci. Total Environ.*, **502**, 276–279, doi:10.1016/j.scitotenv.2014.09.028.
Spencer, T. et al., 2018: The 1.5°C target and coal sector transition: at the limits of societal feasibility. *Clim. Policy*, **18**(3), 335–351, doi:10.1080/14693062.2017.1386540.
Springmann, M. et al., 2018: Options for keeping the food system within environmental limits. *Nature*, **562**, 519–525, doi:10.1038/s41586-018-0594-0.
Srikanth, R., 2018: India's sustainable development goals – Glide path for India's power sector. *Energy Policy*, **123**, 325–336.
Steen, M., and T. Weaver, 2017: Incumbents' diversification and cross-sectorial energy industry dynamics. *Res. Policy*, **46**(6), 1071–1086, doi:10.1016/j.respol.2017.04.001.
Steenkamp, L. A., 2017: A review of policy options for clean electricity supply in South Africa. *2017 6th International Conference on Clean Electrical Power: Renewable Energy Resources Impact, ICCEP 2017*, Santa Marguerita, IEEE, 94–102.
Steffen, W. et al., 2015: Planetary boundaries: Guiding human development on a changing planet. *Science*, **347**(6223), 736–745, doi:10.1126/science.1259855.
Streck, D., 2007: Research and Social Transformation -Notes about Method and Methodology in Participatory Research. *Int. J. Action Res.*, **3**(1+2).
Sušnik, J. et al., 2018: Multi-stakeholder development of a serious game to explore the water-energy-food-land-climate nexus: The SIM4NEXUS approach. *Water (Switzerland)*, **2**(10), 139, doi:10.3390/w10020139.
Svobodova, K., J. R. Owen, J. Harris, and S. Worden, 2020: Complexities and contradictions in the global energy transition: A re-evaluation of country-level factors and dependencies. *Appl. Energy*, **265**, 114778, doi:10.1016/j.apenergy.2020.114778.
Swain, R. B., and A. Karimu, 2020: Renewable electricity and sustainable development goals in the EU. *World Dev.*, **125**, 1046693, doi:10.1016/j.worlddev.2019.104693.
Swart, R., and F. Raes, 2007: Making integration of adaptation and mitigation work: Mainstreaming into sustainable development policies? *Clim. Policy*, **7**(4), 288–303, doi:10.1080/14693062.2007.9685657.
Sweeney, S., and J. Treat, 2018: *Trade unions and just transitions. The Search for a Transformative Politics*. , New York, 52 pp. http://unionsforenergydemocracy.org/wp-content/uploads/2018/04/TUED-Working-Paper-11.pdf.
Swilling, M. Annecke, E., 2010: *Just Transitions : Explorations of Sustainability in an Unfair World*. United Nations University Press, 448 pp.
Teng, F., X. Su, and X. Wang, 2019: Can China Peak Its Non-CO2 GHG Emissions before 2030 by Implementing Its Nationally Determined Contribution? *Environ. Sci. Technol.*, **53**(21), 12168–12176, doi:10.1021/acs.est.9b04162.
The Energy and Resources Institute, 2017: *Energy & Environment Data Diary and Yearbook (TEDDY)*. [TERI, (ed.)]. TERI, New Delhi, 350 pp.
The National BIM Report 2018, 2018: The National BIM Report 2018. *Natl. BIM Rep.*,. https://www.thenbs.com/knowledge/the-national-bim-report-2018 (Accessed September 21, 2021).

The National People's Congress of the People's Republic of China, 2016: *The 13th Five-Year Plan for Economic and Social Development of the People'S Republic of China*. , Beijing, 2019 pp.

Thornbush, M., O. Golubchikov, and S. Bouzarovski, 2013: Sustainable cities targeted by combined mitigation–adaptation efforts for future-proofing. *Sustain. Cities Soc.*, **9**, 1–9, doi:https://doi.org/10.1016/j.scs.2013.01.003.

Thornton, T. F., and C. Comberti, 2017: Synergies and trade-offs between adaptation, mitigation and development. *Clim. Change*, **140**(1), 5–18, doi:10.1007/s10584-013-0884-3.

Tong, D. et al., 2019: Committed emissions from existing energy infrastructure jeopardize 1.5 °C climate target. *Nature*, **572**(7769), 373–377, doi:10.1038/s41586-019-1364-3.

Townshend, T. et al., 2013: How national legislation can help to solve climate change. *Nat. Clim. Chang.*, **3**(5), 430–432, doi:10.1038/nclimate1894.

Tozer, L., 2018: Urban climate change and sustainability planning: an analysis of sustainability and climate change discourses in local government plans in Canada. *J. Environ. Plan. Manag.*, **61**(1), 176–194, doi:10.1080/09640568.2017.1297699.

Trullen, J., and B. Torbert, 2004: First, Second and Third person research in practice. *First, Second Third Pers. Res. Pract.*, **15**(1), 1–2.

Turnheim, B., and B. Nykvist, 2019: Opening up the feasibility of sustainability transitions pathways (STPs): Representations, potentials, and conditions. *Res. Policy*, **48**(3), 775–788, doi:10.1016/j.respol.2018.12.002.

UN- UNDRR, 2019: *UN Office for Disatser Risk Reduction, Sendai Framework*. 425 pp. https://www.undrr.org/publication/global-assessment-report-disaster-risk-reduction-2019 (Accessed August 14, 2021).

UN Women, 2017: *Approaches by African Countries in the Implementation and Localization of SDGs*. , Nairoby, 60 pp. https://www2.unwomen.org/-/media/field office africa/attachments/publications/2017/11/approaches by african countries in the implementation and localization of sdgs- web.pdf?la=en&vs=5752.

UNDESA, 2016: *Voluntary National Reviews - Synthesis Report 2016*. 71 pp. https://sustainabledevelopment.un.org/content/documents/127761701030E_2016_VNR_Synthesis_Report_ver3.pdf.

UNDESA, 2017: *Voluntary National Reviews - Synthesis Report 2017*. 78 pp. https://sustainabledevelopment.un.org/content/documents/17109Synthesis_Report_VNRs_2017.pdf.

UNDESA, 2018: *Voluntary National Reviews - Synthesis Report 2018*. 80 pp. https://sustainabledevelopment.un.org/content/documents/210732018_VNRs_Synthesis_compilation_11118_FS_BB_Format_FINAL_cover.pdf.

UNEP/SEI, 2020: *Production Gap Report 2020:The discrepancy between countries' planned fossil fuel production and global production levels consistent with limiting warming to 1.5°C or 2°C*. 76 pp.

UNFCCC, 2015: *UNFCCC. Synthesis Report on the Aggregate Effect of the Intended Nationally Determined Contributions. Report No. FCCC/CP/2015/7*. http://unfccc.int/resource/docs/2015/cop21/eng/07.pdf.

UNFCCC, 2016: *Report of the Conference of the Parties on its twenty-first session, held in Paris from 30 November to 13 December 2015*. , Paris, https://unfccc.int/resource/docs/2015/cop21/eng/10.pdf.

UNFCCC, 2019: Communication of long-term strategies. *Commun. long-term Strateg.*,. https://unfccc.int/process/the-paris-agreement/long-term-strategies (Accessed July 8, 2021).

UNFCCO, 2020: Petersberg Climate Dialogue Seeks Climate-Resilient Economic Recovery. *Petersb. Clim. Dialogue Seek. Clim. Econ. Recover.*,. https://unfccc.int/news/petersberg-climate-dialogue-seeks-climate-resilient-economic-recovery (Accessed August 11, 2021).

UNIDO, 2018: *Industrial park development in Ethiopia case of study report*. , Vienna, 2–85 pp. https://www.unido.org/api/opentext/documents/download/10694802/unido-file-10694802.

United Nation, 2018: *Sustainable Development Goal 6: Synthesis Report on Water and Sanitation*.

United Nations, 2015a: Summit Charts New Era of Sustainable Development. *United Nations Press release*, , 20. https://sustainabledevelopment.un.org/post2015/summit (Accessed September 5, 2021).

United Nations, 2015b: *Sendai Framework for Disaster Risk Reduction 2015-2030*. , Geneva, 37 pp.

https://www.preventionweb.net/files/43291_sendaiframeworkfordrren.pdf.
United Nations, 2017: The Sustainable Development Goals Report. *Sustain. Dev. Goals Rep.*,. https://www.undp.org/publications/un-sustainable-development-goals-report-2017?utm_source=EN&utm_medium=GSR&utm_content=US_UNDP_PaidSearch_Brand_English&utm_campaign=CENTRAL&c_src=CENTRAL&c_src2=GSR&gclid=Cj0KCQjw5oiMBhDtARIsAJi0qk210sGqvjhlX1DwK1NNf4WGlk (Accessed October 13, 2021).
United Nations, 2019: *Global Sustainable Development Report 2019: The Future is Now – Science for Achieving Sustainable Development*. , New York, 1–252 pp. https://sustainabledevelopment.un.org/content/documents/24797GSDR_report_2019.pdf.
United Nations Environment Programme, U. N., 2019: *Emissions Gap Report 2019.* , Nairoby, 108 pp. https://www.unenvironment.org/resources/emissions-gap-report-2019.
United Nations General Assembly, 2019: Resolution adopted by the General Assembly on 15 October. , 2. https://undocs.org/pdf?symbol=en/A/RES/74/5 (Accessed September 5, 2021).
United Nations General Assembly, 2021: High-Level Meetings of the 76th Session. *High-Level Meet. 76th Sess.*,. https://www.un.org/en/ga/76/meetings/ (Accessed September 28, 2021).
UNU-INRA, 2020: Accra, Ghana. *UNU Inst. Nat. Resour. Africa*,. https://unu.edu/about/unu-system/inra (Accessed August 25, 2020).
Ürge-Vorsatz, D., S. T. Herrero, N. K. Dubash, and F. Lecocq, 2014: Measuring the Co-Benefits of Climate Change Mitigation. *Annu. Rev. Environ. Resour.*, **39**(1), 549–582, doi:10.1146/annurev-environ-031312-125456.
UToronto, 2016: *G20 Action Plan on the 2030 Agenda for Sustainable Development*. 3–48 pp. https://www.b20germany.org/fileadmin/user_upload/G20_Action_Plan_on_the_2030_Agenda_for_Sustainable_Development.pdf.
van Asselt, H., 2014: *The fragmentation of global climate governance: Consequences and management of regime interactions*. Edward Elgar Publishing Ltd., 1–335 pp.
van den Berg, N. J. et al., 2020: Implications of various effort-sharing approaches for national carbon budgets and emission pathways. *Clim. Change*, **162**(4), 1805–1822, doi:10.1007/s10584-019-02368-y.
van der Heijden, J., J. Patterson, S. Juhola, and M. Wolfram, 2019: Special section: advancing the role of cities in climate governance–promise, limits, politics. *J. Environ. Plan. Manag.*, **62**(3), 365–373, doi:10.1080/09640568.2018.1513832.
Van der Heijden, J., 2018: The limits of voluntary programs for low-carbon buildings for staying under 1.5 °C. *Curr. Opin. Environ. Sustain.*, **30**, 59–66, doi:10.1016/j.cosust.2018.03.006.
van der Ploeg, F., and A. Rezai, 2020: Stranded assets in the transition to a carbon-free economy. *Annu. Rev. Resour. Econ.*, **12**, 281–298, doi:10.1146/annurev-resource-110519-040938.
Van Der Ploeg, F., 2011: Natural resources: Curse or blessing? *J. Econ. Lit.*, **49**(2), 366–420, doi:10.1257/jel.49.2.366.
van Rooyen, J. D., A. P. Watson, and J. A. Miller, 2020: Combining quantity and quality controls to determine groundwater vulnerability to depletion and deterioration throughout South Africa. *Environ. Earth Sci.*, **79**(11), 255, doi:10.1007/s12665-020-08998-1.
van Soest, H. L. et al., 2019: Analysing interactions among Sustainable Development Goals with Integrated Assessment Models. *Glob. Transitions*, **1**, 210–225, doi:https://doi.org/10.1016/j.glt.2019.10.004.
van Vliet, M. T. H. et al., 2016: Multi-model assessment of global hydropower and cooling water discharge potential under climate change. *Glob. Environ. Chang.*, **40**, 156–170, doi:10.1016/j.gloenvcha.2016.07.007.
Van Vliet, M. T. H., J. Sheffield, D. Wiberg, and E. F. Wood, 2016a: Impacts of recent drought and warm years on water resources and electricity supply worldwide. *Environ. Res. Lett.*, , doi:10.1088/1748-9326/11/12/124021.
Van Vliet, M. T. H., D. Wiberg, S. Leduc, and K. Riahi, 2016b: Power-generation system vulnerability and adaptation to changes in climate and water resources. *Nat. Clim. Chang.*, , doi:10.1038/nclimate2903.
Vandyck, T., K. Keramidas, B. Saveyn, A. Kitous, and Z. Vrontisi, 2016: A global stocktake of the Paris pledges: Implications for energy systems and economy. *Glob. Environ. Chang.*, **41**, 46–63, doi:https://doi.org/10.1016/j.gloenvcha.2016.08.006.

Vandyck, T. et al., 2018: Air quality co-benefits for human health and agriculture counterbalance costs to meet Paris Agreement pledges. *Nat. Commun.*, **9**(1), 4939, doi:10.1038/s41467-018-06885-9.
Varela, F. J., 1999: and Jonathan Shear First-person Methodologies : What , Why , How ? https://www.semanticscholar.org/paper/and-Jonathan-Shear-First-person-Methodologies-%3A-%2C-%2C-Varela/3852a7981815f05f0a23e0710bbc7d6c52086ca3?p2df.
Veciana, S., and K. Ottmar, 2018: Inner conflict resolution and self-empowerment as contribution for personal sustainability on the case of intentional community practices. In: *Personal Sustainability: Exploring the Far Side of Sustainable Development*, Taylor & Francis Group, Routledge, p. pp. 20.
Veldkamp, T. I. E. et al., 2015: Changing mechanism of global water scarcity events: Impacts of socioeconomic changes and inter-annual hydro-climatic variability. *Glob. Environ. Chang.*, **32**, 18–29, doi:10.1016/j.gloenvcha.2015.02.011.
Wada, Y. et al., 2016: Modeling global water use for the 21st century: The Water Futures and Solutions (WFaS) initiative and its approaches. *Geosci. Model Dev.*, **9**, 175–222, doi:10.5194/gmd-9-175-2016.
Walsh, Z., J. Böhme, and C. Wamsler, 2020: Towards a relational paradigm in sustainability research, practice, and education. *Ambio*, , doi:10.1007/s13280-020-01322-y.
Wamsler, C., and E. Brink, 2018: Mindsets for Sustainability: Exploring the Link Between Mindfulness and Sustainable Climate Adaptation. *Ecol. Econ.*, **151**, 55–61, doi:https://doi.org/10.1016/j.ecolecon.2018.04.029.
Wamsler, C., G. Osberg, W. Osika, H. Herndersson, and L. Mundaca, 2021: Linking internal and external transformation for sustainability and climate action: Towards a new research and policy agenda. *Glob. Environ. Chang.*, **71**, 102373, doi:https://doi.org/10.1016/j.gloenvcha.2021.102373.
Wan, K. K. W., D. H. W. Li, W. Pan, and J. C. Lam, 2012: Impact of climate change on building energy use in different climate zones and mitigation and adaptation implications. *Appl. Energy*, **97**, 274–282, doi:https://doi.org/10.1016/j.apenergy.2011.11.048.
Wang, H., and W. Chen, 2019: Gaps between pre-2020 climate policies with NDC goals and long-term mitigation targets: Analyses on major regions. *Energy Procedia*, **158**, 22–25, doi:10.1016/j.egypro.2019.01.894.
Wang, Y., and Q. Zhi, 2016: The Role of Green Finance in Environmental Protection: Two Aspects of Market Mechanism and Policies. *Energy Procedia*, **104**, 311–316, doi:https://doi.org/10.1016/j.egypro.2016.12.053.
Warmenbol, C., and M. Smith, 2018: International union for conservation of nature (IUCN). In: *The Wetland Book: I: Structure and Function, Management, and Methods*, Springer Netherlands, pp. 665–669.
Warren, B., P. Christoff, and D. Green, 2016: Australia's sustainable energy transition: The disjointed politics of decarbonisation. *Environ. Innov. Soc. Transitions*, **21**, 1–12, doi:10.1016/j.eist.2016.01.001.
WCED, 1987: *World Commission on Environment and Development. 1987. Our Common Future.* , Geneva, 190 pp. https://idl-bnc-idrc.dspacedirect.org/bitstream/handle/10625/8942/WCED_79365.pdf?sequence=1&isAllowed=y.
Westman, L., E. Moores, and S. L. Burch, 2021: Bridging the governance divide: The role of SMEs in urban sustainability interventions. *Cities*, **108**, 102944, doi:https://doi.org/10.1016/j.cities.2020.102944.
White, D. J., K. Hubacek, K. Feng, L. Sun, and B. Meng, 2018: The Water-Energy-Food Nexus in East Asia: A tele-connected value chain analysis using inter-regional input-output analysis. *Appl. Energy*, , doi:10.1016/j.apenergy.2017.05.159.
Wieczorek, A. J., 2018: Sustainability transitions in developing countries: Major insights and their implications for research and policy. *Environ. Sci. Policy*, **84**, 204–216, doi:10.1016/J.ENVSCI.2017.08.008.
Wiedmann, T., M. Lenzen, L. T. Keyßer, and J. K. Steinberger, 2020: Scientists' warning on affluence. *Nat. Commun.*, **11**(1), 3107, doi:10.1038/s41467-020-16941-y.
Wiek, A., F. Farioli, K. Fukushi, and M. Yarime, 2012: Sustainability science: Bridging the gap between

science and society. *Sustain. Sci.*, **7**(1), 1–4, doi:10.1007/s11625-011-0154-0.

Wiktorowicz, J. et al., 2018: WGV: An Australian urban precinct case study to demonstrate the 1.5 °C agenda including multiple SDGs. *Urban Plan.*, **3**(2), 64–81, doi:10.17645/up.v3i2.1245.

Williams, L., 2013: Deepening Ecological Relationality Through Critical Onto-Epistemological Inquiry: Where Transformative Learning Meets Sustainable Science. *J. Transform. Educ.*, **11**(2), 95–113, doi:10.1177/1541344613490997.

Williams, S., and A. Doyon, 2020: The Energy Futures Lab: A case study of justice in energy transitions. *Environ. Innov. Soc. Transitions*, **37**, 29–301, doi:10.1016/j.eist.2020.10.001.

Willis, R., 2018: How Members of Parliament understand and respond to climate changett. *Sociol. Rev.*, **66**(3), doi:10.1177/0038026117731658.

Wilson, C., H. Pettifor, E. Cassar, L. Kerr, and M. Wilson, 2019: The potential contribution of disruptive low-carbon innovations to 1.5 °C climate mitigation. *Energy Effic.*, **12**(2), 423–440, doi:10.1007/s12053-018-9679-8.

Winkler, H., 2020: Putting equity into practice in the global stocktake under the Paris Agreement. *Clim. Policy*, **20**(1), 124–132, doi:10.1080/14693062.2019.1680337.

Wittneben, B., D. Bongardt, H. Dalkmann, W. Sterk, and C. Baatz, 2009: Integrating Sustainable Transport Measures into the Clean Development Mechanism. *Transp. Rev.*, **29**(1), 91–113, doi:10.1080/01441640802133494.

Woiwode, C. et al., 2021: Inner transformation to sustainability as a deep leverage point: fostering new avenues for change through dialogue and reflection Leverage Points for Sustainability Transformations. *Sustain. Sci.*, **16**, 841–858, doi:10.1007/s11625-020-00882-y.

Woiwode, D., and N. Woiwode, 2019: Off the beaten tracks: The neglected significance of interiority for sustainable urban development. In: *Practical Spirituality and the Contemporary City: Awakening the Transformative Power for Sustainable Living* [Giri, A., (ed.)], Palgrave Mcmillan, Simgapore, pp. 129–151.

World Bank, 2019: *Competitiveness, Report of the higth-level commission on carbon princing and competitiveness*. , Washington D.C., 53 pp. https://openknowledge.worldbank.org/bitstream/handle/10986/32419/141917.pdf?sequence=4&isAllowed=y.

World Business Council for Sustainable Developmet, 2010: *Vision 2050*. 80 pp. https://www.wbcsd.org/Overview/About-us/Vision_2050/Resources/Vision-2050-The-new-agenda-for-business.

WRI, 2016: *The sustainable infrastructure imperative*. , London, 152 pp. http://newclimateeconomy.report/2016/wp-content/uploads/sites/4/2014/08/NCE_2016Report.pdf.

WWAP-UNESCO, 2019: *World Water Development Report. Leaving No One Behind*. , Paris, 1–201 pp. https://unesdoc.unesco.org/ark:/48223/pf0000367306.

Yang, X., and F. Teng, 2018: The air quality co-benefit of coal control strategy in China. *Resour. Conserv. Recycl.*, **129**, 373–382, doi:https://doi.org/10.1016/j.resconrec.2016.08.011.

Yarime, M., 2017: Facilitating data-intensive approaches to innovation for sustainability: opportunities and challenges in building smart cities. *Sustain. Sci.*, **12**, 881–885, doi:10.1007/s11625-017-0498-1.

Yaw, N., 2018: One district, one factory. *smartlinewestafrica*,. https://www.moti.gov.gh/1d1f/ (Accessed August 20, 2020).

Zeng, D. Z., L. Cheng, L. Shi, and W. Luetkenhorst, 2020: China's green transformation through eco-industrial parks. *World Dev.*, **140**, 105249, doi:10.1016/j.worlddev.2020.105249.

Zenghelis, D., 2020: Can we be green and grow? https://www.lombardodier.com/contents/corporate-news/responsible-capital/2019/november/can-we-be-green-and-grow.html (Accessed October 5, 2021).

Zhang, C., X. Chen, Y. Li, W. Ding, and G. Fu, 2018a: Water-energy-food nexus: Concepts, questions and methodologies. *J. Clean. Prod.*, , doi:10.1016/j.jclepro.2018.05.194.

Zhang, J. et al., 2018b: The water-food-energy nexus optimization approach to combat agricultural drought: a case study in the United States. *Appl. Energy*, **227**, 449–464,

doi:10.1016/j.apenergy.2017.07.036.
Zhang, R. et al., 2019: A Review of the Role of the Atlantic Meridional Overturning Circulation in Atlantic Multidecadal Variability and Associated Climate Impacts. *Rev. Geophys.*, **57**(2), 316–375, doi:10.1029/2019RG000644.
Zhao, X., S. Zhang, Y. Zou, and J. Yao, 2013: To what extent does wind power deployment affect vested interests? A case study of the Northeast China Grid. *Energy Policy*, **63**, doi:10.1016/j.enpol.2013.08.092.
Zhenmin, L., and P. Espinosa, 2019: Tackling climate change to accelerate sustainable development. *Nat. Clim. Chang.*, **9**(7), 494–496, doi:10.1038/s41558-019-0519-4.
Zusman, E., A. Srinivasan, and S. Dhakal, 2011: *Low carbon transport in Asia: Strategies for optimizing co-benefits*. 1st ed. [Zusman, E., A. Srinivasan, and S. Shobhakar, (eds.)]. 296 pp.