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Sustainable Development, Poverty Eradication and Reducing Inequalities

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Executive Summary

This chapter takes sustainable development as the starting point and focus for analysis. It considers the broad and multifaceted bi-directional interplay between sustainable development, including its focus on eradicating poverty and reducing inequality in their multidimensional aspects, and climate actions in a 1.5°C warmer world. These fundamental connections are embedded in the Sustainable Development Goals (SDGs). The chapter also examines synergies and trade-offs of adaptation and mitigation options with sustainable development and the SDGs and offers insights into possible pathways, especially climate-resilient development pathways towards a 1.5°C warmer world.

Sustainable Development, Poverty and Inequality in a 1.5°C Warmer World

Limiting global warming to 1.5°C rather than 2°C above pre-industrial levels would make it markedly easier to achieve many aspects of sustainable development, with greater potential to eradicate poverty and reduce inequalities (*medium evidence, high agreement*). Impacts avoided with the lower temperature limit could reduce the number of people exposed to climate risks and vulnerable to poverty by 62 to 457 million, and lessen the risks of poor people to experience food and water insecurity, adverse health impacts, and economic losses, particularly in regions that already face development challenges (*medium evidence, medium agreement*). {5.2.2, 5.2.3} Avoided impacts expected to occur between 1.5°C and 2°C warming would also make it easier to achieve certain SDGs, such as those that relate to poverty, hunger, health, water and sanitation, cities and ecosystems (SDGs 1, 2, 3, 6, 11, 14 and 15) (*medium evidence, high agreement*). {5.2.3, Table 5.2 available at the end of the chapter}

Compared to current conditions, 1.5°C of global warming would nonetheless pose heightened risks to eradicating poverty, reducing inequalities and ensuring human and ecosystem well-being (*medium evidence, high agreement*). Warming of 1.5°C is not considered 'safe' for most nations, communities, ecosystems and sectors and poses significant risks to natural and human systems as compared to the current warming of 1°C (*high confidence*). {Cross-Chapter Box 12 in Chapter 5} The impacts of 1.5°C of warming would disproportionately affect disadvantaged and vulnerable populations through food insecurity, higher food prices, income losses, lost livelihood opportunities, adverse health impacts and population displacements (*medium evidence, high agreement*). {5.2.1} Some of the worst impacts on sustainable development are expected to be felt among agricultural and coastal dependent livelihoods, indigenous people, children and the elderly, poor labourers, poor urban dwellers in African cities, and people and ecosystems in the Arctic and Small Island Developing States (SIDS) (*medium evidence, high agreement*). {5.2.1, Box 5.3, Chapter 3, Box 3.5, Cross-Chapter Box 9 in Chapter 4}

Climate Adaptation and Sustainable Development

Prioritization of sustainable development and meeting the SDGs is consistent with efforts to adapt to climate change (*high confidence*). Many strategies for sustainable development enable transformational adaptation for a 1.5°C warmer world, provided attention is paid to reducing poverty in all its forms and to promoting equity and participation in decision-making (*medium evidence, high agreement*). As such, sustainable development has the potential to significantly reduce systemic vulnerability, enhance adaptive capacity, and promote livelihood security for poor and disadvantaged populations (*high confidence*). {5.3.1}

Synergies between adaptation strategies and the SDGs are expected to hold true in a 1.5°C warmer world, across sectors and contexts (*medium evidence, medium agreement*). Synergies between adaptation and sustainable development are significant for agriculture and health, advancing SDGs 1 (extreme poverty), 2 (hunger), 3 (healthy lives and well-being) and 6 (clean water) (*robust evidence, medium agreement*). {5.3.2} Ecosystem- and community-based adaptation, along with the incorporation of indigenous and local knowledge, advances synergies with SDGs 5 (gender equality), 10 (reducing inequalities) and 16 (inclusive societies), as exemplified in drylands and the Arctic (*high evidence, medium agreement*). {5.3.2, Box 5.1, Cross-Chapter Box 10 in Chapter 4}

Adaptation strategies can result in trade-offs with and among the SDGs (*medium evidence, high agreement*). Strategies that advance one SDG may create negative consequences for other SDGs, for instance SDGs 3 (health) versus 7 (energy consumption) and agricultural adaptation and SDG 2 (food security) versus SDGs 3 (health), 5 (gender equality), 6 (clean water), 10 (reducing inequalities), 14 (life below water) and 15 (life on the land) (*medium evidence, medium agreement*). {5.3.2}

Pursuing place-specific adaptation pathways towards a 1.5°C warmer world has the potential for significant positive outcomes for well-being in countries at all levels of development (*medium evidence, high agreement*). Positive outcomes emerge when adaptation pathways (i) ensure a diversity of adaptation options based on people's values and the trade-offs they consider acceptable, (ii) maximize synergies with sustainable development through inclusive, participatory and deliberative processes, and (iii) facilitate equitable transformation. Yet such pathways would be difficult to achieve without redistributive measures to overcome path dependencies, uneven power structures, and entrenched social inequalities (*medium evidence, high agreement*). {5.3.3}

Mitigation and Sustainable Development

The deployment of mitigation options consistent with 1.5°C pathways leads to multiple synergies across a range of sustainable development dimensions. At the same time, the rapid pace and magnitude of change that would be required to limit warming to 1.5°C, if not carefully managed, would lead to trade-offs with some sustainable development dimensions (*high confidence*). The number of synergies between mitigation response options and sustainable development exceeds the number of trade-offs in energy demand and supply sectors; agriculture, forestry and other land use (AFOLU); and for oceans (*very high confidence*). {Figure 5.2, Table 5.2 available at the end of the chapter} The 1.5°C pathways indicate robust synergies, particularly for the SDGs 3 (health), 7 (energy), 12 (responsible consumption and production) and 14 (oceans) (*very high confidence*). {5.4.2, Figure 5.3} For SDGs 1 (poverty), 2 (hunger), 6 (water) and 7 (energy), there is a risk of trade-offs or negative side effects from stringent mitigation actions compatible with 1.5°C of warming (*medium evidence, high agreement*). {5.4.2}

Appropriately designed mitigation actions to reduce energy demand can advance multiple SDGs simultaneously. Pathways compatible with 1.5°C that feature low energy demand show the most pronounced synergies and the lowest number of trade-offs with respect to sustainable development and the SDGs (*very high confidence*). Accelerating energy efficiency in all sectors has synergies with SDGs 7 (energy), 9 (industry, innovation and infrastructure), 11 (sustainable cities and communities), 12 (responsible consumption and production), 16 (peace, justice and strong institutions), and 17 (partnerships for the goals) (*robust evidence, high agreement*). {5.4.1, Figure 5.2, Table 5.2} Low-demand pathways, which would reduce or completely avoid the reliance on bioenergy with carbon capture and storage (BECCS) in 1.5°C pathways, would result in significantly reduced pressure on food security, lower food prices and fewer people at risk of hunger (*medium evidence, high agreement*). {5.4.2, Figure 5.3}

The impacts of carbon dioxide removal options on SDGs depend on the type of options and the scale of deployment (*high confidence*). If poorly implemented, carbon dioxide removal (CDR) options such as bioenergy, BECCS and AFOLU would lead to trade-offs. Appropriate design and implementation requires considering local people's needs, biodiversity and other sustainable development dimensions (*very high confidence*). {5.4.1.3, Cross-Chapter Box 7 in Chapter 3}

The design of the mitigation portfolios and policy instruments to limit warming to 1.5°C will largely determine the overall synergies and trade-offs between mitigation and sustainable development (*very high confidence*). **Redistributive policies that shield the poor and vulnerable can resolve trade-offs for a range of SDGs** (*medium evidence, high agreement*). Individual mitigation options are associated with both positive and negative interactions with the SDGs (*very high confidence*). {5.4.1} However, appropriate choices across the mitigation portfolio can help to maximize positive side effects while minimizing negative side effects (*high confidence*). {5.4.2, 5.5.2} Investment needs for complementary policies resolving trade-offs with a range of SDGs are only a small fraction of the overall mitigation investments in 1.5°C pathways (*medium evidence, high agreement*). {5.4.2, Figure 5.4} Integration of mitigation with adaptation and sustainable development compatible with 1.5°C warming requires a systems perspective (*high confidence*). {5.4.2, 5.5.2}

Mitigation consistent with 1.5°C of warming create high risks for sustainable development in countries with high dependency on fossil fuels for revenue and employment generation (*high confidence*). These risks are caused by the reduction of global demand affecting mining activity and export revenues and challenges to rapidly decrease high carbon intensity of the domestic economy (*robust evidence, high agreement*). {5.4.1.2, Box 5.2} Targeted policies that promote diversification of the economy and the energy sector could ease this transition (*medium evidence, high agreement*). {5.4.1.2, Box 5.2}

Sustainable Development Pathways to 1.5°C

Sustainable development broadly supports and often enables the fundamental societal and systems transformations that would be required for limiting warming to 1.5°C above pre-industrial levels (*high confidence*). Simulated pathways that feature the most sustainable worlds (e.g., Shared Socio-Economic Pathways (SSP) 1) are associated with relatively lower mitigation and adaptation challenges and limit warming to 1.5°C at comparatively lower mitigation costs. In contrast, development pathways with high fragmentation, inequality and poverty (e.g., SSP3) are associated with comparatively higher mitigation and adaptation challenges. In such pathways, it is not possible to limit warming to 1.5°C for the vast majority of the integrated assessment models (*medium evidence, high agreement*). {5.5.2} In all SSPs, mitigation costs substantially increase in 1.5°C pathways compared to 2°C pathways. No pathway in the literature integrates or achieves all 17 SDGs (*high confidence*). {5.5.2} Real-world experiences at the project level show that the actual integration between adaptation, mitigation and sustainable development is challenging as it requires reconciling trade-offs across sectors and spatial scales (*very high confidence*). {5.5.1}

Without societal transformation and rapid implementation of ambitious greenhouse gas reduction measures, pathways to limiting warming to 1.5°C and achieving sustainable development will be exceedingly difficult, if not impossible, to achieve (*high confidence*). The potential for pursuing such pathways differs between and within nations and regions, due to different development trajectories, opportunities and challenges (*very high confidence*). {5.5.3.2, Figure 5.1} Limiting warming to 1.5°C would require all countries and non-state actors to strengthen their contributions without delay. This could be achieved through sharing efforts based on bolder and more committed cooperation, with support for those with the least capacity to adapt, mitigate and transform (*medium evidence, high agreement*). {5.5.3.1, 5.5.3.2} Current efforts towards reconciling low-carbon trajectories and reducing inequalities, including those that avoid difficult trade-offs associated with transformation, are partially successful yet demonstrate notable obstacles (*medium evidence, medium agreement*). {5.5.3.3, Box 5.3, Cross-Chapter Box 13 in this chapter}

Social justice and equity are core aspects of climate-resilient development pathways for transformational social change. Addressing challenges and widening opportunities between and within countries and communities would be necessary to achieve sustainable development and limit warming to 1.5°C, without making the poor and disadvantaged worse off (*high confidence*). Identifying and navigating inclusive and socially acceptable pathways towards low-carbon, climate-resilient futures is a challenging yet important endeavour, fraught with moral, practical and political difficulties and inevitable trade-offs (*very high confidence*). {5.5.2, 5.5.3.3, Box 5.3} It entails deliberation and problem-solving processes to negotiate societal values, well-being, risks and resilience and to determine what is desirable and fair, and to whom (*medium evidence, high agreement*). Pathways that encompass joint, iterative planning and transformative visions, for instance in Pacific SIDS like Vanuatu and in urban contexts, show potential for liveable and sustainable futures (*high confidence*). {5.5.3.1, 5.5.3.3, Figure 5.5, Box 5.3, Cross-Chapter Box 13 in this chapter}

The fundamental societal and systemic changes to achieve sustainable development, eradicate poverty and reduce inequalities while limiting warming to 1.5°C would require meeting a set of institutional, social, cultural, economic and technological conditions (*high confidence*). The coordination and monitoring of policy actions across sectors and spatial scales is essential to support sustainable development in 1.5°C warmer conditions (*very high confidence*). {5.6.2, Box 5.3} External funding and technology transfer better support these efforts when they consider recipients' context-specific needs (*medium evidence, high agreement*). {5.6.1} Inclusive processes can facilitate transformations by ensuring participation, transparency, capacity building and iterative social learning (*high confidence*). {5.5.3.3, Cross-Chapter Box 13, 5.6.3} Attention to power asymmetries and unequal opportunities for development, among and within countries, is key to adopting 1.5°C-compatible development pathways that benefit all populations (*high confidence*). {5.5.3, 5.6.4, Box 5.3} Re-examining individual and collective values could help spur urgent, ambitious and cooperative change (*medium evidence, high agreement*). {5.5.3, 5.6.5}

5.1 Scope and Delineations

This chapter takes sustainable development as the starting point and focus for analysis, considering the broader bi-directional interplay and multifaceted interactions between development patterns and climate actions in a 1.5°C warmer world and in the context of eradicating poverty and reducing inequality. It assesses the impacts of keeping temperatures at or below 1.5°C of global warming above pre-industrial levels on sustainable development and compares the impacts avoided at 1.5°C compared to 2°C (Section 5.2). It then examines the interactions, synergies and trade-offs of adaptation (Section 5.3) and mitigation (Section 5.4) measures with sustainable development and the Sustainable Development Goals (SDGs). The chapter offers insights into possible pathways towards a 1.5°C warmer world, especially through climate-resilient development pathways providing a comprehensive vision across different contexts (Section 5.5). The chapter also identifies the conditions that would be needed to simultaneously achieve sustainable development, poverty eradication, the reduction of inequalities, and the 1.5°C climate objective (Section 5.6).

5.1.1 Sustainable Development, SDGs, Poverty Eradication and Reducing Inequalities

Chapter 1 (see Cross-Chapter Box 4 in Chapter 1) defines sustainable development as 'development that meets the needs of the present and future generations' through balancing economic, social and environmental considerations, and then introduces the United Nations (UN) 2030 Agenda for Sustainable Development, which sets out 17 ambitious goals for sustainable development for all countries by 2030. These SDGs are: no poverty (SDG 1), zero hunger (SDG 2), good health and well-being (SDG 3), quality education (SDG 4), gender equality (SDG 5), clean water and sanitation (SDG 6), affordable and clean energy (SDG 7), decent work and economic growth (SDG 8), industry, innovation and infrastructure (SDG 9), reduced inequalities (SDG 10), sustainable cities and communities (SDG 11), responsible consumption and production (SDG 12), climate action (SDG 13), life below water (SDG 14), life on land (SDG 15), peace, justice and strong institutions (SDG 16) and partnerships for the goals (SDG 17).

The IPCC Fifth Assessment Report (AR5) included extensive discussion of links between climate and sustainable development, especially in Chapter 13 (Olsson et al., 2014) and Chapter 20 (Denton et al., 2014) in Working Group II and Chapter 4 (Fleurbaey et al., 2014) in Working Group III. However, the AR5 preceded the 2015 adoption of the SDGs and the literature that argues for their fundamental links to climate (Wright et al., 2015; Salleh, 2016; von Stechow et al., 2016; Hammill and Price-Kelly, 2017; ICSU, 2017; Maupin, 2017; Gomez-Echeverri, 2018).

The SDGs build on efforts under the UN Millennium Development Goals to reduce poverty, hunger, and other deprivations. According to the UN, the Millennium Development Goals were successful in reducing poverty and hunger and improving water security (UN, 2015a). However, critics argued that they failed to address within-country disparities, human rights and key environmental concerns, focused only on developing countries, and had numerous measurement and attribution problems (Langford et al., 2013; Fukuda-Parr et al., 2014). While improvements in water security, slums and health may have reduced some aspects of climate vulnerability, increases in incomes were linked to rising greenhouse gas (GHG) emissions and thus to a trade-off between development and climate change (Janetos et al., 2012; UN, 2015a; Hubacek et al., 2017).

While the SDGs capture many important aspects of sustainable development, including the explicit goals of poverty eradication and reducing inequality, there are direct connections from climate to other measures of sustainable development including multidimensional poverty, equity, ethics, human security, well-being and climate-resilient development (Bebbington and Larrinaga, 2014; Robertson, 2014; Redclift and Springett, 2015; Barrington-Leigh, 2016; Helliwell et al., 2018; Kirby and O'Mahony, 2018) (see Glossary). The UN proposes sustainable development as 'eradicating poverty in all its forms and dimensions, combating inequality within and among countries, preserving the planet, creating sustained, inclusive and sustainable economic growth and fostering social inclusion' (UN, 2015b). There is *robust evidence* of the links between climate change and poverty (see Chapter 1, Cross-Chapter Box 4). The AR5 concluded with *high confidence* that disruptive levels of climate change would preclude reducing poverty (Denton et al., 2014; Fleurbaey et al., 2014). International organizations have since stated that climate changes 'undermine the ability of all countries to achieve sustainable development' (UN, 2015b) and can reverse or erase improvements in living conditions and decades of development (Hallegatte et al., 2016).

Climate warming has unequal impacts on different people and places as a result of differences in regional climate changes, vulnerabilities and impacts, and these differences then result in unequal impacts on sustainable development and poverty (Section 5.2). Responses to climate change also interact in complex ways with goals of poverty reduction. The benefits of adaptation and mitigation projects and funding may accrue to some and not others, responses may be costly and unaffordable to some people and countries, and projects may disadvantage some individuals, groups and development initiatives (Sections 5.3 and 5.4, Cross-Chapter Box 11 in Chapter 4).

5.1.2 Pathways to 1.5°C

Pathways to 1.5°C (see Chapter 1, Cross-Chapter Box 1 in Chapter 1, Glossary) include ambitious reductions in emissions and strategies for adaptation that are transformational, as well as complex interactions with sustainable development, poverty eradication and reducing inequalities. The AR5 WGII introduced the concept of climate-resilient development pathways (CRDPs) (see Glossary) which combine adaptation and mitigation to reduce climate change and its impacts, and emphasize the importance of addressing structural and intersecting inequalities, marginalization and multidimensional poverty to 'transform […] the development pathways themselves towards greater social and environmental sustainability, equity, resilience, and justice' (Olsson et al., 2014). This chapter assesses literature on CRDPs relevant to 1.5°C global warming (Section 5.5.3), to understand better the possible societal and systems transformations (see Glossary) that reduce inequality and increase well-being

(Figure 5.1). It also summarizes the knowledge on conditions to achieve such transformations, including changes in technologies, culture, values, financing and institutions that support low-carbon and resilient pathways and sustainable development (Section 5.6).

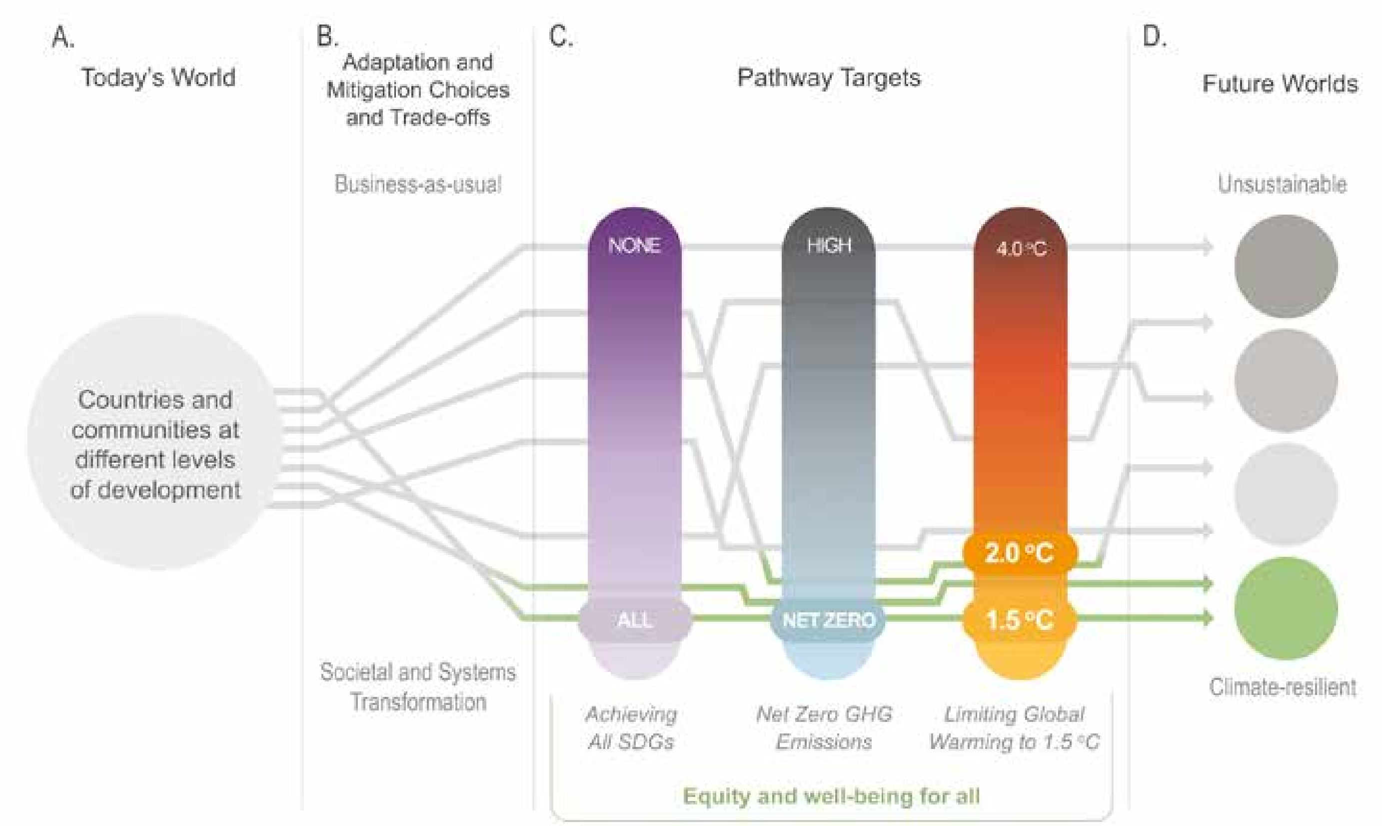

Figure 5.1 | Climate-resilient development pathways (CRDPs) (green arrows) between a current world in which countries and communities exist at different levels of development (A) and future worlds that range from climate-resilient (bottom) to unsustainable (top) (D). CRDPs involve societal transformation rather than business-as-usual approaches, and all pathways involve adaptation and mitigation choices and trade-offs (B). Pathways that achieve the Sustainable Development Goals by 2030 and beyond, strive for net zero emissions around mid-21st century, and stay within the global 1.5°C warming target by the end of the 21st century, while ensuring equity and well-being for all, are best positioned to achieve climate-resilient futures (C). Overshooting on the path to 1.5°C will make achieving CRDPs and other sustainable trajectories more difficult; yet, the limited literature does not allow meaningful estimates.

5.1.3 Types of Evidence

A variety of sources of evidence are used to assess the interactions of sustainable development and the SDGs with the causes, impacts and responses to climate change of 1.5°C warming. This chapter builds on Chapter 3 to assess the sustainable development implications of impacts at 1.5°C and 2°C, and on Chapter 4 to examine the implications of response measures. Scientific and grey literature, with a post-AR5 focus, and data that evaluate, measure and model sustainable development–climate links from various perspectives, quantitatively and qualitatively, across scales, and through well-documented case studies are assessed.

Literature that explicitly links 1.5°C global warming to sustainable development across scales remains scarce; yet we find relevant insights in many recent publications on climate and development that assess impacts across warming levels, the effects of adaptation and mitigation response measures, and interactions with the SDGs. Relevant evidence also stems from emerging literature on possible pathways, overshoot and enabling conditions (see Glossary) for integrating sustainable development, poverty eradication and reducing inequalities in the context of 1.5°C.

5.2 Poverty, Equality and Equity Implications of a 1.5°C Warmer World

Climate change could lead to significant impacts on extreme poverty by 2030 (Hallegatte et al., 2016; Hallegatte and Rozenberg, 2017). The AR5 concluded, with *very high confidence*, that climate change and climate variability worsen existing poverty and exacerbate inequalities, especially for those disadvantaged by gender, age, race, class, caste, indigeneity and (dis)ability (Olsson et al., 2014). New literature on these links is substantial, showing that the poor will continue to experience climate change severely, and climate change will exacerbate poverty (*very high confidence*) (Fankhauser and Stern, 2016; Hallegatte et al., 2016; O'Neill et al., 2017a; Winsemius et al., 2018). The understanding of regional impacts and risks of 1.5°C global warming and interactions with patterns of societal vulnerability and poverty remains limited. Yet identifying and addressing poverty and inequality is at the core of staying within a safe and just space for humanity (Raworth, 2017; Bathiany et al., 2018). Building on relevant findings from Chapter 3 (see Section 3.4), this section examines anticipated impacts and risks of 1.5°C and higher warming on sustainable development, poverty, inequality and equity (see Glossary).

5.2.1 Impacts and Risks of a 1.5°C Warmer World: Implications for Poverty and Livelihoods

Global warming of 1.5°C will have consequences for sustainable development, poverty and inequalities. This includes residual risks, limits to adaptation, and losses and damages (Cross-Chapter Box 12 in this chapter; see Glossary). Some regions have already experienced a 1.5°C warming, with impacts on food and water security, health and other components of sustainable development (*medium evidence, medium agreement*) (see Chapter 3, Section 3.4). Climate change is also already affecting poorer subsistence communities through decreases in crop production and quality, increases in crop pests and diseases, and disruption to culture (Savo et al., 2016). It disproportionally affects children and the elderly and can increase gender inequality (Kaijser and Kronsell, 2014; Vinyeta et al., 2015; Carter et al., 2016; Hanna and Oliva, 2016; Li et al., 2016).

At 1.5°C warming, compared to current conditions, further negative consequences are expected for poor people, and inequality and vulnerability (*medium evidence, high agreement*). Hallegatte and Rozenberg (2017) report that by 2030 (roughly approximating a 1.5°C warming), 122 million additional people could experience extreme poverty, based on a 'poverty scenario' of limited socio-economic progress, comparable to the Shared Socio-Economic Pathway (SSP) 4 (inequality), mainly due to higher food prices and declining health, with substantial income losses for the poorest 20% across 92 countries. Pretis et al. (2018) estimate negative impacts on economic growth in lower-income countries at 1.5°C warming, despite uncertainties. Impacts are likely to occur simultaneously across livelihood, food, human, water and ecosystem security (*limited evidence, high agreement*) (Byers et al., 2018), but the literature on interacting and cascading effects remains scarce (Hallegatte et al., 2014; O'Neill et al., 2017b; Reyer et al., 2017a, b).

Chapter 3 outlines future impacts and risks for ecosystems and human systems, many of which could also undermine sustainable development and efforts to eradicate poverty and hunger, and to protect health and ecosystems. Chapter 3 findings (see Section 3.5.2.1) suggest increasing Reasons for Concern from moderate to high at a warming of 1.1° to 1.6°C, including for indigenous people and their livelihoods, and ecosystems in the Arctic (O'Neill et al., 2017b). In 2050, based on the Hadley Centre Climate Prediction Model 3 (HadCM3) and the Special Report on Emission Scenarios A1b scenario (roughly comparable to 1.5°C warming), 450 million more flood-prone people would be exposed to doubling in flood frequency, and global flood risk would increase substantially (Arnell and Gosling, 2016). For droughts, poor people are expected to be more exposed (85% in population terms) in a warming scenario greater than 1.5°C for several countries in Asia and southern and western Africa (Winsemius et al., 2018). In urban Africa, a 1.5°C warming could expose many households to water poverty and increased flooding (Pelling et al., 2018). At 1.5ºC warming, fisheries-dependent and coastal livelihoods, of often disadvantaged populations, would suffer from the loss of coral reefs (see Chapter 3, Box 3.4).

Global heat stress is projected to increase in a 1.5°C warmer world, and by 2030, compared to 1961–1990, climate change could be responsible for additional annual deaths of 38,000 people from heat stress, particularly among the elderly, and 48,000 from diarrhoea, 60,000 from malaria, and 95,000 from childhood undernutrition (WHO, 2014). Each 1°C increase could reduce work productivity by 1 to 3% for people working outdoors or without air conditioning, typically the poorer segments of the workforce (Park et al., 2015).

The regional variation in the 'warming experience at 1.5°C' (see Chapter 1, Section 1.3.1) is large (see Chapter 3, Section 3.3.2). Declines in crop yields are widely reported for Africa (60% of observations), with serious consequences for subsistence and rain-fed agriculture and food security (Savo et al., 2016). In Bangladesh, by 2050, damages and losses are expected for poor households dependent on freshwater fish stocks due to lack of mobility, limited access to land and strong reliance on local ecosystems (Dasgupta et al., 2017). Small Island Developing States (SIDS) are expected to experience challenging conditions at 1.5°C warming due to increased risk of internal migration and displacement and limits to adaptation (see Chapter 3, Box 3.5, Cross-Chapter Box 12 in this chapter). An anticipated decline of marine fisheries of 3 million metric tonnes per degree warming would have serious regional impacts for the Indo-Pacific region and the Arctic (Cheung et al., 2016).

5.2.2 Avoided Impacts of 1.5°C versus 2°C Warming for Poverty and Inequality

Avoided impacts between 1.5°C and 2°C warming are expected to have significant positive implications for sustainable development, and reducing poverty and inequality. Using the SSPs (see Chapter 1, Cross-Chapter Box 1 in Chapter 1, Section 5.5.2), Byers et al. (2018) model the number of people exposed to multi-sector climate risks and vulnerable to poverty (income < $10/day), comparing 2°C and 1.5°C; the respective declines are from 86 million to 24 million for SSP1 (sustainability), from 498 million to 286 million for SSP2 (middle of the road), and from 1220 million to 763 million for SSP3 (regional rivalry), which suggests overall 62–457 million fewer people exposed and vulnerable at 1.5°C warming. Across the SSPs, the largest populations exposed and vulnerable are in South Asia (Byers et al., 2018). The avoided impacts on poverty at 1.5°C relative to 2°C are projected to depend at least as much or more on development scenarios than on warming (Wiebe et al., 2015; Hallegatte and Rozenberg, 2017).

Limiting warming to 1.5°C is expected to reduce the number of people exposed to hunger, water stress and disease in Africa (Clements, 2009). It is also expected to limit the number of poor people exposed to floods and droughts at higher degrees of warming, especially in African and Asian countries (Winsemius et al., 2018). Challenges for poor populations – relating to food and water security, clean energy access and environmental well-being – are projected to be less at 1.5°C, particularly for vulnerable people in Africa and Asia (Byers et al., 2018). The overall projected socio-economic losses compared to the present day are less at 1.5°C (8% loss of gross domestic product per capita) compared to 2°C (13%), with lower-income countries projected to experience greater losses, which may increase economic inequality between countries (Pretis et al., 2018).

5.2.3 Risks from 1.5°C versus 2°C Global Warming and the Sustainable Development Goals

The risks that can be avoided by limiting global warming to 1.5°C rather than 2°C have many complex implications for sustainable development (ICSU, 2017; Gomez-Echeverri, 2018). There is *high confidence* that constraining warming to 1.5°C rather than 2°C would reduce risks for unique and threatened ecosystems, safeguarding the services they provide for livelihoods and sustainable development and making adaptation much easier (O'Neill et al., 2017b), particularly in Central America, the Amazon, South Africa and Australia (Schleussner et al., 2016; O'Neill et al., 2017b; Reyer et al., 2017b; Bathiany et al., 2018).

In places that already bear disproportionate economic and social challenges to their sustainable development, people will face lower risks at 1.5°C compared to 2°C. These include North Africa and the Levant (less water scarcity), West Africa (less crop loss), South America and Southeast Asia (less intense heat), and many other coastal nations and island states (lower sea level rise, less coral reef loss) (Schleussner et al., 2016; Betts et al., 2018). The risks for food, water and ecosystems, particularly in subtropical regions such as Central America and countries such as South Africa and Australia, are expected to be lower at 1.5°C than at 2°C warming (Schleussner et al., 2016). Fewer people would be exposed to droughts and heat waves and the associated health impacts in countries such as Australia and India (King et al., 2017; Mishra et al., 2017).

Limiting warming to 1.5°C would make it markedly easier to achieve the SDGs for poverty eradication, water access, safe cities, food security, healthy lives and inclusive economic growth, and would help to protect terrestrial ecosystems and biodiversity (*medium evidence, high agreement*) (Table 5.2 available at the end of the chapter). For example, limiting species loss and expanding climate refugia will make it easier to achieve SDG 15 (see Chapter 3, Section 3.4.3). One indication of how lower temperatures benefit the SDGs is to compare the impacts of Representative Concentration Pathway (RCP) 4.5 (lower emissions) and RCP8.5 (higher emissions) on the SDGs (Ansuategi et al., 2015). A low emissions pathway allows for greater success in achieving SDGs for reducing poverty and hunger, providing access to clean energy, reducing inequality, ensuring education for all and making cities more sustainable. Even at lower emissions, a medium risk of failure exists to meet goals for water and sanitation, and marine and terrestrial ecosystems.

Action on climate change (SDG 13), including slowing the rate of warming, would help reach the goals for water, energy, food and land (SDGs 6, 7, 2 and 15) (Obersteiner et al., 2016; ICSU, 2017) and contribute to poverty eradication (SDG 1) (Byers et al., 2018). Although the literature that connects 1.5°C to the SDGs is limited, a pathway that stabilizes warming at 1.5°C by the end of the century is expected to increase the chances of achieving the SDGs by 2030, with greater potential to eradicate poverty, reduce inequality and foster equity (*limited evidence, medium agreement*). There are no studies on overshoot and dimensions of sustainable development, although literature on 4°C of warming suggests the impacts would be severe (Reyer et al., 2017b).

Table 5.1 | Sustainable development implications of avoided impacts between 1.5°C and 2°C global warming.

Impacts	Chapter 3 Section	1.5°C	2°C	Sustainable Development Goals (SDGs) More Easily Achieved when Limiting Warming to 1.5°C
Water scarcity	3.4.2.1	4% more people exposed to water stress	8% more people exposed to water stress, with 184–270 million people more exposed	SDG 6 water availability for all
	Table 3.4	496 (range 103–1159) million people exposed and vulnerable to water stress	586 (range 115–1347) million people exposed and vulnerable to water stress	
Ecosystems	3.4.3, Table 3.4	Around 7% of land area experiences biome shifts	Around 13% (range 8–20%) of land area experiences biome shifts	SDG 15 to protect terrestrial ecosystems and halt biodiversity loss
	Box 3.5	70–90% of coral reefs at risk from bleaching	99% of coral reefs at risk from bleaching	
Coastal cities	3.4.5.1	31–69 million people exposed to coastal flooding	32–79 million exposed to coastal flooding	SDG 11 to make cities and human settlements safe and resilient
	3.4.5.2	Fewer cities and coasts exposed to sea level rise and extreme events	More people and cities exposed to flooding	
Food systems	3.4.6, Box 3.1	Significant declines in crop yields avoided, some yields may increase	Average crop yields decline	SDG 2 to end hunger and achieve food security
	Table 3.4	32–36 million people exposed to lower yields	330–396 million people exposed to lower yields	
Health	3.4.5.1	Lower risk of temperature-related morbidity and smaller mosquito range	Higher risks of temperature-related morbidity and mortality and larger geographic range of mosquitoes	SDG 3 to ensure healthy lives for all
	3.4.5.2	3546–4508 million people exposed to heat waves	5417–6710 million people exposed to heat waves	

Cross-Chapter Box 12 | Residual Risks, Limits to Adaptation and Loss and Damage

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Introduction

Residual climate-related risks, limits to adaptation, and loss and damage (see Glossary) are increasingly assessed in the scientific literature (van der Geest and Warner, 2015; Boyd et al., 2017; Mechler et al., in press). The AR5 (IPCC, 2013; Oppenheimer et al., 2014) documented impacts that have been detected and attributed to climate change, projected increasing climate-related risks with continued global warming, and recognized barriers and limits to adaptation. It recognized that adaptation is constrained by biophysical, institutional, financial, social and cultural factors, and that the interaction of these factors with climate change can lead to soft adaptation limits (adaptive actions currently not available) and hard adaptation limits (adaptive actions appear infeasible leading to unavoidable impacts) (Klein et al., 2014).

Loss and damage: concepts and perspectives

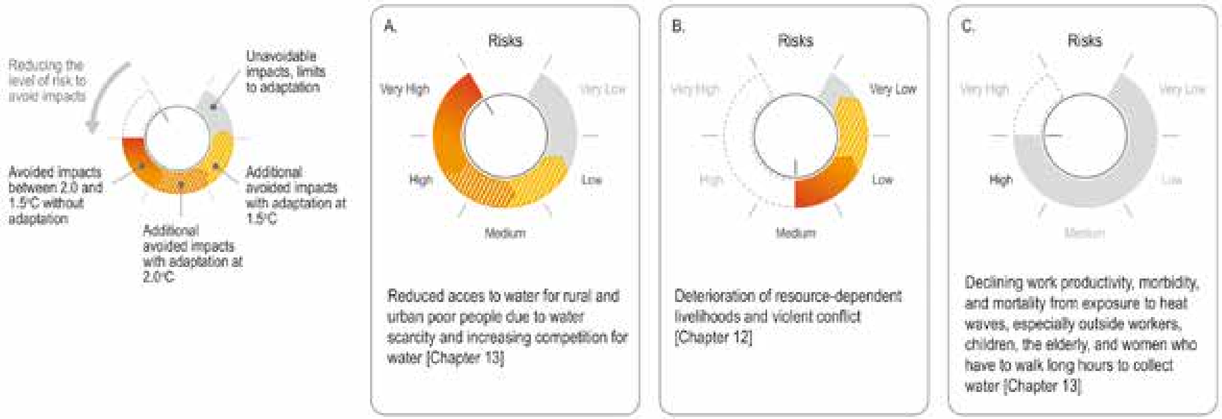
'Loss and Damage' (L&D) has been discussed in international climate negotiations for three decades (INC, 1991; Calliari, 2016; Vanhala and Hestbaek, 2016). A work programme on L&D was established as part of the Cancun Adaptation Framework in 2010 supporting developing countries particularly vulnerable to climate change impacts (UNFCCC, 2011). In 2013, the Conference of the Parties (COP) 19 established the Warsaw International Mechanism for Loss and Damage (WIM) as a formal part of the United Nations Framework Convention on Climate Change (UNFCCC) architecture (UNFCCC, 2014). It acknowledges that L&D 'includes, and in some cases involves more than, that which can be reduced by adaptation' (UNFCCC, 2013). The Paris Agreement recognized 'the importance of averting, minimizing and addressing loss and damage associated with the adverse effects of climate change' through Article 8 (UNFCCC, 2015).

There is no one definition of L&D in climate policy, and analysis of policy documents and stakeholder views has demonstrated ambiguity (Vanhala and Hestbaek, 2016; Boyd et al., 2017). UNFCCC documents suggest that L&D is associated with adverse impacts of climate change on human and natural systems, including impacts from extreme events and slow-onset processes (UNFCCC, 2011b, 2014, 2015). Some documents focus on impacts in developing or particularly vulnerable countries (UNFCCC, 2011b, 2014). They refer to economic (loss of assets and crops) and non-economic (biodiversity, culture, health) impacts, the latter also being an action area under the WIM workplan, and irreversible and permanent loss and damage. Lack of clarity of what the term addresses (avoidance through adaptation and mitigation, unavoidable losses, climate risk management, existential risk) was expressed among stakeholders, with further disagreement ensuing about what constitutes anthropogenic climate change versus natural climate variability (Boyd et al., 2017).

Limits to adaptation and residual risks

The AR5 described adaptation limits as points beyond which actors' objectives are compromised by intolerable risks threatening key objectives such as good health or broad levels of well-being, thus requiring transformative adaptation for overcoming soft limits (see Chapter 4, Sections 4.2.2.3, 4.5.3 and Cross-Chapter Box 9, Section 5.3.1) (Dow et al., 2013; Klein et al., 2014). The AR5 WGII risk tables, based on expert judgment, depicted the potential for, and the limits of, additional adaptation to reduce risk. Near-term (2030–2040) risks can be used as a proxy for 1.5°C warming by the end of the century and compared to longer-term (2080–2100) risks associated with an approximate 2°C warming. Building on the AR5 risk approach, Cross-Chapter Box 12, Figure 1 provides a stylised application example to poverty and inequality.

Cross-Chapter Box 12 (continued)



Cross-Chapter Box 12, Figure 1 | Stylized reduced risk levels due to avoided impacts between 2°C and 1.5°C warming (in solid red-orange), additional avoided impacts with adaptation under 2°C (striped orange) and under 1.5°C (striped yellow), and unavoidable impacts (losses) with no or very limited potential for adaptation (grey), extracted from the AR5 WGII risk tables (Field et al., 2014), and underlying chapters by Adger et al. (2014) and Olsson et al. (2014). For some systems and sectors (A), achieving 1.5°C could reduce risks to low (with adaptation) from very high (without adaptation) and high (with adaptation) under 2°C. For other areas (C), no or very limited adaptation potential is anticipated, suggesting limits, with the same risks for 1.5°C and 2°C. Other risks are projected to be medium under 2°C with further potential for reduction, especially with adaptation, to very low levels (B).

Limits to adaptation, residual risks, and losses in a 1.5°C warmer world

The literature on risks at 1.5°C (versus 2°C and more) and potentials for adaptation remains limited, particularly for specific regions, sectors, and vulnerable and disadvantaged populations. Adaptation potential at 1.5°C and 2°C is rarely assessed explicitly, making an assessment of residual risk challenging. Substantial progress has been made since the AR5 to assess which climate change impacts on natural and human systems can be attributed to anthropogenic emissions (Hansen and Stone, 2016) and to examine the influence of anthropogenic emissions on extreme weather events (NASEM, 2016), and on consequent impacts on human life (Mitchell et al., 2016), but less so on monetary losses and risks (Schaller et al., 2016). There has also been some limited research to examine local-level limits to adaptation (Warner and Geest, 2013; Filho and Nalau, 2018). What constitutes losses and damages is context-dependent and often requires place-based research into what people value and consider worth protecting (Barnett et al., 2016; Tschakert et al., 2017). Yet assessments of non-material and intangible losses are particularly challenging, such as loss of sense of place, belonging, identity, and damage to emotional and mental well-being (Serdeczny et al., 2017; Wewerinke-Singh, 2018a). Warming of 1.5°C is not considered 'safe' for most nations, communities, ecosystems and sectors, and poses significant risks to natural and human systems as compared to the current warming of 1°C (high confidence) (see Chapter 3, Section 3.4, Box 3.4, Box 3.5, Table 3.5, Cross-Chapter Box 6 in Chapter 3). Table 5.2, drawing on findings from Chapters 3, 4 and 5, presents examples of soft and hard limits in natural and human systems in the context of 1.5°C and 2°C of warming.

Cross-Chapter Box 12, Table 1 | Soft and hard adaptation limits in the context of 1.5°C and 2°C of global warming.

System/Region	Example	Soft Limit	Hard Limit
Coral reefs	Loss of 70–90% of tropical coral reefs by mid-century under 1.5°C scenario (total loss under 2°C scenario) (see Chapter 3, Sections 3.4.4 and 3.5.2.1, Box 3.4)		✓
Biodiversity	6% of insects, 8% of plants and 4% of vertebrates lose over 50% of the climatically determined geographic range at 1.5°C (18% of insects, 16% of plants and 8% of vertebrates at 2°C) (see Chapter 3, Section 3.4.3.3)		✓
Poverty	24–357 million people exposed to multi-sector climate risks and vulnerable to poverty at 1.5°C (86–1220 million at 2°C) (see Section 5.2.2)	✓	
Human health	Twice as many megacities exposed to heat stress at 1.5°C compared to present, potentially exposing 350 million additional people to deadly heat wave conditions by 2050 (see Chapter 3, Section 3.4.8)	✓	✓
Coastal livelihoods	Large-scale changes in oceanic systems (temperature and acidification) inflict damage and losses to livelihoods, income, cultural identity and health for coastal-dependent communities at 1.5°C (potential higher losses at 2°C) (see Chapter 3, Sections 3.4.4, 3.4.5, 3.4.6.3, Box 3.4, Box 3.5, Cross-Chapter Box 6, Chapter 4, Section 4.3.5; Section 5.2.3)	✓	✓
Small Island Developing States	Sea level rise and increased wave run up combined with increased aridity and decreased freshwater availability at 1.5°C warming potentially leaving several atoll islands uninhabitable (see Chapter 3, Sections 3.4.3, 3.4.5, Box 3.5, Chapter 4, Cross-Chapter Box 9)		✓

Cross-Chapter Box 12 (continued)

Approaches and policy options to address residual risk and loss and damage

Conceptual and applied work since the AR5 has highlighted the synergies and differences with adaptation and disaster risk reduction policies (van der Geest and Warner, 2015; Thomas and Benjamin, 2017), suggesting more integration of existing mechanisms, yet careful consideration is advised for slow-onset and potentially irreversible impacts and risk (Mechler and Schinko, 2016). Scholarship on justice and equity has provided insight on compensatory, distributive and procedural equity considerations for policy and practice to address loss and damage (Roser et al., 2015; Wallimann-Helmer, 2015; Huggel et al., 2016). A growing body of legal literature considers the role of litigation in preventing and addressing loss and damage and finds that litigation risks for governments and business are bound to increase with improved understanding of impacts and risks as climate science evolves (high confidence) (Mayer, 2016; Banda and Fulton, 2017; Marjanac and Patton, 2018; Wewerinke-Singh, 2018b). Policy proposals include international support for experienced losses and damages (Crosland et al., 2016; Page and Heyward, 2017), addressing climate displacement, donor-supported implementation of regional public insurance systems (Surminski et al., 2016) and new global governance systems under the UNFCCC (Biermann and Boas, 2017).

5.3 Climate Adaptation and Sustainable Development

Adaptation will be extremely important in a 1.5°C warmer world since substantial impacts will be felt in every region (*high confidence*) (Chapter 3, Section 3.3), even if adaptation needs will be lower than in a 2°C warmer world (see Chapter 4, Sections 4.3.1 to 4.3.5, 4.5.3, Cross-Chapter Box 10 in Chapter 4). Climate adaptation options comprise structural, physical, institutional and social responses, with their effectiveness depending largely on governance (see Glossary), political will, adaptive capacities and availability of finance (see Chapter 4, Sections 4.4.1 to 4.4.5) (Betzold and Weiler, 2017; Sonwa et al., 2017; Sovacool et al., 2017). Even though the literature is scarce on the expected impacts of future adaptation measures on sustainable development specific to warming experiences of 1.5°C, this section assesses available literature on how (i) prioritising sustainable development enhances or impedes climate adaptation efforts (Section 5.3.1); (ii) climate adaptation measures impact sustainable development and the SDGs in positive (synergies) or negative (trade-offs) ways (Section 5.3.2); and (iii) adaptation pathways towards a 1.5°C warmer world affect sustainable development, poverty and inequalities (Section 5.3.3). The section builds on Chapter 4 (see Section 4.3.5) regarding available adaptation options to reduce climate vulnerability and build resilience (see Glossary) in the context of 1.5°C-compatible trajectories, with emphasis on sustainable development implications.

5.3.1 Sustainable Development in Support of Climate Adaptation

Making sustainable development a priority, and meeting the SDGs, is consistent with efforts to adapt to climate change (*very high confidence*). Sustainable development is effective in building adaptive capacity if it addresses poverty and inequalities, social and economic exclusion, and inadequate institutional capacities (Noble et al., 2014; Abel et al., 2016; Colloff et al., 2017). Four ways in which sustainable development leads to effective adaptation are described below.

First, sustainable development enables transformational adaptation (see Chapter 4, Section 4.2.2.2) when an integrated approach is adopted, with inclusive, transparent decision-making, rather than addressing current vulnerabilities as stand-alone climate problems (Mathur et al., 2014; Arthurson and Baum, 2015; Shackleton et al., 2015; Lemos et al., 2016; Antwi-Agyei et al., 2017b). Ending poverty in its multiple dimensions (SDG 1) is often a highly effective form of climate adaptation (Fankhauser and McDermott, 2014; Leichenko and Silva, 2014; Hallegatte and Rozenberg, 2017). However, ending poverty is not sufficient, and the positive outcome as an adaptation strategy depends on whether increased household wealth is actually directed towards risk reduction and management strategies (Nelson et al., 2016), as shown in urban municipalities (Colenbrander et al., 2017; Rasch, 2017) and agrarian communities (Hashemi et al., 2017), and whether finance for adaptation is made available (Section 5.6.1).

Second, local participation is effective when wider socio-economic barriers are addressed via multiscale planning (McCubbin et al., 2015; Nyantakyi-Frimpong and Bezner-Kerr, 2015; Toole et al., 2016). This is the case, for instance, when national education efforts (SDG 4) (Muttarak and Lutz, 2014; Striessnig and Loichinger, 2015) and indigenous knowledge (Nkomwa et al., 2014; Pandey and Kumar, 2018) enhance information sharing, which also builds resilience (Santos et al., 2016; Martinez-Baron et al., 2018) and reduces risks for maladaptation (Antwi-Agyei et al., 2018; Gajjar et al., 2018).

Third, development promotes transformational adaptation when addressing social inequalities (Section 5.5.3, 5.6.4), as in SDGs 4, 5, 16 and 17 (O'Brien, 2016; O'Brien et al., 2017). For example, SDG 5 supports measures that reduce women's vulnerabilities and allow women to benefit from adaptation (Antwi-Agyei et al., 2015; Van Aelst and Holvoet, 2016; Cohen, 2017). Mobilization of climate finance, carbon taxation and environmentally motivated subsidies can reduce inequalities (SDG 10), advance climate mitigation and adaptation (Chancel and Picketty, 2015), and be conducive to strengthening and enabling environments for resilience building (Nhamo, 2016; Halonen et al., 2017).

Fourth, when sustainable development promotes livelihood security, it enhances the adaptive capacities of vulnerable communities and households. Examples include SDG 11 supporting adaptation in cities to reduce harm from disasters (Kelman, 2017; Parnell, 2017); access to water and sanitation (SDG 6) with strong institutions (SDG 16) (Rasul and Sharma, 2016); SDG 2 and its targets that promote adaptation in agricultural and food systems (Lipper et al., 2014); and targets for SDG 3 such as reducing infectious diseases and providing health cover are consistent with health-related adaptation (ICSU, 2017; Gomez-Echeverri, 2018).

Sustainable development has the potential to significantly reduce systemic vulnerability, enhance adaptive capacity and promote livelihood security for poor and disadvantaged populations (*high confidence*). Transformational adaptation (see Chapter 4, Sections 4.2.2.2 and 4.5.3) would require development that takes into consideration multidimensional poverty and entrenched inequalities, local cultural specificities and local knowledge in decision-making, thereby making it easier to achieve the SDGs in a 1.5°C warmer world (*medium evidence, high agreement*).

5.3.2 Synergies and Trade-Offs between Adaptation Options and Sustainable Development

There are short-, medium-, and long-term positive impacts (synergies) and negative impacts (trade-offs) between the dual goals of keeping temperatures below 1.5°C global warming and achieving sustainable development. The extent of synergies between development and adaptation goals will vary by the development process adopted for a particular SDG and underlying vulnerability contexts (*medium evidence, high agreement*). Overall, the impacts of adaptation on sustainable development, poverty eradication and reducing inequalities in general, and the SDGs specifically, are expected to be largely positive, given that the inherent purpose of adaptation is to lower risks. Building on Chapter 4 (see Section 4.3.5), this section examines synergies and trade-offs between adaptation and sustainable development for some key sectors and approaches.

Agricultural adaptation: The most direct synergy is between SDG 2 (zero hunger) and adaptation in cropping, livestock and food systems, designed to maintain or increase production (Lipper et al., 2014; Rockström et al., 2017). Farmers with effective adaptation strategies tend to enjoy higher food security and experience lower levels of poverty (FAO, 2015; Douxchamps et al., 2016; Ali and Erenstein, 2017). Vermeulen et al. (2016) report strong positive returns on investment across the world from agricultural adaptation with side benefits for environment and economic well-being. Well-adapted agricultural systems contribute to safe drinking water, health, biodiversity and equity goals (DeClerck et al., 2016; Myers et al., 2017). Climate-smart agriculture has synergies with food security, though it can be biased towards technological solutions, may not be gender sensitive, and can create specific challenges for institutional and distributional aspects (Lipper et al., 2014; Arakelyan et al., 2017; Taylor, 2017).

At the same time, adaptation options increase risks for human health, oceans and access to water if fertiliser and pesticides are used without regulation or when irrigation reduces water availability for other purposes (Shackleton et al., 2015; Campbell et al., 2016). When agricultural insurance and climate services overlook the poor, inequality may rise (Dinku et al., 2014; Carr and Owusu-Daaku, 2015; Carr and Onzere, 2017; Georgeson et al., 2017a). Agricultural adaptation measures may increase workloads, especially for women, while changes in crop mix can result in loss of income or culturally inappropriate food (Carr and Thompson, 2014; Thompson-Hall et al., 2016; Bryan et al., 2017), and they may benefit farmers with more land to the detriment of land-poor farmers, as seen in the Mekong River Basin (see Chapter 3, Cross-Chapter Box 6 in Chapter 3).

Adaptation to protect human health: Adaptation options in the health sector are expected to reduce morbidity and mortality (Arbuthnott et al., 2016; Ebi and Otmani del Barrio, 2017). Heat-early-warning systems help lower injuries, illnesses and deaths (Hess and Ebi, 2016), with positive impacts for SDG 3. Institutions better equipped to share information, indicators for detecting climate-sensitive diseases, improved provision of basic health care services and coordination with other sectors also improve risk management, thus reducing adverse health outcomes (Dasgupta et al., 2016; Dovie et al., 2017). Effective adaptation creates synergies via basic public health measures (K.R. Smith et al., 2014; Dasgupta, 2016) and health infrastructure protected from extreme weather events (Watts et al., 2015). Yet trade-offs can occur when adaptation in one sector leads to negative impacts in another sector. Examples include the creation of urban wetlands through flood control measures which can breed mosquitoes, and migration eroding physical and mental well-being, hence adversely affecting SDG 3 (K.R. Smith et al., 2014; Watts et al., 2015). Similarly, increased use of air conditioning enhances resilience to heat stress (Petkova et al., 2017), yet it can result in higher energy consumption, undermining SDG 13.

Coastal adaptation: Adaptation to sea level rise remains essential in coastal areas even under a climate stabilization scenario of 1.5°C (Nicholls et al., 2018). Coastal adaptation to restore ecosystems (for instance by planting mangrove forests) supports SDGs for enhancing life and livelihoods on land and oceans (see Chapter 4, Sections 4.3.2.3). Synergistic outcomes between development and relocation of coastal communities are enhanced by participatory decision-making and settlement designs that promote equity and sustainability (van der Voorn et al., 2017). Limits to coastal adaptation may rise, for instance in low-lying islands in the Pacific, Caribbean and Indian Ocean, with attendant implications for loss and damage (see Chapter 3 Box 3.5, Chapter 4, Cross-Chapter Box 9 in Chapter 4, Cross-Chapter Box 12 in Chapter 5, Box 5.3).

Migration as adaptation: Migration has been used in various contexts to protect livelihoods from challenges related to climate change (Marsh, 2015; Jha et al., 2017), including through remittances (Betzold and Weiler, 2017). Synergies between migration and the achievement of sustainable development depend on adaptive measures and conditions in both sending and receiving regions (Fatima et al., 2014; McNamara, 2015; Entzinger and Scholten, 2016; Ober and Sakdapolrak, 2017; Schwan and Yu, 2017). Adverse developmental impacts arise when vulnerable women or the elderly are left behind or if migration is culturally disruptive (Wilkinson et al., 2016; Albert et al., 2017; Islam and Shamsuddoha, 2017).

Ecosystem-based adaptation: Ecosystem-based adaptation (EBA) can offer synergies with sustainable development (Morita and Matsumoto, 2015; Ojea, 2015; Szabo et al., 2015; Brink et al., 2016; Butt et al., 2016; Conservation International, 2016; Huq et al., 2017), although assessments remain difficult (see Chapter 4, Section 4.3.2.2) (Doswald et al., 2014). Examples include mangrove restoration reducing coastal vulnerability, protecting marine and terrestrial ecosystems, and increasing local food security, as well as watershed management reducing flood risks and improving water quality (Chong, 2014). In drylands, EBA practices, combined with community-based adaptation, have shown how to link adaptation with mitigation to improve livelihood conditions of poor farmers (Box 5.1). Synergistic developmental outcomes arise where EBA is cost effective, inclusive of indigenous and local knowledge and easily accessible by the poor (Ojea, 2015; Daigneault et al., 2016; Estrella et al., 2016). Payment for ecosystem services can provide incentives to land owners and natural resource managers to preserve environmental services with synergies with SDGs 1 and 13 (Arriagada et al., 2015), when implementation challenges are overcome (Calvet-Mir et al., 2015; Wegner, 2016; Chan et al., 2017). Trade-offs include loss of other economic land use types, tension between biodiversity and adaptation priorities, and conflicts over governance (Wamsler et al., 2014; Ojea, 2015).

Community-based adaptation: Community-based adaptation (CBA) (see Chapter 4, Sections 4.3.3.2) enhances resilience and sustainability of adaptation plans (Ford et al., 2016; Fernandes-Jesus et al., 2017; Grantham and Rudd, 2017; Gustafson et al., 2017). Yet negative impacts occur if it fails to fairly represent vulnerable populations and to foster long-term social resilience (Ensor, 2016; Taylor Aiken et al., 2017). Mainstreaming CBA into planning and decision-making enables the attainment of SDGs 5, 10 and 16 (Archer et al., 2014; Reid and Huq, 2014; Vardakoulias and Nicholles, 2014; Cutter, 2016; Kim et al., 2017). Incorporating multiple forms of indigenous and local knowledge is an important element of CBA, as shown for instance in the Arctic region (see Chapter 4, Section 4.3.5.5, Box 4.3, Cross-Chapter Box 9) (Apgar et al., 2015; Armitage, 2015; Pearce et al., 2015; Chief et al., 2016; Cobbinah and Anane, 2016; Ford et al., 2016). Indigenous and local knowledge can be synergistic with achieving SDGs 2, 6 and 10 (Ayers et al., 2014; Lasage et al., 2015; Regmi and Star, 2015; Berner et al., 2016; Chief et al., 2016; Murtinho, 2016; Reid, 2016).

There are clear synergies between adaptation options and several SDGs, such as poverty eradication, elimination of hunger, clean water and health (*robust evidence, high agreement*), as well-integrated adaptation supports sustainable development (Eakin et al., 2014; Weisser et al., 2014; Adam, 2015; Smucker et al., 2015). Substantial synergies are observed in the agricultural and health sectors, and in ecosystem-based adaptations. However, particular adaptation strategies can lead to adverse consequences for developmental outcomes (*medium evidence, high agreement*). Adaptation strategies that advance one SDG can result in trade-offs with other SDGs; for instance, agricultural adaptation to enhance food security (SDG 2) causing negative impacts for health, equality and healthy ecosystems (SDGs 3, 5, 6, 10, 14 and 15), and resilience to heat stress increasing energy consumption (SDGs 3 and 7) and high-cost adaptation in resource-constrained contexts (*medium evidence, medium agreement*).

5.3.3 Adaptation Pathways towards a 1.5°C Warmer World and Implications for Inequalities

In a 1.5°C warmer world, adaptation measures and options would need to be intensified, accelerated and scaled up. This entails not only the right 'mix' of options (asking 'right for whom and for what?') but also a forward-looking understanding of dynamic trajectories, that is adaptation pathways (see Chapter 1, Cross-Chapter Box 1 in Chapter 1), best understood as decision-making processes over sets of potential action sequenced over time (Câmpeanu and Fazey, 2014; Wise et al., 2014). Given the scarcity of literature on adaptation pathways that navigate place-specific warming experiences at 1.5°C, this section presents insights into current local decision-making for adaptation futures. This grounded evidence shows that choices between possible pathways, at different scales and for different groups of people, are shaped by uneven power structures and historical legacies that create their own, often unforeseen change (Fazey et al., 2016; Bosomworth et al., 2017; Lin et al., 2017; Murphy et al., 2017; Pelling et al., 2018).

Pursuing a place-specific adaptation pathway approach towards a 1.5°C warmer world harbours the potential for significant positive outcomes, with synergies for well-being possibilities to 'leap-frog the SDGs' (J.R.A. Butler et al., 2016), in countries at all levels of development (*medium evidence, high agreement*). It allows for identifying local, socially salient tipping points before they are crossed, based on what people value and trade-offs that are acceptable to them (Barnett et al., 2014, 2016; Gorddard et al., 2016; Tschakert et al., 2017). Yet evidence also reveals adverse impacts that reinforce rather than reduce existing social inequalities and hence may lead to poverty traps (*medium evidence, high agreement*) (Nagoda, 2015; Warner et al., 2015; Barnett et al., 2016; J.R.A. Butler et al., 2016; Godfrey-Wood and Naess, 2016; Pelling et al., 2016; Albert et al., 2017; Murphy et al., 2017).

Past development trajectories as well as transformational adaptation plans can constrain adaptation futures by reinforcing dominant political-economic structures and processes, and narrowing option spaces; this leads to maladaptive pathways that preclude alternative, locally relevant and sustainable development initiatives and increase vulnerabilities (Warner and Kuzdas, 2017; Gajjar et al., 2018). Such dominant pathways tend to validate the practices, visions and values of existing governance regimes and powerful members of a community while devaluing those of less privileged stakeholders. Examples from Romania, the Solomon Islands and Australia illustrate such pathway dynamics in which individual economic gains and prosperity matter more than community cohesion and solidarity; this discourages innovation, exacerbates inequalities and further erodes adaptive capacities of the most vulnerable (Davies et al., 2014; Fazey et al., 2016; Bosomworth et al., 2017). In the city of London, United Kingdom, the dominant adaptation and disaster risk management pathway promotes resilience that emphasizes self-reliance; yet it intensifies the burden on low-income citizens, the elderly, migrants and others unable to afford flood insurance or protect themselves against heat waves (Pelling et al., 2016). Adaptation pathways in the Bolivian Altiplano have transformed subsistence farmers into world-leading quinoa producers, but loss of social cohesion and traditional values, dispossession and loss of ecosystem services now constitute undesirable trade-offs (Chelleri et al., 2016).

A narrow view of adaptation decision-making, for example focused on technical solutions, tends to crowd out more participatory processes (Lawrence and Haasnoot, 2017; Lin et al., 2017), obscures contested values and reinforces power asymmetries (Bosomworth et al., 2017; Singh, 2018). A situated and context-specific understanding of adaptation pathways that galvanizes diverse knowledge, values and joint initiatives helps to overcome dominant path dependencies, avoid trade-offs that intensify inequities and challenge policies detached from place (Fincher et al., 2014; Wyborn et al., 2015; Murphy et al., 2017; Gajjar et al., 2018). These insights suggest that adaptation pathway approaches to prepare for 1.5°C warmer futures would be difficult to achieve without considerations for inclusiveness, place-specific trade-off deliberations, redistributive measures and procedural justice mechanisms to facilitate equitable transformation (*medium evidence, high agreement*).

Box 5.1 | Ecosystem- and Community-Based Practices in Drylands

Drylands face severe challenges in building climate resilience (Fuller and Lain, 2017), yet small-scale farmers can play a crucial role as agents of change through ecosystem- and community-based practices that combine adaptation, mitigation and sustainable development.

Farmer managed natural regeneration (FMNR) of trees in cropland is practised in 18 countries across sub-Saharan Africa, Southeast Asia, Timor-Leste, India and Haiti and has, for example, permitted the restoration of over five million hectares of land in the Sahel (Niang et al., 2014; Bado et al., 2016). In Ethiopia, the Managing Environmental Resources to Enable Transitions programme, which entails community-based watershed rehabilitation in rural landscapes, supported around 648,000 people, resulting in the rehabilitation of 25,400,000 hectares of land in 72 severely food-insecure districts across Ethiopia between 2012 and 2015 (Gebrehaweria et al., 2016). In India, local farmers have benefitted from watershed programmes across different agro-ecological regions (Singh et al., 2014; Datta, 2015).

These low-cost, flexible community-based practices represent low-regrets adaptation and mitigation strategies. These strategies often contribute to strengthened ecosystem resilience and biodiversity, increased agricultural productivity and food security, reduced household poverty and drudgery for women, and enhanced agency and social capital (Niang et al., 2014; Francis et al., 2015; Kassie et al., 2015; Mbow et al., 2015; Reij and Winterbottom, 2015; Weston et al., 2015; Bado et al., 2016; Dumont et al., 2017). Small check dams in dryland areas and conservation agriculture can significantly increase agricultural output (Kumar et al., 2014; Agoramoorthy and Hsu, 2016; Pradhan et al., 2018). Mitigation benefits have also been quantified (Weston et al., 2015); for example, FMNR of more than five million hectares in Niger has sequestered 25–30 Mtonnes of carbon over 30 years (Stevens et al., 2014).

However, several constraints hinder scaling-up efforts: inadequate attention to the socio-technical processes of innovation (Grist et al., 2017; Scoones et al., 2017), difficulties in measuring the benefits of an innovation (Coe et al., 2017), farmers' inability to deal with long-term climate risk (Singh et al., 2017), and difficulties for matching practices with agro-ecological conditions and complementary modern inputs (Kassie et al., 2015). Key conditions to overcome these challenges include: developing agroforestry value chains and markets (Reij and Winterbottom, 2015) and adaptive planning and management (Gray et al., 2016). Others include inclusive processes giving greater voice to women and marginalized groups (MRFCJ, 2015a; UN Women and MRFCJ, 2016; Dumont et al., 2017), strengthening community land and forest rights (Stevens et al., 2014; Vermeulen et al., 2016), and co-learning among communities of practice at different scales (Coe et al., 2014; Reij and Winterbottom, 2015; Sinclair, 2016; Binam et al., 2017; Dumont et al., 2017; Epule et al., 2017).

5.4 Mitigation and Sustainable Development

The AR5 WGIII examined the potential of various mitigation options for specific sectors (energy supply, industry, buildings, transport, and agriculture, forestry, and other land use; AFOLU); it provided a narrative of dimensions of sustainable development and equity as a framing for evaluating climate responses and policies, respectively, in Chapters 4, 7, 8, 9, 10 and 11 (IPCC, 2014a). This section builds on the analyses of Chapters 2 and 4 of this report to re-assess mitigation and sustainable development in the context of 1.5°C global warming as well as the SDGs.

5.4.1 Synergies and Trade-Offs between Mitigation Options and Sustainable Development

Adopting stringent climate mitigation options can generate multiple positive non-climate benefits that have the potential to reduce the costs of achieving sustainable development (IPCC, 2014b; Ürge-Vorsatz et al., 2014, 2016; Schaeffer et al., 2015; von Stechow et al., 2015). Understanding the positive impacts (synergies) but also the negative impacts (trade-offs) is key for selecting mitigation options and policy choices that maximize the synergies between mitigation and developmental actions (Hildingsson and Johansson, 2015; Nilsson et al., 2016; Delponte et al., 2017; van Vuuren et al., 2017b; McCollum et al., 2018). Aligning mitigation response options to sustainable development objectives can ensure public acceptance (IPCC, 2014a), encourage faster action (Lechtenboehmer and Knoop, 2017) and support the design of equitable mitigation (Holz et al., 2018; Winkler et al., 2018) that protect human rights (MRFCJ, 2015b) (Section 5.5.3).

This sub-section assesses available literature on the interactions of individual mitigation options (see Chapter 2, Section 2.3.1.2, Chapter 4, Sections 4.2 and 4.3) with sustainable development and the SDGs and underlying targets. Table 5.2 presents an assessment of these synergies and trade-offs and the strength of the interaction using an SDG-interaction score (see Glossary) (McCollum et al., 2018), with evidence and agreements levels. Figure 5.2 presents the information of Table 5.2, showing gross (not net) interactions with the SDGs. This detailed assessment of synergies and trade-offs of individual mitigation options with the SDGs (Table 5.2 a–d and Figure 5.2) reveals that the number of synergies exceeds that of trade-offs. Mitigation response options in the energy demand sector, AFOLU and oceans have more positive interactions with a larger number of SDGs compared to those on the energy supply side (*robust evidence, high agreement*).

5.4.1.1 Energy Demand: Mitigation Options to Accelerate Reduction in Energy Use and Fuel Switch

For mitigation options in the energy demand sectors, the number of synergies with all sixteen SDGs exceeds the number of trade-offs (Figure 5.2 and Table 5.2) (*robust evidence, high agreement*). Most of the interactions are of a reinforcing nature, hence facilitating the achievement of the goals.

Accelerating energy efficiency in all sectors, which is a necessary condition for a 1.5°C warmer world (see Chapters 2 and 4), has synergies with a large number of SDGs (*robust evidence, high agreement*) (Figure 5.2 and Table 5.2). The diffusion of efficient equipment and appliances across end use sectors has synergies with international partnership (SDG 17) and participatory and transparent institutions (SDG 16) because innovations and deployment of new technologies require transnational capacity building and knowledge sharing. Resource and energy savings support sustainable production and consumption (SDG 12), energy access (SDG 7), innovation and infrastructure development (SDG 9) and sustainable city development (SDG 11). Energy efficiency supports the creation of decent jobs by new service companies providing services for energy efficiency, but the net employment effect of efficiency improvement remains uncertain due to macro-economic feedback (SDG 8) (McCollum et al., 2018).

In the buildings sector, accelerating energy efficiency by way of, for example, enhancing the use of efficient appliances, refrigerant transition, insulation, retrofitting and low- or zero-energy buildings generates benefits across multiple SDG targets. For example, improved cook stoves make fuel endowments last longer and hence reduce deforestation (SDG 15), support equal opportunity by reducing school absences due to asthma among children (SDGs 3 and 4) and empower rural and indigenous women by reducing drudgery (SDG 5) (*robust evidence, high agreement*) (Derbez et al., 2014; Lucon et al., 2014; Maidment et al., 2014; Scott et al., 2014; Cameron et al., 2015; Fay et al., 2015; Liddell and Guiney, 2015; Shah et al., 2015; Sharpe et al., 2015; Wells et al., 2015; Willand et al., 2015; Hallegatte et al., 2016; Kusumaningtyas and Aldrian, 2016; Berrueta et al., 2017; McCollum et al., 2017).

In energy-intensive processing industries, 1.5°C-compatible trajectories require radical technology innovation through maximum electrification, shift to other low emissions energy carriers such as hydrogen or biomass, integration of carbon capture and storage (CCS) and innovations for carbon capture and utilization (CCU) (see Chapter 4, Section 4.3.4.5). These transformations have strong synergies with innovation and sustainable industrialization (SDG 9), supranational partnerships (SDGs 16 and 17) and sustainable production (SDG 12). However, possible trade-offs due to risks of CCS-based carbon leakage, increased electricity demands, and associated price impacts affecting energy access and poverty (SDGs 7 and 1) would need careful regulatory attention (Wesseling et al., 2017). In the mining industry, energy efficiency can be synergetic or face trade-offs with sustainable management (SDG 6), depending on the option retained for water management (Nguyen et al., 2014). Substitution and recycling are also an important driver of 1.5°C-compatible trajectories in industrial systems (see Chapter 4, Section 4.3.4.2). Structural changes and reorganization of economic activities in industrial park/clusters following the principles of industrial symbiosis (circular economy) improves the overall sustainability by reducing energy and waste (Fan et al., 2017; Preston and Lehne, 2017) and reinforces responsible production and consumption (SDG 12) through recycling, water use efficiency (SDG 6), energy access (SDG 7) and ecosystem protection and restoration (SDG 15) (Karner et al., 2015; Zeng et al., 2017).

In the transport sector, deep electrification may trigger increases of electricity prices and adversely affect poor populations (SDG 1), unless pro-poor redistributive policies are in place (Klausbruckner et al., 2016). In cities, governments can lay the foundations for compact, connected low-carbon cities, which are an important component of 1.5°C-compatible transformations (see Chapter 4, Section 4.3.3) and show synergies with sustainable cities (SDG 11) (Colenbrander et al., 2016).

Behavioural responses are important determinants of the ultimate outcome of energy efficiency on emission reductions and energy access (SDG 7) and their management requires a detailed understanding of the drivers of consumption and the potential for and barriers to absolute reductions (Fuchs et al., 2016). Notably, the rebound effect tends to offset the benefits of efficiency for emissions reductions through growing demand for energy services (Sorrell, 2015; Suffolk and Poortinga, 2016). However, high rebound can help in providing faster access to affordable energy (SDG 7.1) where the goal is to reduce energy poverty and unmet energy demand (see Chapter 2, Section 2.4.3) (Chakravarty et al., 2013). Comprehensive policy design – including rebound supressing policies, such as carbon pricing and policies that encourage awareness building and promotional material design – is needed to tap the full potential of energy savings, as applicable to a 1.5°C warming context (Chakravarty and Tavoni, 2013; IPCC, 2014b; Karner et al., 2015; Zhang et al., 2015; Altieri et al., 2016; Santarius et al., 2016) and to address policy-related trade-offs and welfare-enhancing benefits (*robust evidence, high agreement*) (Chakravarty et al., 2013; Chakravarty and Roy, 2016; Gillingham et al., 2016).

Other behavioural responses will affect the interplay between energy efficiency and sustainable development. Building occupants reluctant to change their habits may miss out on welfare-enhancing energy efficiency opportunities (Zhao et al., 2017). Preferences for new products and premature obsolescence for appliances is expected to adversely affect sustainable consumption and production (SDG 12) with ramifications for resource use efficiency (Echegaray, 2016). Changes in user behaviour towards increased physical activity, less reliance on motorized travel over short distances and the use of public transport would help to decarbonize the transport sector in a synergetic manner with SDGs 3, 11 and 12 (Shaw et al., 2014; Ajanovic, 2015; Chakrabarti and Shin, 2017), while reducing inequality in access to basic facilities (SDG 10) (Lucas and Pangbourne, 2014; Kagawa et al., 2015). However, infrastructure design and regulations would need to ensure road safety and address risks of road accidents for pedestrians (Hwang et al., 2017; Khreis et al., 2017) to ensure sustainable infrastructure growth in human settlements (SDGs 9 and 11) (Lin et al., 2015; SLoCaT, 2017).

5.4.1.2 Energy Supply: Accelerated Decarbonization

Decreasing the share of coal in energy supply in line with 1.5°C-compatible scenarios (see Chapter 2, Section 2.4.2) reduces adverse impacts of upstream supply-chain activities, in particular air and water pollution and coal mining accidents, and enhances health by reducing air pollution, notably in cities, showing synergies with SDGs 3, 11 and 12 (Yang et al., 2016; UNEP, 2017).

Fast deployment of renewables such as solar, wind, hydro and modern biomass, together with the decrease of fossil fuels in energy supply (see Chapter 2, Section 2.4.2.1), is aligned with the doubling of renewables in the global energy mix (SDG 7.2). Renewables could also support progress on SDGs 1, 10, 11 and 12 and supplement new technology (*robust evidence, high agreement*) (Chaturvedi and Shukla, 2014; Rose et al., 2014; Smith and Sagar, 2014; Riahi et al., 2015; IEA, 2016; McCollum et al., 2017; van Vuuren et al., 2017a). However, some trade-offs with the SDGs can emerge from offshore installations, particularly SDG 14 in local contexts (McCollum et al., 2017). Moreover, trade-offs between renewable energy production and affordability (SDG 7) (Labordena et al., 2017) and other environmental objectives would need to be scrutinised for potential negative social outcomes. Policy interventions through regional cooperation-building (SDG 17) and institutional capacity (SDG 16) can enhance affordability (SDG 7) (Labordena et al., 2017). The deployment of small-scale renewables, or off-grid solutions for people in remote areas (Sánchez and Izzo, 2017), has strong potential for synergies with access to energy (SDG 7), but the actualization of these potentials requires measures to overcome technology and reliability risks associated with large-scale deployment of renewables (Giwa et al., 2017; Heard et al., 2017). Bundling energy-efficient appliances and lighting with off-grid renewables can lead to substantial cost reduction while increasing reliability (IEA, 2017). Low-income populations in industrialized countries are often left out of renewable energy generation schemes, either because of high start-up costs or lack of home ownership (UNRISD, 2016).

Nuclear energy, the share of which increases in most of the 1.5°C-compatible pathways (see Chapter 2, Section 2.4.2.1), can increase the risks of proliferation (SDG 16), have negative environmental effects (e.g., for water use; SDG 6) and have mixed effects for human health when replacing fossil fuels (SDGs 7 and 3) (see Table 5.2). The use of fossil CCS, which plays an important role in deep mitigation pathways (see Chapter 2, Section 2.4.2.3), implies continued adverse impacts of upstream supply-chain activities in the coal sector, and because of lower efficiency of CCS coal power plants (SDG 12), upstream impacts and local air pollution are likely to be exacerbated (SDG 3). Furthermore, there is a non-negligible risk of carbon dioxide leakage from geological storage and the carbon dioxide transport infrastructure (SDG 3) (Table 5.2).

Economies dependent upon fossil fuel-based energy generation and/or export revenue are expected to be disproportionally affected by future restrictions on the use of fossil fuels under stringent climate goals and higher carbon prices; this includes impacts on employment, stranded assets, resources left underground, lower capacity use and early phasing out of large infrastructure already under construction (*robust evidence, high agreement*) (Box 5.2) (Johnson et al., 2015; McGlade and Ekins, 2015; UNEP, 2017; Spencer et al., 2018). Investment in coal continues to be attractive in many countries as it is a mature technology and provides cheap energy supplies, large-scale employment and energy security (Jakob and Steckel, 2016; Vogt-Schilb and Hallegatte, 2017; Spencer et al., 2018). Hence, accompanying policies and measures would be required to ease job losses and correct for relatively higher prices of alternative energy (Oosterhuis and Ten Brink, 2014; Oei and Mendelevitch, 2016; Garg et al., 2017; HLCCP, 2017; Jordaan et al., 2017; OECD, 2017; UNEP, 2017; Blondeel and van de Graaf, 2018; Green, 2018). Research on historical transitions shows that managing the impacts on workers through retraining programmes is essential in order to align the phase-down of mining industries with meeting ambitious climate targets, and the objectives of a 'just transition' (Galgóczi, 2014; Caldecott et al., 2017; Healy and Barry, 2017). This aspect is even more important in developing countries where the mining workforce is largely semi- or unskilled (Altieri et al., 2016; Tung, 2016). Ambitious emissions reduction targets can unlock very strong decoupling potentials in industrialized fossil exporting economies (Hatfield-Dodds et al., 2015).

Box 5.2 | Challenges and Opportunities of Low-Carbon Pathways in Gulf Cooperative Council Countries

The Gulf Cooperative Council (GCC) region (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and United Arab Emirates) is characterized by high dependency on hydrocarbon resources (natural oil and gas), with high risks of socio-economic impacts of policies and response measures to address climate change. The region is also vulnerable to the decrease of the global demand and price of hydrocarbons as a result of climate change response measures. The projected declining use of oil and gas under low emissions pathways creates risks of significant economic losses for the GCC region (e.g., Waisman et al., 2013; Van de Graaf and Verbruggen, 2015; Al-Maamary et al., 2016; Bauer et al., 2016), given that natural gas and oil revenues contributed to about 70% of government budgets and > 35% of the gross domestic product in 2010 (Callen et al., 2014).

The current high energy intensity of the domestic economies (Al-Maamary et al., 2017), triggered mainly by low domestic energy prices (Alshehry and Belloumi, 2015), suggests specific challenges for aligning mitigation towards 1.5°C-consistent trajectories, which would require strong energy efficiency and economic development for the region.

The region's economies are highly reliant on fossil fuel for their domestic activities. Yet the renewables deployment potentials are large, deployment is already happening (Cugurullo, 2013; IRENA, 2016) and positive economic benefits can be envisaged (Sgouridis et al., 2016). Nonetheless, the use of renewables is currently limited by economics and structural challenges (Lilliestam and Patt, 2015; Griffiths, 2017a). Carbon capture and storage (CCS) is also envisaged with concrete steps towards implementation (Alsheyab, 2017; Ustadi et al., 2017); yet the real potential of this technology in terms of scale and economic dimensions is still uncertain.

Beyond the above mitigation-related challenges, the region's human societies and fragile ecosystems are highly vulnerable to the impacts of climate change, such as water stress (Evans et al., 2004; Shaffrey et al., 2009), desertification (Bayram and Öztürk, 2014), sea level rise affecting vast low coastal lands, and high temperature and humidity with future levels potentially beyond adaptive capacities (Pal and Eltahir, 2016). A low-carbon pathway that manages climate-related risks within the context of sustainable development requires an approach that jointly addresses both types of vulnerabilities (Al Ansari, 2013; Lilliestam and Patt, 2015; Babiker, 2016; Griffiths, 2017b).

The Nationally Determined Contributions (NDCs) for GCC countries identified energy efficiency, deployment of renewables and technology transfer to enhance agriculture, food security, protection of marine resources, and management of water and costal zones (Babiker, 2016). Strategic vision documents, such as Saudi Arabia's 'Vision 2030', identify emergent opportunities for energy price reforms, energy efficiency, turning emissions into valuable products, and deployment of renewables and other clean technologies, if accompanied with appropriate policies to manage the transition and in the context of economic diversification (Luomi, 2014; Atalay et al., 2016; Griffiths, 2017b; Howarth et al., 2017).

5.4.1.3 Land-based agriculture, forestry and ocean: mitigation response options and carbon dioxide removal

In the AFOLU sector, dietary change towards global healthy diets, that is, a shift from over-consumption of animal-related to plant-related diets, and food waste reduction (see Chapter 4, Section 4.3.2.1) are in synergy with SDGs 2 and 6, and SDG 3 through lower consumption of animal products and reduced losses and waste throughout the food system, contributing to achieving SDGs 12 and 15 (Bajželj et al., 2014; Bustamante et al., 2014; Tilman and Clark, 2014; Hiç et al., 2016).

Power dynamics play an important role in achieving behavioural change and sustainable consumption (Fuchs et al., 2016). In forest management (see Chapter 4, Section 4.3.2.2), encouraging responsible sourcing of forest products and securing indigenous land tenure has the potential to increase economic benefits by creating decent jobs (SDG 8), maintaining biodiversity (SDG 15), facilitating innovation and upgrading technology (SDG 9), and encouraging responsible and just decision-making (SDG 16) (*medium evidence, high agreement*) (Ding et al., 2016; WWF, 2017).

Emerging evidence indicates that future mitigation efforts that would be required to reach stringent climate targets, particularly those associated with carbon dioxide removal (CDR) (e.g., afforestation and reforestation and bioenergy with carbon capture and storage; BECCS), may also impose significant constraints upon poor and vulnerable communities (SDG 1) via increased food prices and competition for arable land, land appropriation and dispossession (Cavanagh and Benjaminsen, 2014; Hunsberger et al., 2014; Work, 2015; Muratori et al., 2016; Smith et al., 2016; Burns and Nicholson, 2017; Corbera et al., 2017) with disproportionate negative impacts upon rural poor and indigenous populations (SDG 1) (*robust evidence, high agreement*) (Section 5.4.2.2, Table 5.2, Figure 5.2) (Grubert et al., 2014; Grill et al., 2015; Zhang and Chen, 2015; Fricko et al., 2016; Johansson et al., 2016; Aha and Ayitey, 2017; De Stefano et al., 2017; Shi et al., 2017). Crops for bioenergy may increase irrigation needs and exacerbate water stress with negative associated impacts on SDGs 6 and 10 (Boysen et al., 2017).

Ocean iron fertilization and enhanced weathering have two-way interactions with life under water and on land and food security (SDGs

2, 14 and 15) (Table 5.2). Development of blue carbon resources through coastal (mangrove) and marine (seaweed) vegetative ecosystems encourages: integrated water resource management (SDG 6) (Vierros, 2017); promotes life on land (SDG 15) (Potouroglou et al., 2017); poverty reduction (SDG 1) (Schirmer and Bull, 2014; Lamb et al., 2016); and food security (SDG 2) (Ahmed et al., 2017a, b; Duarte et al., 2017; Sondak et al., 2017; Vierros, 2017; Zhang et al., 2017).

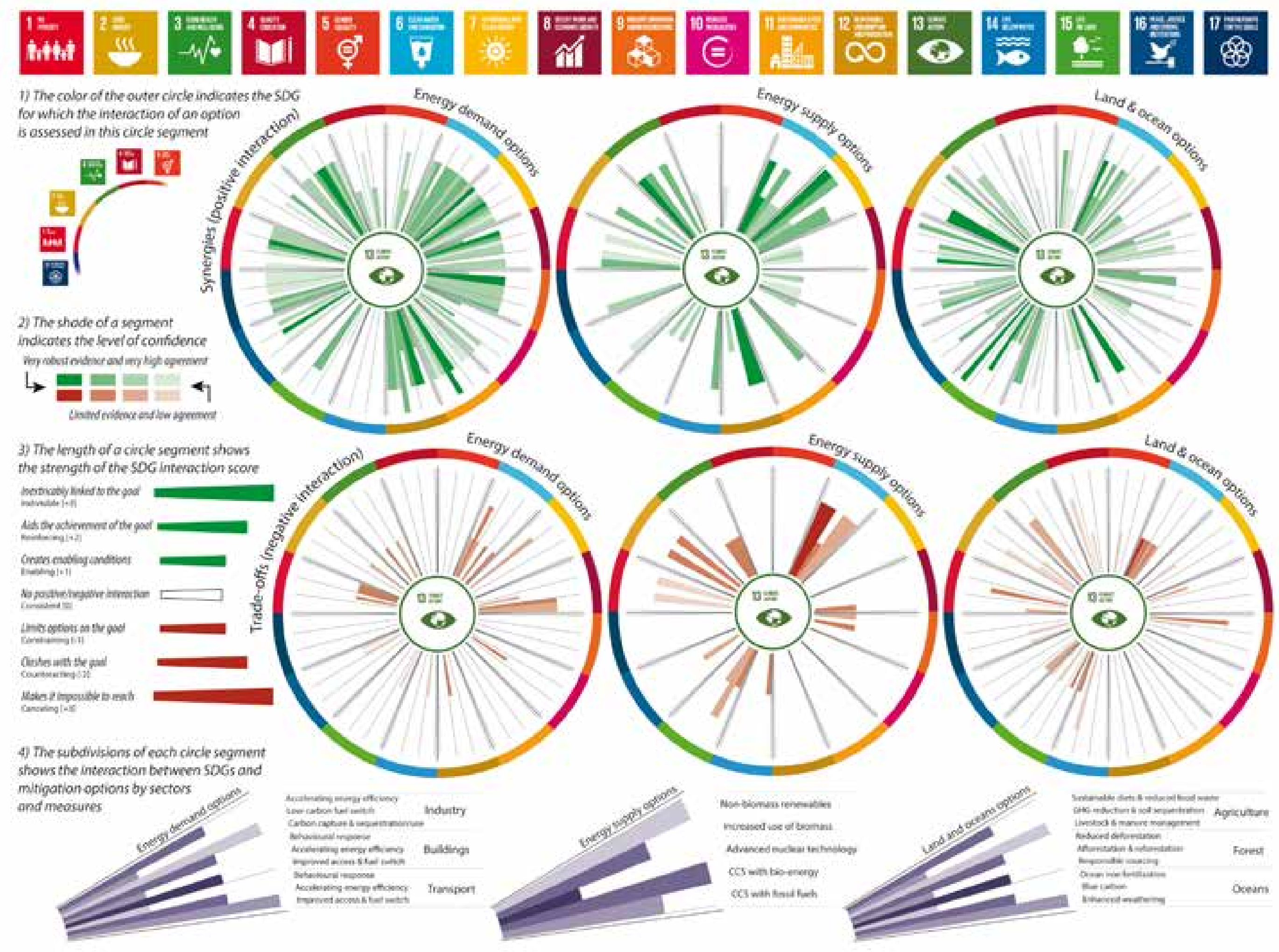


Figure 5.2 | Synergies and trade-offs and gross Sustainable Development Goal (SDG)-interaction with individual mitigation options. The top three wheels represent synergies and the bottom three wheels show trade-offs. The colours on the border of the wheels correspond to the SDGs listed above, starting at the 9 o'clock position, with reading guidance in the top-left corner with the quarter circle (Note 1). Mitigation (climate action, SDG 13) is at the centre of the circle. The coloured segments inside the circles can be counted to arrive at the number of synergies (green) and trade-offs (red). The length of the coloured segments shows the strength of the synergies or trade-offs (Note 3) and the shading indicates confidence (Note 2). Various mitigation options within the energy demand sector, energy supply sector, and land and ocean sector, and how to read them within a segment are shown in grey (Note 4). See also Table 5.2.

5.4.2 Sustainable Development Implications of 1.5°C and 2°C Mitigation Pathways

While previous sections have focused on individual mitigation options and their interaction with sustainable development and the SDGs, this section takes a systems perspective. Emphasis is on quantitative pathways depicting path-dependent evolutions of human and natural systems over time. Specifically, the focus is on fundamental transformations and thus stringent mitigation policies consistent with 1.5°C or 2°C, and the differential synergies and trade-offs with respect to the various sustainable development dimensions.

Both 1.5°C and 2°C pathways would require deep cuts in greenhouse gas (GHG) emissions and large-scale changes of energy supply and demand, as well as in agriculture and forestry systems (see Chapter 2, Section 2.4). For the assessment of the sustainable development implications of these pathways, this chapter draws upon studies that show the aggregated impact of mitigation for multiple sustainable development dimensions (Grubler et al., 2018; McCollum et al., 2018; Rogelj et al., 2018) and across multiple integrated assessment modelling (IAM) frameworks. Often these tools are linked to disciplinary models covering specific SDGs in more detail (Cameron et al., 2016; Rao et al., 2017; Grubler et al., 2018; McCollum et al., 2018). Using multiple IAMs and disciplinary models is important for a robust assessment of the sustainable development implications of different pathways. Emphasis is on multi-regional studies, which can be aggregated to the global scale. The recent literature on 1.5°C mitigation pathways has begun to provide quantifications for a range of sustainable development dimensions, including air pollution and health, food security and hunger, energy access, water security, and multidimensional poverty and equity.

5.4.2.1 Air pollution and health

GHGs and air pollutants are typically emitted by the same sources. Hence, mitigation strategies that reduce GHGs or the use of fossil fuels typically also reduce emissions of pollutants, such as particulate matter (e.g., PM2.5 and PM10), black carbon (BC), sulphur dioxide (SO_2), nitrogen oxides (NO_x) and other harmful species (Clarke et al., 2014) (Figure 5.3), causing adverse health and ecosystem effects at various scales (Kusumaningtyas and Aldrian, 2016).

Mitigation pathways typically show that there are significant synergies for air pollution, and that the synergies increase with the stringency of the mitigation policies (Amann et al., 2011; Rao et al., 2016; Klimont et al., 2017; Shindell et al., 2017; Markandya et al., 2018). Recent multimodel comparisons indicate that mitigation pathways consistent with 1.5°C would result in higher synergies with air pollution compared to pathways that are consistent with 2°C (Figures 5.4 and 5.5). Shindell et al. (2018) indicate that health benefits worldwide over the century of 1.5°C pathways could be in the range of 110 to 190 million fewer premature deaths compared to 2°C pathways. The synergies for air pollution are highest in the developing world, particularly in Asia. In addition to significant health benefits, there are also economic benefits from mitigation, reducing the investment needs in air pollution control technologies by about 35% globally (or about 100 billion USD2010 per year to 2030 in 1.5°C pathways; McCollum et al., 2018) (Figure 5.4).

5.4.2.2 Food security and hunger

Stringent climate mitigation pathways in line with 'well below 2°C' or '1.5°C' goals often rely on the deployment of large-scale land-related measures, like afforestation and/or bioenergy supply (Popp et al., 2014; Rose et al., 2014; Creutzig et al., 2015). These land-related measures can compete with food production and hence raise food security concerns (Section 5.4.1.3) (P. Smith et al., 2014). Mitigation studies indicate that so-called 'single-minded' climate policy, aiming solely at limiting warming to 1.5°C or 2°C without concurrent measures in the food sector, can have negative impacts for global food security (Hasegawa et al., 2015; McCollum et al., 2018). Impacts of 1.5°C mitigation pathways can be significantly higher than those of 2°C pathways (Figures 5.4 and 5.5). An important driver of the food security impacts in these scenarios is the increase of food prices and the effect of mitigation on disposable income and wealth due to GHG pricing. A recent study indicates that, on aggregate, the price and income effects on food may be bigger than the effect due to competition over land between food and bioenergy (Hasegawa et al., 2015).

In order to address the issue of trade-offs with food security, mitigation policies would need to be designed in a way that shields the population at risk of hunger, including through the adoption of different complementary measures, such as food price support. The investment needs of complementary food price policies are found to be globally relatively much smaller than the associated mitigation investments of 1.5°C pathways (Figure 5.3) (McCollum et al., 2018). Besides food support price, other measures include improving productivity and efficiency of agricultural production systems (FAO and NZAGRC, 2017a, b; Frank et al., 2017) and programmes focusing on forest land-use change (Havlík et al., 2014). All these lead to additional benefits of mitigation, improving resilience and livelihoods.

Van Vuuren et al. (2018) and Grubler et al. (2018) show that 1.5°C pathways without reliance on BECCS can be achieved through a fundamental transformation of the service sectors which would significantly reduce energy and food demand (see Chapter 2, Sections 2.1.1, 2.3.1 and 2.4.3). Such low energy demand (LED) pathways would result in significantly reduced pressure on food security, lower food prices and fewer people at risk of hunger. Importantly, the trade-offs with food security would be reduced by the avoided impacts in the agricultural sector due to the reduced warming associated with the 1.5°C pathways (see Chapter 3, Section 3.5). However, such feedbacks are not comprehensively captured in the studies on mitigation.

5.4.2.3 Lack of energy access/energy poverty

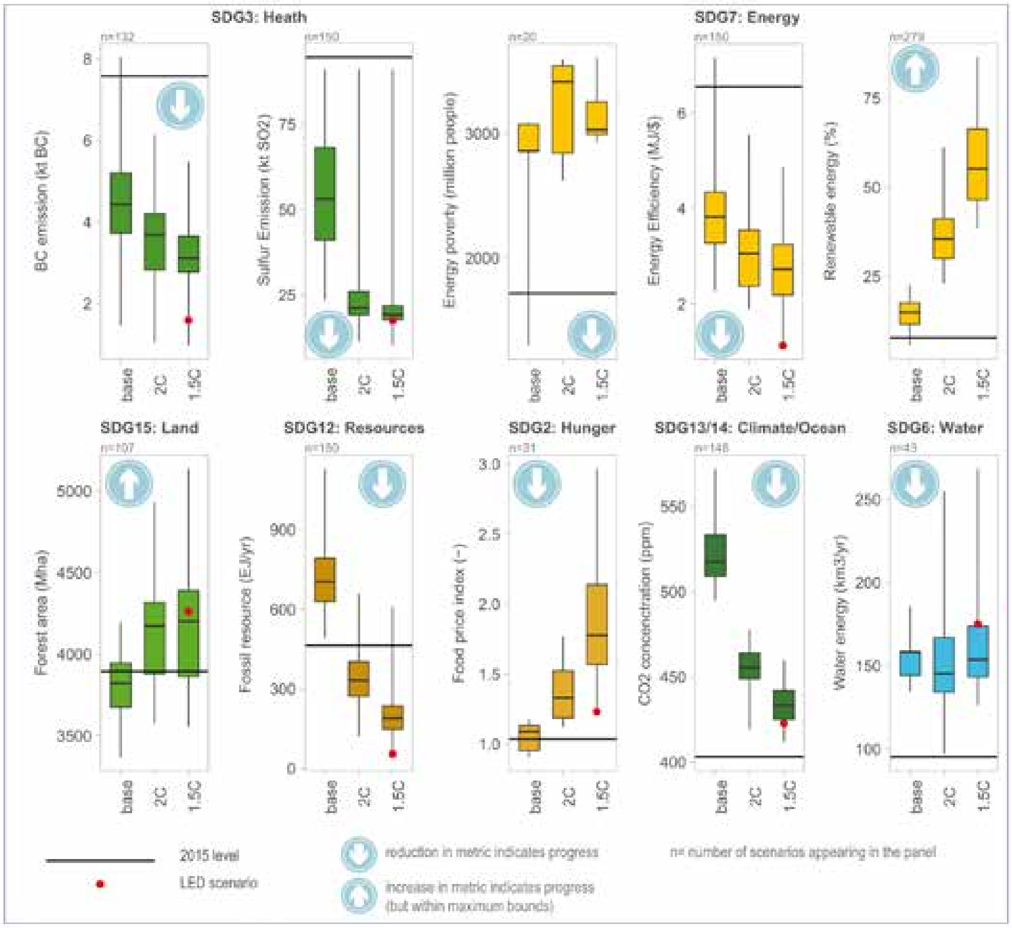
A lack of access to clean and affordable energy (especially for cooking) is a major policy concern in many countries, especially in those in South Asia and Africa where major parts of the population still rely primarily on solid fuels for cooking (IEA and World Bank, 2017). Scenario studies which quantify the interactions between climate mitigation and energy access indicate that stringent climate policy which would affect energy prices could significantly slow down the transition to clean cooking fuels, such as liquefied petroleum gas or electricity (Cameron et al., 2016).

Estimates across six different IAMs (McCollum et al., 2018) indicate that, in the absence of compensatory measures, the number of people without access to clean cooking fuels may increase. Redistributional measures, such as subsidies on cleaner fuels and stoves, could compensate for the negative effects of mitigation on energy access. Investment costs of the redistributional measures in 1.5°C pathways (on average around 120 billion USD2010 per year to 2030; Figure 5.4) are much smaller than the mitigation investments of 1.5°C pathways (McCollum et al., 2018). The recycling of revenues from climate policy might act as a means to help finance the costs of providing energy access to the poor (Cameron et al., 2016).

5.4.2.4 Water security

Transformations towards low emissions energy and agricultural systems can have major implications for freshwater demand as well as water pollution. The scaling up of renewables and energy efficiency as depicted by low emissions pathways would, in most instances, lower water demands for thermal energy supply facilities ('water-for-energy') compared to fossil energy technologies, and thus reinforce targets related to water access and scarcity (see Chapter 4, Section 4.2.1). However, some low-carbon options such as bioenergy, centralized solar

a) Scenario ranges for selected sustainable development dimensions (2050)



b) Synergies and trade-offs of 1.5°C pathways
(compared to baseline , 2050)

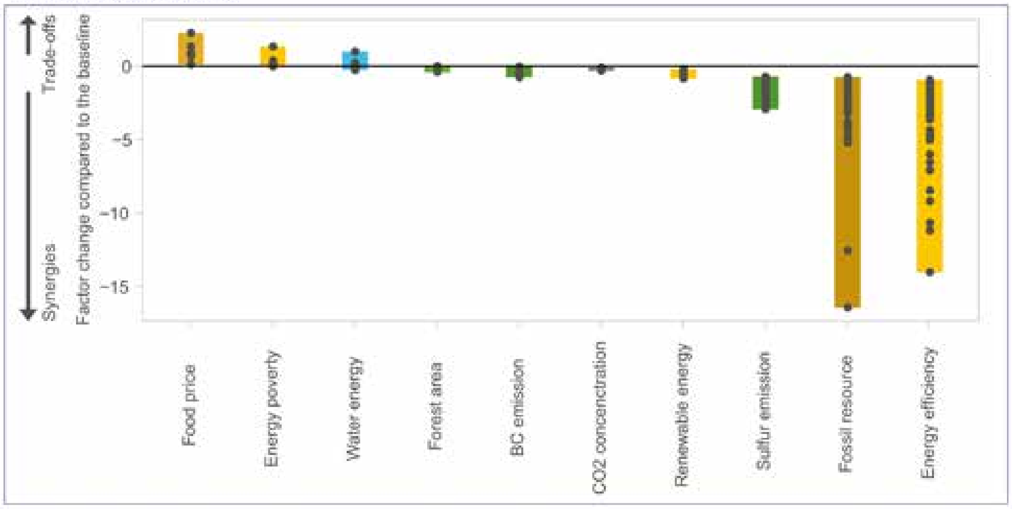


Figure 5.3 | Sustainable development implications of mitigation actions in 1.5°C pathways. Panel (a) shows ranges for 1.5°C pathways for selected sustainable development dimensions compared to the ranges of 2°C pathways and baseline pathways. The panel (a) depicts interquartile and the full range across the scenarios for Sustainable Development Goal (SDG) 2 (hunger), SDG 3 (health), SDG 6 (water), SDG 7 (energy), SDG 12 (resources), SDG 13/14 (climate/ocean) and SDG 15 (land). Progress towards achieving the SDGs is denoted by arrow symbols (increase or decrease of indicator). Black horizontal lines show 2015 values for comparison. Note that sustainable development effects are estimated for the effect of mitigation and do not include benefits from avoided impacts (see Chapter 3, Section 3.5). Low energy demand (LED) denotes estimates from a pathway with extremely low energy demand reaching 1.5°C without bioenergy with carbon capture and storage (BECCS). Panel (b) presents the resulting full range for synergies and trade-offs of 1.5°C pathways compared to the corresponding baseline scenarios. The y-axis in panel (b) indicates the factor change in the 1.5°C pathway compared to the baseline. Note that the figure shows gross impacts of mitigation and does not include feedbacks due to avoided impacts. The realization of the side effects will critically depend on local circumstances and implementation practice. Trade-offs across many sustainable development dimensions can be reduced through complementary/re-distributional measures. The figure is not comprehensive and focuses on those sustainable development dimensions for which quantifications across models are available. Sources: 1.5°C pathways database from Chapter 2 (Grubler et al., 2018; McCollum et al., 2018).

power, nuclear and hydropower technologies could, if not managed properly, have counteracting effects that compound existing water-related problems in a given locale (Byers et al., 2014; Fricko et al., 2016; IEA, 2016; Fujimori et al., 2017a; McCollum et al., 2017; Wang, 2017).

Under stringent mitigation efforts, the demand for bioenergy can result in a substantial increase of water demand for irrigation, thereby potentially contributing to water scarcity in water-stressed regions (Berger et al., 2015; Bonsch et al., 2016; Jägermeyr et al., 2017). However, this risk can be reduced by prioritizing rain-fed production of bioenergy (Hayashi et al., 2015, 2018; Bonsch et al., 2016), but might have adverse effects for food security (Boysen et al., 2017).

Reducing food and energy demand without compromising the needs of the poor emerges as a robust strategy for both water conservation and GHG emissions reductions (von Stechow et al., 2015; IEA, 2016; Parkinson et al., 2016; Grubler et al., 2018). The results underscore the importance of an integrated approach when developing water, energy and climate policy (IEA, 2016).

Estimates across different models for the impacts of stringent mitigation pathways on energy-related water uses seem ambiguous. Some pathways show synergies (Mouratiadou et al., 2018) while others indicate trade-offs and thus increases of water use due to mitigation (Fricko et al., 2016). The synergies depend on the adopted policy implementation or mitigation strategies and technology portfolio. A number of adaptation options exist (e.g., dry cooling), which can effectively reduce electricity-related water trade-offs (Fricko et al., 2016; IEA, 2016). Similarly, irrigation water use will depend on the regions where crops are produced, the sources of bioenergy (e.g., agriculture vs. forestry) and dietary change induced by climate policy. Overall, and also considering other water-related SDGs, including access to safe drinking water and sanitation as well as waste-water treatment, investments into the water sector seem to be only modestly affected by stringent climate policy compatible with 1.5°C (Figure 5.4) (McCollum et al., 2018).

In summary, the assessment of mitigation pathways shows that to meet the 1.5°C target, a wide range of mitigation options would need to be deployed (see Chapter 2, Sections 2.3 and 2.4). While pathways aiming at 1.5°C are associated with high synergies for some sustainable development dimensions (such as human health and air pollution, forest preservation), the rapid pace and magnitude of the required changes would also lead to increased risks for trade-offs for other sustainable development dimensions (particularly food security) (Figures 5.4 and 5.5). Synergies and trade-offs are expected to be unevenly distributed between regions and nations (Box 5.2), though little literature has formally examined such distributions under 1.5°C-consistent mitigation scenarios. Reducing these risks requires smart policy designs and mechanisms that shield the poor and redistribute the burden so that the most vulnerable are not disproportionately affected. Recent scenario analyses show that associated investments for reducing the trade-offs for, for example, food, water and energy access to be significantly lower than the required mitigation investments (McCollum et al., 2018). Fundamental transformation of demand, including efficiency and behavioural changes, can help to significantly reduce the reliance on risky technologies, such as BECCS, and thus reduce the risk of potential trade-offs between mitigation and other sustainable development dimensions (von Stechow et al., 2015; Grubler et al., 2018; van Vuuren et al., 2018). Reliance on demand-side measures only, however, would not be sufficient for meeting stringent targets, such as 1.5°C and 2°C (Clarke et al., 2014).

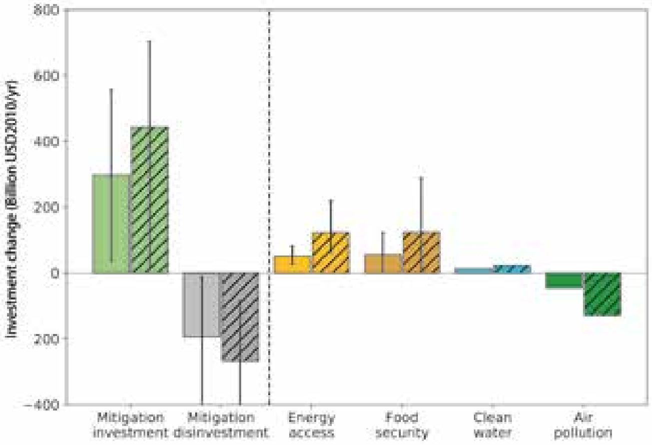


Figure 5.4 | Investment into mitigation up until 2030 and implications for investments for four sustainable development dimensions. Cross-hatched bars show the median investment in 1.5°C pathways across results from different models, and solid bars for 2°C pathways, respectively. Whiskers on bars represent minima and maxima across estimates from six models. Clean water and air pollution investments are available only from one model. Mitigation investments show the change in investments across mitigation options compared to the baseline. Negative mitigation investments (grey bars) denote disinvestment (reduced investment needs) into fossil fuel sectors compared to the baseline. Investments for different sustainable development dimensions denote the investment needs for complementary measures in order to avoid trade-offs (negative impacts) of mitigation. Negative sustainable development investments for air pollution indicate cost savings, and thus synergies of mitigation for air pollution control costs. The values compare to about 2 trillion USD2010 (range of 1.4 to 3 trillion) of total energy-related investments in the 1.5°C pathways. Source: Estimates from CD-LINKS scenarios summarised by McCollum et al. (2018).

5.5 Sustainable Development Pathways to 1.5°C

This section assesses what is known in the literature on development pathways that are sustainable and climate-resilient and relevant to a 1.5°C warmer world. Pathways, transitions from today's world to achieving a set of future goals (see Chapter 1, Section 1.2.3, Cross-Chapter Box 1), follow broadly two main traditions: first, as integrated pathways describing the required societal and systems transformations, combining quantitative modelling and qualitative narratives at multiple spatial scales (global to sub-national); and second, as country- and community-level, solution-oriented trajectories and decision-making processes about context- and place-specific opportunities, challenges and trade-offs. These two notions of pathways offer different, though complementary, insights into the nature of 1.5°C-relevant trajectories and the short-term actions that enable long-term goals. Both highlight to varying degrees the urgency, ethics and equity dimensions of possible trajectories and society- and system-wide transformations, yet at different scales, building on Chapter 2 (see Section 2.4) and Chapter 4 (see Section 4.5).

5.5.1 Integration of Adaptation, Mitigation and Sustainable Development

Insights into climate-compatible development (see Glossary) illustrate how integration between adaptation, mitigation and sustainable development works in context-specific projects, how synergies are achieved and what challenges are encountered during implementation (Stringer et al., 2014; Suckall et al., 2014; Antwi-Agyei et al., 2017a; Bickersteth et al., 2017; Kalafatis, 2017; Nunan, 2017). The operationalization of climate-compatible development, including climate-smart agriculture and carbon-forestry projects (Lipper et al., 2014; Campbell et al., 2016; Quan et al., 2017), shows multilevel and multisector trade-offs involving 'winners' and 'losers' across governance levels (*high confidence*) (Kongsager and Corbera, 2015; Naess et al., 2015; Karlsson et al., 2017; Tanner et al., 2017; Taylor, 2017; Wood, 2017; Ficklin et al., 2018). Issues of power, participation, values, equity, inequality and justice transcend case study examples of attempted integrated approaches (Nunan, 2017; Phillips et al., 2017; Stringer et al., 2017; Wood, 2017), also reflected in policy frameworks for integrated outcomes (Stringer et al., 2014; Di Gregorio et al., 2017; Few et al., 2017; Tanner et al., 2017).

Ultimately, reconciling trade-offs between development needs and emissions reductions towards a 1.5°C warmer world requires a dynamic view of the interlinkages between adaptation, mitigation and sustainable development (Nunan, 2017). This entails recognition of the ways in which development contexts shape the choice and effectiveness of interventions, limit the range of responses afforded to communities and governments, and potentially impose injustices upon vulnerable groups (UNRISD, 2016; Thornton and Comberti, 2017). A variety of approaches, both quantitative and qualitative, exist to examine possible sustainable development pathways under which climate and sustainable development goals can be achieved, and synergies and trade-offs for transformation identified (Sections 5.3 and 5.4).

5.5.2 Pathways for Adaptation, Mitigation and Sustainable Development

This section focuses on the growing body of pathways literature describing the dynamic and systemic integration of mitigation and adaptation with sustainable development in the context of a 1.5°C warmer world. These studies are critically important for the identification of 'enabling' conditions under which climate and the SDGs can be achieved, and thus help the design of transformation strategies that maximize synergies and avoid potential trade-offs (Sections 5.3 and 5.4). Full integration of sustainable development dimensions is, however, challenging, given their diversity and the need for high temporal, spatial and social resolution to address local effects, including heterogeneity related to poverty and equity (von Stechow et al., 2015). Research on long-term climate change mitigation and adaptation pathways has covered individual SDGs to different degrees. Interactions between climate and other SDGs have been explored for SDGs 2, 3, 4, 6, 7, 8, 12, 14 and 15 (Clarke et al., 2014; Abel et al., 2016; von Stechow et al., 2016; Rao et al., 2017), while interactions with SDGs 1, 5, 11 and 16 remain largely underexplored in integrated long-term scenarios (Zimm et al., 2018).

Quantitative pathways studies now better represent 'nexus' approaches to assess sustainable development dimensions. In such approaches (see Chapter 4, Section 4.3.3.8), a subset of sustainable development dimensions are investigated together because of their close relationships (Welsch et al., 2014; Conway et al., 2015; Keairns et al., 2016; Parkinson et al., 2016; Rasul and Sharma, 2016; Howarth and Monasterolo, 2017). Compared to single-objective climate–SDG assessments (Section 5.4.2), nexus solutions attempt to integrate complex interdependencies across diverse sectors in a systems approach for consistent analysis. Recent pathways studies show how water, energy and climate (SDGs 6, 7 and 13) interact (Parkinson et al., 2016; McCollum et al., 2018) and call for integrated water–energy investment decisions to manage systemic risks. For instance, the provision of bioenergy, important in many 1.5°C-consistent pathways, can help resolve 'nexus challenges' by alleviating energy security concerns, but can also have adverse 'nexus impacts' on food security, water use and biodiversity (Lotze-Campen et al., 2014; Bonsch et al., 2016). Policies that improve resource use efficiency across sectors can maximize synergies for sustainable development (Bartos and Chester, 2014; McCollum et al., 2018; van Vuuren et al., 2018). Mitigation compatible with 1.5°C can significantly reduce impacts and adaptation needs in the nexus sectors compared to 2°C (Byers et al., 2018). In order to avoid trade-offs due to high carbon pricing of 1.5°C pathways, regulation in specific areas may complement price-based instruments. Such combined policies generally lead also to more early action maximizing synergies and avoiding some of the adverse climate effects for sustainable development (Bertram et al., 2018).

The comprehensive analysis of climate change in the context of sustainable development requires suitable reference scenarios that lend themselves to broader sustainable development analyses. The Shared Socio-Economic Pathways (SSPs) (Chapter 1, Cross-Chapter Box 1 in Chapter 1) (O'Neill et al., 2017a; Riahi et al., 2017) constitute an important first step in providing a framework for the integrated assessment of adaptation and mitigation and their climate–development linkages (Ebi et al., 2014). The five underlying SSP narratives (O'Neill et al., 2017a) map well into some of the key SDG dimensions, with one of the pathways (SSP1) explicitly depicting sustainability as the main theme (van Vuuren et al., 2017b).

To date, no pathway in the literature proves to achieve all 17 SDGs because several targets are not met or not sufficiently covered in the analysis, hence resulting in a sustainability gap (Zimm et al., 2018). The SSPs facilitate the systematic exploration of different sustainable dimensions under ambitious climate objectives. SSP1 proves to be in line with eight SDGs (3, 7, 8, 9, 10, 11, 13 and 15) and several of their targets in a 2°C warmer world (van Vuuren et al., 2017b; Zimm et al., 2018). However, important targets for SDGs 1, 2 and 4 (i.e., people living in extreme poverty, people living at the risk of hunger and gender gap in years of schooling) are not met in this scenario.

The SSPs show that sustainable socio-economic conditions will play a key role in reaching stringent climate targets (Riahi et al., 2017; Rogelj et al., 2018). Recent modelling work has examined 1.5°C-consistent, stringent mitigation scenarios for 2100 applied to the SSPs, using six different IAMs. Despite the limitations of these models, which are coarse approximations of reality, robust trends can be identified

(Rogelj et al., 2018). SSP1 – which depicts broader 'sustainability' as well as enhancing equity and poverty reductions – is the only pathway where all models could reach 1.5°C and is associated with the lowest mitigation costs across all SSPs. A decreasing number of models was successful for SSP2, SSP4 and SSP5, respectively, indicating distinctly higher risks of failure due to high growth and energy intensity as well as geographical and social inequalities and uneven regional development. And reaching 1.5°C has even been found infeasible in the less sustainable SSP3 – 'regional rivalry' (Fujimori et al., 2017b; Riahi et al., 2017). All these conclusions hold true if a 2°C objective is considered (Calvin et al., 2017; Fujimori et al., 2017b; Popp et al., 2017; Riahi et al., 2017). Rogelj et al. (2018) also show that fewer scenarios are, however, feasible across different SSPs in case of 1.5°C, and mitigation costs substantially increase in 1.5°C pathways compared to 2°C pathways.

There is a wide range of SSP-based studies focusing on the connections between adaptation/impacts and different sustainable development dimensions (Hasegawa et al., 2014; Ishida et al., 2014; Arnell et al., 2015; Bowyer et al., 2015; Burke et al., 2015; Lemoine and Kapnick, 2016; Rozenberg and Hallegatte, 2016; Blanco et al., 2017; Hallegatte and Rozenberg, 2017; O'Neill et al., 2017a; Rutledge et al., 2017; Byers et al., 2018). New methods for projecting inequality and poverty (downscaled to sub-national rural and urban levels as well as spatially explicit levels) have enabled advanced SSP-based assessments of locally sustainable development implications of avoided impacts and related adaptation needs. For instance, Byers et al. (2018) find that, in a 1.5°C warmer world, a focus on sustainable development can reduce the climate risk exposure of populations vulnerable to poverty by more than an order of magnitude (Section 5.2.2). Moreover, aggressive reductions in between-country inequality may decrease the emissions intensity of global economic growth (Rao and Min, 2018). This is due to the higher potential for decoupling of energy from income growth in lower-income countries, due to high potential for technological advancements that reduce the energy intensity of growth of poor countries – critical also for reaching 1.5°C in a socially and economically equitable way. Participatory downscaling of SSPs in several European Union countries and in Central Asia shows numerous possible pathways of solutions to the 2°C–1.5°C goal, depending on differential visions (Tàbara et al., 2018). Other participatory applications of the SSPs, for example in West Africa (Palazzo et al., 2017) and the southeastern United States (Absar and Preston, 2015), illustrate the potentially large differences in adaptive capacity within regions and between sectors.

Harnessing the full potential of the SSP framework to inform sustainable development requires: (i) further elaboration and extension of the current SSPs to cover sustainable development objectives explicitly; (ii) the development of new or variants of current narratives that would facilitate more SDG-focused analyses with climate as one objective (among other SDGs) (Riahi et al., 2017); (iii) scenarios with high regional resolution (Fujimori et al., 2017b); (iv) a more explicit representation of institutional and governance change associated with the SSPs (Zimm et al., 2018); and (v) a scale-up of localized and spatially explicit vulnerability, poverty and inequality estimates, which have emerged in recent publications based on the SSPs (Byers et al., 2018) and are essential to investigate equity dimensions (Klinsky and Winkler, 2018).

5.5.3 Climate-Resilient Development Pathways

This section assesses the literature on pathways as solution-oriented trajectories and decision-making processes for attaining transformative visions for a 1.5°C warmer world. It builds on climate-resilient development pathways (CRDPs) introduced in the AR5 (Section 5.1.2) (Olsson et al., 2014) as well as growing literature (e.g., Eriksen et al., 2017; Johnson, 2017; Orindi et al., 2017; Kirby and O'Mahony, 2018; Solecki et al., 2018) that uses CRDPs as a conceptual and aspirational idea for steering societies towards low-carbon, prosperous and ecologically safe futures. Such a notion of pathways foregrounds decision-making processes at local to national levels to situate transformation, resilience, equity and well-being in the complex reality of specific places, nations and communities (Harris et al., 2017; Ziervogel et al., 2017; Fazey et al., 2018; Gajjar et al., 2018; Klinsky and Winkler, 2018; Patterson et al., 2018; Tàbara et al., 2018).

Pathways compatible with 1.5°C warming are not merely scenarios to envision possible futures but processes of deliberation and implementation that address societal values, local priorities and inevitable trade-offs. This includes attention to politics and power that perpetuate business-as-usual trajectories (O'Brien, 2016; Harris et al., 2017), the politics that shape sustainability and capabilities of everyday life (Agyeman et al., 2016; Schlosberg et al., 2017), and ingredients for community resilience and transformative change (Fazey et al., 2018). Chartering CRDPs encourages locally situated and problem-solving processes to negotiate and operationalize resilience 'on the ground' (Beilin and Wilkinson, 2015; Harris et al., 2017; Ziervogel et al., 2017). This entails contestation, inclusive governance and iterative engagement of diverse populations with varied needs, aspirations, agency and rights claims, including those most affected, to deliberate trade-offs in a multiplicity of possible pathways (*high confidence*) (see Figure 5.5) (Stirling, 2014; Vale, 2014; Walsh-Dilley and Wolford, 2015; Biermann et al., 2016; J.R.A. Butler et al., 2016; O'Brien, 2016, 2018; Harris et al., 2017; Jones and Tanner, 2017; Mapfumo et al., 2017; Rosenbloom, 2017; Gajjar et al., 2018; Klinsky and Winkler, 2018; Lyon, 2018; Tàbara et al., 2018).

5.5.3.1 Transformations, equity and well-being

Most literature related to CRDPs invokes the concept of transformation, underscoring the need for urgent and far-reaching changes in practices, institutions and social relations in society. Transformations towards a 1.5°C warmer world would need to address considerations for equity and well-being, including in trade-off decisions (see Figure 5.1).

To attain the anticipated *transformations*, all countries as well as non-state actors would need to strengthen their contributions, through bolder and more committed cooperation and equitable effort-sharing (*medium evidence, high agreement*) (Rao, 2014; Frumhoff et al., 2015; Ekwurzel et al., 2017; Millar et al., 2017; Shue, 2017; Holz et al., 2018; Robinson and Shine, 2018). Sustaining decarbonization rates at a 1.5°C-compatible level would be unprecedented and not possible without rapid transformations to a net-zero-emissions global economy by mid-century or the later half of the century (see Chapters 2 and 4). Such efforts would entail overcoming technical, infrastructural, institutional and behavioural barriers across all sectors and levels

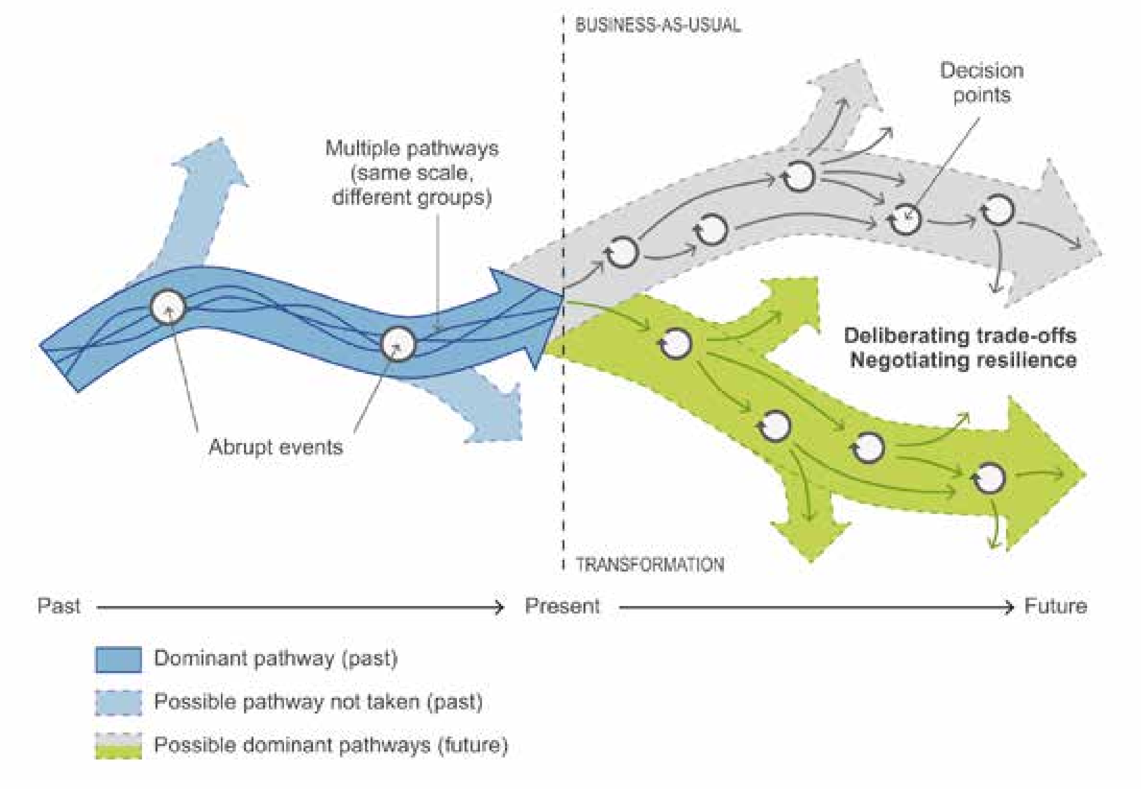


Figure 5.5 | Pathways into the future, with path dependencies and iterative problem-solving and decision-making (after Fazey et al. 2016).

of society (Pfeiffer et al., 2016; Seto et al., 2016) and defeating path dependencies, including poverty traps (Boonstra et al., 2016; Enqvist et al., 2016; Lade et al., 2017; Haider et al., 2018). Transformation also entails ensuring that 1.5°C-compatible pathways are inclusive and desirable, build solidarity and alliances, and protect vulnerable groups, including against disruptions of transformation (Patterson et al., 2018).

There is growing emphasis on the role of *equity, fairness* and *justice* (see Glossary) regarding context-specific transformations and pathways to a 1.5°C warmer world (*medium evidence, high agreement*) (Shue, 2014; Thorp, 2014; Dennig et al., 2015; Moellendorf, 2015; Klinsky et al., 2017b; Roser and Seidel, 2017; Sealey-Huggins, 2017; Klinsky and Winkler, 2018; Robinson and Shine, 2018). Consideration for what is equitable and fair suggests the need for stringent decarbonization and up-scaled adaptation that do not exacerbate social injustices, locally and at national levels (Okereke and Coventry, 2016), uphold human rights (Robinson and Shine, 2018), are socially desirable and acceptable (von Stechow et al., 2016; Rosenbloom, 2017), address values and beliefs (O'Brien, 2018), and overcome vested interests (Normann, 2015; Patterson et al., 2016). Attention is often drawn to huge disparities in the cost, benefits, opportunities and challenges involved in transformation within and between countries, and the fact that the suffering of already poor, vulnerable and disadvantaged populations may be worsened, if care to protect them is not taken (Holden et al., 2017; Klinsky and Winkler, 2018; Patterson et al., 2018).

Well-being for all (Dearing et al., 2014; Raworth, 2017) is at the core of an ecologically safe and socially just space for humanity, including health and housing, peace and justice, social equity, gender equality and political voices (Raworth, 2017). It is in alignment with transformative social development (UNRISD, 2016) and the 2030 Agenda of 'leaving no one behind'. The social conditions to enable well-being for all are to reduce entrenched inequalities within and between countries (Klinsky and Winkler, 2018); rethink prevailing values, ethics and behaviours (Holden et al., 2017); allow people to live a life in dignity while avoiding actions that undermine capabilities (Klinsky and Golub, 2016); transform economies (Popescu and Ciurlau, 2016; Tàbara et al., 2018); overcome uneven consumption and production patterns (Dearing et al., 2014; Häyhä et al., 2016; Raworth, 2017) and conceptualize development as well-being rather than mere economic growth (*medium evidence, high agreement*) (Gupta and Pouw, 2017).

5.5.3.2 Development trajectories, sharing of efforts and cooperation

The potential for pursuing sustainable and climate-resilient development pathways towards a 1.5°C warmer world differs between and within nations, due to differential development achievements and trajectories, and opportunities and challenges (*very high confidence*) (Figure 5.1). There are clear differences between high-income countries where social achievements are high, albeit often with negative effects on the environment, and most developing nations where vulnerabilities to climate change are high and social support and life satisfaction are low, especially in the Least Developed Countries (LDCs) (Sachs et al., 2017; O'Neill et al., 2018). Differential starting points for CRDPs between and within countries, including path dependencies (Figure 5.5), call for sensitivity to context (Klinsky and Winkler, 2018). For the developing world, limiting warming to 1.5°C also means potentially severely curtailed development prospects (Okereke and Coventry, 2016) and risks to human rights from both climate action and inaction to achieve this goal (Robinson and Shine, 2018) (Section 5.2). Within-country development differences remain, despite efforts to ensure inclusive societies (Gupta and Arts, 2017; Gupta and Pouw, 2017). Cole et al. (2017), for instance, show how differences between provinces in South Africa constitute barriers to sustainable development trajectories and for operationalising nation-level SDGs, across various dimensions of social deprivation and environmental stress, reflecting historic disadvantages.

Moreover, various equity and effort- or burden-sharing approaches to climate stabilization in the literature describe how to sketch national potentials for a 1.5°C warmer world (e.g., Anand, 2004; CSO Equity Review, 2015; Meinshausen et al., 2015; Okereke and Coventry, 2016; Bexell and Jönsson, 2017; Otto et al., 2017; Pan et al., 2017; Robiou du Pont et al., 2017; Winkler et al., 2018; Holz et al., 2018; Kartha et al., 2018). Many approaches build on the AR5 'responsibility – capacity – need' assessment (Clarke et al., 2014), complement other proposed national-level metrics for capabilities, equity and fairness (Heyward and Roser, 2016; Klinsky et al., 2017a), or fall under the wider umbrella of fair share debates on responsibility, capability and the right to development in climate policy (Fuglestvedt and Kallbekken, 2016). Importantly, different principles and methodologies generate different calculated contributions, responsibilities and capacities (Skeie et al., 2017).

The notion of nation-level fair shares is now also discussed in the context of limiting global warming to 1.5°C and the Nationally Determined Contributions (NDCs) (see Chapter 4, Cross-Chapter Box 11 in Chapter 4) (CSO Equity Review, 2015; Mace, 2016; Pan et al., 2017; Robiou du Pont et al., 2017; Holz et al., 2018; Kartha et al., 2018; Winkler et al., 2018). A study by Pan et al. (2017) concluded that all countries would need to contribute to ambitious emissions reductions and that current pledges for 2030 by seven out of eight high-emitting countries would be insufficient to meet 1.5°C. Emerging literature on justice-centred pathways to 1.5°C points towards ambitious emissions reductions domestically and committed cooperation internationally whereby wealthier countries support poorer ones, technologically, financially and otherwise to enhance capacities (Okereke and Coventry, 2016; Holz et al., 2018; Robinson and Shine, 2018; Shue, 2018). These findings suggest that equitable and 1.5°C-compatible pathways would require fast action across all countries at all levels of development rather than late accession of developing countries (as assumed under SSP3, see Chapter 2), with external support for prompt mitigation and resilience-building efforts in the latter (*medium evidence, medium agreement*).

Scientific advances since the AR5 now also make it possible to determine contributions to climate change for non-state actors (see Chapter 4, Section 4.4.1) and their potential to contribute to CRDPs (*medium evidence, medium agreement*). These non-state actors includes cities (Bulkeley et al., 2013, 2014; Byrne et al., 2016), businesses (Heede, 2014; Frumhoff et al., 2015; Shue, 2017), transnational initiatives (Castro, 2016; Andonova et al., 2017) and industries. Recent work demonstrates the contributions of 90 industrial carbon producers to global temperature and sea level rise, and their responsibilities to contribute to investments in and support for mitigation and adaptation (Heede, 2014; Ekwurzel et al., 2017; Shue, 2017) (Sections 5.6.1 and 5.6.2).

At the level of groups and individuals, equity in pursuing climate resilience for a 1.5°C warmer world means addressing disadvantage, inequities and empowerment that shape transformative processes and pathways (Fazey et al., 2018), and deliberate efforts to strengthen the capabilities, capacities and well-being of poor, marginalized and vulnerable people (Byrnes, 2014; Tokar, 2014; Harris et al., 2017; Klinsky et al., 2017a; Klinsky and Winkler, 2018). Community-driven CRDPs can flag potential negative impacts of national trajectories on disadvantaged groups, such as low-income families and communities of colour (Rao, 2014). They emphasize social equity, participatory governance, social inclusion and human rights, as well as innovation, experimentation and social learning (see Glossary) (*medium evidence, high agreement*) (Sections 5.5.3.3 and 5.6).

5.5.3.3 Country and community strategies and experiences

There are many possible pathways towards climate-resilient futures (O'Brien, 2018; Tàbara et al., 2018). Literature depicting different sustainable development trajectories in line with CRDPs is growing, with some of it being specific to 1.5°C global warming. Most experiences to date are at local and sub-national levels (Cross-Chapter Box 13 in this chapter), while state-level efforts align largely with green economy trajectories or planning for climate resilience (Box 5.3). Due to the fact that these strategies are context-specific, the literature is scarce on comparisons, efforts to scale up and systematic monitoring.

States can play an enabling or hindering role in a transition to a 1.5°C warmer world (Patterson et al., 2018). The literature on strategies to reconcile low-carbon trajectories with sustainable development and ecological sustainability through green growth, inclusive growth, de-growth, post-growth and development as well-being *shows low agreement* (see Chapter 4, Section 4.5). Efforts that align best with CRDPs are described as 'transformational' and 'strong' (Ferguson, 2015). Some view 'thick green' perspectives as enabling equity, democracy and agency building (Lorek and Spangenberg, 2014; Stirling, 2014; Ehresman and Okereke, 2015; Buch-Hansen, 2018), others show how green economy and sustainable development pathways can align (Brown et al., 2014; Georgeson et al., 2017b), and how a green economy can help link the SDGs with NDCs, for instance in Mongolia, Kenya and Sweden (Shine, 2017). Others still critique the continuous reliance on market mechanisms (Wanner, 2014; Brockington and Ponte, 2015) and disregard for equity and distributional and procedural justice (Stirling, 2014; Bell, 2015).

Country-level pathways and achievements vary significantly (*robust evidence, medium agreement*). For instance, the Scandinavian countries rank at the top of the Global Green Economy Index (Dual Citizen LLC, 2016), although they also tend to show high spill-over effects (Holz et al., 2018) and transgress their biophysical boundaries (O'Neill et al., 2018). State-driven efforts in non-member countries of the Organisation for Economic Co-operation and Development include Ethiopia's 'Climate-resilient Green Economy Strategy', Mozambique's 'Green Economy Action Plan' and Costa Rica's ecosystem- and conservation-driven green transition paths. China and India have adopted technology and renewables pathways (Brown et al., 2014; Death, 2014, 2015, 2016; Khanna et al., 2014; Chen et al., 2015; Kim and Thurbon, 2015; Wang et al., 2015; Weng et al., 2015). Brazil promotes low per capita GHG emissions, clean energy sources, green jobs, renewables and sustainable transportation, while slowing rates of deforestation (see Chapter 4, Box 4.7) (Brown et al., 2014; La Rovere, 2017). Yet concerns remain regarding persistent inequalities, ecosystem monetization, lack of participation in green-style projects (Brown et al., 2014) and labour conditions and risk of displacement in the sugarcane ethanol sector (McKay et al., 2016). Experiences with low-carbon development pathways in LDCs highlight the crucial role of identifying synergies across scale, removing institutional barriers and ensuring equity and fairness in distributing benefits as part of the right to development (Rai and Fisher, 2017).

In small islands states, for many of which climate change hazards and impacts at 1.5°C pose significant risks to sustainable development (see Chapter 3 Box 3.5, Chapter 4 Box 4.3, Box 5.3), examples of CRDPs have emerged since the AR5. This includes the SAMOA Pathway: SIDS Accelerated Modalities of Action (see Chapter 4, Box 4.3) (UNGA, 2014; Government of Kiribati, 2016; Steering Committee on Partnerships for SIDS and UNDESA, 2016; Lefale et al., 2017) and the Framework for Resilient Development in the Pacific, a leading example of integrated regional climate change adaptation planning for mitigation and sustainable development, disaster risk management and low-carbon economies (SPC, 2016). Small islands of the Pacific vary significantly in their capacity and resources to support effective integrated planning (McCubbin et al., 2015; Barnett and Walters, 2016; Cvitanovic et al., 2016; Hemstock et al., 2017; Robinson and Dornan, 2017). Vanuatu (Box 5.3) has developed a significant coordinated national adaptation plan to advance the 2030 Agenda for Sustainable Development, respond to the Paris Agreement and reduce the risk of disasters in line with the Sendai targets (UNDP, 2016; Republic of Vanuatu, 2017).

Box 5.3 | Republic of Vanuatu – National Planning for Development and Climate Resilience

The Republic of Vanuatu is leading Pacific Small Island Developing States (SIDS) to develop a nationally coordinated plan for climate-resilient development in the context of high exposure to hazard risk (MoCC, 2016; UNU-EHS, 2016). The majority of the population depends on subsistence, rain-fed agriculture and coastal fisheries for food security (Sovacool et al., 2017). Sea level rise, increased prolonged drought, water shortages, intense storms, cyclone events and degraded coral reef environments threaten human security in a 1.5°C warmer world (see Chapter 3, Box 3.5) (SPC, 2015; Aipira et al., 2017). Given Vanuatu's long history of climate hazards and disasters, local adaptive capacity is relatively high, despite barriers to the use of local knowledge and technology, and low rates of literacy and women's participation (McNamara and Prasad, 2014; Aipira et al., 2017; Granderson, 2017). However, the adaptive capacity of Vanuatu and other SIDS is increasingly constrained due to more frequent severe weather events (see Chapter 3, Box 3.5, Chapter 4, Cross-Chapter Box 9 in Chapter 4) (Gero et al., 2013; Kuruppu and Willie, 2015; SPC, 2015; Sovacool et al., 2017).

Vanuatu has developed a national sustainable development plan for 2016–2030: the People's Plan (Republic of Vanuatu, 2016). This coordinated, inclusive plan of action on economy, environment and society aims to strengthen adaptive capacity and resilience to climate change and disasters. It emphasizes rights of all Ni-Vanuatu, including women, youth, the elderly and vulnerable groups (Nalau et al., 2016). Vanuatu has also developed a Coastal Adaptation Plan (Republic of Vanuatu, 2016), an integrated Climate Change and Disaster Risk Reduction Policy (2016–2030) (SPC, 2015) and the first South Pacific National Advisory Board on Climate Change & Disaster Risk Reduction (SPC, 2015; UNDP, 2016).

Vanuatu aims to integrate planning at multiple scales, and increase climate resilience by supporting local coping capacities and iterative processes of planning for sustainable development and integrated risk assessment (Aipira et al., 2017; Eriksson et al., 2017; Granderson, 2017). Climate-resilient development is also supported by non-state partnerships, for example, the 'Yumi stap redi long climate change'–the Vanuatu non-governmental organization Climate Change Adaptation Program (Maclellan, 2015). This programme focuses on equitable governance, with particular attention to supporting women's voices in decision-making through allied programmes addressing domestic violence, and rights-based education to reduce social marginalization; alongside institutional reforms for greater transparency, accountability and community participation in decision-making (Davies, 2015; Maclellan, 2015; Sterrett, 2015; Ensor, 2016; UN Women, 2016).

Power imbalances embedded in the political economy of development (Nunn et al., 2014), gender discrimination (Aipira et al., 2017) and the priorities of climate finance (Cabezon et al., 2016) may marginalize the priorities of local communities and influence how local risks are understood, prioritised and managed (Kuruppu and Willie, 2015; Baldacchino, 2017; Sovacool et al., 2017). However, the experience of the low death toll after Cyclone Pam suggests effective use of local knowledge in planning and early warning may support resilience at least in the absence of storm surge flooding (Handmer and Iveson, 2017; Nalau et al., 2017). Nevertheless, the very severe infrastructure damage of Cyclone Pam 2015 highlights the limits of individual Pacific SIDS efforts and the need for global and regional responses to a 1.5°C warmer world (see Chapter 3, Box 3.5, Chapter 4, Box 4.3) (Dilling et al., 2015; Ensor, 2016; Shultz et al., 2016; Rey et al., 2017).

Communities, towns and cities also contribute to low-carbon pathways, sustainable development and fair and equitable climate resilience, often focused on processes of power, learning and contestation as entry points to more localised CRDPs (*medium evidence, high agreement*) (Cross-Chapter Box 13 in this chapter, Box 5.2). In the Scottish Borders Climate Resilient Communities Project (United Kingdom), local flood management is linked with national policies to foster cross-scalar and inclusive governance, with attention to systemic disadvantages, shocks and stressors, capacity building, learning for change and climate narratives to inspire hope and action, all of which are essential for community resilience in a 1.5°C warmer world (Fazey et al., 2018). Narratives and storytelling are vital for realizing place-based 1.5°C futures as they create space for agency, deliberation, co-constructing meaning, imagination and desirable and dignified pathways (Veland et al., 2018). Engagement with possible futures, identity and self-reliance is also documented for Alaska, where warming has already exceeded 1.5°C and indigenous communities invest in renewable energy, greenhouses for food security and new fishing practices to overcome loss of sea ice, flooding and erosion (Chapin et al., 2016; Fazey et al., 2018). The Asian Cities Climate Change Resilience Network facilitates shared learning dialogues, risk-to-resilience workshops, and iterative, consultative planning in flood-prone cities in India; vulnerable communities, municipal governmental agents, entrepreneurs and technical experts negotiate different visions, trade-offs and local politics to identify desirable pathways (Harris et al., 2017).

Transforming our societies and systems to limit global warming to 1.5°C and ensuring equity and well-being for human populations and ecosystems in a 1.5°C warmer world would require ambitious and well-integrated adaptation–mitigation–development pathways that deviate fundamentally from high-carbon, business-as-usual futures (Okereke and Coventry, 2016; Arts, 2017; Gupta and Arts, 2017; Sealey-Huggins, 2017). Identifying and negotiating socially acceptable, inclusive and equitable pathways towards climate-resilient futures is a challenging, yet important, endeavour, fraught with complex moral, practical and political difficulties and inevitable trade-offs (*very high confidence*). The ultimate questions are: what futures do we want (Bai et al., 2016; Tàbara et al., 2017; Klinsky and Winkler, 2018; O'Brien, 2018; Veland et al., 2018), whose resilience matters, for what, where, when and why (Meerow and Newell, 2016), and 'whose vision … is being pursued and along which pathways' (Gillard et al., 2016).

Cross-Chapter Box 13 | Cities and Urban Transformation

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Global Urbanization in a 1.5°C Warmer World

The concentration of economic activity, dense social networks, human resource capacity, investment in infrastructure and buildings, relatively nimble local governments, close connection to surrounding rural and natural environments, and a tradition of innovation provide urban areas with transformational potential (see Chapter 4, Section 4.3.3) (Castán Broto, 2017). In this sense, the urbanization megatrend that will take place over the next three decades, and add approximately 2 billion people to the global urban population (UN, 2014), offers opportunities for efforts to limit warming to 1.5°C.

Cities can also, however, concentrate the risks of flooding, landslides, fire and infectious and parasitic disease that are expected to heighten in a 1.5°C warmer world (Chapter 3). In African and Asian countries where urbanization rates are highest, these risks could expose and amplify pre-existing stresses related to poverty, exclusion, and governance (Gore, 2015; Dodman et al., 2017; Jiang and O'Neill, 2017; Pelling et al., 2018; Solecki et al., 2018). Through its impact on economic development and investment, urbanization often leads to increased consumption and environmental degradation and enhanced vulnerability and risk (Rosenzweig et al., 2018). In the absence of innovation, the combination of urbanization and urban economic development could contribute 226 GtCO2 in emissions by 2050 (Bai et al., 2018). At the same time, some new urban developments are demonstrating combined carbon and Sustainable Development Goals (SDG) benefits (Wiktorowicz et al., 2018), and it is in towns and cities that building renovation rates can be most easily accelerated to support the transition to 1.5°C pathways (Kuramochi et al., 2018), including through voluntary programmes (Van der Heijden, 2018).

Urban transformations and emerging climate-resilient development pathways

The 1.5°C pathways require action in all cities and urban contexts. Recent literature emphasizes the need to deliberate and negotiate how resilience and climate-resilient pathways can be fostered in the context of people's daily lives, including the failings of everyday development such as unemployment, inadequate housing and a growing informal sector and settlements (informality), in order

Cross-Chapter Box 13 (continued)

to acknowledge local priorities and foster transformative learning (Vale, 2014; Shi et al., 2016; Harris et al., 2017; Ziervogel et al., 2017; Fazey et al., 2018; Macintyre et al., 2018). Enhancing deliberate transformative capacities in urban contexts also entails new and relational forms of envisioning agency, equity, resilience, social cohesion and well-being (Section 5.5.3) (Gillard et al., 2016; Ziervogel et al., 2016). Two examples of urban transformation are explored here.

The built environment, spatial planning, infrastructure, energy services, mobility and urban–rural linkages necessary in rapidly growing cities in South Asia and Africa in the next three decades present mitigation, adaptation and development opportunities that are crucial for a 1.5°C world (Newman et al., 2017; Lwasa et al., 2018; Teferi and Newman, 2018). Realizing these opportunities would require the structural challenges of poverty, weak and contested local governance, and low levels of local government investment to be addressed on an unprecedented scale (Wachsmuth et al., 2016; Chu et al., 2017; van Noorloos and Kloosterboer, 2017; Pelling et al., 2018).

Urban governance is critical to ensuring that the necessary urban transitions deliver economic growth and equity (Hughes et al., 2018). The proximity of local governments to citizens and their needs can make them powerful agents of climate action (Melica et al., 2018), but urban governance is enhanced when it involves multiple actors (Ziervogel et al., 2016; Pelling et al., 2018), supportive national governments (Tait and Euston-Brown, 2017), and sub-national climate networks (see Chapter 4, Section 4.4.1). Governance is complicated for the urban population currently living in informality. This population is expected to triple, to three billion, by 2050 (Satterthwaite et al., 2018), placing a significant portion of the world's population beyond the direct reach of formal climate mitigation and adaptation policies (Revi et al., 2014). How to address the co-evolved and structural conditions that lead to urban informality and associated vulnerability to 1.5°C of warming is a central question for this report. Brown and McGranahan (2016) cite evidence that the informal urban 'green economy' that has emerged out of necessity in the absence of formal service provisions is frequently low-carbon and resource-efficient.

Realising the potential for low carbon transitions in informal urban settlements would require an express recognition of the unpaid-for contributions of women in the informal economy, and new partnerships between the state and communities (Ziervogel et al., 2017; Pelling et al., 2018; Satterthwaite et al., 2018). There is no guarantee that these partnerships will evolve or cohere into the type of service delivery and climate governance system that could steer the change on a scale required to limit to warming to 1.5°C (Jaglin, 2014). However, work by transnational networks, such as Shack/Slum Dwellers International, C40, the Global Covenant of Mayors, and the International Council for Local Environmental Initiatives, as well as efforts to combine in-country planning for Nationally Determined Contributions (NDCs) (Andonova et al., 2017; Fuhr et al., 2018) with those taking place to support the New Urban Agenda and National Urban Policies, represent one step towards realizing the potential (Tait and Euston-Brown, 2017). So too do 'old urban agendas', such as slum upgrading and universal water and sanitation provision (McGranahan et al., 2016; Satterthwaite, 2016; Satterthwaite et al., 2018).

Transition Towns (TTs) are a type of urban transformation that have emerged mainly in high-income countries. The grassroots TT movement (origin in the United Kingdom) combines adaptation, mitigation and just transitions, mainly at the level of communities and small towns. It now has more than 1,300 registered local initiatives in more than 40 countries (Grossmann and Creamer, 2017), many of them in the United Kingdom, the United States, and other high-income countries. TTs are described as 'progressive localism' (Cretney et al., 2016), aiming to foster a 'communitarian ecological citizenship' that goes beyond changes in consumption and lifestyle (Kenis, 2016). They aspire to promote equitable communities resilient to the impacts of climate change, peak oil and unstable global markets; re-localization of production and consumption; and transition pathways to a post-carbon future (Feola and Nunes, 2014; Evans and Phelan, 2016; Grossmann and Creamer, 2017).

TT initiatives typically pursue lifestyle-related low-carbon living and economies, food self-sufficiency, energy efficiency through renewables, construction with locally sourced material and cottage industries (Barnes, 2015; Staggenborg and Ogrodnik, 2015; Taylor Aiken, 2016). Social and iterative learning through the collective involves dialogue, deliberation, capacity building, citizen science engagements, technical re-skilling to increase self-reliance, for example canning and preserving food and permaculture, future visioning and emotional training to share difficulties and loss (Feola and Nunes, 2014; Barnes, 2015; Boke, 2015; Taylor Aiken, 2015; Kenis, 2016; Mehmood, 2016; Grossmann and Creamer, 2017).

Important conditions for successful transition groups include flexibility, participatory democracy, care ethics, inclusiveness and consensus-building, assuming bridging or brokering roles, and community alliances and partnerships (Feola and Nunes, 2014; Mehmood, 2016; Taylor Aiken, 2016; Grossmann and Creamer, 2017). Smaller scale rural initiatives allow for more experimentation

Cross-Chapter Box 13 (continued)

(Cretney et al., 2016), while those in urban centres benefit from stronger networks and proximity to power structures (North and Longhurst, 2013; Nicolosi and Feola, 2016). Increasingly, TTs recognize the need to participate in policymaking (Kenis and Mathijs, 2014; Barnes, 2015).

Despite high self-ratings of success, some TT initiatives are too inwardly focused and geographically isolated (Feola and Nunes, 2014), while others have difficulties in engaging marginalized, non-white, non-middle-class community members (Evans and Phelan, 2016; Nicolosi and Feola, 2016; Grossmann and Creamer, 2017). In the United Kingdom, expectations of innovations growing in scale (Taylor Aiken, 2015) and carbon accounting methods required by funding bodies (Taylor Aiken, 2016) undermine local resilience building. Tension between explicit engagements with climate change action and efforts to appeal to more people have resulted in difficult trade-offs and strained member relations (Grossmann and Creamer, 2017) though the contribution to changing an urban culture that prioritizes climate change is sometimes underestimated (Wiktorowicz et al., 2018).

Urban actions that can highlight the 1.5°C agenda include individual actions within homes (Werfel, 2017; Buntaine and Prather, 2018); demonstration zero carbon developments (Wiktorowicz et al., 2018); new partnerships between communities, government and business to build mass transit and electrify transport (Glazebrook and Newman, 2018); city plans to include climate outcomes (Millard-Ball, 2013); and support for transformative change across political, professional and sectoral divides (Bai et al., 2018).

5.6 Conditions for Achieving Sustainable Development, Eradicating Poverty and Reducing Inequalities in 1.5°C Warmer Worlds

This chapter has described the fundamental, urgent and systemic transformations that would be needed to achieve sustainable development, eradicate poverty and reduce inequalities in a 1.5°C warmer world, in various contexts and across scales. In particular, it has highlighted the societal dimensions, putting at the centre people's needs and aspirations in their specific contexts. Here we synthesize some of the most pertinent enabling conditions (see Glossary) to support these profound transformations. These conditions are closely interlinked and connected by the overarching concept of governance, which broadly includes institutional, socio-economic, cultural and technological elements (see Chapter 1, Cross-Chapter Box 4 in Chapter 1).

5.6.1 Finance and Technology Aligned with Local Needs

Significant gaps in green investment constrain transitions to a low-carbon economy aligned with development objectives (Volz et al., 2015; Campiglio, 2016). Hence, unlocking new forms of public, private and public–private financing is essential to support environmental sustainability of the economic system (Croce et al., 2011; Blyth et al., 2015; Falcone et al., 2018) (see Chapter 4, Section 4.4.5). To avoid risks of undesirable trade-offs with the SDGs caused by national budget constraints, improved access to international climate finance is essential for supporting adaptation, mitigation and sustainable development, especially for LDCs and SIDS (*medium evidence, high agreement*) (Shine and Campillo, 2016; Wood, 2017). Care needs to be taken when international donors or partnership arrangements influence project financing structures (Kongsager and Corbera, 2015; Purdon, 2015; Phillips et al., 2017; Ficklin et al., 2018). Conventional climate funding schemes, especially the Clean Development Mechanism (CDM), have shown positive effects on sustainable development but also adverse consequences, for example, on adaptive capacities of rural households and uneven distribution of costs and benefits, often exacerbating inequalities (*robust evidence, high agreement*) (Aggarwal, 2014; Brohé, 2014; He et al., 2014; Schade and Obergassel, 2014; Smits and Middleton, 2014; Wood et al., 2016a; Horstmann and Hein, 2017; Kreibich et al., 2017). Close consideration of recipients' context-specific needs when designing financial support helps to overcome these limitations as it better aligns community needs, national policy objectives and donors' priorities; puts the emphasis on the increase of transparency and predictability of support; and fosters local capacity building (*medium evidence, high agreement*) (Barrett, 2013; Boyle et al., 2013; Shine and Campillo, 2016; Ley, 2017; Sánchez and Izzo, 2017).

The development and transfer of technologies is another enabler for developing countries to contribute to the requirements of the 1.5°C objective while achieving climate resilience and their socio-economic development goals (see Chapter 4, Section 4.4.4). International-level governance would be needed to boost domestic innovation and the deployment of new technologies, such as negative emission technologies, towards the 1.5°C objective (see Chapter 4, Section 4.3.7), but the alignment with local needs depends on close consideration of the specificities of the domestic context in countries at all levels of development (de Coninck and Sagar, 2015; IEA, 2015; Parikh et al., 2018). Technology transfer supporting development in developing countries would require an understanding of local and national actors and institutions (de Coninck and Puig, 2015; de Coninck and Sagar, 2017; Michaelowa et al., 2018), careful attention to the capacities in the entire innovation chain (Khosla et al., 2017; Olawuyi, 2017) and transfer of not only equipment but also knowledge (*medium evidence, high agreement*) (Murphy et al., 2015).

5.6.2 Integration of Institutions

Multilevel governance in climate change has emerged as a key enabler for systemic transformation and effective governance (see Chapter 4, Section 4.4.1). On the one hand, low-carbon and climate-resilient development actions are often well aligned at the lowest scale possible (Suckall et al., 2015; Sánchez and Izzo, 2017), and informal, local institutions are critical in enhancing the adaptive capacity of countries and marginalized communities (Yaro et al., 2015). On the other hand, international and national institutions can provide incentives for projects to harness synergies and avoid trade-offs (Kongsager et al., 2016).

Governance approaches that coordinate and monitor multiscale policy actions and trade-offs across sectoral, local, national, regional and international levels are therefore best suited to implement goals towards 1.5°C warmer conditions and sustainable development (Ayers et al., 2014; Stringer et al., 2014; von Stechow et al., 2016; Gwimbi, 2017; Hayward, 2017; Maor et al., 2017; Roger et al., 2017; Michaelowa et al., 2018). Vertical and horizontal policy integration and coordination is essential to take into account the interplay and trade-offs between sectors and spatial scales (Duguma et al., 2014; Naess et al., 2015; von Stechow et al., 2015; Antwi-Agyei et al., 2017a; Di Gregorio et al., 2017; Runhaar et al., 2018), enable the dialogue between local communities and institutional bodies (Colenbrander et al., 2016), and involve non-state actors such as business, local governments and civil society operating across different scales (*robust evidence, high agreement*) (Hajer et al., 2015; Labriet et al., 2015; Hale, 2016; Pelling et al., 2016; Kalafatis, 2017; Lyon, 2018).

5.6.3 Inclusive Processes

Inclusive governance processes are critical for preparing for a 1.5°C warmer world (Fazey et al., 2018; O'Brien, 2018; Patterson et al., 2018). These processes have been shown to serve the interests of diverse groups of people and enhance empowerment of often excluded stakeholders, notably women and youth (MRFCJ, 2015a; Dumont et al., 2017). They also enhance social- and co-learning which, in turn, facilitates accelerated and adaptive management and the scaling up of capacities for resilience building (Ensor and Harvey, 2015; Reij and Winterbottom, 2015; Tschakert et al., 2016; Binam et al., 2017; Dumont et al., 2017; Fazey et al., 2018; Lyon, 2018; O'Brien, 2018), and provides opportunities to blend indigenous, local and scientific knowledge (*robust evidence, high agreement*) (see Chapter 4, Section 4.3.5.5, Box 4.3, Section 5.3) (Antwi-Agyei et al., 2017a; Coe et al., 2017; Thornton and Comberti, 2017) . Such co-learning has been effective in improving deliberative decision-making processes that incorporate different values and world views (Cundill et al., 2014; C. Butler et al., 2016; Ensor, 2016; Fazey et al., 2016; Gorddard et al., 2016; Aipira et al., 2017; Chung Tian Fook, 2017; Maor et al., 2017), and create space for negotiating diverse interests and preferences (*robust evidence, high agreement*) (O'Brien et al., 2015; Gillard et al., 2016; DeCaro et al., 2017; Harris et al., 2017; Lahn, 2018).

5.6.4 Attention to Issues of Power and Inequality

Societal transformations to limit global warming to 1.5°C and strive for equity and well-being for all are not power neutral (Section 5.5.3). Development preferences are often shaped by powerful interests that determine the direction and pace of change, anticipated benefits and beneficiaries, and acceptable and unacceptable trade-offs (Newell et al., 2014; Fazey et al., 2016; Tschakert et al., 2016; Winkler and Dubash, 2016; Wood et al., 2016b; Karlsson et al., 2017; Quan et al., 2017; Tanner et al., 2017). Each development pathway, including legacies and path dependencies, creates its own set of opportunities and challenges and winners and losers, both within and across countries (Figure 5.5) (*robust evidence, high agreement*) (Mathur et al., 2014; Phillips et al., 2017; Stringer et al., 2017; Wood, 2017; Ficklin et al., 2018; Gajjar et al., 2018).

Addressing the uneven distribution of power is critical to ensure that societal transformation towards a 1.5°C warmer world does not exacerbate poverty and vulnerability or create new injustices but rather encourages equitable transformational change (Patterson et al., 2018). Equitable outcomes are enhanced when they pay attention to just outcomes for those negatively affected by change (Newell et al., 2014; Dilling et al., 2015; Naess et al., 2015; Sovacool et al., 2015; Cervigni and Morris, 2016; Keohane and Victor, 2016) and promote human rights, increase equality and reduce power asymmetries within societies (*robust evidence, high agreement*) (UNRISD, 2016; Robinson and Shine, 2018).

5.6.5 Reconsidering Values

The profound transformations that would be needed to integrate sustainable development and 1.5°C-compatible pathways call for examining the values, ethics, attitudes and behaviours that underpin societies (Hartzell-Nichols, 2017; O'Brien, 2018; Patterson et al., 2018). Infusing values that promote sustainable development (Holden et al., 2017), overcome individual economic interests and go beyond economic growth (Hackmann, 2016), encourage desirable and transformative visions (Tàbara et al., 2018), and care for the less fortunate (Howell and Allen, 2017) is part and parcel of climate-resilient and sustainable development pathways. This entails helping societies and individuals to strive for sufficiency in resource consumption within planetary boundaries alongside sustainable and equitable well-being (O'Neill et al., 2018). Navigating 1.5°C societal transformations, characterized by action from local to global, stresses the core commitment to social justice, solidarity and cooperation, particularly regarding the distribution of responsibilities, rights and mutual obligations between nations (*medium evidence, high agreement*) (Patterson et al., 2018; Robinson and Shine, 2018).

5.7 Synthesis and Research Gaps

The assessment in Chapter 5 illustrates that limiting global warming to 1.5°C above pre-industrial levels is fundamentally connected with achieving sustainable development, poverty eradication and reducing inequalities. It shows that avoided impacts between 1.5°C and 2°C temperature stabilization would make it easier to achieve many aspects of sustainable development, although important risks would remain at 1.5°C (Section 5.2). Synergies between adaptation and mitigation response measures with sustainable development and the SDGs can often be enhanced when attention is paid to well-being and equity while, when unaddressed, poverty and inequalities may be exacerbated (Section 5.3 and 5.4). Climate-resilient development pathways (CRDPs) open up routes towards socially desirable futures that are sustainable and liveable, but concrete evidence reveals complex trade-offs along a continuum of different pathways, highlighting the role of societal values, internal contestations and political dynamics (Section 5.5). The transformations towards sustainable development in a 1.5°C warmer world, in all contexts, involve fundamental societal and systemic changes over time and across scale, and a set of enabling conditions without which the dual goal is difficult if not impossible to achieve (Sections 5.5 and 5.6).

This assessment is supported by growing knowledge on the linkages between a 1.5°C warmer world and different dimensions of sustainable development. However, several gaps in the literature remain:

Limited evidence exists that explicitly examines the real-world implications of a 1.5°C warmer world (and overshoots) as well as avoided impacts between 1.5°C versus 2°C for the SDGs and sustainable development more broadly. Few projections are available for households, livelihoods and communities. And literature on differential localized impacts and their cross-sector interacting and cascading effects with multidimensional patterns of societal vulnerability, poverty and inequalities remains scarce. Hence, caution is needed when global-level conclusions about adaptation and mitigation measures in a 1.5°C warmer world are applied to sustainable development in local, national and regional settings.

Limited literature has systematically evaluated context-specific synergies and trade-offs between and across adaptation and mitigation response measures in 1.5°C-compatible pathways and the SDGs. This hampers the ability to inform decision-making and fair and robust policy packages adapted to different local, regional or national circumstances. More research is required to understand how trade-offs and synergies will intensify or decrease, differentially across geographic regions and time, in a 1.5°C warmer world and as compared to higher temperatures.

Limited availability of interdisciplinary studies also poses a challenge for connecting the socio-economic transformations and the governance aspects of low emissions, climate-resilient transformations. For example, it remains unclear how governance structures enable or hinder different groups of people and countries to negotiate pathway options, values and priorities.

The literature does not demonstrate the existence of 1.5°C-compatible pathways achieving the ‘universal and indivisible’ agenda of the 17 SDGs, and hence does not show whether and how the nature and pace of changes that would be required to meet 1.5°C climate stabilization could be fully synergetic with all the SDGs.

The literature on low emissions and CRDPs in local, regional and national contexts is growing. Yet the lack of standard indicators to monitor such pathways makes it difficult to compare evidence grounded in specific contexts with differential circumstances, and therefore to derive generic lessons on the outcome of decisions on specific indicators. This knowledge gap poses a challenge for connecting local-level visions with global-level trajectories to better understand key conditions for societal and systems transformations that reconcile urgent climate action with well-being for all.

Frequently Asked Questions

FAQ 5.1 | What are the Connections between Sustainable Development and Limiting Global Warming to 1.5°C above Pre-Industrial Levels?

Summary: *Sustainable development seeks to meet the needs of people living today without compromising the needs of future generations, while balancing social, economic and environmental considerations. The 17 UN Sustainable Development Goals (SDGs) include targets for eradicating poverty; ensuring health, energy and food security; reducing inequality; protecting ecosystems; pursuing sustainable cities and economies; and a goal for climate action (SDG 13). Climate change affects the ability to achieve sustainable development goals, and limiting warming to 1.5°C will help meet some sustainable development targets. Pursuing sustainable development will influence emissions, impacts and vulnerabilities. Responses to climate change in the form of adaptation and mitigation will also interact with sustainable development with positive effects, known as synergies, or negative effects, known as trade-offs. Responses to climate change can be planned to maximize synergies and limit trade-offs with sustainable development.*

For more than 25 years, the United Nations (UN) and other international organizations have embraced the concept of sustainable development to promote well-being and meet the needs of today's population without compromising the needs of future generations. This concept spans economic, social and environmental objectives including poverty and hunger alleviation, equitable economic growth, access to resources, and the protection of water, air and ecosystems. Between 1990 and 2015, the UN monitored a set of eight Millennium Development Goals (MDGs). They reported progress in reducing poverty, easing hunger and child mortality, and improving access to clean water and sanitation. But with millions remaining in poor health, living in poverty and facing serious problems associated with climate change, pollution and land-use change, the UN decided that more needed to be done. In 2015, the UN Sustainable Development Goals (SDGs) were endorsed as part of the 2030 Agenda for Sustainable Development. The 17 SDGs (Figure FAQ 5.1) apply to all countries and have a timeline for success by 2030. The SDGs seek to eliminate extreme poverty and hunger; ensure health, education, peace, safe water and clean energy for all; promote inclusive and sustainable consumption, cities, infrastructure and economic growth; reduce inequality including gender inequality; combat climate change and protect oceans and terrestrial ecosystems.

Climate change and sustainable development are fundamentally connected. Previous IPCC reports found that climate change can undermine sustainable development, and that well-designed mitigation and adaptation responses can support poverty alleviation, food security, healthy ecosystems, equality and other dimensions of sustainable development. Limiting global warming to 1.5°C would require mitigation actions and adaptation measures to be taken at all levels. These adaptation and mitigation actions would include reducing emissions and increasing resilience through technology and infrastructure choices, as well as changing behaviour and policy.

These actions can interact with sustainable development objectives in positive ways that strengthen sustainable development, known as synergies. Or they can interact in negative ways, where sustainable development is hindered or reversed, known as trade-offs.

An example of a synergy is sustainable forest management, which can prevent emissions from deforestation and take up carbon to reduce warming at reasonable cost. It can work synergistically with other dimensions of sustainable development by providing food (SDG 2) and clean water (SDG 6) and protecting ecosystems (SDG 15). Other examples of synergies are when climate adaptation measures, such as coastal or agricultural projects, empower women and benefit local incomes, health and ecosystems.

An example of a trade-off can occur if ambitious climate change mitigation compatible with 1.5°C changes land use in ways that have negative impacts on sustainable development. An example could be turning natural forests, agricultural areas, or land under indigenous or local ownership to plantations for bioenergy production. If not managed carefully, such changes could undermine dimensions of sustainable development by threatening food and water security, creating conflict over land rights and causing biodiversity loss. Another trade-off could occur for some countries, assets, workers and infrastructure already in place if a switch is made from fossil fuels to other energy sources without adequate planning for such a transition. Trade-offs can be minimized if effectively managed, as when care is taken to improve bioenergy crop yields to reduce harmful land-use change or where workers are retrained for employment in lower carbon sectors.

(continued on next page)

FAQ 5.1 (continued)

Limiting temperature increase to 1.5°C can make it much easier to achieve the SDGs, but it is also possible that pursuing the SDGs could result in trade-offs with efforts to limit climate change. There are trade-offs when people escaping from poverty and hunger consume more energy or land and thus increase emissions, or if goals for economic growth and industrialization increase fossil fuel consumption and greenhouse gas emissions. Conversely, efforts to reduce poverty and gender inequalities and to enhance food, health and water security can reduce vulnerability to climate change. Other synergies can occur when coastal and ocean ecosystem protection reduces the impacts of climate change on these systems. The sustainable development goal of affordable and clean energy (SDG 7) specifically targets access to renewable energy and energy efficiency, which are important to ambitious mitigation and limiting warming to 1.5°C.

The link between sustainable development and limiting global warming to 1.5°C is recognized by the SDG for climate action (SDG 13), which seeks to combat climate change and its impacts while acknowledging that the United Nations Framework Convention on Climate Change (UNFCCC) is the primary international, intergovernmental forum for negotiating the global response to climate change.

The challenge is to put in place sustainable development policies and actions that reduce deprivation, alleviate poverty and ease ecosystem degradation while also lowering emissions, reducing climate change impacts and facilitating adaptation. It is important to strengthen synergies and minimize trade-offs when planning climate change adaptation and mitigation actions. Unfortunately, not all trade-offs can be avoided or minimized, but careful planning and implementation can build the enabling conditions for long-term sustainable development.

FAQ 5.1, Figure 1 | Climate change action is one of the United Nations Sustainable Development Goals (SDGs) and is connected to sustainable development more broadly. Actions to reduce climate risk can interact with other sustainable development objectives in positive ways (synergies) and negative ways (trade-offs).

Frequently Asked Questions

FAQ 5.2 | What are the Pathways to Achieving Poverty Reduction and Reducing Inequalities while Reaching a 1.5°C World?

***Summary:** There are ways to limit global warming to 1.5°C above pre-industrial levels. Of the pathways that exist, some simultaneously achieve sustainable development. They entail a mix of measures that lower emissions and reduce the impacts of climate change, while contributing to poverty eradication and reducing inequalities. Which pathways are possible and desirable will differ between and within regions and nations. This is due to the fact that development progress to date has been uneven and climate-related risks are unevenly distributed. Flexible governance would be needed to ensure that such pathways are inclusive, fair and equitable to avoid poor and disadvantaged populations becoming worse off. Climate-resilient development pathways (CRDPs) offer possibilities to achieve both equitable and low-carbon futures.*

Issues of equity and fairness have long been central to climate change and sustainable development. Equity, like equality, aims to promote justness and fairness for all. This is not necessarily the same as treating everyone equally, since not everyone comes from the same starting point. Often used interchangeably with fairness and justice, equity implies implementing different actions in different places, all with a view to creating an equal world that is fair for all and where no one is left behind.

The Paris Agreement states that it ‘will be implemented to reflect equity… in the light of different national circumstances’ and calls for ‘rapid reductions’ of greenhouse gases to be achieved ‘on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty’. Similarly, the UN SDGs include targets to reduce poverty and inequalities, and to ensure equitable and affordable access to health, water and energy for all.

Equity and fairness are important for considering pathways that limit warming to 1.5°C in a way that is liveable for every person and species. They recognize the uneven development status between richer and poorer nations, the uneven distribution of climate impacts (including on future generations) and the uneven capacity of different nations and people to respond to climate risks. This is particularly true for those who are highly vulnerable to climate change, such as indigenous communities in the Arctic, people whose livelihoods depend on agriculture or coastal and marine ecosystems, and inhabitants of small island developing states. The poorest people will continue to experience climate change through the loss of income and livelihood opportunities, hunger, adverse health effects and displacement.

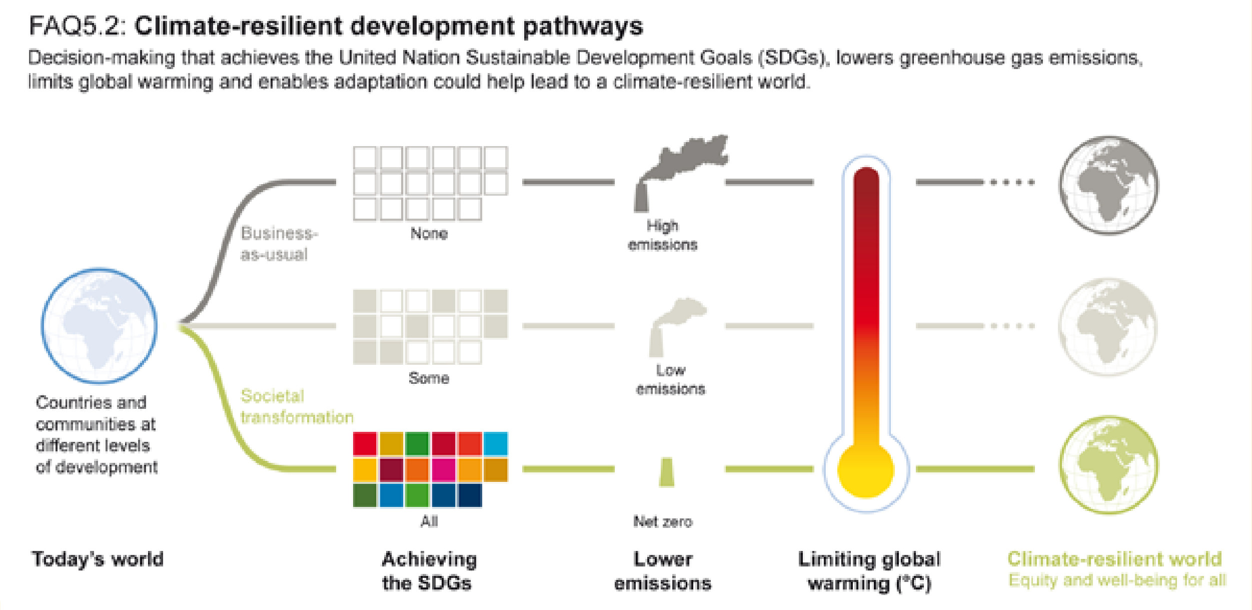
Well-planned adaptation and mitigation measures are essential to avoid exacerbating inequalities or creating new injustices. Pathways that are compatible with limiting warming to 1.5°C and aligned with the SDGs consider mitigation and adaptation options that reduce inequalities in terms of who benefits, who pays the costs and who is affected by possible negative consequences. Attention to equity ensures that disadvantaged people can secure their livelihoods and live in dignity, and that those who experience mitigation or adaptation costs have financial and technical support to enable fair transitions.

CRDPs describe trajectories that pursue the dual goal of limiting warming to 1.5°C while strengthening sustainable development. This includes eradicating poverty as well as reducing vulnerabilities and inequalities for regions, countries, communities, businesses and cities. These trajectories entail a mix of adaptation and mitigation measures consistent with profound societal and systems transformations. The goals are to meet the short-term SDGs, achieve longer-term sustainable development, reduce emissions towards net zero around the middle of the century, build resilience and enhance human capacities to adapt, all while paying close attention to equity and well-being for all.

The characteristics of CRDPs will differ across communities and nations, and will be based on deliberations with a diverse range of people, including those most affected by climate change and by possible routes towards transformation. For this reason, there are no standard methods for designing CRDPs or for monitoring their progress towards climate-resilient futures. However, examples from around the world demonstrate that flexible and inclusive governance structures and broad participation often help support iterative decision-making, continuous learning and experimentation. Such inclusive processes can also help to overcome weak institutional arrangements and power structures that may further exacerbate inequalities.

(continued on next page)

FAQ 5.2 (continued)



FAQ 5.2, Figure 1 | Climate-resilient development pathways (CRDPs) describe trajectories that pursue the dual goals of limiting warming to 1.5°C while strengthening sustainable development. Decision-making that achieves the SDGs, lowers greenhouse gas emissions and limits global warming could help lead to a climate-resilient world, within the context of enhancing adaptation.

Ambitious actions already underway around the world can offer insight into CRDPs for limiting warming to 1.5°C. For example, some countries have adopted clean energy and sustainable transport while creating environmentally friendly jobs and supporting social welfare programmes to reduce domestic poverty. Other examples teach us about different ways to promote development through practices inspired by community values. For instance, *Buen Vivir*, a Latin American concept based on indigenous ideas of communities living in harmony with nature, is aligned with peace; diversity; solidarity; rights to education, health, and safe food, water, and energy; and well-being and justice for all. The Transition Movement, with origins in Europe, promotes equitable and resilient communities through low-carbon living, food self-sufficiency and citizen science. Such examples indicate that pathways that reduce poverty and inequalities while limiting warming to 1.5°C are possible and that they can provide guidance on pathways towards socially desirable, equitable and low-carbon futures.

Table 5.2 | Mitigation – SDG table

Social-Demand

		1 NO POVERTY				
		Interaction	Score	Evidence	Agreement	Confidence
Industry	**Accelerating Energy Efficiency Improvement**	**Reduces Poverty**				
		↑	[+2]	🕮	☺	★
		% of people living below poverty line declines from 49% to 18% in South African context.				
		Altieri et al., 2016				
	Low-carbon Fuel Switch		[0]			
		No direct interaction				
	Decarbonization/CCS/CCU		[0]			
		No direct interaction				

		2 ZERO HUNGER				
		Interaction	Score	Evidence	Agreement	Confidence
Industry	**Accelerating Energy Efficiency Improvement**		[0]			
		No direct interaction				
	Low-carbon Fuel Switch		[0]			
		No direct interaction				
	Decarbonization/CCS/CCU		[0]			
		No direct interaction				

		3 GOOD HEALTH AND WELL-BEING				
		Interaction	Score	Evidence	Agreement	Confidence
Industry	**Accelerating Energy Efficiency Improvement**	**Air, Water Pollution Reduction and Better Health (3.9)**				
		↑	[+2]	🕮🕮	☺☺	★★
		People living in deprived communities feel positive and predict considerable financial savings. Efficiency changes in the industrial sector that lead to reduced energy demand can lead to reduced requirements on energy supply. As water is used to convert energy into useful forms, the reduction in industrial demand is anticipated to reduce water consumption and wastewater, resulting in more clean water for other sectors and the environment. In extractive industries there are trade-off unless strategically managed. Behavioural changes in the industrial sector that lead to reduced energy demand can lead to reduced requirements on energy supply. As water is used to convert energy into useful forms, the reduction in industrial demand is anticipated to reduce water consumption and wastewater, resulting in more clean water for other sectors and the environment.				
		Vassolo and Döll, 2005; Xi et al., 2013; Nguyen et al., 2014; Holland et al., 2015; Zhang et al., 2015; Fricko et al., 2016				
	Low-carbon Fuel Switch	**Water and Air Pollution Reduction and Better Health (3.9)**				
		↑	[+2]	🕮🕮	☺☺	★★
		Industries are becoming suppliers of energy, waste heat, water and roof tops for solar energy generation, and hence helping to improve air and water quality.				
		Vassolo and Döll, 2005; Nguyen et al., 2014; Holland et al., 2015; Karner et al., 2015; Fricko et al., 2016				
	Decarbonization/CCS/CCU	**Disease and Mortality (3.1/3.2/3.3/3.4)**				
		↓	[-1]	🕮🕮	☺☺☺	★★★
		There is a risk of CO_2 leakage both from geological formations as well as from the transportation infrastructure from source to sequestration locations.				
		Wang and Jaffe, 2004; Hertwich et al., 2008; Apps et al., 2010; Veltman et al., 2010; Koornneef et al., 2011; Singh et al., 2011; Siirila et al., 2012; Atchley et al., 2013; Corsten et al., 2013; IPCC, 2014				

		4 QUALITY EDUCATION				
		Interaction	Score	Evidence	Agreement	Confidence
Industry	**Accelerating Energy Efficiency Improvement**	**Technical Education, Vocational Training, Education for Sustainability (4.3/4.4/4.5/4.7)**				
		↑	[+1]	🕮🕮	☺☺	★★
		Awareness, knowledge, technical and managerial capability are closely linked, energy audit, information for trade unions, product/appliance labeling help in sustainability education.				
		Apeaning and Thollander, 2013; Fernando and Evans, 2015; Roy et al., 2018				
	Low-carbon Fuel Switch	**Technical Education, Vocational Training, Education for Sustainability (4.b/4.7)**				
		↑	[+1]	🕮🕮	☺☺	★★
		New technology deployment creates demand for awareness and knowledge with technical and managerial capability; otherwise acts as barrier for rapid expansion.				
		Apeaning and Thollander, 2013; Fernando and Evans, 2015; Roy et al., 2018				
	Decarbonization/CCS/CCU		[0]			
		No direct interaction				

Social-Demand (continued)

1 NO POVERTY

		Interaction	Score	Evidence	Agreement	Confidence
Buildings	Behavioural Response	**Poverty Reduction via Financial Savings (1.1)**				
		↑	[+2]	📖	☺	★
		People living in deprived communities feel positive and predict considerable financial savings.				
		Scott et al., 2014				
	Accelerating Energy Efficiency Improvement	**Poverty and Development (1.1/1.2/1.3/1.4)**				
		↑ / ↓	[+2,-1]	📖📖📖	☺☺☺	★★★
		Energy efficiency interventions lead to cost savings which are realized due to reduced energy bills that further lead to poverty reduction. Participants with low incomes experience greater benefits. 'Energy efficiency and biomass strategies benefitted the poor more than wind and solar, whose benefits are captured by industry. Carbon mitigation can increase or decrease inequalities. The distributional costs of new energy policies (e.g., supporting renewables and energy efficiency) are dependent on instrument design. If costs fall disproportionately on the poor, then this could impair progress towards universal energy access and, by extension, counteract the fight to eliminate poverty. (Quote from McCollum et al., 2018).				
		Casillas and Kammen, 2012; Hirth and Ueckerdt, 2013; Jakob and Steckel, 2014; Maidment et al., 2014; Scott et al., 2014; Fay et al., 2015; Cameron et al., 2016; Hallegatte et al., 2016b; Berrueta et al., 2017; McCollum et al., 2018				
	Improved Access and Fuel Switch to Modern Low-carbon Energy	**Poverty and Development (1.1/1.2/1.3/1.4)**				
		↑	[+2]	📖📖📖	☺☺☺	★★★★
		Access to modern energy forms (electricity, clean stoves, high-quality lighting) is fundamental to human development since the energy services made possible by them help alleviate chronic and persistent poverty. Strength of the impact varies in the literature. (Quote from McCollum et al., 2018)				
		Kirubi et al., 2009; Casillas and Kammen, 2010; Cook, 2011; Pachauri et al., 2012; Pode, 2013; Pueyo et al., 2013; Zulu and Richardson, 2013; Bonan et al., 2014; Rao et al., 2014; Burlig and Preonas, 2016; McCollum et al., 2018				

2 ZERO HUNGER

		Interaction	Score	Evidence	Agreement	Confidence
Buildings	Behavioural Response		[0]			
		No direct interaction				
	Accelerating Energy Efficiency Improvement	**Food Security (2.1)**				
		↑	[+2]	📖	☺	★
		Using the improved stoves supports local food security and has significantly impacted on food security. By making fuel last longer, the improved stoves help improve food security and also provide a better buffer against fuel shortages induced by climate change-related events such as droughts, floods or hurricanes (Berrueta et al. 2017).				
		Berrueta et al., 2017				
	Improved Access and Fuel Switch to Modern Low-carbon Energy	**Food Security and Agricultural Productivity (2.1/2.4)**				
		~ / ↓	[0,-1]	📖📖	☺☺☺	★★
		Modern energy access is critical to enhance agricultural yields/productivity, decrease post-harvest losses and mechanize agri-processing – all of which can aid food security. However, large-scale bioenergy and food production may compete for scarce land and other inputs (e.g., water, fertilizers), depending on how and where biomass supplies are grown and the indirect land use change impacts that result. If not implemented thoughtfully, this could lead to higher food prices globally, and thus reduce access to affordable food for the poor. Enhanced agricultural productivities can ameliorate the situation by allowing as much bioenergy to be produced on as little land as possible.				
		Cabraal et al., 2005; Tilman et al., 2009; van Vuuren et al., 2009; Asaduzzaman et al., 2010; Finco and Doppler, 2010; Msangi et al., 2010; Smith et al., 2013, 2014; Lotze-Campen et al., 2014; Hasegawa et al., 2015; Sola et al., 2016; McCollum et al., 2018				

3 GOOD HEALTH AND WELL-BEING

		Interaction	Score	Evidence	Agreement	Confidence
Buildings	Behavioural Response	**Improved Warmth and Comforts**				
		↑	[+2]	📖📖📖	☺☺☺	★★★
		Home occupants reported warmth as the most important aspect of comfort which was largely temperature-related and low in energy costs. Residents living in deprived areas expect improved warmth in their properties after energy efficiency measures are employed.				
		Huebner et al., 2013; Yue et al., 2013; Scott et al., 2014; Zhao et al., 2017				
	Accelerating Energy Efficiency Improvement	**Healthy Lives and Well-being for All at All Ages (3.2/3.9)**				
		↑	[+2]	📖📖📖📖	☺☺☺☺	★★★★
		Efficient stoves improve health, especially for indigenous and poor rural communities. Household energy efficiency has positive health impacts on children's respiratory health, weight and susceptibility to illness, and the mental health of adults. Household energy efficiency improves winter warmth, lowers relative humidity with benefits for cardiovascular and respiratory health. Further improved indoor air quality by thermal regulation and occupant comfort are realised. However, in one instance, negative health impacts (asthma) of increased household energy efficiency were also noted when housing upgrades took place without changes in occupant behaviours. Home occupants reported warmth as the most important aspect of comfort which was largely temperature-related and low in energy costs. Residents living in the deprived areas expect improved warmth in their properties after energy efficiency measures are employed.				
		Djamila et al., 2013; Huebner et al., 2013; Yue et al., 2013; Bhojvaid et al., 2014; Derbez et al., 2014; Maidment et al., 2014; Scott et al., 2014; Cameron et al., 2015; Liddell and Guiney, 2015; Sharpe et al., 2015; Wells et al., 2015; Willand et al., 2015; Berrueta et al., 2017; Zhao et al., 2017				
	Improved Access and Fuel Switch to Modern Low-carbon Energy	**Disease and Mortality (3.1/3.2/3.3/3.4)**				
		↑	[+2]	📖📖📖	☺☺☺	★★★★
		Access to modern energy services can contribute to fewer injuries and diseases related to traditional solid fuel collection and burning, as well as utilization of kerosene lanterns. Access to modern energy services can facilitate improved health care provision, medicine and vaccine storage, utilization of powered medical equipment, and dissemination of health-related information and education. Such services can also enable thermal comfort in homes and contribute to food preservation and safety. (Quote from McCollum et al., 2018)				
		Lam et al., 2012; Lim et al., 2012; Smith et al., 2013; Aranda et al., 2014; McCollum et al., 2018				

4 QUALITY EDUCATION

		Interaction	Score	Evidence	Agreement	Confidence
Buildings	Behavioural Response		[0]			
		No direct interaction				
	Accelerating Energy Efficiency Improvement	**Equal Access to Educational Institutions (4.1/4.2/4.3/4.5)**				
		↑	[+2]	📖	☺	★
		Household energy efficiency measures reduce school absences for children with asthma due to indoor pollution.				
		Maidment et al., 2014				
	Improved Access and Fuel Switch to Modern Low-carbon Energy	**Equal Access to Educational Institutions (4.1/4.2/4.3/4.5)**				
		↑	[+1]	📖	☺☺☺	★★
		Access to modern energy is necessary for schools to have quality lighting and thermal comfort, as well as modern information and communication technologies. Access to modern lighting and energy allows for studying after sundown and frees constraints on time management that allow for higher school enrolment rates and better literacy outcomes. (Quote from McCollum et al., 2018)				
		Lipscomb et al., 2013; van de Walle et al., 2013; McCollum et al., 2018				

Social-Demand (continued)

		Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence
Transport	**Behavioural Response**	**Equal Right to Economic Resources Access Basic Services (1.1/1.4/1.a/1.b)**					**Ensure Access to Safe Nutritious Food (2.1/2.2)**					**Road Traffic Accidents (3.4/3.6)**					**Equal Safe Access to Educational Institutions (4.1/4.2/4.3/4.5)**				
		↑/↓	[+2,-1]	🕮🕮🕮	☺☺☺	★★★	↑	[+2]	🕮	☺	★★★	↑/↓	[+2,-1]	🕮🕮🕮	☺☺☺	★★	↑	[+1]	🕮	☺☺☺	★★
		The costs of daily mobility can have important economic stress impacts, not only impacting carless families with low-mobility, but in countries with high levels of car dependence, the costs of motoring can be burdensome, raising questions of affordability for households with limited economic resources. During economic crisis, public transport authorities may react by reducing levels of service and increasing fares, likely exacerbating the situation for low-income households.					Low-income community residents (non-white) who lack local access to affordable, quality sources of nutrition have to travel outside their immediate neighbourhood to find better sources of food to feed themselves and their families. Lack of locally available healthy food often exacerbates the rates of obesity in many of these communities since it is often difficult or expensive to travel long distances on a regular basis to shop for food.					Active travel modes, such as walking and cycling, represent strategies not only for boosting energy efficiency but also, potentially, for improving health and well-being (e.g., lowering rates of diabetes, obesity, heart disease, dementia and some cancers). However, a risk associated with these measures is that they could increase rates of road traffic accidents, if the existing infrastructure is unsatisfactory. Overall health effects will depend on the severity of the injuries sustained from these potential accidents relative to the health benefits accruing from increased exercise (McCollum et al., 2018).					Poor road quality affects school travel safety, so collaborative efforts need to address safety issues from a dual perspective, first by working to change the existing infrastructure and use of roads to better address the traffic problems that children currently face walking to school, and then to better situate schools and control the roadways and land uses around them in the future.				
		Dodson et al., 2004; Cascajo et al., 2017					Clifton, 2004; Hillier, 2011; Krukowski et al., 2013; LeDoux and Vojnovic, 2013; Ghosh-Dastidar et al., 2014; Zenk et al., 2015; Lowery et al., 2016					Woodcock et al., 2009; Creutzig et al., 2012; Haines and Dora, 2012; Saunders et al., 2013; Shaw et al., 2014, 2017; Chakrabarti and Shin, 2017; Hwang et al., 2017; McCollum et al., 2018					Yu, 2015				
	Accelerating Energy Efficiency Improvement	**End Poverty in all its Forms Everywhere (1.1/1.4/1.a/1.b)**										**Reduce Illnesses from Hazardous Air, Water and Soil Pollution (3.9)**									
		↑/↓	[+2,-1]	🕮🕮🕮	☺☺☺	★★★		[0]				↑	[+2]	🕮🕮🕮	☺☺☺	★★★		[0]			
		Decarbonization of public buses in Sweden is receiving attention more than efficiency improvement. With more electrification, electricity prices go up and affordability can worsen for the poor unless redistributive policies are in place.					No direct interaction					Locally relevant policies targeting traffic reductions and ambitious diffusion of electric vehicles results in measured changes in non-climatic exposure for population, including ambient air pollution, physical activity and noise. The transition to low-carbon equitable and sustainable transport can be fostered by numerous short- and medium-term strategies that would benefit energy security, health, productivity and sustainability. An evidence-based approach that takes into account GHG emissions, ambient air pollutants, economic factors (affordability, cost optimization), social factors (poverty alleviations, public health benefits) and political acceptability is needed to tackle these challenges.					No direct interaction				
		Xylia and Silveira, 2017										Figueroa et al., 2014; Schucht et al., 2015; Klausbruckner et al., 2016; Peng et al., 2017									
	Improved Access and Fuel Switch to Modern Low-carbon Energy	**End Poverty in all its Forms Everywhere (1.1/1.4/1.a/1.b)**					**Ensure Access to Food Security (2.1/2.3/2.a/2.b/2.c)**					**Reduce Illnesses from Hazardous Air Pollution (3.9)**									
		↑/↓	[+2,-1]	🕮🕮🕮	☺☺☺	★★★	~	[0]	🕮	☺	★	↑	[+2]	🕮	☺	★		[0]			
		Increasingly volatile global oil prices have raised concerns for the vulnerability of households to fuel price increases. Pricing measures as a key component of sustainable transport policy need to consider equity. Pro-poor mitigation policies are needed to reduce climate impact and reduce threat; for example, investing more and better in infrastructure by leveraging private resources and using designs that account for future climate change and the related uncertainty. Communities in poor areas cope with and adapt to multiple-stressors including climate change. Coping strategies provide short-term relief but in the long-term may negatively affect development goals. And responses generate a trade-off between adaptation, mitigation and development. For African cities with slums, due to high commuting costs, many walk to work places which limit access. In Latin America triple informality leading to low productivity and living standards.					21 projects aiming at resilient transport infrastructure development to improve access (e.g., C40 Cities Clean Bus Declaration, UITP Declaration on Climate Leadership, Cycling Delivers on the Global Goals, Global Sidewalk Challenge) do not substantially contribute to realizing the (indirect) transport targets with mostly a rural focus: agricultural productivity (SDG 2) and access to safe drinking water (SDG 6).					Projects aiming at resilient transport infrastructure development (e.g., C40 Cities Clean Bus Declaration, UITP Declaration on Climate Leadership, Cycling Delivers on the Global Goals, Global Sidewalk Challenge) are targeted at reducing air pollution; electric vehicles using electricity from renewables or low carbon sources combined with e-mobility options such as trolley buses, metros, trams and electro buses, as well as promoting walking and biking, especially for short distances, need consideration.					No direct interaction				
		Dodson and Sipe, 2008; Suckall et al., 2014; Hallegatte et al., 2016a; Klausbruckner et al., 2016; CAF, 2017; Lall et al., 2017					SLoCaT, 2017					Ajanovic, 2015; SLoCaT, 2017									

		1 NO POVERTY					2 ZERO HUNGER					3 GOOD HEALTH AND WELL-BEING					4 QUALITY EDUCATION				
		Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence
Replacing Coal	**Non-biomass Renewables - solar, wind, hydro**	**Poverty and Development (1.1/1.2/1.3/1.4)**										**Air Pollution (3.9)**					**Vocational Trainig, Education for Sustainability (4.b/4.7)**				
		↑	[+2]	📖📖📖	☺☺☺	★★★		[0]				↑	[+2]	📖📖📖	☺☺☺	★★★★	↑	[+1]	📖	☺	★
		Deployment of renewable energy and improvements in energy efficiency globally will aid climate change mitigation efforts, and this, in turn, can help to reduce the exposure of the world's poor to climate-related extreme events, negative health impacts and other environmental shocks (McCollum et al., 2018).					No direct interaction					Promoting most types of renewables and boosting efficiency greatly aids the achievement of targets to reduce local air pollution and improve air quality; however, the order of magnitude of the effects, both in terms of avoided emissions and monetary valuation, varies significantly between different parts of the world. Benefits would especially accrue to those living in the dense urban centres of rapidly developing countries. Utilization of biomass and biofuels might not lead to any air pollution benefits, however, depending on the control measures applied. In addition, household air quality can be significantly improved through lowered particulate emissions from access to modern energy services (McCollum et al., 2018).					Decentralized renewable energy systems (e.g., home- or village-scale solar power) can support education and vocational training.				
		Riahi et al., 2012; IPCC, 2014; Hallegatte et al., 2016b; McCollum et al., 2018										Haines et al., 2007; Nemet et al., 2010; Kaygusuz, 2011; Riahi et al., 2012; van Vliet et al., 2012; Anenberg et al., 2013; Rafaj et al., 2013; Rao et al., 2013, 2016; West et al., 2013; Chaturvedi and Shukla, 2014; Rose et al., 2014; Smith and Sagar, 2014; IEA, 2016; McCollum et al., 2018					Anderson et al., 2017				
	Increased Use of Biomass	**Poverty and Development (1.1/1.2/1.3/1.4)**					**Farm Employment and Incomes (2.3)**					**Disease and Mortality (3.1/3.2/3.3/3.4), Air Pollution (3.9)**									
		↑/↓	[+2,-2]	📖📖	☺☺	★	↑/↓	[+2,-2]	📖📖📖	☺☺☺	★★★	↑	[+2]	📖📖📖	☺☺☺	★★★		[0]			
		Large-scale bioenergy production could lead to the creation of agricultural jobs, as well as higher farm wages and more diversified income streams for farmers. Modern energy access can make marginal lands more cultivable, thus potentially generating on-farm jobs and incomes; on the other hand, greater farm mechanization can also displace labour. However, large-scale bioenergy production could alter the structure of global agricultural markets in a way that is, potentially, unfavourable to small-scale food producers. See SDG2 (McCollum et al., 2018).					Large-scale bioenergy production could lead to the creation of agricultural jobs, as well as higher farm wages and more diversified income streams for farmers. Modern energy access can make marginal lands more cultivable, thus potentially generating on-farm jobs and incomes; on the other hand, greater farm mechanization can also displace labour. However, large-scale bioenergy production could alter the structure of global agricultural markets in a way that is, potentially, unfavourable to small-scale food producers. The distributional effects of bioenergy production are underexplored in the literature (McCollum et al., 2018).					Replacing coal by biomass can reduce adverse impacts of upstream supply-chain activities, in particular local air and water pollution, and prevent coal mining accidents. Improvements to local air pollution in power generation compared to coal-fired power plants depend on the technology and fuel of biomass power plants, but could be significant when switching from outdated coal combustion technologies to state-of-the-art biogas power generation.					No direct interaction				
		Balishter and Singh, 1991; Gohin, 2008; de Moraes et al., 2010; van der Horst and Vermeylen, 2011; Corbera and Pascual, 2012; Rud, 2012; Creutzig et al., 2013; Davis et al., 2013; Satolo and Bacchi, 2013; Muys et al., 2014; Ertem et al., 2017; McCollum et al., 2018					Balishter and Singh, 1991; Gohin, 2008; de Moraes et al., 2010; van der Horst and Vermeylen, 2011; Corbera and Pascual, 2012; Rud, 2012; Creutzig et al., 2013; Davis et al., 2013; Satolo and Bacchi, 2013; Muys et al., 2014; Ertem et al., 2017; McCollum et al., 2018					IPCC, 2005, 2014; Miller et al., 2007; Hertwich et al., 2008; de Best-Waldhober et al., 2009; Shackley et al., 2009; Wallquist et al., 2009, 2010; Wong-Parodi and Ray, 2009; Chan and Griffiths, 2010; Veltman et al., 2010; Epstein et al., 2011; Koornneef et al., 2011; Reiner and Nuttall, 2011; Singh et al., 2011; Ashworth et al., 2012; Burgherr et al., 2012; Chen et al., 2012; Asfaw et al., 2013; Corsten et al., 2013; Einsiedel et al., 2013									

Social-Supply (continued)

1 NO POVERTY

		Interaction	Score	Evidence	Agreement	Confidence
Replacing Coal	**Nuclear/Advanced Nuclear**	No direct interaction	[0]			
	CCS: Bioenergy	**Poverty and Development (1.1/1.2/1.3/1.4)** ↑/↓	[+2,-2]	📖📖	☺☺	★
		See effects of increased bioenergy use.				
Advanced Coal	**CCS: Fossil**	No direct interaction	[0]			

2 ZERO HUNGER

		Interaction	Score	Evidence	Agreement	Confidence
Replacing Coal	**Nuclear/Advanced Nuclear**	No direct interaction	[0]			
	CCS: Bioenergy	**Farm Employment and Incomes (2.3)** ↑/↓	[+1,-2]	📖📖📖	☺☺☺	★★★
		See increased use of biomass effects. In addition, the concern that more bioenergy (for BECCS) necessarily leads to unacceptably high food prices is not founded on large agreement in the literature. AR5, for example, finds a significantly lower effect of large-scale bioenergy deployment on food prices by mid-century than the effect of climate change on crop yields. Also, Muratori et al. (2016) show that BECCS reduces the upward pressure on food crop prices by lowering carbon prices and lowering the total biomass demand in climate change mitigation scenarios. On the other hand, competition for land use may increase food prices and thereby increase risk of hunger. Use of agricultural residue for bioenergy can reduce soil carbon, thereby threatening agricultural productivity. See literature on increased biomass use: IPCC, 2014; Muratori et al., 2016; Dooley and Kartha, 2018				
Advanced Coal	**CCS: Fossil**	No direct interaction	[0]			

3 GOOD HEALTH AND WELL-BEING

		Interaction	Score	Evidence	Agreement	Confidence
Replacing Coal	**Nuclear/Advanced Nuclear**	**Disease and Mortality (3.1/3.2/3.3/3.4)** ↓	[-1]	📖📖📖	☺☺☺	★★★
		In spite of the industry's overall safety track record, a non-negligible risk for accidents in nuclear power plants and waste treatment facilities remains. The long-term storage of nuclear waste is a politically fraught subject, with no large-scale long-term storage operational worldwide. Negative impacts from upstream uranium mining and milling are comparable to those of coal, hence replacing fossil fuel combustion by nuclear power would be neutral in that aspect. Increased occurrence of childhood leukaemia in populations living within 5 km of nuclear power plants was identified by some studies, even though a direct causal relation to ionizing radiation could not be established and other studies could not confirm any correlation (*low evidence/agreement* on this issue). Abdelouas, 2006; Cardis et al., 2006; Kaatsch et al., 2008; Al-Zoughool and Krewski, 2009; Heinävaara et al., 2010; Schnelzer et al., 2010; Brugge and Buchner, 2011; Møller and Mousseau, 2011; Møller et al., 2011, 2012; Moomaw et al., 2011; UNSCEAR, 2011; Sermage-Faure et al., 2012; Ten Hoeve and Jacobson, 2012; Tirmarche et al., 2012; Hiyama et al., 2013; Mousseau and Møller, 2013; Smith et al., 2013; WHO, 2013; IPCC, 2014; von Stechow et al., 2016				
	CCS: Bioenergy	**Disease and Mortality (3.1/3.2/3.3/3.4)** ↑/↓	[+2,-1]	📖📖	☺☺☺	★★★
		See positive impacts of increased biomass use. At the same time, there is a non-negligible risk of CO_2 leakage both from geological formations as well as from the transportation infrastructure from source to sequestration locations. Wang and Jaffe, 2004; Hertwich et al., 2008; Apps et al., 2010; Veltman et al., 2010; Koornneef et al., 2011; Singh et al., 2011; Siirila et al., 2012; Atchley et al., 2013; Corsten et al., 2013; IPCC, 2014				
Advanced Coal	**CCS: Fossil**	**Disease and Mortality (3.1/3.2/3.3/3.4)** ↓	[-1]	📖📖	☺☺☺	★★★
		The use of fossil CCS implies continued adverse impacts of upstream supply-chain activities in the coal sector, and because of lower efficiency of CCS coal power plants, upstream impacts and local air pollution are likely to be exacerbated. Furthermore, there is a non-negligible risk of CO_2 leakage from geological storage or the CO_2 transport infrastructure from source to sequestration location. Wang and Jaffe, 2004; Hertwich et al., 2008; Apps et al., 2010; Veltman et al., 2010; Koornneef et al., 2011; Singh et al., 2011; Siirila et al., 2012; Atchley et al., 2013; Corsten et al., 2013; IPCC, 2014				

4 QUALITY EDUCATION

		Interaction	Score	Evidence	Agreement	Confidence
Replacing Coal	**Nuclear/Advanced Nuclear**	No direct interaction	[0]			
	CCS: Bioenergy	No direct interaction	[0]			
Advanced Coal	**CCS: Fossil**	No direct interaction	[0]			

		1 NO POVERTY Interaction | Score | Evidence | Agreement | Confidence	2 ZERO HUNGER Interaction | Score | Evidence | Agreement | Confidence	3 GOOD HEALTH AND WELL-BEING Interaction | Score | Evidence | Agreement | Confidence	4 QUALITY EDUCATION Interaction | Score | Evidence | Agreement | Confidence
Agriculture and Livestock	**Behavioural Response: Sustainable Healthy Diets and Reduced Food Waste**	**Poverty and Development (1.1/1.2/1.3/1.4)** ~ / ↓ | [0,-1] | 🕮🕮 | ☺☺☺ | ★★ Cutting livestock consumption can increase food security for some if land grows food not feed, but can also undermine livelihoods and culture where livestock has long been the best use of land, such as in parts of Sub-Saharan Africa. IPCC, 2014	**Food Security, Promoting Sustainable Agriculture (2.1/2.4/2a)** ↑ | [+2] | 🕮🕮🕮🕮 | ☺☺☺☺ | ★★★★ Curbing consumer waste of major food crops (i.e., wheat, rice and vegetables) and meats (i.e., beef, pork and poultry) in China, USA and India alone could feed ~413 million people per year (West et al., 2014). One billion extra people could be fed if food crop losses could be halved (Kummu et al., 2012). Reducing waste, especially from meat and dairy, could play a role in delivering food security and reduce the need for sustainable intensification (Smith, 2013). Dietary change toward global healthy diets could improve nutritional health, food security and reduce emissions. Garnett, 2011; Beddington et al., 2012; Kummu et al., 2012; Smith, 2013; Bajželj et al., 2014; Tilman and Clark, 2014; West et al., 2014; Lamb et al., 2016	**Tobacco Control (3.a/3.a.1)** ↑ | [+1] | 🕮 | ☺ | ★ Consume fewer foods with low nutritional value, e.g., alcohol (Garnett, 2011). Demand-side measures aimed at reducing the proportion of livestock products in human diets, where the consumption of animal products is higher than recommended, are associated with multiple health benefits, especially in industrialized countries (Bustamante et al., 2014). Garnett, 2011; Bustamante et al., 2014	[0] No direct interaction
	Land-based GHG Reduction and Soil Carbon Sequestration	**Poverty and Development (1.1/1.2/1.3/1.4)** ↑ | [+2] | 🕮🕮🕮🕮 | ☺☺☺☺ | ★★★★ Many CSA interventions aim to improve rural livelihoods, thereby contributing to poverty alleviation. Agroforestry or integrated crop–livestock–biogas systems can substitute costly, external inputs, saving on household expenditures – or even lead to the selling of some of the products, providing the farmer with extra income, leading to increased adaptive capacity (Bogdanski, 2012). Branca et al., 2011; Bogdanski, 2012; Scherr et al., 2012; Vermeulen et al., 2012; Campbell et al., 2014; Lipper et al., 2014; Mbow et al., 2014; Steenwerth et al., 2014; Hammond et al., 2017	**Food Security, Promoting Sustainable Agriculture (2.1/2.4/2a)** ↑ | [+2] | 🕮🕮🕮🕮 | ☺☺☺☺ | ★★★★ Safe application of biotechnology, both conventional and modern methods, can help to improve agricultural productivity, improving crop adaptability and thereby catering to food security. Reducing tillage, eliminating fallow and keeping the soil covered with residue, cover crops or perennial vegetation helps prevent soil erosion and has the potential to increase soil organic matter. Efficient land-management techniques can help in increasing crop yields, and so food security issues can be addressed. Yield projections are actually higher for developing countries than for developed countries, reflecting the fact that they have more 'catch-up' potential (Evenson, 1999). Action is needed throughout the food system on moderating demand, reducing waste, improving governance and producing more food (Godfray and Garnett, 2014). Improving cropland management is the key to increase crop productivity without further degrading soil and water resources (Branca et al., 2011). CSA practices increase productivity and prioritize food security. Evenson, 1999; West and Post, 2002; Johnson et al., 2007; Branca et al., 2011; McCarthy et al., 2011; Behnassi et al., 2014; Campbell et al., 2014; Godfray and Garnett, 2014; Harvey et al., 2014; Lipper et al., 2014	**Ensure Healthy Lives (3.c)** ↑ / ↓ | [+2,-2] | 🕮🕮 | ☺☺ | ★★ Growing crops such as cassava, sorghum and millet, even in harsh conditions, is important to the diets of very poor people. Policy scenarios show that reduced research support, delayed industrialization, delayed biotechnology and climate change will delay progress in reducing childhood malnutrition. The global effects are small, but local effects for some countries, e.g., Bangladesh and Nigeria, are significant (Evenson, 1999). Evenson, 1999; Godfray and Garnett, 2014	**Ensure Inclusive and Quality Education (4.4/4.7)** ↑ / ↓ | [+2,-2] | 🕮🕮 | ☺ | ★ Science-based action within CSA is required to integrate data sets and sound metrics for testing hypotheses about feedback regarding climate, weather data products and agricultural productivity, such as the nonlinearity of temperature effects on crop yield and the assessment of trade-offs and synergies that arise from different agricultural intensification strategies (Steenwerth et al., 2014). Low commodity prices have led to declining investment in research and development, farmer education, etc. (Lamb et al., 2016). Steenwerth et al., 2014; Lamb et al., 2016
	Greenhouse Gas Reduction from Improved Livestock Production and Manure Management Systems	**Poverty Reduction and Minimize Exposure to Risk (1.5)** ↑ | [+2] | & | J | « With mixed-farming systems farmers can not only mitigate risks by producing a multitude of commodities, but they can also increase the productivity of both crops and animals in a more profitable and sustainable way. Sansoucy, 1995	**Food Security, Promoting Sustainable Agriculture (2.1/2.4/2a)** ↑ | [+2] | &&&& | JJJJ | «««« Fostering transitions towards more productive livestock production systems targeting land-use change appears to be the most efficient lever to deliver food availability outcomes. Genomic selection should be able to at least double the rate of genetic gain in the dairy industry. Given the prevalence of mixed crop–livestock systems in many parts of the world, closer integration of crops and livestock in such systems can give rise to increased productivity and increased soil fertility (Thornton, 2010). Managing the indirect effects of livestock systems intensification is critical for the sustainability of the global food system: such as improving productivity and the close link to land sparing (Herrero and Thornton, 2013). In East Africa pastoralists have shifted from cows to camels, which are better adapted to survive periods of water scarcity and able to consistently provide more milk (Steenwerth et al., 2014). Scenarios where zero human-edible concentrate feed is used for livestock, soil erosion potential reduces by 12%. Thornton, 2010, 2013; Herrero and Thornton, 2013; Havlík et al., 2014; Steenwerth et al., 2014; Schader et al., 2015	**Ensure Healthy Lives (3.c)** ↑ / ↓ | [+2,-2] | && | JJ | «« Biodigestion, which has positive public health aspects, particularly where toilets are coupled with the biodigester; anaerobic conditions kill pathogenic organisms as well as digestive toxins. Separation processes can improve or worsen health risks related to food crops or to livestock. Sansoucy, 1995; Burton, 2007	[0] No direct interaction

Social-Other (continued)

		1 NO POVERTY Interaction | Score | Evidence | Agreement | Confidence	2 ZERO HUNGER Interaction | Score | Evidence | Agreement | Confidence	3 GOOD HEALTH AND WELL-BEING Interaction | Score | Evidence | Agreement | Confidence	4 QUALITY EDUCATION Interaction | Score | Evidence | Agreement | Confidence
Forest	**Reduced Deforestation, REDD+**	**Poverty Reduction (1.5)** ↑ [+2] 🕮 ☺ ★ Partnerships between local forest managers, community enterprises and private sector companies can support local economies and livelihoods, and boost regional and national economic growth. Katila et al., 2017	**Food Security, Promoting Sustainable Agriculture (2.1/2.4/2a)** ↑/↓ [+1,-2] 🕮🕮 ☺ ★ Food security may lead to the conversion of productive land under forest, including community forests, into agricultural production. In a similar fashion, the production of biomass for energy purposes (SDG 7) may reduce land available for food production and/or for community forest activities . Efforts by the Government of Zambia to reduce emissions by REDD+ have contributed erosion control, ecotourism and pollination valued at 2.5% of the country's GDP. Turpie et al., 2015; Epstein and Theuer, 2017; Katila et al., 2017; Dooley and Kartha, 2018	[0] No direct interaction	**Ensure Inclusive and Quality Education (4.4/4.7)** ↑ [+1] 🕮 ☺ ★ Local forest users learn to understand laws, regulations and policies which facilitate their participation in society. Education and capacity building provide technical skill and knowledge (Katila et al., 2017). Katila et al., 2017
	Afforestation and Reforestation	**Poverty and Development (1.1/1.2/1.3/1.4)** ↑/↓ [+2,-2] 🕮🕮 ☺☺ ★★★ Clean Development Mechanism (CDM) can have different implications on local community livelihoods. For example, willingness to adopt afforestation is influenced in particular by Australian landholder's perceptions of its potential to provide a diversified income stream, and its impacts on flexibility of land management ; land sparing would have far reaching implications for the UK countryside and would affect landowners and rural communities ; and livelihoods could be threatened if subsistence agriculture is targeted . Zomer et al., 2008; Schirmer and Bull, 2014; Lamb et al., 2016; Dooley and Kartha, 2018	**Food Security (2.1)** ↑/↓ [+1,-1] 🕮 ☺ ★ CDM can have different implications on local to regional food security and local community livelihoods. Zomer et al., 2008; Dooley and Kartha, 2018	**Ensure Healthy Lives (3.c)** ↑ [+1] 🕮 ☺ ★ Urban trees are increasingly seen as a way to reduce harmful air pollutants and therefore improve cardio-respiratory health. Jones and McDermott, 2018	**Promote Knowledge and Skill to Promote SD (4.7)** ↓ [-1] 🕮 ☺ ★ Most landholders reported having low levels of knowledge about tree planting for carbon sequestration – particularly available programmes, prices and markets, and government rules and regulations . Schirmer and Bull, 2014
	Behavioural Response (Responsible	[0] No direct interaction	[0] No direct interaction	[0] No direct interaction	[0] No direct interaction
Oceans	**Ocean Iron Fertilization**	[0] No direct interaction	**Food Security (2.2/2.3)** ↑/↓ [+1,-1] 🕮🕮 ☺ ★ OIF can have different implications on fish stocks and aquaculture, and it might actually increase food availability for fish stocks (increasing yields); but potentially at the cost of reducing the yields of fisheries outside the enhancement region by depleting other nutrients. Lampitt et al., 2008; Smetacek and Naqvi, 2008; Williamson et al., 2012	[0] No direct interaction	[0] No direct interaction
	Blue Carbon	**Poverty and Development (1.1/1.2/1.5)** ↑ [+3] 🕮🕮🕮 ☺☺☺ ★★★ Avoiding loss of mangroves and maintaining the 2000 stock could save a value of ecosystem services from mangroves in South East Asia of approximately 2.16 billion USD until 2050 (2007 prices), with a 95% prediction interval of 1.58–2.76 billion USD (case study area South East Asia); seaweed aquaculture will enhance carbon uptake and provide employment; traditional management systems provide benefits for blue carbon and support livelihoods for local communities; greening of aquaculture can significantly enhance carbon storage; PES schemes could help capture the benefits derived from multiple ecosystem services beyond carbon sequestration. Zomer et al., 2008; Schirmer and Bull, 2014; Lamb et al., 2016	**Food Production (2.3/2.4)** ↑ [+3] 🕮🕮🕮 ☺☺☺ ★★★ Avoiding loss of mangroves and maintaining the 2000 stock could save a value of ecosystem services from mangroves in South East Asia including fisheries; seaweed aquaculture will provide employment; traditional management systems provide livelihoods for local communities; greening of aquaculture can increase income and well-being; and mariculture is a promising approach for China. Brander et al., 2012; Ahmed et al., 2017a, 2017b; Duarte et al., 2017; Sondak et al., 2017; Vierros, 2017; Zhang et al., 2017	[0] No direct interaction	[0] No direct interaction
	Enhanced Weathering	[0] No direct interaction	[0] No direct interaction	[0] No direct interaction	[0] No direct interaction

<table>
<tr><th></th><th></th><th colspan="5">5 GENDER EQUALITY</th><th colspan="5">10 REDUCED INEQUALITIES</th><th colspan="5">16 PEACE, JUSTICE AND STRONG INSTITUTIONS</th><th colspan="5">17 PARTNERSHIPS FOR THE GOALS</th></tr>
<tr><th></th><th></th><th>Interaction</th><th>Score</th><th>Evidence</th><th>Agreement</th><th>Confidence</th><th>Interaction</th><th>Score</th><th>Evidence</th><th>Agreement</th><th>Confidence</th><th>Interaction</th><th>Score</th><th>Evidence</th><th>Agreement</th><th>Confidence</th><th>Interaction</th><th>Score</th><th>Evidence</th><th>Agreement</th><th>Confidence</th></tr>
<tr><td rowspan="12">Industry</td><td rowspan="4">Accelerating Energy Efficiency Improvement</td><td></td><td>[0]</td><td></td><td></td><td></td><td colspan="5">Knowledge and Skills Needed to Promote SD (4.7)</td><td></td><td>[0]</td><td></td><td></td><td></td><td colspan="5">Global Partnership (17.6/17.7)</td></tr>
<tr><td colspan="5" rowspan="3">No direct interaction</td><td>↑</td><td>[+1]</td><td>📖</td><td>☺☺☺</td><td>★★★</td><td colspan="5" rowspan="3">No direct interaction</td><td>↑</td><td>[+2]</td><td>📖📖</td><td>☺☺☺</td><td>★★★</td></tr>
<tr><td colspan="5">There is need for skill in managing in-house energy efficiency. Sometimes ESCOs also help. Energy audits, but many times absence of skill acts as barrier for energy efficiency improvement. In many countries, especially developing countries, these act as barriers.</td><td colspan="5">A driving force for energy efficiency is collaboration among companies, networks, experience sharing and management tools. Sharing among countries can help accelerate managerial action. Absence of information, budgetary funding, lack of access to capital, etc. are</td></tr>
<tr><td colspan="5">Apeaning and Thollander, 2013; Johansson and Thollander, 2018</td><td colspan="5">Apeaning and Thollander, 2013; Griffin et al., 2018; Johansson and Thollander, 2018; Lawrence et al., 2018</td></tr>
<tr><td rowspan="4">Low-carbon Fuel Switch</td><td></td><td>[0]</td><td></td><td></td><td></td><td></td><td>[0]</td><td></td><td></td><td></td><td></td><td>[0]</td><td></td><td></td><td></td><td colspan="5">Global Partnership (17.6/17.7)</td></tr>
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<tr><td colspan="5">Ultra-low carbon steel making and breakthrough technologies are under trial across many countries and helping in enhancing the learning.</td></tr>
<tr><td colspan="5">Abdul Quader et al., 2016</td></tr>
<tr><td rowspan="4">Decarbonization/CCS/CCU</td><td></td><td>[0]</td><td></td><td></td><td></td><td></td><td>[0]</td><td></td><td></td><td></td><td></td><td>[0]</td><td></td><td></td><td></td><td colspan="5">Global Partnership (17.6/17.7)</td></tr>
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<tr><td colspan="5">EPI plants are capital intensive and are mostly operated by multinationals with long investment cycles. In developed countries new innovation investments are happening in brown fields. Such large innovation investments need strong collaboration among partners/competitors which can be facilitated by public funds. They happen at national and supranational scales and across sectors, needs fresh revisit at Intellectual Property Rights issues. Global production of bio-based polymers increasingly need public support and incentives to push forward.</td></tr>
<tr><td colspan="5">Wesseling et al., 2017; Griffin et al., 2018</td></tr>
</table>

Social 2-Demand (continued)

5 GENDER EQUALITY

		Interaction	Score	Evidence	Agreement	Confidence
Buildings	Behavioural Response		[0]			
		No direct interaction				
	Accelerating Energy Efficiency Improvement	**Gender Equality and Women's Empowerment (5.1/5.4)**				
		↑	[+1]	🕮	☺☺	★★
		Efficient stoves lead to empowerment of rural and indigenous women.				
		Bhojvaid et al., 2014; Berrueta et al., 2017				
	Improved Access and Fuel Switch to Modern Low-carbon Energy	**Women's Safety and Worth (5.1/5.2/5.4)/Opportunities for Women (5.1/5.5)**				
		↑	[+1]	🕮🕮	☺☺	★★
		Improved access to electric lighting can improve women's safety and girls' school enrolment. Cleaner cooking fuel and lighting access can reduce health risks and drudgery, which women disproportionately face. Access to modern energy services has the potential to empower women by improving their income-earning and entrepreneurial opportunities and reducing drudgery. Participating in energy supply chains can increase women's opportunities and agency and improve business outcomes.				
		Chowdhury, 2010; Dinkelman, 2011; Kaygusuz, 2011; Köhlin et al., 2011; Clancy et al., 2012; Haves, 2012; Matinga, 2012; Anenberg et al., 2013; Pachauri and Rao, 2013; Burney et al., 2017; McCollum et al.,				

10 REDUCED INEQUALITIES

		Interaction	Score	Evidence	Agreement	Confidence
Buildings	Behavioural Response		[0]			
		No direct interaction				
	Accelerating Energy Efficiency Improvement	**Empowerment and Inclusion (10.1/10.2/10.3/10.4)**				
		↑ / ↓	[1,-1]	🕮🕮🕮	☺☺☺	★★★
		Energy efficiency measures and the provision of energy access can free up resources that can then be put towards other productive uses (e.g., educational and employment opportunities), especially for women and children in poor, rural areas. The distributional costs of new energy policies are dependent on instrument design. If costs fall disproportionately on the poor, then this could work against the promotion of social, economic and political equality for all. The impacts of energy efficiency measures and policies on inequality can be both positive, if they reduce energy costs, or negative, if mandatory standards increase the need for purchasing more expensive equipment and appliances.				
		Dinkelman, 2011; Casillas and Kammen, 2012; Pachauri et al., 2012; Cayla and Osso, 2013; Hirth and Ueckerdt, 2013; Pueyo et al., 2013; Jakob and Steckel, 2014; Fay et al., 2015; Cameron et al., 2016; Hallegatte et al., 2016b; McCollum et al., 2018				
	Improved Access and Fuel Switch to Modern Low-carbon Energy		[0]			
		No direct interaction				

16 PEACE, JUSTICE AND STRONG INSTITUTIONS

		Interaction	Score	Evidence	Agreement	Confidence
Buildings	Behavioural Response	**Environmental Justice (16.7)**				
		↑	[+2]	🕮	☺	★
		Consumption perspectives strengthen environmental justice discourse (as it claims to be a more just way of calculating global and local environmental effects) while possibly also increasing the participatory environmental discourse.				
		Hult and Larsson, 2016				
	Accelerating Energy Efficiency Improvement	**Capacity and Accountability (16.1/16.3/16.5/16.6/16.7/16.8)**				
		↑	[+2]	🕮🕮🕮	☺☺☺	★★★★
		Institutions that are effective, accountable and transparent are needed at all levels of government (local to national to international) for providing energy access, promoting modern renewables and boosting efficiency. Strengthening the participation of developing countries in international institutions (e.g., international energy agencies, UN organizations, WTO, regional development banks and beyond) will be important for issues related to energy trade, foreign direct investment, labour migration and knowledge and technology transfer. Reducing corruption, where it exists, will help these bodies and related domestic institutions maximize their societal impacts. Limiting armed conflict and violence will aid most efforts related to sustainable development, including progress in the energy dimension.				
		Acemoglu, 2009; Tabellini, 2010; Acemoglu et al., 2014; ICSU and ISSC, 2015; McCollum et al., 2018				
	Improved Access and Fuel Switch to Modern Low-carbon Energy	**Capacity and Accountability (16.1/16.3/16.5/16.6/16.7/16.8)**				
		↑	[+2]	🕮🕮🕮	☺☺☺	★★★★
		Institutions that are effective, accountable and transparent are needed at all levels of government (local to national to international) for providing energy access, promoting modern renewables and boosting efficiency. Strengthening the participation of developing countries in international institutions (e.g., international energy agencies, UN organizations, WTO, regional development banks and beyond) will be important for issues related to energy trade, foreign direct investment, labour migration, and knowledge and technology transfer. Reducing corruption, where it exists, will help these bodies and related domestic institutions maximize their societal impacts. Limiting armed conflict and violence will aid most efforts related to sustainable development, including progress in the energy dimension.				
		Acemoglu, 2009; Tabellini, 2010; Acemoglu et al., 2014; ICSU and ISSC, 2015; McCollum et al., 2018				

17 PARTNERSHIPS FOR THE GOALS

		Interaction	Score	Evidence	Agreement	Confidence
Buildings	Behavioural Response		[0]			
		No direct interaction				
	Accelerating Energy Efficiency Improvement	**Enhance Policy Coherence for Sustainable Development (17.4)**				
		↑	[+2]	🕮	☺	★
		Implementing refrigerant transition and energy efficiency improvement policies in parallel for room ACs, roughly doubles the benefit of either policy implemented in isolation.				
		Shah et al., 2015				
	Improved Access and Fuel Switch to Modern Low-carbon Energy	**Promote Transfer and Diffusion of Technology (17.6/17.7)**				
		↑	[+2]	🕮	☺	★
		Green building technology in Kazakhstan was based on transfer of knowledge among various parties.				
		Kim and Sun, 2017				

Social 2-Demand (continued)

		5 GENDER EQUALITY					10 REDUCED INEQUALITIES					16 PEACE, JUSTICE AND STRONG INSTITUTIONS					17 PARTNERSHIPS FOR THE GOALS				
		Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence
Transport	**Behavioural response**	**Recognize Women's Unpaid Work (5.1/5.4)/Opportunities for Women (5.1/5.5)**					**Reduce Inequality (10.2)**					**Accountable and Transparent Institutions at All Levels (16.6/16.8)**					**Help Promote Global Partnership (17.1/17.3/17.5/17.6/17.7)**				
		↑	[+1]	🕮🕮	☺☺	★★	↑	[+2]	🕮🕮	☺☺	★★	↑/↓	[+1, -1]	🕮	☺	★	↑	[+2]	🕮	☺	★
		The woman's average trip to work differs markedly from the man's average trip. Working-poor women rely on extensive social networks creating communities of spatial necessity, bartering for basic needs to overcome transportation constraints. Women earn lower wages and so are less likely to justify longer commutes. Many women need to manage dual roles as workers and mothers. Women tend to perform multi-purpose commuting, combining both work and household needs .					The equity impacts of climate change mitigation measures for transport, and indeed of transport policy intervention overall, are poorly understood by policymakers. This is in large part because standard assessment of these impacts is not a statutory requirement of current policymaking. Managing transport energy demand growth will have to be advanced alongside efforts in passenger travel towards reducing the deep inequalities in access to transport services that currently affect the poor worldwide. Free provision of roads and parking spaces converts vast amounts of public land and capital into under-priced space for cars, in extreme cases like Los Angeles, USA, roads and streets free for parking and driving are 20% of land area; as governments give drivers free land, people drive more than they would otherwise. High levels of car dependence and the costs of motoring can be burdensome, and lead to increasing debt, raising questions of affordability for households with limited resources, particularly low-income houses located in suburban areas					With behavioural change towards walking for short distances, pedestrian safety on the road might reduce, unless public policy is appropriately formulated. Prevalence of high levels of triple forms of informality, in jobs, housing and transportation, are responsible for low productivity and low standards of living, and are a major challenge for policies targeting urban growth in Latin America.					Projects aiming at resilient transport infrastructure development (e.g., C40 Cities Clean Bus Declaration, UITP Declaration on Climate Leadership, Cycling Delivers on the Global Goals, Global Sidewalk Challenge) are happening through multi-stakeholder coalitions.				
		Crane, 2007; Rogalsky, 2010					Figueroa et al., 2014; Lucas and Pangbourne, 2014; Walks, 2015; Manville, 2017; Belton Chevallier et al., 2018					CAF, 2017; SLoCaT, 2017					SLoCaT, 2017				
	Accelerating Energy Efficiency Improvement		[0]					[0]					**Responsive, Inclusive, Participatory Decision-making (16.7)**					**Help Promote Global Partnership (17.1/17.3/17.5/17.6/17.7)**				
												↑	[+2]	🕮🕮	☺☺	★★	↑	[+2]	🕮	☺	★
		No direct interaction					No direct interaction					In transport mitigation it is necessary to conduct needs assessments and stakeholder consultation to determine plausible challenges, prior to introducing desired planning reforms. Further, the involved personnel should actively engage transport-based stakeholders during policy identification and its implementation to achieve the desired results. User behaviour and stakeholder integration are key for successful transport policy implementation.					Projects aiming at resilient transport infrastructure development and technology adoption (e.g. C40 Cities Clean Bus Declaration, UITP Declaration on Climate Leadership, Cycling Delivers on the Global Goals, Global Sidewalk Challenge) are happening through multi-stakeholder coalitions.				
												Aggarwal, 2017; AlSabbagh et al., 2017					SLoCaT, 2017				
	Improved Access and Fuel Switch to Modern Low-carbon Energy		[0]				**Reduce Inequality (10.2)**					**Responsive, Inclusive, Participatory Decision-making (16.7)**					**Help Promote Global Partnership (17.1/17.3/17.5/17.6/17.7)**				
							↑	[+2]	🕮🕮	☺☺	★★	↑/↓	[+1, -1]	🕮	☺	★	↑	[+2]	🕮	☺	★
		No direct interaction					The equity impacts of climate change mitigation measures for transport, and indeed of transport policy intervention overall, are poorly understood by policymakers. This is in large part because standard assessment of these impacts is not a statutory requirement of current policymaking. Managing transport energy demand growth will have to be advanced alongside efforts in passenger travel towards reducing the deep inequalities in access to transport services that currently affect the poor worldwide.					Formal transport infrastructure improvement in many cities in developing countries leads to eviction from informal settlements; need for appropriate redistributive policies and cooperation and partnerships with all stakeholders.					Projects aiming at resilient transport infrastructure development (e.g. C40 Cities Clean Bus Declaration, UITP Declaration on Climate Leadership, Cycling Delivers on the Global Goals, Global Sidewalk Challenge) are happening through multi-stakeholder coalitions.				
							Figueroa et al., 2014; Lucas and Pangbourne, 2014					Colenbrander et al., 2016					SLoCaT, 2017				

Social 2-Supply

		Interaction	Score	Evidence	Agreement	Confidence
Replacing Coal	Non-biomass Renewables - solar, wind, hydro	**Gender Equality and Women's Empowerment (5.1/5.4)**				
		↑	[+1]	📖	☺	★
		Decentralized renewable energy systems (e.g., home- or village-scale solar power) can reduce the burden on girls and women of procuring traditional biomass.				
		Schwerhoff and Sy, 2017				
	Increased use of Biomass		[0]	No direct interaction		
	Nuclear/Advanced Nuclear		[0]	No direct interaction		
	CCS: Bioenergy		[0]	No direct interaction		
Advanced Coal	CCS: Fossil		[0]	No direct interaction		

		Interaction	Score	Evidence	Agreement	Confidence
Replacing Coal	Non-biomass Renewables - solar, wind, hydro	**Empowerment and Inclusion (10.1/10.2/10.3/10.4)**				
		↑	[+1]	📖📖	☺☺	★★
		Decentralized renewable energy systems (e.g., home- or village-scale solar power) can enable a more participatory, democratic process for managing energy-related decisions within communities.				
		Walker and Devine-Wright, 2008; Cass et al., 2010; Cumbers, 2012; Kunze and Becker, 2015; McCollum et al., 2018				
	Increased use of Biomass		[0]	No direct interaction		
	Nuclear/Advanced Nuclear		[0]	No direct interaction		
	CCS: Bioenergy		[0]	No direct interaction		
Advanced Coal	CCS: Fossil		[0]	No direct interaction		

		Interaction	Score	Evidence	Agreement	Confidence
Replacing Coal	Non-biomass Renewables - solar, wind, hydro	**Energy Justice**				
		↑	[+2]	📖	☺	★
		The energy justice framework serves as an important decision-making tool in order to understand how different principles of justice can inform energy systems and policies. Islar et al. (2017) state that off-grid and micro-scale energy development offers an alternative path to fossil-fuel use and top-down resource management as they democratize the grid and increase marginalized communities' access to renewable energy, education and health care.				
		Islar et al., 2017				
	Increased use of Biomass		[0]	No direct interaction		
	Nuclear/Advanced Nuclear	**Reduce Illicit Arms Trade (16.4)**				
		↓	[-1]	📖📖	☺☺	★★
		Continued use of nuclear power poses a constant risk of proliferation.				
		Adamantiades and Kessides, 2009; Rogner, 2010; Sagan, 2011; von Hippel et al., 2011, 2012; Yim and Li, 2013; IPCC, 2014				
	CCS: Bioenergy		[0]	No direct interaction		
Advanced Coal	CCS: Fossil		[0]	No direct interaction		

		Interaction	Score	Evidence	Agreement	Confidence
Replacing Coal	Non-biomass Renewables - solar, wind, hydro	**International Cooperation (All Goals)**				
		↑ / ~	[+2,0]	📖📖	☺☺	★★
		International cooperation (in policy) and collaboration (in science) is required for the protection of shared resources. Fragmented approaches have been shown to be more costly. Specific to SDG7, to achieve the targets for energy access, renewables and efficiency, it will be critical that all countries: (i) are able to mobilize the necessary financial resources (e.g., via taxes on fossil energy, sustainable financing, foreign direct investment, financial transfers from industrialized to developing countries); (ii) are willing to disseminate knowledge and share innovative technologies between each other; (iii) follow recognized international trade rules while at the same time ensuring that the least developed countries are able to take part in that trade; (iv) respect each other's policy space and decisions; (v) forge new partnerships between their public and private entities and within civil society; and (vi) support the collection of high-quality, timely and reliable data relevant to furthering their missions. There is some disagreement in the literature on the effect of some of the above strategies, such as free trade. Regarding international agreements, 'no-regrets options', where all sides gain through cooperation, are seen as particularly beneficial (e.g., nuclear test ban treaties) (McCollum et al., 2018).				
		UN, 1989; Ramaker et al., 2003; Clarke et al., 2009; NCE, 2015; Riahi et al., 2015, 2017; Eis et al., 2016; O'Neill et al., 2017; McCollum et al., 2018				
	Increased use of Biomass		[0]	No direct interaction		
	Nuclear/Advanced Nuclear		[0]	No direct interaction		
	CCS: Bioenergy		[0]	No direct interaction		
Advanced Coal	CCS: Fossil		[0]	No direct interaction		

5

<table>
<tr><th></th><th></th><th colspan="5">5 GENDER EQUALITY</th><th colspan="5">10 REDUCED INEQUALITIES</th><th colspan="5">16 PEACE, JUSTICE AND STRONG INSTITUTIONS</th><th colspan="5">17 PARTNERSHIPS FOR THE GOALS</th></tr>
<tr><th></th><th></th><th>Interaction</th><th>Score</th><th>Evidence</th><th>Agreement</th><th>Confidence</th><th>Interaction</th><th>Score</th><th>Evidence</th><th>Agreement</th><th>Confidence</th><th>Interaction</th><th>Score</th><th>Evidence</th><th>Agreement</th><th>Confidence</th><th>Interaction</th><th>Score</th><th>Evidence</th><th>Agreement</th><th>Confidence</th></tr>
<tr><td rowspan="12">Agriculture and Livestock</td><td rowspan="4">Behavioural Response: Sustainable Healthy Diets and Reduced Food Waste</td><td colspan="5"></td><td colspan="5"></td><td colspan="5">making (16.6/16.7/16.a)</td><td colspan="5">Resource Mobilization and Strengthen Partnership</td></tr>
<tr><td></td><td>[0]</td><td></td><td></td><td></td><td></td><td>[0]</td><td></td><td></td><td></td><td>↑ / ↓</td><td>[+1,-1]</td><td>🕮🕮🕮</td><td>☺☺</td><td>★★</td><td>↑ / ↓</td><td>[+1,-1]</td><td>🕮</td><td>☺</td><td>★</td></tr>
<tr><td colspan="5">No direct interaction</td><td colspan="5">No direct interaction</td><td colspan="5">Appropriate incentives to reduce food waste may require some policy innovation and experimentation, but a strong commitment for devising and monitoring them seems essential.
A financial incentive to minimize waste could be created through effective taxation (e.g., by taxing foods with the highest wastage rates, or by increasing taxes on waste disposal). Decision makers should try to integrate agricultural, environmental and nutritional objectives through appropriate policy measures to achieve sustainable healthy diets coupled with reduction in food waste. It is surprising that politicians and policymakers demonstrate little regarding the need to have strategies to reduce meat consumption and to encourage more sustainable eating practices.</td><td colspan="5">Decision makers should try to integrate agricultural, environmental and nutritional objectives through appropriate policy measures to achieve sustainable healthy diets coupled with reduction in food waste. It is surprising that politicians and policymakers demonstrate little regarding the need to have strategies to reduce meat consumption and to encourage more sustainable eating practices .</td></tr>
<tr><td colspan="5"></td><td colspan="5"></td><td colspan="5">Garnett, 2011; Dagevos and Voordouw, 2013; Bajželj et al., 2014; Lamb et al., 2016</td><td colspan="5">Garnett, 2011; Dagevos and Voordouw, 2013</td></tr>
<tr><td rowspan="4">Land-based Greenhouse Gas Reduction and Soil Carbon Sequestration</td><td colspan="5">Equal Access, Empowerment of Women (5.5)</td><td colspan="5">Empower Economic and Political Inclusion of All, Irrespective of Sex (10.2)</td><td colspan="5">Build Effective, Accountable and Inclusive Institutions (16.6/16.7/16.8)</td><td colspan="5">Resource Mobilization and Strengthen Multi-stakeholder Partnership
(17.1/ 17.3/17.5/17.17)</td></tr>
<tr><td>↑ / ~</td><td>[+2,0]</td><td>🕮🕮</td><td>☺☺</td><td>★★★</td><td>↑ / ~</td><td>[+1,0]</td><td>🕮🕮</td><td>☺☺</td><td>★★</td><td>~ / ↓</td><td>[0,-1]</td><td>🕮🕮🕮</td><td>☺☺</td><td>★★</td><td>↑</td><td>[+2]</td><td>🕮🕮🕮</td><td>☺☺☺</td><td>★★★</td></tr>
<tr><td colspan="5">Many programmes for CSA have been used to empower women and to improve gender equality. Women often have an especially important role to play in adaptation, because of their gendered indigenous knowledge on matters such as agriculture (Terry, 2009). Without access to land, credit and agricultural technologies, women farmers face major constraints in their capacity to diversify into alternative livelihoods (Demetriades and Esplen, 2008).</td><td colspan="5">In many rural societies women are side-lined from decisions regarding agriculture even when male household heads are absent, and they often lack access to important inputs such as irrigation water, credit, tools and fertilizer. To be effective, agricultural mitigation strategies need to take these and other aspects of local gender relations into account (Terry, 2009). Women's key role in maintaining biodiversity, through conserving and domesticating wild edible plant seed, and in food crop breeding, is not sufficiently recognized in agricultural and economic policymaking; nor is the importance of biodiversity to sustainable rural livelihoods in the face of predicted climate changes (Nelson et al., 2002).</td><td colspan="5">Action is needed throughout the food system for improving governance and producing more food (Godfray and Garnett, 2014). CSA requires policy intervention for careful adjustment of agricultural practices to natural conditions, a knowledge-intensive approach, huge financial investment, etc., so having strong institutional frameworks is very important. The main source of climate finance for CSA in developing countries is the public sector. Lack of institutional capacity (as a means for securing creation of equal institutions among social groups and individuals) can reduce feasibility of AFOLU mitigation measures in the near future, especially in areas where small-scale farmers or forest users are the main stakeholders (Bustamante et al., 2014).</td><td colspan="5">CSA requires more careful adjustment of agricultural practices to natural conditions, a knowledge-intensive approach, huge financial investment and policy and institutional innovation, etc. Besides private investment, quality of public investment is also important (Behnass et al., 2014). Sources of climate finance for CSA in developing countries include bilateral donors and multilateral financial institutions, besides public sector finance. CSA is committed to new ways of engaging in participatory research and partnerships with producers (Steenwerth et al., 2014).</td></tr>
<tr><td colspan="5">Denton, 2002; Nelson et al., 2002; Morton, 2007; Demetriades and Esplen, 2009; Terry, 2009; Bernier et al., 2013; Jost et al., 2016</td><td colspan="5">Nelson et al., 2002; Demetriades and Esplen, 2009; Terry, 2009</td><td colspan="5">Behnassi et al., 2014; Bustamante et al., 2014; Godfray and Garnett, 2014; Lipper et al., 2014; Steenwerth et al., 2014</td><td colspan="5">Behnassi et al., 2014; Lipper et al., 2014; Steenwerth et al., 2014</td></tr>
<tr><td rowspan="4">Greenhouse Gas Reduction from Improved Livestock Production and Manure Management Systems</td><td colspan="5">Equal Access to Economic Resources, Promote Empowerment of Women (5.5/5.a/5.b)</td><td colspan="5">Empower Economic and Political Inclusion of All, Irrespective of Sex (10.2)</td><td colspan="5">Responsible Decision-making (16.7)</td><td colspan="5">Improve Domestic Capacity for Tax Collection (17.1)</td></tr>
<tr><td>↑ / ~</td><td>[+2,0]</td><td>🕮</td><td>☺</td><td>★</td><td>↑ / ~</td><td>[+1,0]</td><td>🕮</td><td>☺</td><td>★</td><td>↑</td><td>[+1]</td><td>🕮</td><td>☺</td><td>★</td><td>↑</td><td>[+2]</td><td>🕮🕮</td><td>☺☺</td><td>★★</td></tr>
<tr><td colspan="5">Most of the animal farming activities such as fodder collection and feeding are performed by women. Alongside the considerable involvement and contribution of women, gender inequalities are pervasive in Indian villages in terms of accessing natural resources, extension services, marketing opportunities and financial services as well as in exercising their decision-making powers. Therefore, there is a need to correct gender bias in the farming sector. Efforts are needed to increase the capacity of women to negotiate with confidence and meet their strategic needs. Access to and control and management of small ruminants, grazing areas and feed resources empower women and lead to an overall positive impact on the welfare of the household.</td><td colspan="5">Livestock ownership is increasing women's decision-making and economic power within both the household and the community. Access to and control and management of small ruminants, grazing areas and feed resources empower women and lead to an overall positive impact on the welfare of the household.</td><td colspan="5">To minimize the economic and social cost, policies should target emissions at their source—on the supply side—rather than on the demand side as supply-side policies have lower calorie cost than demand-side policies. The role of livestock system transitions in emission reductions depends on the level of the carbon price and which emissions sector is targeted by the policies.</td><td colspan="5">The role of livestock system transitions in emission reductions depends on the level of the carbon price and which emissions sector is targeted by the policies (Havlík et al., 2014). Mechanisms for affecting behavioural change in livestock systems need to be better understood by implementing combinations of incentives and taxes simultaneously in different parts of the world (Herrero and Thornton, 2013).</td></tr>
<tr><td colspan="5">Patel et al., 2016</td><td colspan="5">Patel et al., 2016</td><td colspan="5">Havlík et al., 2014</td><td colspan="5">Herrero and Thornton, 2013; Havlík et al., 2014</td></tr>
</table>

Social 2-Other (continued)

5 GENDER EQUALITY

		Interaction	Score	Evidence	Agreement	Confidence
Forest	**Reduced Deforestation, REDD+**	**Opportunities for Women (5.1/5.5)**				
		↑/↓	[+1,-1]	🕮	☺	★
		Women have been less involved in REDD+ initiative (pilot project) design decisions and processes than men. Girls and women have an important role in forestry activities, related to fuel-wood, forest-food and pharmaceutical. Their empowerment contributes to sustainable forestry as well as reducing inequality .				
		Brown, 2011; Larson et al., 2014; Katila et al., 2017				
	Afforestation and Reforestation	**Opportunities for Women (5.1/5.5)**				
		↑	[+1]	🕮	☺	★
		Many women in developing countries are already prominently engaged in economic sectors related to climate adaptation and mitigation efforts such as agriculture, renewable energy and forest management and are important drivers and leaders in climate responses that are innovative and effective, benefitting not only their families but also their wider communities. Women's participation in the decision-making process of forest management, for example, has been shown to increase rates of reforestation while decreasing the illegal extraction of forest products.				
		UN-Women et al., 2015				
	Behavioural Response (Responsible Sourcing)		[0]			
		No direct interaction				

10 REDUCED INEQUALITIES

		Interaction	Score	Evidence	Agreement	Confidence
Forest	**Reduced Deforestation, REDD+**	**Reduced Inequality, Empowerment and Inclusion (10.1/10.2/10.3/10.4)**				
		↑	[+2]	🕮	☺	★
		Urges developed countries to support, through multilateral and bilateral channels, the development of REDD+ national strategies or action plans and implementation . Girls and women have an important role in forestry activities, related to fuel-wood, forest-food and medicine. Their empowerment contributes to sustainable forestry as well as reducing inequality .				
		Bastos Lima et al., 2017; Katila et al., 2017				
	Afforestation and Reforestation	**Empower Economic and Political Inclusion of All, Irrespective of Sex (10.2)**				
		↑	[+1]	🕮	☺	★
		Women's participation in the decision-making process of forest management, for example, has been shown to increase rates of reforestation while decreasing the illegal extraction of forest products.				
		UN-Women et al., 2015				
	Behavioural Response (Responsible Sourcing)		[0]			
		No direct interaction				

16 PEACE, JUSTICE AND STRONG INSTITUTIONS

		Interaction	Score	Evidence	Agreement	Confidence
Forest	**Reduced Deforestation, REDD+**	**Build Effective, Accountable and Inclusive Institutions, Responsible Decision-making (16.6/16.7/16.8)**				
		↑	[+2]	🕮🕮	☺☺☺	★★★
		Institutional building (National Forest Monitoring Systems, Safeguard Information Systems, etc.), with full and effective participation of all relevant countries . REDD+ actions also deliver non-carbon benefits (e.g. local socioeconomic benefits, governance improvements). Forest governance is another central aspect in recent studies, including the debate on decentralization of forest management, logging concessions in public-owned commercially valuable forests and timber certification, primarily in temperate forests .				
		Bustamante et al., 2014; Bastos Lima et al., 2015, 2017				
	Afforestation and Reforestation	**Responsible Decision-making (16.7)**				
		↑	[+1]	🕮	☺	★
		Land-related mitigation, such as biofuel production, as well as conservation and reforestation action can increase competition for land and natural resources, so these measures should be accompanied by complementary policies. (Quoted from Epstein and Theur, 2017)				
		Epstein and Theuer, 2017				
	Behavioural Response (Responsible Sourcing)	**Responsible Decision-making (16.7)**				
		↑	[+1]	🕮🕮	☺☺	★★
		Indonesian factories may seek advantages through non-price competition—perhaps by highlighting decent working conditions or the existence of a union—or to see trade associations or government agencies promoting the country as a responsible sourcing location (Bartley, 2010). In the absence of domestic legal instruments providing incentives to improve sustainability of sourcing, it appears that initiatives to engage the major importing enterprises in developing responsible sourcing practices and policies is a practical approach. Unless initiatives involve all the major importers, they are unlikely to be successful since the high costs associated with accreditation would increase production costs for these firms relative to their competitors (Huang et al., 2013).				
		Bartley, 2010; Huang et al., 2013				

17 PARTNERSHIPS FOR THE GOALS

		Interaction	Score	Evidence	Agreement	Confidence
Forest	**Reduced Deforestation, REDD+**	**Resource Mobilization and Strengthen Multi-stakeholder Partnership (17.1/ 17.3/17.5/17.17)**				
		↑/↓	[+1,-1]	🕮	☺	★
		To provide finance and technology to developing countries to support emissions reductions. Be supported by adequate and predictable financial and technology support, including support for capacity building . Partnerships in the form of significant aid money from, e.g., Norway, other bilateral donors and the World Bank's Forest Carbon Partnership Facility (FCPF) are forthcoming . Estimates of opportunity cost for REDD+ are very low. Lower costs and/or higher carbon prices could combine to protect more forests, including those with lower carbon content. Conversely, where the cost of action is high, a large amount of additional funding would be required for the forest to be protected (Miles and Kapos, 2008). Forest governance is another central aspect in recent studies, including debate on decentralization of forest management, logging concessions in public-owned commercially valuable forests and timber certification, primarily in temperate forests . Partnerships between local forest managers, community enterprises and private sector companies can support local economies and livelihoods and boost regional and national economic growth .				
		Miles and Kapos, 2008; Bustamante et al., 2014; Andrew, 2017; Bastos Lima et al., 2017; Katila et al., 2017				
	Afforestation and Reforestation	**Resource Mobilization and Strengthen Partnership (17.1/17.14)**				
		↑	[+2]	🕮🕮	☺☺	★★
		Financing at the national and international level is required to grow more seedlings/sapling, restore land, create awareness and education factsheets, provide training to local communities regarding the benefits of afforestation and reforestation. Article 12 of the Kyoto Protocol further sets a Clean Development Mechanism through which countries in Annex I earn 'certified emissions reductions' through projects implemented in developing countries (Montanarella and Alva, 2015). Afforestation and reforestation in India are being carried out under various programmes, namely social forestry initiated in the early 1980s, the Joint Forest Management Programme initiated in 1990, afforestation under National Afforestation and Eco-development Board programmes since 1992, and private farmer and industry initiated plantation forestry. If the current rate of afforestation and reforestation is assumed to continue, the carbon stock could increase by 11% by 2030 (Ravindranath et al., 2008)				
		Ravindranath et al., 2008; Kibria, 2015; Montanarella and Alva, 2015				
	Behavioural Response (Responsible Sourcing)	**Finance and Trade (17.1/17.10)**				
		↑	[+1]	🕮🕮	☺☺	★★
		Private certification initiatives for wood product and biomass sourcing may extend their schemes with criteria for 'leakage' (external GHG effects). Also recycling of waste wood in pellets is not yet practiced, due to unclear rules in the EU Waste Directive about overseas shipping (Sikkema et al., 2014). Engagement of Chinese government and private sector stakeholders in supply-country sustainability initiatives may be the best way to support this gradual process of improvement. Although carrying out due diligence in timber sourcing can require considerable internal resources, it may be substantially less of a financial burden than the potential fines and reputational damage resulting from sourcing unknown or controversial timber (Huang et al., 2013).				
		Huang et al., 2013; Sikkema et al., 2014				

Social 2-Other (continued)

		5 GENDER EQUALITY					10 REDUCED INEQUALITIES					16 PEACE, JUSTICE AND STRONG INSTITUTIONS					17 PARTNERSHIPS FOR THE GOALS				
		Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence
Oceans	**Ocean Iron Fertilization**		**[0]**	No direct interaction				**[0]**	No direct interaction				**[0]**	No direct interaction				**[0]**	No direct interaction		
	Blue Carbon		**[0]**	No direct interaction				**[0]**	No direct interaction				**[0]**	No direct interaction				**[0]**	No direct interaction		
	Enhanced Weathering		**[0]**	No direct interaction				**[0]**	No direct interaction				**[0]**	No direct interaction				**[0]**	No direct interaction		

Environment-Demand

		6 CLEAN WATER AND SANITATION					12 RESPONSIBLE CONSUMPTION AND PRODUCTION					14 LIFE BELOW WATER					15 LIFE ON LAND				
		Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence
Industry	**Accelerating Energy Efficiency Improvement**	**Water Efficiency and Pollution Prevention (6.3/6.4/6.6)**					**Sustainable and Efficient Resource (12.2/12.5/12.6/12.7/12.a)**														
		↑/↓	[+2,-1]	📖📖	☺☺	★★	↑	[+1]	📖📖📖	☺☺☺	★★★		[0]					[0]			
		Efficiency and behavioural changes in the industrial sector that lead to reduced energy demand can lead to reduced requirements on energy supply. As water is used to convert energy into useful forms, the reduction in industrial demand is anticipated to reduce water consumption and waste water, resulting in more clean water for other sectors and the environment. Likewise, reducing material inputs for industrial processes through efficiency and behavioural changes will reduce water inputs in the material supply chains. In extractive industries there can be a trade-off with production unless strategically managed.					Once started leads to chain of actions within the sector and policy space to sustain the effort. Helps in expansion of sustainable industrial production (Ghana).					No direct interaction					No direct interaction				
		Vassolo and Döll, 2005; Nguyen et al., 2014; Holland et al., 2015; Fricko et al., 2016					Apeaning and Thollander, 2013; Fernando et al., 2017														
	Low-carbon Fuel Switch	**Water Efficiency and Pollution Prevention (6.3/6.4/6.6)**					**Sustainable Production (12.2/12.3/12.a)**										**Sustainable Production (15.1/15.5/15.9/15.10)**				
		↑/↓	[+2,-2]	📖📖	☺☺	★★★	↑	[+2]	📖📖📖📖	☺☺☺☺	★★★★		[0]				↑	[+1,-1]	📖	☺	★
		A switch to low-carbon fuels can lead to a reduction in water demand and waste water if the existing higher-carbon fuel is associated with a higher water intensity than the lower-carbon fuel. However, in some situations the switch to a low-carbon fuel such as, for example, biofuel could increase water use compared to existing conditions if the biofuel comes from a water-intensive feedstock.					A circular economy instead of linear global economy can achieve climate goals and can help in economic growth through industrialization which saves on resources, the environment and supports small, medium and even large industries, and can lead to employment generation. So new regulations, incentives and a tax regime can help in achieving the goal, especially in newly emerging developing countries - although also applicable for large industrialized countries.					No direct interaction					A circular economy help in managing local biodiversity better by having less resource use footprint				
		Hejazi et al., 2015; Fricko et al., 2016; Song et al., 2016					Liu and Bai, 2014; Lieder and Rashid, 2016; Stahel, 2016; Supino et al., 2016; Fan et al., 2017; Shi et al., 2017; Zeng et al., 2017										Shi et al., 2017				
	Decarbonisation/CCS/CCU	**Water Efficiency and Pollution Prevention (6.3/6.4/6.6)**					**Sustainable Production and Consumption (12.1/12.6/12.a)**					**Conserve and Sustainably Use Ocean (14.1/14.5)**									
		↑/↓	[+1,-1]	📖📖📖	☺	★★	↑	[+2]	📖	☺☺☺☺	★★★★	↓	[-1]	📖	☺	★		[0]			
		CCU/S requires access to water for cooling and processing which could contribute to localized water stress. CCS/U processes can potentially be configured for increased water efficiency compared to a system without carbon capture via process integration.					EPI plants are capital intensive and are mostly operated by multinationals with long investment cycles. In developed countries new investments are happening in brown fields, while in developing countries these are in green fields. Collaboration among partners and user demand change, policy change is essential for encouraging these large risky investments.					CCU/S in the chemical industry faces challenges for transport costs and storage. In the UK cluster region have been identified for storage under sea.					No direct interaction				
		Meldrum et al., 2013; Byers et al., 2016; Fricko et al., 2016; Brandl et al., 2017					Wesseling et al., 2017					Griffin et al., 2018									

Environment-Demand (continued)

		6 CLEAN WATER AND SANITATION					12 RESPONSIBLE CONSUMPTION AND PRODUCTION					14 LIFE BELOW WATER					15 LIFE ON LAND				
		Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence
Buildings	**Behavioural Response**	**Water Efficiency and Pollution Prevention (6.3/6.4/6.6)**					**Responsible and Sustainable Consumption**														
		↑	[+2]	📖📖	☺☺☺	★★★	↑	[+2]	📖📖📖	☺☺☺	★★★		[0]					[0]			
		Behavioural changes in the residential sector that lead to reduced energy demand can lead to reduced requirements on energy supply. As water is used to convert energy into useful forms, the reduction in residential demand is anticipated to reduce water consumption and waste water, resulting in more clean water for other sectors and the environment.					Technological improvements alone are not sufficient to increase energy savings. Zhao et al. (2017) found that building technology and occupant behaviours interact with each other and finally affect energy consumption from home. They found that occupant habits could not take advantage of more than 50% of energy efficiency potential allowed by an efficient building. In the electronic segment, product obsolescence represents a key challenge for sustainability. Echegaray (2016) discusses the dissonance between consumers' product durability experience, orientations to replace devices before terminal technical failure, and perceptions of industry responsibility and performance. The results from their urban sample survey indicate that technical failure is far surpassed by subjective obsolescence as a cause for fast product replacement. At the same time Liu et al. (2017) suggest that we need to go beyond individualist and structuralist perspectives to analyse sustainable consumption (i.e., combines both human agency paradigm and social structural perspective).					No direct interaction					No direct interaction				
		Bartos and Chester (2014); Fricko et al. (2016); Holland et al. (2016)					Sweeney et al., 2013; Webb et al., 2013; Allen et al., 2015; Echegaray (2015); He et al., 2016; Hult and Larsson, 2016; Isenhour and Feng, 2016; van Sluisveld et al., 2016; Zhao et al., 2017; Liu et al., 2017; Sommerfeld et al., 2017														
	Accelerating Energy Efficiency Improvement	**Water Efficiency and Pollution Prevention (6.3/6.4/6.6)**					**Sustainable Practices and Lifestyles (12.6/12.7/12.8)**										**Reduced Deforestation (15.2)**				
		↑	[+2]	📖📖📖	☺☺☺	★★★	↑	[+1]	📖📖📖	☺☺☺	★★★		[0]				↑	[+2]	📖📖	☺☺☺	★★★
		Efficiency changes in the residential sector that lead to reduced energy demand can lead to reduced requirements on energy supply. As water is used to convert energy into useful forms, the reduction in residential demand is anticipated to reduce water consumption and waste water, resulting in more clean water for other sectors and the environment. A switch to low-carbon fuels in the residential sector can lead to a reduction in water demand and waste water if the existing higher-carbon fuel is associated with a higher water intensity than the lower-carbon fuel. However, in some situations the switch to a low-carbon fuel such as, for example, biofuel could increase water use compared to existing conditions if the biofuel comes from a water-intensive feedstock. As water is used to convert energy into useful forms, energy efficiency is anticipated to reduce water consumption and waste water, resulting in more clean water for other sectors and the environment. Subsidies for renewables are anticipated to lead to the benefits and trade-offs outlined when deploying renewables. Subsidies for renewables could lead to improved water access and treatment if subsidies support projects that provide both water and energy services (e.g., solar desalination).					Sustainable practices adopted by public and private bodies in their operations (e.g., for goods procurement, supply chain management and accounting) create an enabling environment in which renewable energy and energy efficiency measures may gain greater traction (McCollum et al., 2018).					No direct interaction					Improved stoves has helped halt deforestation in rural India.				
		Bilton et al., 2011; Scott, 2011; Kumar et al., 2012; Meldrum et al., 2013; Bartos and Chester, 2014; Hendrickson and Horvath, 2014; Kern et al., 2014; Holland et al., 2015; Fricko et al., 2016; Kim et al., 2017					Stefan and Paul, 2008; ECF, 2014; CDP, 2015; Khan et al., 2015; NCE, 2015; McCollum et al., 2018										Bhojvaid et al., 2014				

Environment-Demand (continued)

6 CLEAN WATER AND SANITATION

		Interaction	Score	Evidence	Agreement	Confidence
Buildings	**Improved Access and Fuel Switch to Modern Low-carbon Energy**	**Access to Improved Water and Sanitation (6.1/6.2), Water Efficiency and Pollution Prevention (6.3/6.4/6.6)**				
		↑/↓	[+2,-1]	📖📖	☺☺	★★★
		A switch to low-carbon fuels in the residential sector can lead to a reduction in water demand and waste water if the existing higher-carbon fuel is associated with a higher water intensity than the lower-carbon fuel. However, in some situations the switch to a low-carbon fuel such as, for example, biofuel could increase water use compared to existing conditions if the biofuel comes from a water-intensive feedstock. Improved access to energy can support clean water and sanitation technologies. If energy access is supported with water-intensive energy sources, there could be trade-offs with water efficiency targets.				
		Hejazi et al., 2015; Cibin et al., 2016; Fricko et al., 2016; Song et al., 2016; Rao and Pachauri, 2017				
Transport	**Behavioural Response**	**Water Efficiency and Pollution Prevention (6.3/6.4/6.6)**				
		↑	[+2]	📖📖	☺☺	★★
		Behavioural changes in the transport sector that lead to reduced transport demand can lead to reduced transport energy supply. As water is used to produce a number of important transport fuels, the reduction in transport demand is anticipated to reduce water consumption and waste water, resulting in more clean water for other sectors and the environment.				
		Vidic et al., 2013; Holland et al., 2015; Fricko et al., 2016; Tiedeman et al., 2016				
	Accelerating Energy Efficiency Improvement	**Water Efficiency and Pollution Prevention (6.3/6.4/6.6)**				
		↑	[+2]	📖📖📖	☺☺☺	★★★
		Similar to behavioural changes, efficiency measures in the transport sector that lead to reduced transport demand can lead to reduced transport energy supply. As water is used to produce a number of important transport fuels, the reduction in transport demand is anticipated to reduce water consumption and waste water, resulting in more clean water for other sectors and the environment.				
		Vidic et al., 2013; Holland et al., 2015; Fricko et al., 2016; Tiedeman et al., 2016				

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

		Interaction	Score	Evidence	Agreement	Confidence
Buildings	**Improved Access and Fuel Switch to Modern Low-carbon Energy**	**Sustainable Use and Management of Natural Resource (12.2)**				
		↑/↓	[+2,-1]	📖📖	☺☺	★★★
		A switch to low-carbon fuels in the residential sector can lead to a reduction in water demand and waste water if the existing higher-carbon fuel is associated with a higher water intensity than the lower-carbon fuel. However, in some situations the switch to a low-carbon fuel such as, for example, biofuel could increase water use compared to existing conditions if the biofuel comes from a water-intensive feedstock. Improved access to energy can support clean water and sanitation technologies. If energy access is supported with water-intensive energy sources, there could be trade-offs with water efficiency targets.				
		Hejazi et al., 2015; Cibin et al., 2016; Fricko et al., 2016; Song et al., 2016; Rao and Pachauri, 2017				
Transport	**Behavioural Response**	**Ensure Sustainable Consumption amd Production Patterns (12.3)**				
		↑	[+2]	📖📖	☺☺	★★
		Urban carbon mitigation must consider the supply chain management of imported goods, the production efficiency within the city, the consumption patterns of urban consumers, and the responsibility of the ultimate consumers outside the city. Important for climate policy of monitoring the CO_2 clusters that dominate CO_2 emissions in global supply chains, because they offer insights on where climate policy can be effectively directed.				
		Kagawa et al., 2015; Lin et al., 2015; Creutzig et al., 2016				
	Accelerating Energy Efficiency Improvement	**Sustainable Consumption (12.2/12.8)**				
		↑	[+2]	📖📖📖	☺☺☺	★★★
		Relational complex transport behaviour resulting in significant growth in energy-inefficient car choices, as well as differences in mobility patterns (distances driven, driving styles) and actual fuel consumption between different car segments all affect non-progress on transport decarbonization. Consumption choices and individual lifestyles are situated and tied to the form of the surrounding urbanization. Major behavioural changes and emissions reductions require understanding of this relational complexity, consideration of potential interactions with other policies, and the local context and implementation of both command-and-control as well as market-based measures.				
		Stanley et al., 2011; Gallego et al., 2013; Heinonen et al., 2013; Aamaas and Peters, 2017; Azevedo and Leal, 2017; Gössling and Metzler, 2017				

14 LIFE BELOW WATER

		Interaction	Score	Evidence	Agreement	Confidence
Buildings	**Improved Access and Fuel Switch to Modern Low-carbon Energy**		[0]			
			No direct interaction			
Transport	**Behavioural Response**		[0]			
			No direct interaction			
	Accelerating Energy Efficiency Improvement		[0]			
			No direct interaction			

15 LIFE ON LAND

		Interaction	Score	Evidence	Agreement	Confidence
Buildings	**Improved Access and Fuel Switch to Modern Low-carbon Energy**	**Healthy Terrestrial Ecosystems (15.1/15.2/15.4/15.5/15.8)**				
		↑	[+2]	📖📖	☺☺☺	★★★
		Ensuring that the world's poor have access to modern energy services would reinforce the objective of halting deforestation, since firewood taken from forests is a commonly used energy resource among the poor (McCollum et al., 2018).				
		Bazilian et al., 2011; Karekezi et al., 2012; Bailis et al., 2015; Winter et al., 2015; McCollum et al., 2018				
Transport	**Behavioural Response**		[0]			
			No direct interaction			
	Accelerating Energy Efficiency Improvement		[0]			
			No direct interaction			

Environment-Demand (continued)

		6 CLEAN WATER AND SANITATION					12 RESPONSIBLE CONSUMPTION AND PRODUCTION					14 LIFE BELOW WATER					15 LIFE ON LAND				
		Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence
Transport	**Improved Access and Fuel Switch to Modern Low-carbon Energy**	**Water Efficiency and Pollution Prevention (6.3/6.4/6.6)**					**Ensure Sustainable Consumption and Production Patterns (12.3)**						**[0]**						**[0]**				
		↑ / ↓	[+2,-1]	📖📖	☺☺	★★★	↑	[+2]	📖📖📖	☺☺☺	★★★			No direct interaction					No direct interaction		
		A switch to low-carbon fuels in the transport sector can lead to a reduction in water demand and waste water if the existing higher-carbon fuel is associated with a higher water intensity than the lower-carbon fuel. However, in some situations the switch to a low-carbon fuel such as, for example, biofuel could increase water use compared to existing conditions if the biofuel comes from a water-intensive feedstock. Transport electrification could lead to trade-offs with water use if the electricity is provided with water intensive power generation.					Due to persistent reliance on fossil fuels, it is posited that transport is more difficult to decarbonize than other sectors. This study partially confirms that transport is less reactive to a given carbon tax than the non-transport sectors: in the first half of the century, transport mitigation is delayed by 10–30 years compared to non-transport mitigation. The extent to which earlier mitigation is possible strongly depends on implemented technologies and model structures.														
		Hejazi et al., 2015; Fricko et al., 2016; Song et al., 2016					Figueroa et al., 2014; IPCC, 2014; Pietzcker et al., 2014; Creutzig et al., 2015														

Environement-Supply

		Interaction	Score	Evidence	Agreement	Confidence
Replacing Coal	**Non-biomass Renewables - solar, wind hydro**	**Water Efficiency and Pollution Prevention (6.3/6.4/6.6)/ Access to Improved Water and Sanitation (6.1/6.2)**				
		↑ / ↓	[+2,-2]	📖📖📖📖📖	☺☺☺☺	★★★★
		Wind/solar renewable energy technologies are associated with very low water requirements compared to existing thermal power plant technologies. Widespread deployment is therefore anticipated to lead to improved water efficiency and avoided thermal pollution. However, managing wind and solar variability can increase water use at thermal power plants and can cause poor water quality downstream from hydropower plants. Access to distributed renewables can provide power to improve water access, but could also lead to increased groundwater pumping and stress if mismanaged. Developing dams to support reliable hydropower production can fragment rivers and alter natural flows reducing water and ecosystem quality. Developing dams to support reliable hydropower production can result in disputes for water in basins with up- and down-stream users. Storing water in reservoirs increases evaporation, which could offset water conservation targets and reduce availability of water downstream. However, hydropower plays an important role in energy access for water supply in developing regions, can support water security, and has the potential to reduce water demands if used without reservoir storage to displace other water intensive energy processes.				
		Bilton et al., 2011; Scott et al., 2011; Kumar et al., 2012; Ziv et al., 2012; Meldrum et al., 2013; Kern et al., 2014; Grill et al., 2015; Fricko et al., 2016; Grubert, 2016; De Stefano et al., 2017				
	Increased Use of Biomass	**Water Efficiency and Pollution Prevention (6.3/6.4/6.6)**				
		↑ / ↓	[+1,-2]	📖📖📖📖📖	☺☺	★★★★
		Biomass expansion could lead to increased water stress when irrigated feedstocks and water-intensive processing steps are used. Bioenergy crops can alter flow over land and through soils as well as require fertilizer, and this can reduce water availability and quality. Planting bioenergy crops on marginal lands or in some situations to replace existing crops can lead to reductions in soil erosion and fertilizer inputs, improving water quality.				
		Hejazi et al., 2015; Bonsch et al., 2016; Cibin et al., 2016; Song et al., 2016; Gao and Bryan, 2017; Griffiths et al., 2017; Ha and Wu, 2017; Taniwaki et al., 2017; Woodbury et al., 2018				

		Interaction	Score	Evidence	Agreement	Confidence
Replacing Coal	**Non-biomass Renewables - solar, wind hydro**	**Natural Resource Protection (12.2/12.3/12.4/12.5)**				
		↑	[+2]	📖📖📖	☺☺☺	★★★★
		Renewable energy and energy efficiency slow the depletion of several types of natural resources, namely coal, oil, natural gas and uranium. In addition, the phasing-out of fossil fuel subsidies encourages less wasteful energy consumption; but if that is done, then the policies implemented must take care to minimize any counteracting adverse side-effects on the poor (e.g., fuel price rises). (Quote from McCollum et al., 2018)				
		Banerjee et al., 2012; Riahi et al., 2012; Schwanitz et al., 2014; Bhattacharyya et al., 2016; Cameron et al., 2016; McCollum et al., 2018				
	Increased Use of Biomass	**Natural Resource Protection (12.2/12.3/12.4/12.5)**				
		↑	[+2]	📖📖📖	☺☺☺	★★★★
		Switching to renewable energy reduces the depletion of finite natural resources.				
		Banerjee et al., 2012; Riahi et al., 2012; Schwanitz et al., 2014; Bhattacharyya et al., 2016; Cameron et al., 2016; McCollum et al., 2018				

		Interaction	Score	Evidence	Agreement	Confidence
Replacing Coal	**Non-biomass Renewables - solar, wind hydro**	**Marine Economies (14.7)/ Marine Protection (14.1/14.2/14.4/14.5)**				
		↑ / ↓	[2,-1]	📖📖	☺☺☺	★★★
		Ocean-based energy from renewable sources (e.g., offshore wind farms, wave and tidal power) are potentially significant energy resource bases for island countries and countries situated along coastlines. Multi-use platforms combining renewable energy generation, aqua-culture, transport services and leisure activities can lay the groundwork for more diversified marine economies. Depending on the local context and prevailing regulations, ocean-based energy installations could either induce spatial competition with other marine activities, such as tourism, shipping, resources exploitation, and marine and coastal habitats and protected areas, or provide further grounds for protecting those exact habitats, therefore enabling marine protection. (Quote from McCollum et al., 2018) Hydropower disrupts the integrity and connectivity of aquatic habitats and impacts the productivity of inland waters and their fisheries.				
		Inger et al., 2009; Michler-Cieluch et al., 2009; Buck and Krause, 2012; WBGU, 2013; Cooke et al., 2016; Matthews and McCartney, 2018; McCollum et al., 2018				
	Increased Use of Biomass		[0]			
		No direct interaction				

		Interaction	Score	Evidence	Agreement	Confidence
Replacing Coal	**Non-biomass Renewables - solar, wind hydro**	**Healthy Terrestrial Ecosystems (15.1/15.2/15.4/15.5/15.8)**				
		↓	[-1]	📖📖📖	☺☺☺	★★★
		Landscape and wildlife impact for wind; habitat impact for hydropower.				
		Alho, 2011; Garvin et al., 2011; Grodsky et al., 2011; Jain et al., 2011; Kumar et al., 2011; Kunz et al., 2011; Wiser et al., 2011; Dahl et al., 2012; de Lucas et al., 2012; Ziv et al., 2012; Lovich and Ennen, 2013; Smith et al., 2013; Matthews and McCartney, 2018				
	Increased Use of Biomass	**Healthy Terrestrial Ecosystems (15.1/15.2/15.4/15.5/15.8)**				
		↑ / ↓	[+1,-2]	📖	☺☺☺	★★
		Protecting terrestrial ecosystems, sustainably managing forests, halting deforestation, preventing biodiversity loss and controlling invasive alien species could potentially clash with renewable energy expansion, if that would mean constraining large-scale utilization of bioenergy or hydropower. Good governance, cross-jurisdictional coordination and sound implementation practices are critical for minimizing trade-offs (McCollum et al., 2018).				
		Smith et al., 2010, 2014; Acheampong et al., 2017; McCollum et al., 2018				

Environement-Supply (continued)

		6 CLEAN WATER AND SANITATION					12 RESPONSIBLE CONSUMPTION AND PRODUCTION					14 LIFE BELOW WATER					15 LIFE ON LAND				
		Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence
Replacing Coal	**Nuclear/Advanced Nuclear**	**Water Efficiency and Pollution Prevention (6.3/6.4/6.6)**															**Healthy Terrestrial Ecosystems (15.1/15.2/15.4/15.5/15.8)**				
		↑ / ↓	[+2,-1]	&&&	JJJ	«««		[0]					[0]				↓	[-1]	&&	JJ	««
		Nuclear power generation requires water for cooling which can lead to localized water stress and the resulting cooling effluents can cause thermal pollution in rivers and oceans.					No direct interaction					No direct interaction					Safety and waste concerns from uranium mining and milling.				
		Webster et al., 2013; Holland et al., 2015; Fricko et al., 2016; Raptis et al., 2016															Bickerstaff et al., 2008; Sjoberg and Sjoberg, 2009; Ahearne, 2011; Corner et al., 2011; Visschers and Siegrist, 2012; IPCC, 2014				
	CCS: Bioenergy	**Water Efficiency and Pollution Prevention (6.3/6.4/6.6)**					**Natural Resource Protection (12.2/12.3/12.4/12.5)**										**Healthy Terrestrial Ecosystems (15.1/15.2/15.4/15.5/15.8)**				
		↑ / ↓	[+1,-2]	📖📖	☺	★★	↑	[+1]	📖📖	☺☺	★★		[0]				↑ / ↓	[+1,-2]	📖	☺☺☺	★★
		CCU/S requires access to water for cooling and processing which could contribute to localized water stress. However, CCS/U processes can potentially be configured for increased water efficiency compared to a system without carbon capture via process integration. The bioenergy component adds the additional trade-offs associated with bioenergy use. Large-scale bioenergy increases input demand, resulting in environmental degradation and water stress.					Switching to renewable energy reduces the depletion of finite natural resources. On the other hand, the availability of underground storage is limited and therefore reduces the benefits of switching from finite resources to bioenergy.					No direct interaction					Protecting terrestrial ecosystems, sustainably managing forests, halting deforestation, preventing biodiversity loss and controlling invasive alien species could potentially clash with renewable energy expansion, if that would mean constraining large-scale utilization of bioenergy or hydropower. Good governance, cross-jurisdictional coordination and sound implementation practices are critical for minimizing trade-offs (McCollum et al., 2018). Large-scale bioenergy increases input demand, resulting in environmental degradation and water stress.				
		Meldrum et al., 2013; Byers et al., 2016; Fricko et al., 2016; Brandl et al., 2017; Dooley and Kartha, 2018					Banerjee et al., 2012; Riahi et al., 2012; Schwanitz et al., 2014; Bhattacharyya et al., 2016; Cameron et al., 2016; McCollum et al., 2018										Smith et al., 2010, 2014; Acheampong et al., 2017; Dooley and Kartha, 2018, McCollum et al., 2018)				
Advanced Coal	**CCS: Fossil**	**Water Efficiency and Pollution Prevention (6.3/6.4/6.6)**																			
		↑ / ↓	[+1,-2]	📖📖📖	☺	★★		[0]					[0]					[0]			
		CCU/S requires access to water for cooling and processing which could contribute to localized water stress. However, CCS/U processes can potentially be configured for increased water efficiency compared to a system without carbon capture via process integration. Coal mining to support clean coal CCS will negatively impact water resources due to the associated water demands, waste water and land-use requirements.					No direct interaction					No direct interaction					No direct interaction				
		Meldrum et al., 2013; Byers et al., 2016; Fricko et al., 2016; Brandl et al., 2017																			

Environement-Other

		6 CLEAN WATER AND SANITATION					12 RESPONSIBLE CONSUMPTION AND PRODUCTION					14 LIFE BELOW WATER					15 LIFE ON LAND				
		Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence
Agriculture and Livestock	**Behavioural Response: Sustainable Healthy Diets and Reduced Food Waste**	**Water Efficiency and Pollution Prevention (6.3/6.4/6.6)**					**Ensure Sustainable Consumption and Production Patterns, Sustainable Practices and Lifestyle (12.3/12.4/12.6/12.7/12.8)**										**Conservation of Biodiversity and Restoration of Land (15.1/15.5/15.9)**				
		↑ / ↓	[+2,-1]	📖📖📖📖	☺☺☺☺	★★★★	↑	[+2]	📖📖📖📖	☺☺☺☺	★★★★		[0]				↑	[+1]	📖	☺	★
		Reduced food waste avoids direct water demand and waste water for crops and food processing, and avoids water used for energy supply by reducing agricultural, food processing and waste management energy inputs. Healthy diets will support water efficiency targets if the shift towards healthy foods results in food supply chains that are less water intensive than the supply chains supporting the historical dietary pattern.					Reduce loss and waste in food systems, processing, distribution and by changing household habits. To reduce environmental impact of livestock both production and consumption trends in this sector should be traced. Livestock production needs to be intensified in a responsible way (i.e., be made more efficient in the way that it uses natural resources). Wasted food represents a waste of all the emissions generated during the course of producing and distributing that food. Mitigation measures include: eat no more than needed to maintain a healthy body weight; eat seasonal, robust, field-grown vegetables rather than protected, fragile foods prone to spoilage and requiring heating and lighting in their cultivation, refrigeration stage; consume fewer foods with low nutritional value e.g., alcohol, tea, coffee, chocolate and bottled water (these foods are not needed in our diet and need not be produced); shop on foot or over the Internet (reduced energy use). Reduction in food waste will not only pave the path for sustainable production but will also help in achieving sustainable consumption (Garnett, 2011). Reduce meat consumption to encourage more sustainable eating practices.							No direct interaction			Reducing food waste has secondary benefits like protecting soil from degradation, and decreasing pressure for land conversion into agriculture and thereby protecting biodiversity. The agricultural area that becomes redundant through the dietary transitions can be used for other agricultural purposes such as energy crop production, or will revert to natural vegetation. A global food transition to less meat, or even a complete switch to plant-based protein food, could have a dramatic effect on land use. Up to 2,700 Mha of pasture and 100 Mha of crop land could be abandoned (Quoted from Stehfest et al., 2009)				
		Khan et al., 2009; Ingram, 2011; Kummu et al., 2012; Haileselassie et al., 2013; Bajželj et al., 2014; Tilman and Clark, 2014; Walker et al., 2014; Ran et al., 2016					Stehfest et al., 2009; Steinfeld and Gerber, 2010; Garnett, 2011; Ingram, 2011; Beddington et al., 2012; Kummu et al., 2012; Bellarby et al., 2013; Dagevos and Voordouw, 2013; Smith, 2013; Bajželj et al., 2014; Hedenus et al., 2014; Tilman and Clark, 2014; West et al., 2014; Hiç et al., 2016; Lamb et al., 2016										Stehfest et al., 2009; Kummu et al., 2012				
	Land-based Greenhouse Gas Reduction and Soil Carbon Sequestration	**Water Efficiency and Pollution Prevention (6.3/6.4/6.6)**					**Ensure Sustainable Production Patterns (12.3)**										**Conservation of Biodiversity and Restoration of Land (15.1/15.5/15.9)**				
		↑ / ↓	[+1,-1]	📖📖📖	☺☺	★★★	↑	[+1]	📖	☺	★		[0]				↑ / ↓	[+1,-1]	📖📖📖	☺☺☺	★★★
		Soil carbon sequestration can alter the capacity of soils to store water, which impacts the hydrological cycle and could be positive or negative from a water perspective, dependent on existing conditions. CSA enrich linkages across sectors including management of water resources. Minimum tillage systems have been reported to reduce water erosion and thus sedimentation of water courses (Bustamante et al., 2014).					Millet or sorghum yield can double as compared with unimproved land by more than 1 tonne per hectare due to sustainable intensification. An integrated approach to safe applications of both conventional and modern agricultural biotechnologies will contribute to increased yield (Lakshmi et al., 2015).							No direct interaction			Agricultural intensification can promote conservation of biological diversity by reducing deforestation, and by rehabilitation and restoration of biodiverse communities on previously developed farm or pasture land. However, planting monocultures on biodiversity hot spots can have adverse side-effects, reducing biodiversity. Genetically modified crops reduce demand for cultivated land. Adaptation of integrated landscape approaches can provide various ecosystem services. CSA enrich linkages across sectors including management of land and bio-resources. Land sparing has the potential to be beneficial for biodiversity, including for many species of conservation concern, but benefits will depend strongly on the use of spared land. In addition, high yield farming involves trade-offs and is likely to be detrimental for wild species associated with farm land (Lamb et al., 2016).				
		Behnassi et al., 2014; Bustamante et al., 2014; P. Smith et al., 2016b					Campbell et al., 2014; Lakshmi et al., 2015										Lybbert and Sumner, 2010; Behnassi et al., 2014; Harvey et al., 2014; IPCC, 2014; Lamb et al., 2016)				

Environement-Other (continued)

6 CLEAN WATER AND SANITATION		Interaction	Score	Evidence	Agreement	Confidence
Agriculture and Livestock	**Greenhouse Gas Reduction from Improved Livestock Production and Manure Management Systems**	**Water Efficiency and Pollution Prevention (6.3/6.4/6.6)**				
		↑ / ↓	[+2,-1]	📖📖📖	☺☺☺	★★★
		Livestock efficiency measures are expected to reduce water required for livestock systems as well as associated livestock waste water flows. However, efficiency measures that include agricultural intensification could increase water demands locally, leading to increased water stress if the intensification is mismanaged. In scenarios where zero human-edible concentrate feed is used for livestock, freshwater use reduces by 21%.				
		Haileselassie et al., 2013; Schader et al., 2015; Kong et al., 2016; Ran et al., 2016				
Forest	**Reduced Deforestation, REDD+**	**Water Efficiency and Pollution Prevention (6.3/6.4/6.6)**				
		↑ / ↓	[+1,-1]	📖📖	☺☺	★★
		Forest management alters the hydrological cycle which could be positive or negative from a water perspective and is dependent on existing conditions. Conservation of ecosystem services indirectly could help countries maintain watershed integrity. Forests provide sustainable and regulated provision and help in water purification.				
		Zomer et al., 2008; Kibria, 2015; Bonsch et al., 2016; Gao and Bryan, 2017; Griffiths et al., 2017; Katila et al., 2017				
	Afforestation and Reforestation	**Enhance Water Quality (6.3)**				
		↑ / ↓	[+2,-1]	📖📖📖	☺☺☺	★★★
		Similar to REDD+, forest management alters the hydrological cycle which could be positive or negative from a water perspective and is dependent on existing conditions. Forest landscape restoration can have a large impact on water cycles. Strategic placement of tree belts in lands affected by dryland salinity can remediate the affected lands by modifying landscape water balances. Watershed scale reforestation can result in the restoration of water quality. Fast-growing species can increase nutrient input and water inputs that can cause ecological damage and alter local hydrological patterns. Reforestation of mixed native species and in carefully chosen sites could increase biodiversity and restore waterways, reducing run-off and erosion (Dooley and Kartha, 2018).				
		Zomer et al., 2008; Bustamante et al., 2014; Kibria, 2015; Lamb et al., 2016; Dooley and Kartha, 2018				

12 RESPONSIBLE CONSUMPTION AND PRODUCTION		Interaction	Score	Evidence	Agreement	Confidence
Agriculture and Livestock	**Greenhouse Gas Reduction from Improved Livestock Production and Manure Management Systems**	**Ensure Sustainable Production Patterns and Restructing Taxation (12.3/12c)**				
		↑	[+1]	📖📖	☺☺	★★
		In the future, many developed countries will see a continuing trend in which livestock breeding focuses on other attributes in addition to production and productivity, such as product quality, increasing animal welfare, disease resistance (Thornton, 2010). Diet composition and quality are key determinants of the productivity and feed-use efficiency of farm animals (Herrero, et al., 2013). Mechanisms for effecting behavioural change in livestock systems need to be better understood by implementing combinations of incentives and taxes simultaneously in different parts of the world (Herrero and Thornton, 2013). Reducing the amount of human-edible crops that are fed to livestock represents a reversal of the current trend of steep increases in livestock production, and especially of monogastrics, so would require drastic changes in production and consumption (Schader et al., 2015).				
		Thornton, 2010; Herrero and Thornton, 2013; Herrero et al., 2013; Schader et al., 2015				
Forest	**Reduced Deforestation, REDD+**	**Ensure Sustainable Consumption (12.3)**				
		↑	[+1]	📖	☺	★
		Reduce the human pressure on forests, including actions to address drivers of deforestation.				
		Bastos Lima et al., 2017				
	Afforestation and Reforestation		[0]			
		No direct interaction				

14 LIFE BELOW WATER		Interaction	Score	Evidence	Agreement	Confidence
Agriculture and Livestock	**Greenhouse Gas Reduction from Improved Livestock Production and Manure Management Systems**		[0]			
		No direct interaction				
Forest	**Reduced Deforestation, REDD+**		[0]			
		No direct interaction				
	Afforestation and Reforestation	**Marine Economies (14.7)/Marine Protection and Income Generation (14.1/14.2/14.4/14.5)**				
		↑	[+2]	📖	☺	★
		Mangroves would help to enhance fisheries and tourism businesses.				
		Kibria, 2015				

15 LIFE ON LAND		Interaction	Score	Evidence	Agreement	Confidence
Agriculture and Livestock	**Greenhouse Gas Reduction from Improved Livestock Production and Manure Management Systems**	**Restoration of Land (15.1)**				
		↑	[+1]	📖	☺	★
		Grasslands are valuable, but improved management is required as grass accounts for close to 50% of feed use in livestock systems . The scenario with 100% reduction of food-competing-feedstuffs resulted in a 335 Mha decrease in arable land area, which corresponds to a decrease of 22% in arable and 7% in the total agricultural area .				
		Herrero et al., 2013; Schader et al., 2015				
Forest	**Reduced Deforestation, REDD+**	**Conservation of Biodiversity, Sustainability of Terrestrial Ecosystems (15.2/15.3/15.4/15.5/15.9)**				
		↑	[+1]	📖📖📖	☺☺☺	★★★
		Policies and programmes for reducing deforestation and forest degradation for rehabilitation and restoration of degraded lands can promote conservation of biological diversity. Reduce the human pressure on forests, including actions to address drivers of deforestation. Efforts by the Government of Zambia to reduce emissions by REDD+ have contributed erosion control, ecotourism and pollination valued at 2.5% of the country's GDP.				
		Miles and Kapos, 2008; IPCC, 2014; Bastos Lima et al., 2015; Turpie et al., 2015; Epstein and Theuer, 2017; Katila et al., 2017				
	Afforestation and Reforestation	**Conservation of Biodiversity and Restoration of Land (15.1/15.5/15.9)**				
		↑	[+2]	📖📖📖📖	☺☺☺☺	★★★★
		Identified large amounts of land (749 Mha) globally as biophysically suitable and meeting the CDM eligibility criteria . Forest landscape restoration can conserve biodiversity and reduce land degradation. Mangroves reduce impacts of disasters (cyclones/storms/floods) acting as live seawalls and enhance forest resources/biodiversity. Forest goal can conserve/restore 3.9–8.8 m ha/year average, 77.2–176.9 m ha in total and 7.7–17.7 m ha /year in 2030 of forest area by 2030 (Wolosin, 2014). Forest and biodiversity conservation, protected area formation and forestry-based afforestation are practices that enhance resilience of forest ecosystems to climate change (IPCC, 2014). Strategic placement of tree belts in lands affected by dryland salinity can remediate the affected lands by modifying landscape water balances and protect livestock. It can restore biologically diverse communities on previously developed farmland . Large-scale restoration is likely to benefit ecosystem service provision, including recreation, biodiversity, conservation and flood mitigation. Reforestation of mixed native species and in carefully chosen sites could increase biodiversity, reducing run-off and erosion .				
		Zomer et al., 2008; Bustamante et al., 2014; IPCC, 2014; Kibria, 2015; Lamb et al., 2016; Epstein and Theuer, 2017; Dooley and Kartha, 2018				

Environement-Other (continued)

		6 CLEAN WATER AND SANITATION					12 RESPONSIBLE CONSUMPTION AND PRODUCTION					14 LIFE BELOW WATER					15 LIFE ON LAND				
		Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence
Forest	**Behavioural Response (Responsible Sourcing)**	**Water Efficiency and Pollution Prevention (6.3/6.4/6.6)**					**Ensure Sustainable Production Patterns (12.3)**										**Sustainability and Conservation (15.1/15.2/15.3)**				
		↑ / ↓	[+2,-1]	🕮	☺☺	★★	↑	[+1]	🕮	☺	★		[0]				↑ / ↓	[+1,-1]	🕮	☺	★
		Responsible sourcing will have co-benefits for water efficiency and pollution prevention if the sourcing strategies incorporate water metrics. There is a risk that shifting supply sources could lead to increased water use in another part of the economy. At local levels, forest certification programmes and practicing sustainable forest management provide freshwater supplies.					At local levels, forest certification programmes and practicing sustainable forest management provide the provision of raw materials for a 'low ecological footprint' economy.					No direct interaction					At the macro level, forest certification has done little to stem the tide of forest degradation, conversion of forest land to agriculture, and illegal logging—all of which remain serious threats to Indonesian forests (Bartley, 2010). At local levels, forest certification programmes and practicing sustainable forest management help in biodiversity protection.				
		van Oel and Hoekstra, 2012; Launiainen et al., 2014; Hontelez, 2016					Hontelez, 2016										Bartley, 2010; Hontelez, 2016				
Oceans	**Ocean Iron Fertilization**											**Nutrient Pollution, Ocean Acidification, Fish Stocks, MPAs, SISD (14.1/14.3/14.4/14.5/14.7)**									
			[0]					[0]				↑ / ↓	[+1,-2]	🕮🕮🕮	☺☺	★		[0]			
		No direct interaction					No direct interaction					OIF could exacerbate or reduce nutrient pollution, increase the likelihood of mid-water deoxygenation, increase ocean acidification, might contribute to the rebuilding of fish stocks in producing plankton, therefore generating benefits for SISD, but might also be in conflict with designing MPAs.					No direct interaction				
												Gnanadesikan et al., 2003; Jin and Gruber, 2003; Denman, 2008; Lampitt et al., 2008; Smetacek and Naqvi, 2008; Güssow et al., 2010; Oschlies et al., 2010; Trick et al., 2010; Williamson et al., 2012									
	Blue Carbon	**Integrated Water Resources Management (6.3/6.5)**										**Ocean Acidification, Nutrient Pollution (14.3/14.1)**					**Conservation of Biodiversity and Restoration of Land (15.1/15.2/15.3/15.4/15.9)**				
		↑	[+2]	🕮	☺	★		[0]				↑ / ~	[+2,0]	🕮	☺☺☺	★★★	↑	[+3]	🕮	☺☺☺☺	★★★★
		Development of blue carbon resources (coastal and marine vegetated ecosystems) can lead to coordinated management of water in coastal areas.					No direct interaction					Mangroves could buffer acidification in their immediate vicinity; seaweeds have not been able to mitigate the effect on ocean foraminifera.					Average difference of 31 mm per year in elevation rates between areas with seagrass and unvegetated areas (case study areas: Scotland, Kenya, Tanzania and Saudi Arabia); mangroves fostering sediment accretion of about 5mm a year.				
		Vierros et al., 2015										Pettit et al., 2015; Sippo et al., 2016					Alongi, 2012; Potouroglou et al., 2017				
	Enhanced Weathering											**Ocean Acidification, Nutrient Pollution (14.3/14.1)**					**Protect Inland Freshwater Systems (14.1)**				
			[0]					[0]				↑ / ↓	[+2,-1]	🕮🕮🕮	☺☺☺	★★★	↓	[-2]	🕮	☺	★
		No direct interaction					No direct interaction					Enhanced weathering (either by spreading lime or quicklime, in combination with CCS, over the ocean or olivine at beaches or the catchment area of rivers) opposes ocean acidification. "End-of-century ocean acidification is reversed under RCP4.5 and reduced by about two-thirds under RCP8.5; additionally, surface ocean aragonite saturation state, a key control on coral calcification rates, is maintained above 3.5 throughout the low latitudes, thereby helping maintain the viability of tropical coral reef ecosystems ." However, marine biology would also be affected, in particular if spreading olivine is used, which works like ocean (iron) fertilization.					Olivine can contain toxic metals such as nickel which could accumulate in the environment or disrupt the local ecosystem by changing the pH of the water (in case of spreading in the catchment area of rivers).				
												Köhler et al., 2010, 2013; Hartmann et al., 2013; Paquay and Zeebe, 2013; P. Smith et al., 2016a; Taylor et al., 2016					Hartmann et al., 2013				

		Interaction	Score	Evidence	Agreement	Confidence
Industry	**Accelerating Energy Efficiency Improvement**	**Energy Savings (7.1/7.3/7.a/7.b)**				
		↑	[+2]	📖📖📖📖	☺☺☺	★★★★
		Energy efficiency leads to reduced energy demand and hence energy supply and energy security, reduces import. Positive rebound effect can raise demand but to a very less extent due to low rebound effect in industry sector in many countries and by appropriate mix of industries (China) can maintain energy savings gain. Supplying surplus energy to cities is also happening, proving maintenance culture, switching off idle equipment helps in saving energy (e.g Ghana).				
		Apeaning and Thollander, 2013; Chakravarty et al., 2013; IPCC, 2014; Karner et al., 2015; Zhang et al., 2015; Li et al., 2016; Fernando et al., 2017; Wesseling et al., 2017				
	Low-Carbon Fuel Switch	**Sustainable and Modern (7.2/7.a)**				
		↑	[+2]	📖	☺	★
		Industries are becoming suppliers of energy, waste heat, water and roof tops used for solar energy generation, and therefore helping to reduce primary energy demand. CHP in chemical industries can help in providing surplus power in the grid.				
		Karner et al., 2015; Griffin et al., 2018				
	Decarbonization/CCS/CCU	**Affordable and Sustainable Energy Sources**				
		↑/↓	[+2,-2]	📖📖	☺☺	★★
		CCS for EPIs can be incremental, but need additional space and can need additional energy, sometimes compensating for higher efficiency. For example, recirculating blast R furnace and CCS for iron steel means high energy demand; electric melting in glass can mean higher electricity prices; in the paper industry, new separation and drying technologies are key to reducing the energy intensity, allowing for carbon neutral operation in the future; bio-refineries can reduce petro-refineries; DRI in iron and steel with H2 encourages innovation in hydrogen infrastructure; and the chemicals industry also encourage renewable electricity and hydrogen as bio-based polymers can increase biomass price.				
		Griffin et al., 2017; Wesseling et al., 2017				

		Interaction	Score	Evidence	Agreement	Confidence
Industry	**Accelerating Energy Efficiency Improvement**	**Reduces Unemployment (8.2/8.3/8.4/8.5/8.6)**				
		↑	[+1]	📖📖	☺☺☺	★★★
		Unemployment rate reduction from 25% to 12% in South Africa. Enhances firm productivity and technical and managerial capacity of the employees. New jobs for managing energy efficiency opens up opportunities in energy service delivery sector.				
		Altieri et al., 2016; Fernando et al., 2017; Johansson and Thollander, 2018				
	Low-Carbon Fuel Switch	**Economic Growth with Decent Employment (8.1/8.2/8.3/8.4)**				
		↑	[+2]	📖📖📖📖	☺☺☺☺	★★★★
		The circular economy instead of linear global economy can achieve climate goals and can help in economic growth through industrialization, which saves on resources and the environment and supports small, medium and even large industries, which can lead to employment generation. So new regulations, incentives and a revised tax regime can help in achieving the goal.				
		Stahel, 2013, 2017; Liu et al., 2014; Leider et al., 2015; Supino et al., 2015; Zheng et al., 2016; Fan et al., 2017; Shi et al., 2017				
	Decarbonization/CCS/CCU	**Decouple Growth from Environmental Degradation (8.1/8.2/8.4)**				
		↑	[+2]	📖📖	☺☺☺	★★★
		EPI s are important players for economic growth. Deep decarbonization of EPIs through radical innovation is consistent with well-below 2°C scenarios.				
		Denis-Ryan et al., 2016; Åhman et al., 2017; Wesseling et al., 2017				

		Interaction	Score	Evidence	Agreement	Confidence
Industry	**Accelerating Energy Efficiency Improvement**	**Infrastructure Renewal (9.1/9.3/9.5/9.a)**				
		↑	[+1]	📖📖	☺☺	★★
		Transitioning to a more renewables-based energy system that is highly energy efficient is well-aligned with the goal of upgrading energy infrastructure and making the energy industry more sustainable. At the same time, infrastructure upgrades in other parts of the economy, such as modernized telecommunications networks, can create the conditions for a successful expansion of renewable energy and energy efficiency measures (e.g., smart metering and demand-side management; McCollum et al., 2018).				
		Riahi et al., 2012; Apeaning and Thollander, 2013; Goldthau, 2014; Bhattacharyya et al., 2016; Meltzer, 2016; McCollum et al., 2018				
	Low-Carbon Fuel Switch	**Innovation and New Infrastructure (9.2/9.3/9.4/9.5/9.a)**				
		↑	[+2]	📖📖📖📖	☺☺☺☺	★★★★
		A circular economy instead of linear global economy is helping new innovation, and infrastructure can achieve climate goals and can help in economic growth through industrialization which saves on resources and the environment and supports small, medium and even large industries, which can lead to employment generation. So new regulations, incentives and revised tax regime can help in achieving the goal.				
		Stahel, 2013, 2017; Liu et al., 2014; Leider et al., 2015; Supino et al., 2015; Zheng et al., 2016; Fan et al., 2017; Shi et al., 2017				
	Decarbonization/CCS/CCU	**Innovation and New Infrastructure (9.2/9.4/9.5)**				
		↑	[+2]	📖	☺☺☺☺	★★★★
		Deep decarbonization through radical technological change in EPI will lead to radical innovations, for example, in completely changing industries' innovation strategies, plants and equipment, skills, production techniques, design, etc. Radical CCS will need new infrastructure to transport CO_2.				
		Denis-Ryan et al., 2016; Åhman et al., 2017; Wesseling et al., 2017; Griffin et al., 2018				

		Interaction	Score	Evidence	Agreement	Confidence
Industry	**Accelerating Energy Efficiency Improvement**	**Sustainable Cities (15.6/15.8/15.9)**				
		↑	[+2]	📖	☺	★
		Industries are becoming suppliers of energy, waste heat and water to neighbourial human settlements, and therefore there is a reduced primary energy demand, which also makes towns and cities grow sustainably.				
		Karner et al., 2015				
	Low-Carbon Fuel Switch	**Sustainable Cities (15.6/15.8/15.9)**				
		↑	[+2]	📖	☺	★
		Industries are becoming suppliers of energy, waste heat, water and roof tops used for solar energy generation, and supply to neighbourial human settlements, therefore reducing primary energy demand, which also makes towns and cities grow sustainably.				
		Karner et al., 2015				
	Decarbonization/CCS/CCU		[0]			
		No direct interaction				

Economic-Demand (continued)

7

		Interaction	Score	Evidence	Agreement	Confidence
Buildings	Behavioural Response	**Saving Energy, Improvement in Energy Efficiency (7.3/7.a/7.b)**				
		↑	[+2]	📖📖📖📖	☺☺☺☺	★★★
		Lifestyle change measures and adoption behaviour affect residential energy use and implementation of efficient technologies as residential HVAC systems. Also, social influence can drive energy savings in users exposed to energy consumption feedback. Effect of autonomous motivation on energy savings behaviour is greater than that of other more established predictors, such as intentions, subjective norms, perceived behavioural control and past behaviour. Use of a hybrid engineering approach using social psychology and economic behaviour models are suggested for residential peak electricity demand response. However, some take-back in energy savings can happen due to rebound effects unless managed appropriately or accounted for welfare improvement. Adjusting thermostats helps in saving energy. Uptake of energy efficient appliances by households with an introduction to appliance standards, training, promotional material dissemination and the desire to save on energy bills are helping to change acquisition behaviour.				
		Chakravarty et al., 2013; Gyamfi et al., 2013; Hori et al., 2013; Huebner et al., 2013; Jain et al., 2013; Sweeney et al., 2013; Webb et al., 2013; Yue et al., 2013; Anda and Temmen, 2014; Allen et al., 2015; Noonan et al., 2015; de Koning et al., 2016; Isenhour and Feng, 2016; Santarius et al., 2016; Song et al., 2016; van Sluisveld et al., 2016; Sommerfeld et al., 2017; Zhao et al., 2017; Roy et al., 2018				
	Accelerating Energy Efficiency Improvement	**Increase in Energy Savings (7.3)**				
		↑	[+2]	📖📖📖	☺☺☺	★★★★
		There is high agreement among researchers based on a great deal of evidence across various countries that energy efficiency improvement reduces energy consumption and therefore leads to energy savings (e.g., efficient stoves save bioenergy). Countries with higher hours of use due to higher ambient temperatures or more carbon intensive electricity grids benefit more from available improvements in energy efficiency and use of refrigerant transition.				
		McLeod et al., 2013; Noris et al., 2013; Bhojvaid et al., 2014; Holopainen et al., 2014; Kwong et al., 2014; Yang et al., 2014; Cameron et al., 2015; Liddell and Guiney, 2015; Shah et al., 2015; Berrueta et al., 2017; Kim et al., 2017; Salvalai et al., 2017				

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		Interaction	Score	Evidence	Agreement	Confidence
Buildings	Behavioural Response	**Progressively Improve Resource Efficiency (8.4), Employment Opportunities (8.2/8.3/8.5/8.6)**				
		↑	[+2]	📖	☺	★
		Behavioural change programmes help in sustaining energy savings through new infrastructure developments.				
		Anda and Temmen, 2014				
	Accelerating Energy Efficiency Improvement	**Employment Opportunities (8.2/8.3/8.5/8.6)/Strong Financial Institutions (8.10)**				
		↑ / ↓	[+2,-1]	📖📖	☺	★★
		Deploying renewables and energy efficient technologies, when combined with other targeted monetary and fiscal policies, can help spur innovation and reinforce local, regional and national industrial and employment objectives. Gross employment effects seem likely to be positive; however, uncertainty remains regarding the net employment effects due to several uncertainties surrounding macro-economic feedback loops playing out at the global level. Moreover, the distributional effects experienced by individual actors may vary significantly. Strategic measures may need to be taken to ensure that a large-scale switch to renewable energy minimizes any negative impacts on those currently engaged in the business of fossil fuels (e.g., government support could help businesses re-tool and workers re-train). To support clean energy and energy efficiency efforts, strengthened financial institutions in developing country communities are necessary for providing capital, credit and insurance to local entrepreneurs attempting to enact change (McCollum et al., 2018).				
		Babiker and Eckaus, 2007; Fankhauser and Tepic, 2007; Gohin, 2008; Frondel et al., 2010; Dinkelman, 2011; Guivarch et al., 2011; Jackson and Senker, 2011; Borenstein, 2012; Creutzig et al., 2013; Blyth et al., 2014; Clarke et al., 2014; Dechezleprêtre and Sato, 2014; Bertram et al., 2015; Johnson et al., 2015; IRENA, 2016; A. Smith et al., 2016; Berrueta et al., 2017; McCollum et al., 2018				

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		Interaction	Score	Evidence	Agreement	Confidence
Buildings	Behavioural Response	**Innovation and New Infrastructure (9.2/9.4/9.5)**				
		↑	[+2]	📖📖	☺☺	★★
		Adoption of smart meters and smart grids following community-based social marketing help with infrastructure expansion. People are adopting solar rooftops, white roof/vertical garden/green roofs at much faster rates due to new innovations and regulations.				
		Anda and Temmen, 2014; Roy et al., 2018				
	Accelerating Energy Efficiency Improvement	**Innovation and New Infrastructure (9.2/9.4/9.5)**				
		↑	[+2]	📖📖	☺☺	★★
		Adoption of smart meters and smart grids following community-based social marketing help in infrastructure expansion. Statutory norms to enhance energy and resource efficiency in buildings is encouraging green building projects.				
		Anda and Temmen, 2014; Roy et al., 2018				

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		Interaction	Score	Evidence	Agreement	Confidence
Buildings	Behavioural Response	**Sustainable Cities (15.6/15.8/15.9)**				
		↑	[+2]	📖📖	☺☺	★★
		Behavioural change programmes help in making cities more sustainable.				
		Anda and Temmen, 2014; Roy et al., 2018				
	Accelerating Energy Efficiency Improvement	**Urban Environmental Sustainability (11.3/11.6/11.b/11.c)**				
		↑	[+2]	📖📖	☺☺☺	★★★★
		Renewable energy technologies and energy efficient urban infrastructure solutions (e.g., public transit) can also promote urban environmental sustainability by improving air quality and reducing noise. Efficient transportation technologies powered by renewably based energy carriers will be a key building block of any sustainable transport system (McCollum et al., 2018). Green buildings help in sustainable construction.				
		Creutzig et al., 2012; Kahn Ribeiro et al., 2012; Riahi et al., 2012; Bongardt et al., 2013; Grubler and Fisk, 2013; Raji et al., 2015; Kim et al., 2017; McCollum et al., 2018				

Economic-Demand (continued)

		7 AFFORDABLE AND CLEAN ENERGY	8 DECENT WORK AND ECONOMIC GROWTH	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	11 SUSTAINABLE CITIES AND COMMUNITIES
		Interaction / Score / Evidence / Agreement / Confidence	Interaction / Score / Evidence / Agreement / Confidence	Interaction / Score / Evidence / Agreement / Confidence	Interaction / Score / Evidence / Agreement / Confidence
Buildings	**Improved Access and Fuel Switch to Modern Low-carbon Energy**	**Meeting Energy Demand** ↑ [+2] 📖📖📖 ☺☺☺ ★★★ Renewable energies could potentially serve as the main source to meet energy demand in rapidly growing developing country cities. Ali et al. (2015) estimated the potential of solar, wind and biomass renewable energy options to meet part of the electricity demand in Karachi, Pakistan. Li et al., 2013; Peng and Lu, 2013; Pietzcker, 2013; Pode, 2013; Yanine and Sauma, 2013; Zulu and Richardson, 2013; Connolly et al., 2014; Creutzig et al., 2014; Pietzcker et al., 2014; Ali et al., 2015; O'Mahony and Dufour, 2015; Abanda et al., 2016; Mittlefehldt, 2016; Biligii et al., 2017; Byravan et al., 2017; Islar et al., 2017; Ozturk et al., 2017	**Sustainable Economic Growth and Employment** ↑ [+2] 📖📖 ☺☺☺ ★★ Creutzig et al. (2014) assessed the potential for renewable energies in the European region. They found that a European energy transition with a high-level of renewable energy installations in the periphery could act as an economic stimulus, decrease trade deficits and possibly have positive employment effects. Provision of energy access can play a critical enabling role for new productive activities, livelihoods and employment. Reliable access to modern energy services can have an important influence on productivity and earnings (McCollum et al., 2018). Grogan and Sadanand, 2013; Pueyo et al., 2013; Rao et al., 2013; Chakravorty et al., 2014; Creutzig et al., 2014; Ali et al., 2015; Bernard and Torero, 2015; Byravan et al., 2017; McCollum et al., 2018	**Innovation and New Infrastructure (9.2/9.4/9.5)** ↑ [+2] 📖📖 ☺☺ ★★ Adoption of smart meters and smart grids following community-based social marketing help in infrastructure expansion. Statutory norms to enhance energy and resource efficiency in buildings is encouraging green building projects. Introduction of incentives and norms for solar rooftops/white/green roofs in cities are helping to accelerate innovation and the expansion of infrastructure. Roy et al., 2018; Anda and Temmen, 2014	**Housing (11.1)** ↑ [+3] 📖📖📖 ☺☺☺ ★★★★ Ensuring access to basic housing services implies that households have access to modern energy forms. (Quote from McCollum et al., 2018) Solar roof tops in Macau make cities sustainable. Introduction of incentives and norms for solar/white/green rooftops in cities are helping to accelerate the expansion of the infrastructure. Bhattacharyya et al., 2016; Song et al., 2016; UN, 2016; McCollum et al., 2018; Roy et al., 2018
Transport	**Behavioural Response**	**Energy Savings (7.3/7.a/7.b)** ↑ [+2] 📖📖 ☺☺ ★★ Behavioural responses will reduce the volume of transport needs and, by extension, energy demand. Figueroa and Ribeiro, 2013; Ahmad and Puppim de Oliveira, 2016	**Promote Sustained, Inclusive Economic Growth (8.3)** ↓ [-2] 📖📖📖 ☺☺☺ ★★★ Policy contradictions (e.g., standards, efficient technologies leading to increased electricity prices leading the poor to switch away from clean(er) fuels) and unintended outcomes (e.g., redistribution of income generated by carbon taxes) results in contradictions of the primary aims of (productive) job creation and poverty alleviation, and in trade-offs between mitigation, adaptation and development policies. Detailed assessments of mitigation policies consequences requires developing methods and reliable evidence to enable policymakers to more systematically identify how different social groups may be affected by the different available policy options. Lucas and Pangbourne, 2014; Suckall et al., 2014; Klausbruckner et al., 2016	**Build Resilient Infrastructure (9.1)** ↑ [+2] 📖📖 ☺☺ ★★ As people prefer more mass transportation – train lines, tram lines, BRTs, gondola lift systems, bicycle-sharing systems and hybrid buses – and telecommuting, the need for new infrastructure increases. Dulac, 2013; Aamaas and Peters, 2017; Martínez-Jaramillo et al., 2017; Xylia and Silveira, 2017	**Make Cities and Human Settlements Inclusive, Safe, Resilient** ↑ [+2] 📖📖 ☺☺ ★★ Climate change threatens to worsen poverty, therefore pro-poor mitigation policies are needed to reduce this threat; for example, investing more and better in infrastructure by leveraging private resources and using designs that account for future climate change and the related uncertainty. Ahmad and Puppim de Oliveira, 2016; Hallegatte et al., 2016a
	Accelerating Energy Efficiency Improvement	**Energy Savings (7.3/7.a/7.b)** ↑ [+2] 📖 ☺ ★ Accelerating efficiency in tourism transport reduces energy demand (China). Shukxin et al., 2016	**Promote Sustained, Inclusive Economic Growth (8.3)** ↑/↓ [+2,-2] 📖📖 ☺☺ ★★ Significant opportunities to slow travel growth and improve efficiency exist and, similarly, alternatives to petroleum exist but have different characteristics in terms of availability, cost, distribution, infrastructure, storage and public acceptability. Production of new technologies, fuels and infrastructure can favour economic growth; however, efficient financing of increased capital spending and infrastructure is critical. Gouldson et al., 2015; Karkatsoulis et al., 2016	**Build Resilient Infrastructure (9.1)** ↑ [+2] 📖📖 ☺☺ ★★ Combining promotion of mass transportation – train lines, tram lines, BRTs, gondola lift systems, bicycle-sharing systems and hybrid buses – and telecommuting reduces traffic and significantly contributes to meeting climate targets. A comprehensive package of complementary mitigation options is necessary for deep and sustained emissions reductions. In Sweden, a public bus fleet is aiming more towards decarbonization than efficiency. Dulac, 2013; Aamaas and Peters, 2017; Martínez-Jaramillo et al., 2017; Xylia and Silveira, 2017	**Make Cities Sustainable (11.2/11.3)** ↑ [+2] 📖 ☺ ★ The two most important elements of making cities sustainable are efficient buildings and transport (e.g., Macau). Song et al., 2016
	Improved Access and Fuel Switch to Modern Low-carbon Energy	**Increase Share of Renewable (7.2)** ↑ [+2] 📖📖 ☺☺ ★★ Biofuel increases share of the renewables but can perform poorly if too many countries increase their use of biofuel, whereas electrification performs best when many other countries implement this technology. The strategies are not mutually exclusive and simultaneous implementation of some provides synergies for national energy security. Therefore, it is important to consider the results of material and contextual factors that co-evolve. Electric vehicles using electricity from renewables or low carbon sources combined with e-mobility options such as trolley buses, metros, trams and electro buses, as well as promote walking and biking, especially for short distances, need consideration. Ajanovic, 2015; Månsson, 2016; Alahakoon, 2017; Wolfram et al., 2017	**Promote Sustained, Inclusive Economic Growth (8.3)** ↑/↓ [+2,-2] 📖📖 ☺☺ ★★ The decarbonization of the freight sector tends to occur in the second part of the century, and the sector decarbonizes by a lower extent than the rest of the economy. Decarbonizing road freight on a global scale remains a challenge even when notable progress in biofuels and electric vehicles has been accounted for. IPCC, 2014; Creutzig et al., 2015; Carrara and Longden, 2017	**Help Building Inclusive Infrastructure (9.1/9.a)** ↑ [+2] 📖📖📖 ☺☺☺ ★★★ Lack of appropriate infrastructure leads to limited access to jobs for the urban poor (Africa, Latin America, India). Figueroa et al., 2013; Gouldson et al., 2015; Vasconcellos and Mendonça, 2016; Lall et al., 2017	**Make Cities and Human Settlements Inclusive, Safe, Resilient** ↑ [+2] 📖📖 ☺☺ ★★ In rapidly growing cities, the carbon savings from investments at scale, in cost-effective low-carbon measures, could be quickly overwhelmed – in as little as 7 years – by the impacts of sustained population and economic growth, highlighting the need to build capacities that enable the exploitation not only of the economically attractive options in the short term but also of those deeper and more structural changes that are likely to be needed in the longer term. With hybrid electric vehicles and plug-in electric vehicles, there is the emergence of new concepts in transportation, such as electric highways. Figueroa et al., 2013; Gouldson et al., 2015; Vasconcellos and Mendonça, 2016; Alahakoon, 2017

Economic-Supply

		7 AFFORDABLE AND CLEAN ENERGY					8 DECENT WORK AND ECONOMIC GROWTH					9 INDUSTRY, INNOVATION AND INFRASTRUCTURE					11 SUSTAINABLE CITIES AND COMMUNITIES				
		Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence
Replacing Coal	**Non-biomass Renewables - solar, wind, hydro**	**Sustainable and Modern Energy (7.2/7.a)**					**Innovation and Growth (8.1/8.2/8.4)**					**Inclusive and Sustainable Industrialization (9.2/9.4)**					**Disaster Preparedness and Prevention (11.5)**				
		↑	[+3]	📖📖📖	☺☺☺	★★★★	~	[0]	📖📖	☺☺	★★	~ / ↓	[0,-1]	📖📖	☺☺☺	★★	↑	[+2]	📖📖📖	☺☺	★★★
		Decarbonization of the energy system through an upscaling of renewables will greatly facilitate access to clean, affordable and reliable energy. Hydropower plays an increasingly important role for the global electricity supply. This mitigation option is in line with the targets of SDG7 under the caveat of a transition to modern biomass.					Decarbonization of the energy system through an upscaling of renewables and energy efficiency is consistent with sustained economic growth and resource decoupling. Long-term scenarios point towards slight consumption losses caused by a rapid and pervasive expansion of such energy solutions. Whether sustainable growth, as an overarching concept, is attainable or not is more disputed in the literature. Existing literature is also undecided as to whether or not access to modern energy services causes economic growth (McCollum et al., 2018).					A rapid upscaling of renewable energies could necessitate the early retirement of fossil energy infrastructure (e.g., power plants, refineries, pipelines) on a large scale. The implications of this could in some cases be negative, unless targeted policies can help alleviate the burden on industry (McCollum et al., 2018).					Deployment of renewable energy and improvements in energy efficiency globally will aid climate change mitigation efforts, and this, in turn, can help to reduce the exposure of people to certain types of disasters and extreme events (McCollum et al., 2018).				
		Rogelj et al., 2013; Cherian, 2015; Jingura and Kamusoko, 2016					Jackson and Senker, 2011; Bonan et al., 2014; Clarke et al., 2014; NCE, 2014; OECD, 2017; York and McGee, 2017; McCollum et al., 2018					Fankhaeser et al., 2008; McCollum et al., 2008; Guivarch et al., 2011; Bertram et al., 2015; Johnson et al., 2015					Tully, 2006; Riahi et al., 2012; Daut et al., 2013; IPCC, 2014; Hallegatte et al., 2016b; McCollum et al., 2018				
	Increased Use of Biomass	**Sustainable and Modern Energy (7.2/7.a)**					**Innovation and Growth (8.1/8.2/8.4)**					**Innovation and New Infrastructure (9.2/9.4/9.5)**									
		↑	[+3]	📖📖📖	☺☺☺	★★★	↑	[+1]	📖	☺	★	↑	[+1]	📖📖	☺☺☺	★★		[0]			
		Increased use of modern biomass will facilitate access to clean, affordable and reliable energy. This mitigation option is in line with the targets of SDG7.					Decarbonization of the energy system through an upscaling of renewables will greatly facilitate access to clean, affordable and reliable energy.					Access to modern and sustainable energy will be critical to sustain economic growth.					No direct interaction				
		Rogelj et al., 2013; Cherian, 2015; Jingura and Kamusoko, 2016					Jingura and Kamusoko, 2016					Jingura and Kamusoko, 2016; Shahbaz et al., 2016									
	Nuclear/Advanced Nuclear	**Sustainable and Modern Energy (7.2/7.a)**					**Innovation and Growth (8.1/8.2/8.4)**					**Innovation and New Infrastructure (9.2/9.4/9.5)**									
		↑	[1]	📖📖	☺	★★	↑	[1]	📖📖	☺	★★	↓	[-1]	📖📖	☺☺☺	★★★		[0]			
		Increased use of nuclear power can provide stable baseload power supply and reduce price volatility.					Local employment impact and reduced price volatility.					Legacy cost of waste and abandoned reactors.					No direct interaction				
		IPCC, 2014					IPCC, 2014					Marra and Palmer, 2011; Greenberg et al., 2013; Schwenk-Ferrero, 2013; Skipperud et al., 2013; Tyler et al., 2013; IPCC, 2014									
	CCS: Bioenergy	**Sustainable and Modern Energy (7.2/7.a)**					**Innovation and Growth (8.1/8.2/8.4)**					**Innovation and New Infrastructure (9.2/9.4/9.5)**									
		↑	[+2]	📖📖📖	☺☺☺	★★★	↑	[+1]	📖	☺	★	↑	[+1]	📖	☺	★		[0]			
		Increased use of modern biomass will facilitate access to clean, affordable and reliable energy.					See positive impacts of bioenergy use.					See positive impacts of bioenergy use and CCS/CCU in industrial demand.					No direct interaction				
		IPCC, 2014																			
Advanced Coal	**CCS: Fossil**	**Ensure energy access and promote investment in new technologies (7.1/7.b)**					**Innovation and Growth (8.1/8.2/8.4)**					**Innovation and New Infrastructure (9.2/9.4/9.5)**									
		↑	[+2]	📖📖📖	☺☺☺	★★★	↓	[-1]	📖📖📖	☺☺☺	★★★	↑	[+1]	📖	☺	★		[0]			
		Advanced and cleaner fossil fuel technology is in line with the targets of SDG7.					Lock-in of human and physical capital in the fossil resources industry.					See positive impacts of CCS/CCU in industrial demand.					No direct interaction				
		IPCC, 2014					IPCC, 2005, 2014; Benson and Cole, 2008; Fankhaeser et al., 2008; Vergragt et al., 2011; Markusson et al., 2012; Shackley and Thompson, 2012; Bertram et al., 2015; Johnson et al., 2015														

Economic-Other

		Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence	Interaction	Score	Evidence	Agreement	Confidence
Agriculture and Livestock	**Behavioural Response: Sustainable Healthy Diets and Reduced Food Waste**	**Energy Efficiency, Universal Access (7.1/7.3)**					**Sustained and Inclusive Economic Growth (8.2)**					**Infrastructure Building and Promotion of Inclusive Industrialization (9.1/9.2)**									
		↑	[+1]	🕮	☺	★	↑	[+1]	🕮🕮🕮	☺☺☺	★★★	↑	[+1]	🕮🕮🕮	☺☺☺	★★★		[0]			
		Reducing global food supply chain losses have several important secondary benefits like conserving energy.					23–24% of total cropland and fertilizers are used to produce losses. So reduction in food losses will help to diversify these valuable resources into other productive activities.					By targeting infrastructure, processing and distribution losses, wastage in food systems can be minimized. 23–24% of total cropland and fertilizers are used to produce losses. So reduction in food losses will help to diversify these valuable resources into other productive activities.							No interaction		
		Kummu et al., 2012					Kummu et al., 2012; Hiç et al., 2016					Ingram, 2011; Beddington et al., 2012; Kummu et al., 2012; Hiç et al., 2016; Lamb et al., 2016									
	Land-based Greenhouse Gas Reduction and Soil Carbon Sequestration	**Sustainable and Modern Energy (7.b)**					**Sustainable Growth (8.2)**					**Infrastructure Building, Promotion of Inclusive Industrialization and Innovation (9.1/9.2/9.5/9.b)**									
		↑	[+1]	🕮🕮🕮	☺☺☺	★★★	↑ / ↓	[+2,-1]	🕮🕮	☺☺	★★	↑ / ↓	[+2,-2]	🕮🕮🕮	☺☺☺	★★★		[0]			
		Conventional agricultural biotechnology methods such as energy efficient farming can help in sequestration of soil carbon. Modern biotechnologies such as green energy and N-efficient GM crops can also help in C-sequestration. Biotech crops allow farmers to use less – and environmentally friendly – energy and practice soil carbon sequestration. Biofuels, both from traditional and GMO crops, such as sugar cane, oilseed, rapeseed and jatropha, can be produced. Green energy programmes through plantations of perennial nonedible oilseed producing plants and production of biodiesel for direct use in the energy sector or blending biofuels with fossil fuels in certain proportions can thereby minimize fossil fuel use. (Quoted from Lakshmi et al., 2015) GM crops reduce demand for fossil fuel-based inputs.					Many developing countries including Gulf States will benefit from CSA given the central role of agriculture in their economic and social development. (Quoted from Behnassi et al. 2014). Low commodity prices have reduced the incentive to invest in yield growth and have led to declining farm labour and farm capital investment. (Quoted from Lamb et al., 2016)					Reduced research support and delayed industrialization will have an adverse effect on food security and nourishment of children. Organic farming technologies utilizing bio-based fertilizers (composted human and animal manure) are some of the conventional biotechnological options for reducing artificial fertilizer use (Lakshmi et al., 2015). CSA requires huge financial investment and institutional innovation. CSA is committed to new ways of engaging in participatory research and partnerships with producers (Steenwerth et al., 2014). Technologies used on-farm and during food processing to increase productivity which also helps in adaptation and/or mitigation are new, so convincing potential customers is difficult. Also, low-awareness of CSA, inaccessible language, high costs, lack of verified impact of technologies, hard to reach and train farmers, low consumer demand and unequal distribution of costs/benefits across supply chains are barriers to CSA technology adoption (Long et al., 2016). Low commodity prices have reduced the incentive to invest in yield growth and have led to declining investment in research and development (Lamb et al.,							no direct interaction		
		Johnson et al., 2007; Sarin et al., 2007; Treasury, 2009; Jain and Sharma, 2010; Lybbert and Sumner, 2010; Mtui, 2011; Lakshmi et al.,					Behnassi et al., 2014; Lamb et al., 2016					Evenson, 1999; Behnassi et al., 2014; Steenwerth et al., 2014; Lakshmi et al., 2015; Lamb et al., 2016; Long et al., 2016									
	Greenhouse Gas Reduction from Improved Livestock Production and Manure	**Energy Efficiency (7.3)**					**Sustainable Economic Growth (8.4)**					**Technological Upgradation and Innovation (9.2)**									
		↑	[+1]	&	J	«	↑	[+1]	&	J	«	↑	[+2]	🕮🕮🕮	☺☺☺	★★★		[0]			
		Scenarios where zero human-edible concentrate feed is used for livestock, non-renewable energy use is reduced by 36%.					Exploiting the increasingly decoupled interactions between crops and livestock could be beneficial for promoting structural changes in the livestock sector and is a prerequisite for the sustainable growth of the sector. (Quoted from Herrero et al., 2013)					Complete genome maps for poultry and cattle now exist, and these open up the way to possible advances in evolutionary biology, animal breeding and animal models for human diseases. Genomic selection should be able to at least double the rate of genetic gain in the dairy industry. (Quoted from Thornton, 2010) Nanotechnology, biogas technology and separation technologies are disruptive technologies that enhance biogas production from anaerobic digesters or to reduce							No direct interaction		
		Schader et al., 2015					Herrero and Thornton, 2013; Herrero et al., 2013					Sansoucy, 1995; Burton, 2007; Thornton, 2010									

Economic-Other (continued)

7 AFFORDABLE AND CLEAN ENERGY

		Interaction	Score	Evidence	Agreement	Confidence
Forest	**Reduced Deforestation, REDD+**	**Energy Efficiency (7.3)**				
		↑/↓	[+1,-1]	🕮	☺	★
		Consider the entire sinks and reservoirs of GHG while developing the nationally appropriate mitigation actions. For countries with a significant contribution of forest degradation (and GHG emissions) from wood fuels, this should be considered. (Quoted from Bastos Lima et al., 2017). Biomass for energy is recognized as often being inefficient, and is often harvested in an unsustainable manner, but is a renewable energy source.				
		Bastos Lima et al., 2017; Katila et al., 2017				
	Afforestation and Reforestation	**Energy Conservation (7.3/7.b)**				
		↑	[+1]	🕮	☺	★
		The US Forest Service estimates that an average NYC street tree (urban afforestation) produces 209 USD in annual benefits, which is primarily driven by aesthetic (90 USD per tree) and energy savings (from shade) benefits (47.63 USD per tree).				
		Jones and McDermott, 2018				
	Behavioural Response (Responsible Sourcing)	**Universal Access (7.3)**				
		↑	[+1]	🕮	☺	★
		The trade of wood pellets from clean wood waste should be facilitated with less administrative import barriers by the EU, in order to have this new option seriously accounted for as a future resource for energy. (Quoted from Sikkema et al., 2014) Recommends further harmonization of legal harvesting, sustainable sourcing and cascaded use requirements for woody biomass for energy with the current requirements of voluntary SFM certification schemes.				
		Sikkema et al., 2014				
Oceans	**Ocean Iron Fertilization**		[0]	No direct interaction		
	Blue Carbon		[0]	No direct interaction		
	Enhanced Weathering		[0]	No direct interaction		

8 DECENT WORK AND ECONOMIC GROWTH

		Interaction	Score	Evidence	Agreement	Confidence
Forest	**Reduced Deforestation, REDD+**	**Sustainable Economic Growth (8.4)**				
		↑	[+1]	🕮	☺	★
		Efforts by the Government of Zambia to reduce emissions by REDD+ have contributed to erosion control, ecotourism and pollination valued at 2.5% of the country's GDP. Partnerships between local forest managers, community enterprises and private sector companies can support local economies and livelihoods, and boost regional and national economic growth.				
		Turpie et al., 2015; Epstein and Theuer, 2017; Katila et al., 2017				
	Afforestation and Reforestation	**Decent Job Creation and Sustainable Economic Growth (8.3/8.4)**				
		↑	[+2]	🕮🕮	☺☺	★★
		Many tree plantations worldwide have higher growth rates which can provide higher rates of returns for investors. Agroforestry initiatives that offer significant opportunities for projects to provide benefits to smallholder farmers can also help address land degradation through community-based efforts in more marginal areas. Mangroves reduce impacts of disasters (cyclones/storms/floods) and enhance water quality, fisheries, tourism businesses and livelihoods.				
		Zomer et al., 2008; Kibria, 2015				
	Behavioural Response (Responsible Sourcing)	**Decent Job Creation and Sustainable Economic Growth (8.3/8.4)**				
		↑	[+2]	🕮	☺	★
		Some standards seek primarily to coordinate global trade, many purport to promote ecological sustainability and social justice or to institutionalize CSR, for example, labour standards developed in the wake of sweatshops and child labour scandals. Environmental standards for pollution control, etc. Indonesian factories may seek advantages through non-price competition—perhaps by highlighting decent working conditions or the existence of a union—or to see trade associations or government promoting the country as a responsible sourcing location.				
		Bartley, 2010				
Oceans	**Ocean Iron Fertilization**		[0]	No direct interaction		
	Blue Carbon		[0]	No direct interaction		
	Enhanced Weathering		[0]	No direct interaction		

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

		Interaction	Score	Evidence	Agreement	Confidence
Forest	**Reduced Deforestation, REDD+**	**Infrastructure, Promotion of Inclusive Industrialization (9.1/9.2/9.5)**				
		↑/↓	[+1,-1]	🕮	☺	★
		Expanding road networks are recognized as one of the main drivers of deforesting and forest degradation, diminishing forest benefits to communities, On the other hand, roads can enhance market access, thereby boosting local benefits (SDG 1) from the commercialization of forest products. (Quoted from Katila et al., 2017). Efforts by the Government of Zambia to reduce emissions by REDD+ have contributed to erosion control, ecotourism and pollination valued at 2.5% of the country's GDP				
		Turpie et al., 2015; Epstein and Theuer, 2017; Katila et al., 2017				
	Afforestation and Reforestation		[0]	No direct interaction		
	Behavioural Response (Responsible Sourcing)	**Technological Upgradation and Innovation, Promotion of Inclusive Industrialization (9.1/9.2/9.5)**				
		↑	[+2]	🕮🕮	☺☺	★
		Capacity for processing certified timber is often underutilized, due to the limited supply available. As a result, manufacturing firms that are seeking to tap into green markets often turn to other sources of timber. (Quoted from Bartley, 2010) Responsible sourcing, when integrated into business practices, can enable retailers to better manage brand value and reputation by avoiding negative public relations, as well as maintaining and enhancing brand integrity (Huang et al., 2013).				
		Bartley, 2010; Huang et al., 2013				
Oceans	**Ocean Iron Fertilization**		[0]	No direct interaction		
	Blue Carbon		[0]	No direct interaction		
	Enhanced Weathering		[0]	No direct interaction		

11 SUSTAINABLE CITIES AND COMMUNITIES

		Interaction	Score	Evidence	Agreement	Confidence
Forest	**Reduced Deforestation, REDD+**		[0]	No direct interaction		
	Afforestation and Reforestation	**Improving Air Quality, Green and Public Spaces (11.6/11.7/11.a/11.b)**				
		↑	[+2]	🕮🕮🕮🕮	☺☺☺☺	★★★★
		Many urban tree plantations worldwide are created with a focus on multiple benefits, like air quality improvement, cultural preference for green nature, healthy community interaction as well as temperature control and biodiversity enhancement goals.				
		Chen and Qi, 2018; Fu et al., 2018; Kowarik, 2018; McKinney and Ingo, 2018; McPherson et al., 2018; Pei et al., 2018				
	Behavioural Response (Responsible Sourcing)	**Improving Air Quality, Green and Public Spaces, Peri-urban Spaces (11.6/11.7/11.a/11.b)**				
		↑	[+2]	🕮🕮🕮🕮	☺☺☺☺	★★★★
		Many urban tree plantations worldwide are created with a focus on multiple benefits, like air quality improvement, cultural preference for green nature, healthy community interaction as well as temperature control and biodiversity enhancement goals. People's preference for urban forest gardens are encouraging new urban green spaces, and tree selection helps in building resilience to disaster.				
		Chen and Qi, 2018; Fu et al., 2018; Kowarik, 2018; McKinney and Ingo, 2018; McPherson et al., 2018; Pei et al., 2018				
Oceans	**Ocean Iron Fertilization**		[0]	No direct interaction		
	Blue Carbon		[0]	No direct interaction		
	Enhanced Weathering		[0]	No direct interaction		

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Note that this reference list does not account for the references in Table 5.2, for which a separate reference list is provided.

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