Chapter 5: Sustainable Development, Poverty Eradication and Reducing Inequalities

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Executive Summary

Assessing the connections between sustainable development, poverty eradication, reducing inequalities, and pathways to limit global warming to 1.5°C above-preindustrial times is a fundamental contribution to this Special Report. This chapter presents findings on the many ways in which the impacts of a 1.5°C warmer world, and the impacts of possible adaptation and mitigation responses, interact with efforts to achieve the Sustainable Development Goals (SDGs). The chapter also explores the impacts of pursuing the SDGs on the goal of limiting warming to 1.5°C and on adaptive capacities, particularly for the most vulnerable populations. The concept of climate-resilient development pathways highlights the interconnectedness between wellbeing and pathways to 1.5°C, through simultaneous and conscious efforts to reduce vulnerabilities, enhance adaptation, implement accelerated and stringent emission reduction and promote equity, fairness and justice for all.

Staying within 1.5°C of global warming compared to pre-industrial times while simultaneously achieving the Sustainable Development Goals (SDGs) is challenging, but possible, and an ethical imperative (*high confidence*).

A number of potential impacts for poor people can be avoided in a 1.5°C warmer world, compared to higher rates of warming (including 2°C). That said, the impacts of 1.5°C warming above pre-industrial times still pose significant challenges for human and ecosystem well-being, poverty eradication, and reducing inequalities (*high confidence*).

- The impacts of 1.5°C global warming will disproportionately affect disadvantaged populations, given existing inequalities and further erosion of human capabilities anticipated to occur with both incremental temperature changes and extreme events (*medium evidence, high agreement*). {5.2.2}
- The poorest people are projected to experience the impacts of 1.5°C global warming predominantly through increased food prices and adverse health impacts (*limited evidence, medium agreement*). {5.2.2}
- Limiting global warming to 1.5°C versus 2°C reduces the risks across various aspects of security, including livelihoods, human security, food and water availability, and ecosystems. However, not all avoided impacts also imply higher potential for adaptation. (*medium confidence*) {5.2.3}

There is wide diversity and flexibility in the choice of potential adaptation and mitigation pathways. However, all choices come with synergies and trade-offs that will affect people's lives and development trajectories differently (*medium-high confidence*).

- The impacts of adaptation efforts are expected to be largely positive for sustainable development in general, and on the SDGs specifically. This is especially the case in the agricultural and health sectors, and through ecosystem-based adaption. However, negative impacts can occur when existing inequalities are exacerbated. Hidden trade-offs in adaptation pathways risk reinforcing existing inequalities, potentially leading to lock-ins and poverty traps (*medium confidence*). {5.3.2, 5.3.3}
- Pursuing stringent climate mitigation options can generate potential benefits for several dimensions of sustainable development, and advance short-term targets under the SDGs. Best available technologies for enhancing sectoral and regional efficiency in resource use will make it easier to advance toward the 1.5°C target, even if they are insuffient to meet it on their own. Technological and behavioural changes will help to realise the full potential of mitigation (*high confidence*). {5.4, Table 5.1}
- Improving access to affordable and reliable energy enhances human wellbeing and contributes to poverty reduction. Low-carbon, zero-carbon, or carbon-removing modern energy sources best serve the dual goals of climate and sustainable development. But these transitions must be handled carefully. For example, major shifts towards biofuels, if poorly managed, can threaten food and water security, cause competion for land, spikes in food prices, and lead to disproportionate consequences upon poor and indigenous populations (*high confidence*). {5.4, 5.5, Table 5.1}
- Land use, especially forestry, is vital to meet pledged emission reductions in many countries and to meet longer-term strategies towards 1.5°C. But again, this needs careful planning to ensure equitable distributional outcomes (*high agreement, medium evidence*). {5.4, 5.5, Table 5.1}

- GHG emission reduction pathways consistent with 1.5°C would have considerably higher co-benefits for reducing air pollution and improving health compared to pathways that stay below 2°C. The co-benefits for air pollution are biggest in the developing world, particularly in Asia (*medium confidence*). {5.4.3}

Policy choices that prioritise human well-being and equity can minimise disproportionate impacts for poor and disadvantaged populations arising from 1.5°C of global warming, and from the pathways required to keep global warning within the 1.5°C limit (*medium-high confidence*).

- Comprehensive packages of adaptation and mitigation options supported by coordinated governance across sectors and nations will enhance sustainable development (*high agreement*, *medium evidence*). {5.3.1, 5.4.1, 5.5.2}
- Postponing 'easy' responses with potential co-benefits for sustainable development and poverty eradication will increase longer-term reliance on more difficult, potentially more expensive, and riskier technological solutions. These may have trade-offs that increase uneven distributional impacts between countries at different stages of development (*high agreement*, *medium evidence*). {5.4.2, 5.6}
- Policy frameworks and strong institutions that align development, equity objectives and climate have the potential to deliver 'triple-wins'. Regions with low synergistic potential and high climate risks, such as the Tropics, however, could experience 'triple losses', with trade-offs worsening between 1.5°C and 2°C (*medium confidence*). {5.6.2}

Climate-resilient development pathways are prerequisites for achieving a fair and just society in a 1.5°C warmer world. Common elements include enhancing adaptation, reducing vulnerabilities, pursuing stringent mitigation reductions, contributing to poverty eradication, ecosystem resilience, and promoting equity, fairness, justice and wellbeing for all (*medium-high confidence*).

- Participatory governance, iterative learning, and social policies that reduce entrenched deprivations and inequalities constitute key enabling conditions for equitable, liveable, just, and low-carbon futures. They open up synergistic opportunities, from the local to the global, and counteract measures that erode well-being (*high confidence*). {5.7.1; 5.7.2}
- Community to state level efforts to realise climate-resilient development pathways in the global North and South show partial successes as well as inherent difficulties in simultaneously pursuing social, climate, and equity goals. These difficulties will need to be overcome if the target to limit global target to 1.5°C is to be met (*high agreement, medium evidence*). {5.7.3}

5.1 Scope and Delineations

This chapter assesses what is known about the connections between sustainable development and pathways to 1.5°C, especially how impacts at 1.5°C warming and the implications of climate responses interact with the near term Sustainable Development Goals (SDGs) and efforts to eradicate poverty, reduce inequality, and strive for equity. It builds on prior IPCC reports and assesses new literature that examines bi-directional links between climate and development efforts and how choices about mitigation and adaptation options and possible pathways affect sustainable development opportunities and outcomes, generating both synergies and trade-offs. The chapter offers insights into possible climate-resilient development pathways, their enabling conditions, and successes and challenges encountered, from the level of nation states to communities.

5.1.1 Sustainable Development, Poverty, Equality, and Equity: Core Concepts and Trends

As discussed in Chapter 1, *Sustainable development* has been defined in many ways and in prior IPCC reports was defined as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'.

The UN General Assembly has accepted sustainable development as balancing economic development, social development, and environmental protection. However, the definitions and goals of sustainable development are inconsistent and contested, and measuring it in practice remains a challenge (Bebbington and Larrinaga 2014; Redclift and Springett 2015). The AR5 reported with high confidence that sustainable development is strongly connected to climate change and that disruptive levels of climate change would preclude sustainable development including reducing poverty (Denton et al. 2014; Fleurbaey et al. 2014). It also identified synergies and trade-offs in solving climate and development challenges (e.g. synergies between energy access and low carbon development paths and trade-offs between controlling emissions and increasing incomes) and assessed literature that showed that the responses to climate change – mitigation, adaptation, and geoengineering – could have significant positive and negative impacts and distributional implications for development.

The AR5 also assessed how climate change interacts with poverty, with 'poverty' referring to 'material circumstances (e.g. needs, patterns of deprivation, or limited resources), economic conditions (e.g. standard of living, inequality, or economic position), and/or social relationships (e.g. social class, dependency, lack of basic security, exclusion, or lack of entitlement)'; the definition included the multiple dimensions of poverty beyond low incomes, such as hunger, illiteracy, poor housing, lack of access to services, social exclusion and powerlessness (Olsson et al. 2014). Intersectional dimensions of inequality and equity at smaller scales were explored, along the axes of gender, class, ethnicity, age, race, and (dis)ability, and their relation to vulnerability and risk (Olsson et al. 2014). The AR5 concluded that risks from climate change are 'unevenly distributed and generally greater for disadvantaged people and communities in countries at all level of development' (IPCC 2014a: 64) and that multidimensional inequalities, often produced by uneven development processes, shape differential vulnerabilities to and risks from climate change (IPCC 2014b).

A Multidimensional Poverty Index for 2005-2015 reported nearly 1.5 billion people in developing countries as multi-dimensionally poor, and notes that deprivation also occurs in high-income countries (UNDP 2016). The majority of the multi-dimensionally poor live in South Asia (53.9%) and Sub-Saharan Africa (33.5%), and more in rural than in urban areas; projections (which do not include climate change) suggest that poverty will increase by 2030 if development goals are not met (UNDP 2016). Nearly half a billion people are trapped in chronic poverty, meaning poverty over many years, possibly a life time, and the lives of their children (Shepherd et al. 2014). By 2030, projections indicate up to 950 million people still living on $1.25/day, split evenly between low-income countries (LICs) and low-middle-income countries (LMICs), mostly in South Asia, East Africa, and the Sahel; this includes up to 25 countries (pessimistic scenario) with > 10 million poor at this threshold, with the highest number per country in India (between 76-256 million) (Shepherd et al. 2014). More than 20 countries in Africa, as well as Nepal, Honduras, and Haiti, are projected to be highly vulnerable to poverty by 2030 (high numbers and high proportion of poor people) (Shepherd et al. 2014).

The AR5 discussed, but did not define, *equality* and *equity*. In general, *equality* involves treating everyone the same and providing them with the same things (e.g. opportunities and rights). But because people embark from different starting points (e.g. lower incomes or health status), equality does not always provide what the more disadvantaged need to thrive. The Special Report on Extreme Events recognised the need to address structural inequalities that perpetuate poverty and inequality and create vulnerability as a precondition for dealing with climate change (IPCC 2012). These structural inequalities are overlaid onto income inequalities between and within countries. In 2015, the total wealth of the poorest 50% equalled the wealth of the 62 richest people in the world (Oxfam 2015, cited in (ISSC IDS and UNESCO 2016)). Income inequality has risen along with a rise in incomes (Roine and Waldenström 2015), particularly in high-income countries (e.g. USA and UK) and continues to be even higher in MICs such as South Africa, Brazil, Mexico, India, and China (ISSC IDS and UNESCO 2016).

Equity is often seen as synonymous with justice and entails treating everyone fairly, often in terms of giving people what they deserve. Core dimensions include distributive (outcome) and procedural (process) equity, and equity between and within generations (Klinsky et al. 2017a). The relationship between equity, effective climate action, and sustainable development is complex and contested. Many hold that closer attention to equity will help to reduce climate vulnerability among the world's poorest populations and facilitate global sustainable development (Okereke and Schroeder 2009; Klinsky et al. 2017a; World Commission on Environment and Development 1987; Okereke 2007) while others assert that these ideals are not necessarily coterminous or mutually reinforcing (Campbell 2013; Dobson 1998; Keohane and Victor 2016).

Achieving the 1.5°C target and resolving the issue of loss and damage have been identified as key issues of equity and justice (Hulme 2016; Rogelj et al. 2016; Okereke and Coventry 2016). However, Okereke and Coventry (2016) argue that the relationship between the 1.5°C goal and equity can be complex because the 1.5°C target could create false hopes of action, could entail a significantly reduced global carbon use and jeopardise the development aspirations of some developing countries, and could have negative implications for justice, rights, jobs and inequality, if not designed and implemented carefully (Newell and Mulvaney 2013).

5.1.2 Sustainable Development Goals

The AR5 did not explicitly connect climate change to the development goals then articulated by the UN. The UN Millennium Declaration prioritised global reductions in poverty and hunger, improvements in health, education, and gender equity, debt reduction, and improved access to water and sanitation between 1990 and 2015. Considerable success was claimed in reaching many of the targets of the *Millennium Development Goals* (MDGs), including halving poverty, reducing hunger, and increasing water security. Improvements in water security, slums and health may have reduced some aspects of climate vulnerability; yet, increases in incomes have been linked to rising GHG emissions and thus to a trade-off between development and climate change (United Nations 2015; Janetos et al. 2012). Critics argued that the MDGs failed to address within country disparities and human rights, were developed by a small group of experts, only focused on developing countries, did not address key environmental concerns, and had numerous measurement and attribution problems (Amin 2006; Clemens et al. 2007; Fukuda-Parr et al. 2014; Langford et al. 2013).

The articulation of a new set of development goals - the UN *Sustainable Development Goals* (see Chapter 1 and Box 5.1) – raises the ambition for eliminating poverty and other deprivations while protecting the environment and reducing the risks of climate change. The SDGs apply to all countries and include ending poverty (SDG1) and hunger (SDG2); ensuring health (SDG3) and access to education (SDG4), gender equality (SDG5), access to water and sanitation (SDG6), energy (SDG7), and inclusive economic growth (SDG8); resilient infrastructure and sustainable industrialisation (SDG9), reduced inequality (SDG10), sustainable cities (SDG11) and sustainable consumption and production (SDG12); combat climate change (SDG13), conserve oceans and marine resources (SDG14) and protect terrestrial ecosystems (SDG15); promote peace and justice (SDG16) and strengthen partnerships (SDG17).

Box 5.1: The Sustainable Development Goals (SDGs)

In September 2015, international community endorsed a universal agenda entitled 'Transforming our World: the 2030 Agenda for Sustainable Development', known as the Sustainable Development Goals (SDGs). The 17 goals and 169 targets to be met by 2030 were developed with widespread participation and were adopted in 2012 for the overarching goals of sustaining people, prosperity, peace, partnerships and the planet. The preamble to the SDGs announces 'to take the bold and transformative steps which are urgently needed to shift the world onto a sustainable and resilient path'. With their explicit aim to 'leave no one behind', the SDGs provide a promising basis for addressing inclusive growth, shared prosperity, and multi-dimensional equalities (UNRISD 2016). They are seen as an 'indivisible' package of goals that need to be pursued in an integrated way (Coopman et al. 2016); yet, the policy challenges to realise this integration are enormous.

Most significant for this report is the specific goal for climate: Goal 13 to 'Take urgent action to combat climate change and its impacts' (United Nations, n.d.). This goal recognises that climate change is the major threat to development and to success on the other 16 goals. The specific targets under the goal include strengthening resilience and adaptive capacity, integrating climate change measures into policies and planning, and improving climate change education, awareness and institutional capacity. The targets also included implementing the UNFCCC goal of $100b annually for developing countries and addressing the capacity needs in least developed and small island developing states including a focus on women, youth, local and marginalised communities (United Nations, n.d.).

Despite their ambitious and integrative vision, the 2030 Agenda has met with some scholarly criticism. Some analysts suggest the SDGs are too many and complex, lack realistic targets, are focused on 2030 at the expense of longer term objectives, and may contradict each other (Death and Gabay 2015; Horton 2014). There are tensions between the progressive and normative aims and the means of implementation; because implementation requires some fundamental transformations, beyond global partnerships and international trade, and will need to address the entrenched inequalities and uneven power dynamics that have long been pervading unsustainable development (UNRISD 2016). The climate goal refers to commitments made under the UNFCCC framework, but otherwise has rather general non-quantitative targets (ICSU 2017).

5.1.3 Climate-Resilient Development Pathways

The AR5 introduced the notion of '*climate-resilient pathways*', defined as 'sustainable-development trajectories that combine adaptation and mitigation to reduce climate change and its impacts; they include iterative processes to ensure that effective risk management can be maintained' (IPCC 2014b: 28). These pathways are best seen as 'future trajectories of development' with a variety of alternative pathways at any possible scale, each of which requires an evaluation of associated risks and benefits regarding climate resilience (Denton et al. 2014: 1122). Climate-resilient pathways rely on flexible, innovative, and participatory problem solving and, especially in the context of severe effects of climate change, require transformational change, including transformation in social processes (Denton et al. 2014: 1122). The concept of transformation implies fundamental changes in natural and human systems including changes in values, institutions, technologies, and biological systems and can be contrasted with more incremental responses to climate change (Pelling et al. 2015; Fazey et al. 2017). These pathways build on the concept of resilience, defined in AR5 as 'the capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation'.

Despite high agreement in the literature on the conceptual nature of such pathways, concrete evidence and empirical examples in the AR5 were rather limited. However, since then, the literature on climate-resilient pathways and transformation has expanded. Moreover, with the adoption of the SDGs and the efforts to achieve both sustainable development and the Paris Agreement, the word ‘development’ now emerges as an even more fundamental and visible goal to combine with climate objectives, justifying the term ‘climate-resilient *development* pathways’. This notion implies deliberate emphasis on understanding how development, transformation, and resilience go hand in hand with efforts to limit global warming, through simultaneous and conscious efforts to reduce vulnerabilities, enhance adaptation, and implement stringent emission reductions, and promote equity, fairness, and justice (see 5.7). Figure 5.1 depicts such pathways.

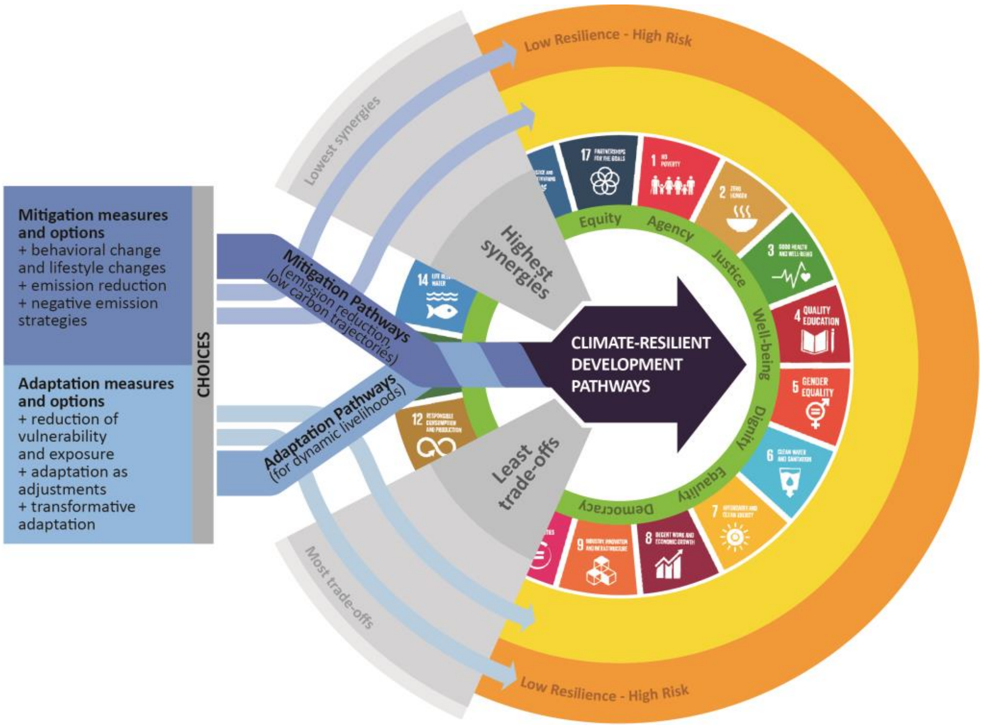

Figure 5.1: A conceptual illustration of climate-resilient development pathways, rooted in the core social dimensions of human development, poverty eradication, and reducing inequalities and guided by the SDGs, while climate resilience being shaped by the highest synergies and least trade-offs that emerge from adaptation and mitigation pathways.

The UN resolution which adopted the SDGs has the title ‘Transforming Our World: the 2030 Agenda for Sustainable Development’ and highlights the need to address ‘the root causes that generate and reproduce economic, social, political and environmental inequities, not merely their symptoms’; this entails inclusive and rights-based development that offers tangible path-ways to ‘break […] the vicious circle of poverty, inequality and environmental destruction confronting people and the planet’ (UNRISD 2016: 3). It stresses the challenge of pursuing sustainable human development against the backdrop of increasing global inequality, future climate change, and current environmental damages (Fleurbaey and Blanchet 2013). Climate-resilient development pathways can help meet these challenges.

5.1.4 Chapter Structure and Types of Evidence

The chapter proceeds as follows: Section 5.2 describes future impacts (risks) of a 1.5°C warmer for poverty eradication, reducing inequalities, and equity, including avoided impacts compared to a 2°C warmer world. Section 5.3 presents evidence regarding the impacts of adaptation response measures and pathways on sustainable development in general and the SDGs specifically, including synergies and trade-offs. Section 5.4 provides similar evidence from mitigation response measures and pathways. Section 5.5 examines how meeting the SDGs could increase or decrease chances of successful low-emission pathways and implications for vulnerabilities and adaptive capacities. Section 5.6 presents opportunities and challenges that result from the integration of adaptation, mitigation, and sustainable development, including distributional impacts. Section 5.7 introduces climate-resilient development pathways, enabling conditions, and emerging evidence of such pathways at different spatial scales, challenges encountered, and lessons learned. The chapter ends with a brief synthesis of findings and identified gaps (Section 5.8), closing the arch of this Special Report that was opened in Chapter 1.

In this chapter, we use a variety of sources of evidence to assess the interactions of sustainable development broadly and the SDGs in particular with the causes, impacts, and responses to climate change of 1.5°C. We draw upon various types of knowledge and experiences, from measurable data and simulations to lived and embodied experiences of people affected by climate change. We refer to published literature and data that assess, measure, and model sustainable development–climate links from various angles and across scales as well as well documented case studies that illustrate connections, synergies, and trade-offs. There is a scarcity of literature that explicitly links a 1.5°C target to sustainable development and the SDGs; nonetheless, we are able to draw on interpolations of work that examines trajectories to and beyond 1.5°C of warming.

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

5.2.1 Future Impacts and Risks at Sub-regional to Sub-national Levels

Climate change could lead to significant impacts on extreme poverty by 2030 (Hallegatte et al. 2016a; Hallegatte and Rozenberg 2017). The AR5 concluded with high confidence that future impacts (risks) will be experienced differentially according to caste, gender, or ethnicity within and across societies (Olsson et al. 2014; Vincent et al. 2014). Some of these impacts can be easily detected and attributed to climate change (Cramer et al. 2014) while others are less visible, although no less real to the people who experience them. Drawing attention to these less visible impacts is compounded not only by scarce climate data and other observational records in certain parts of the world (Hansen et al. 2016). It is also compounded by the fact that any global temperature target, including 1.5°C, is not experienced as such on the ground but will manifest itself in higher warming and/or extreme events in certain parts of the world with highly different patterns of societal vulnerability. Temperature overshoot towards 1.5°C at the end of the century (see Chapter 3) is expected to be even more detrimental for specific populations and places. These are comparable to high and very high risks for instance for Arctic systems and agriculture-dependent livelihoods (O'Neill et al. 2017a); yet the literature is exceedingly scarce on implications for poverty reduction, inequalities, and equity.

This section complements the Chapter 3 assessment of future impacts and risks of 1.5°C and higher warming at the regional and global level. It does so through the lens of livelihood, human, food, water, and ecosystem security below the regional level, building on key risks (Oppenheimer et al. 2014). We acknowledge the difficulty in making visible the 'invisible' future impacts and risks at these lower levels as they entail embodied experiences to emerge at the intersection of systemic inequalities and multi-dimensional vulnerabilities along the axes of gender, class, ethnicity, age, race, and (dis)ability, marginalisation and deprivation, and social inclusion and exclusion that are exacerbated by uneven development patterns (e.g. Olsson et al. 2014; Brandi, C. 2015). The literature on such risks is exceedingly scarce; yet, identifying and addressing inequality is at the core of staying within a safe and just space for humanity (Raworth 2012).

5.2.2 Risks of a 1.5°C Warmer World

Insights from the updated Reasons for Concern (RFC) suggest transitions from moderate to high risk, for instance, for indigenous Arctic peoples, their livelihoods, and their ecosystems within the range of ~1.1-1.6°C global warming (O'Neill et al. 2017a). Yet, more nuanced risk assessments for vulnerable groups have so far remained beyond the scope of the RFC approach, despite emerging attempts, for example to quantify risks of hunger for the poor under different development trajectories, with up to an additional 400 million people due to climate change under ~3.5°C warming and high trends of vulnerability and exposure (O'Neill et al. 2017a). Bottom-up approaches that start with household-level data and then overlay future demographic and socio-economic trajectories with climate change scenarios offer a promising alternative. For instance, Hallegatte and Rozenberg (2017) project that, under ~1.5°C warming by 2030, up to 122 million additional people could be in poverty due to climate change under a ‘poverty scenario’ similar to SSP4 (Inequality), mainly due to increased food prices and health impacts, especially through malaria, diarrhoea, and stunting. The same study projects most detrimental income losses for the poorest 20%, modelled for household data sets across 92 countries, suggesting that the already poor will get poorer and the poverty headcount will increase. Without redistributive policies, the impacts of climate mitigation measures on poor people, through increased food and energy prices, could be even more damaging, especially taking into account gender discrepancies and the high vulnerability of children (Hallegatte and Rozenberg 2017).

In terms of livelihood security, risks associated with labour productivity, economic losses, and loss of life are anticipated to have significant implications for poverty, inequality, and equity. Past empirical evidence on the impact of extreme temperatures on labour productivity from the US and India suggest that an increase of 1°C in warming could reduce productivity by 1-3% for people working outdoors or without air conditioning, typically the poorer segments of the workforce (Deryugina and Hsiang 2014; Sudarshan et al. 2015; Zivin and Neidell 2010; Park et al. 2015). Further warming is projected to increase economic losses from tropical cyclones by 9-417%, from extratropical cyclones by 11-120%, and river floods from 7-124% by 2040, with significant implications for populations living in most exposed areas (Bouwer 2013). Such loss estimates, however, may not adequately reflect welfare impacts for poor households; they often own relatively little (hence are underrepresented in loss statistics) but suffer much more in terms of loss of income, savings, and health (Hallegatte et al. 2017). By 2030, climate change could be responsible for an additional 38,000 annual deaths due to heat exposure among elderly people, 48,000 due to diarrhoea, 60,000 due to malaria, and about 95,000 due to childhood undernutrition (World Health Organisation 2014). Health shocks and poor health already exacerbate poverty through income losses, health expenses and caregiver responsibilities; moreover, higher morbidity and mortality will slow down poverty reduction and increase inequality (Hallegatte et al. 2016a). For food security, heterogeneous effects are expected regarding risks for poor people from food production and price fluctuations. Net consumers of food products are likely to be harmed while those depending on agricultural wages may experience mixed impacts (Hallegatte et al. 2016a).

5.2.3 Avoided Impacts of 1.5°C versus 2°C Warming

As risks increase with every level of additional warming, avoided future impacts can be expected when global warming is limited to 1.5°C rather than 2°C. Yet, limited literature exists that assesses such avoided impacts regarding poverty eradication, inequalities, and equities.

A useful proxy to reveal avoided impacts stems from the AR5 WGII risk tables, based on expert judgment. These tables suggest near-term (2030-40) risks roughly comparable to those expected under 1.5°C warming by the end of the century compared to long-term (2080-2100) risks associated with 2°C warming. Figure 5.2 depicts sectoral and regional avoided impacts extracted for five domains of security. It highlights where the lower temperature target could prevent the widening of poverty and inequality gaps and save precious resources. For certain categories, no difference in risk between 1.5°C and 2°C warming emerged, e.g. deterioration of agricultural livelihoods in drylands (Olsson et al. 2014) and artisanal fishing livelihoods (Pörtner et al. 2014), although the potential for adaptation was identified for both. For other areas with no avoided impacts, the possibilities to lower risks through adaptation were seen as exceedingly limited, e.g. ecosystems in polar regions (Larsen et al. 2014) and morbidity and mortality from heat waves, especially among homeless people, the elderly, and children (Olsson et al. 2014). The high to very-high risk of coral reef mortality may differ only marginally between 1.5°C and 2°C, with some limited potential for adaptation at the lower warming level (Magrin et al. 2014; Nurse et al. 2014; Hoegh-Guldberg et al. 2014).

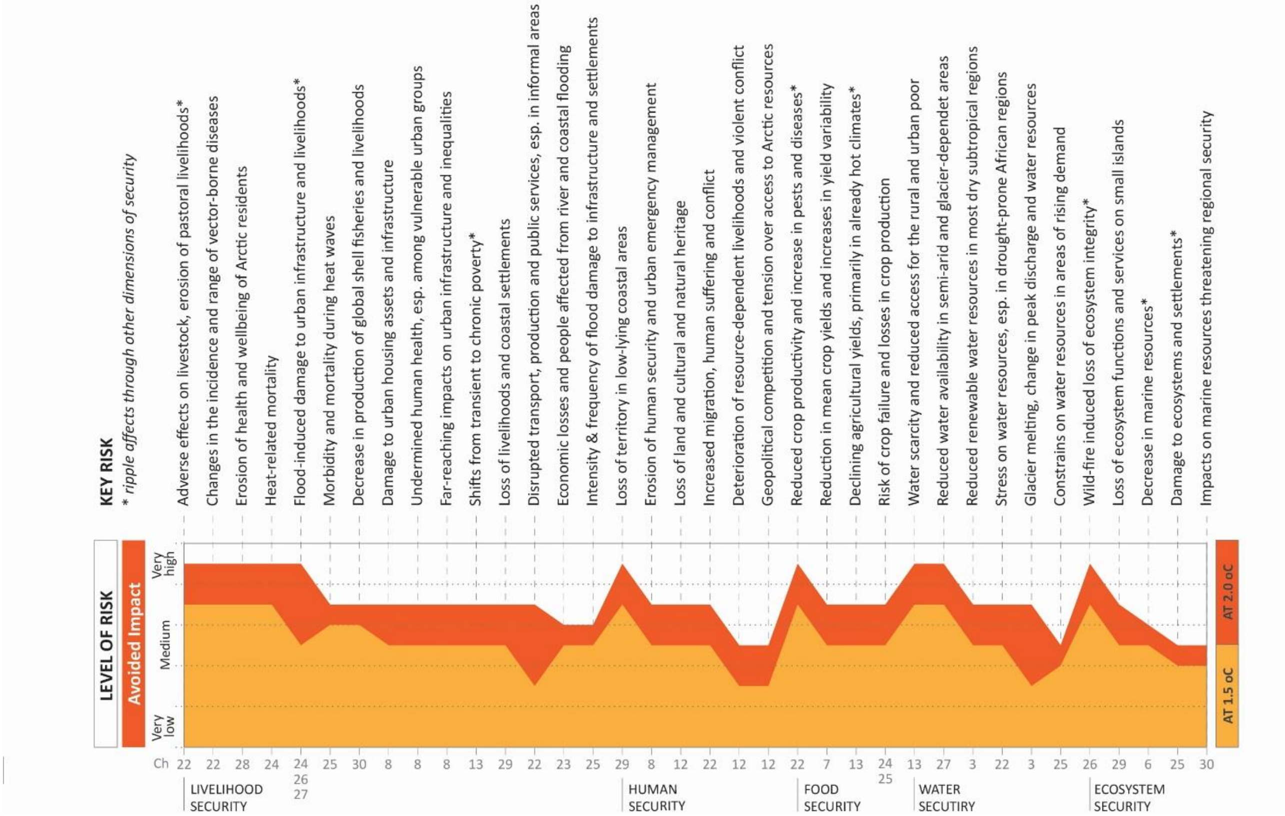

Figure 5.2: Avoided impacts between 2°C and 1.5°C warming (in orange), extracted from the AR5 WGII risk tables (Field et al. 2014, and underlying chapters). The risk estimates are not necessarily comparable between chapters.

5.2.4 Implications of Differential and Avoided Risks from 1.5°C Global Warming for Achieving the SDGs

Highlighting such fine-grained risks and avoided impacts, even if difficult to quantify, is important because it draws attention to the dynamics under which these risks undermine human capabilities and limit people's options to live dignified lives (Klinsky et al. 2017b), exacerbate inequalities, inhibit adaptive capacities and action, and ultimately curtail the potential for wellbeing and sustainable development (see 5.5 and 5.7). Additional and avoided risks can be further exacerbated by negative impacts from adaptation and mitigation response options, especially when they disproportionally affect already disadvantaged populations (see 5.4.2), hence constituting possibly double and triple injustices and losses (see 5.6).

Global warming of 1.5°C compared to 2°C by the end of the century is expected to provide better chances to achieve the SDGs by 2030, with higher potentials to eradicate poverty, reduce inequality, and foster equity. Yet, the literature supporting this expectation remains scarce with the different timelines further compounding the challenge of meaningful conclusions. Projections for ≤2°C (equivalent to RCPs 2.6 and 4.5) and 2.6-4.8°C (equivalent to RCP 8.5) suggest very low to low risk of failure for the former compared to very high risk of failure for the latter in terms of achieving SDG1 (poverty), with poverty levels 80-140% lower for Asia and sub-Saharan Africa, as well as for SDGs 3 (health), 5 (gender equality), 6 (water and sanitation), and 10 (inequality), although there will be differences between countries (Ansuategi et al. 2015). In addition to direct implications, links between the individuals SDGs, particularly #1, 3, 5, and 10, indicate that delayed or diminished progress in one or several of the underlying targets also results in lower food security (OECD 2016) and hence further threats to human capabilities and wellbeing.

5.3 Impacts of Adaptation on Sustainable Development

In addition to the impacts of 1.5°C global warming, climate change response options, both from adaptation and mitigation, will affect poor people, inequalities and equity, with implications for reaching the SDGs. There are synergies and trade-offs between the dual goal of keeping temperatures below 1.5°C and achieving sustainable development, in the short and the long term. This section focuses on the impacts from adaptation. Adaptation to climate change is already underway, is being planned, and will be necessary to limit warming to 1.5°C. Adaptation response measures and options include structural and physical adaptations (e.g. water storage, plant breeding, transport and urban infrastructure, and ecosystem management), social adaptations (e.g. education, information, and changes in behaviour), and institutional adaptations (e.g. insurance, land use regulation, and government planning) (Noble et al. 2014). Although engineering and technological measures still dominate, ecosystem-based, community-based, and institutional and social approaches are increasing (Chong, 2014; Munang et al., 2014; Reid, 2016). Adaptation and development are to be understood, best holistically, as a two-way relationship, to improve local community adaptive capacity and livelihood security against the negative impacts of climate change (Castellanos-Navarrete and Jansen 2015; Lee et al. 2014). Yet, the high diversity of adaptation options across sectors, individuals, communities, and locations makes assessing impacts for sustainable development a challenging task.

The impacts of adaptation measures on sustainable development, poverty alleviation, and equity in general, and the SDGs specifically, are expected to be largely positive, given that the inherent purpose of adaptation is to lower risks. Section 5.3.1 assesses cases with highest evidence. However, certain adaptation options create negative side-effects, particularly for poor and vulnerable populations, and may impede progress on development goals or increase inequality; these are examined in Section 5.3.2. Understanding interactions between sustainable development and adaptation response options allows policy makers and practitioners to identify win-win outcomes that connect adaptation and sustainable development, reduce poverty, and move towards equity for the local and the global community, including non-human species and future generations. It also makes it possible to identify potential poverty traps and lock-ins that exacerbate poor peoples' lives.

5.3.1 Synergies between Adaptation Response Options and Sustainable Development

Adaptation response options that show significant synergies with sustainable development and the SDGs are abundant. Most robust evidence stems from the agricultural and health sectors, and from ecosystem-based and cultural-based adaptation particularly among indigenous peoples (see Box 4.14 on Cities).

In the agricultural sector, the most direct synergy is between adaptation in cropping and food systems designed to maintain or increase production and the SDG2 (eliminating hunger) (Rockström et al. 2017; Lipper and Al. 2014; Neufeldt et al. 2013). Vermeulen et al. (2016) report strongly positive returns on investment across the world from agricultural adaptation plus side benefits for environment and economic wellbeing. Well adapted agricultural systems have shown to contribute to safe drinking water, health, biodiversity and equity goals (DeClerck et al. 2016b; Myers et al. 2017). Similar synergies have been observes for water resources adaptation, specifically SDG6 on clean water and when attention is paid to local needs and governance (Schoeman et al. 2014; Bhaduri et al. 2016). Insurance and climate services are additional options that suggest synergies in terms of protecting incomes and livelihoods (Linnerooth-Bayer and Hochrainer-Stigler 2015; Lourenço et al. 2015; Carter et al. 2016).

Adaptation responses in the health sector that reduce morbidity and mortality among human populations in countries at all levels of development show a close relationship between lower incidence of communicable diseases and periods of heat stress, flooding, and extreme events, with positive impacts for SDG3, as well as between climatic events and subsequent loss of life and property where adaptation responses facilitate SDG3 (good health and well-being) and SDG13 (climate action). Positive responses which build adaptive capacity and resilience range from early warning systems, to better institutions for sharing information, additional indicators for detecting climate sensitive diseases, improved provision of basic health care services and coordination with other sectors to improve risk management (Dovie et al. 2017; Dasgupta 2016).

Ecosystem Based Adaptation (EBA), including ecological restoration (e.g. of wetlands and floodplains), afforestation, fire management, and green infrastructure, is found to yield mostly positive benefits for SD (Ojea 2015; Munang et al. 2013a; Jones et al. 2012; Butt et al. 2016; Brink et al. 2016), although there are research and data gaps that make assessment difficult (Doswald et al. 2014). EBA with mangrove restoration has reduced coastal vulnerability while protecting marine and terrestrial ecosystems; river basin EBA has reduced flood risk and improved water quality; and wetland and mangrove restoration has increased local food security (Chong 2014; Munang et al. 2013b). EBA may be more cost effective than other options, can be inclusive of local knowledge, and more easily accessed by the poor (Estrella et al. 2016; Ojea 2015; Daigneault et al. 2016). The AR5 noted biodiversity, hazard reduction, and water protection co-benefits as well as economic benefits such as ecotourism through improving ecosystem services. Because ecosystems themselves are sensitive to temperatures and sea level, a 1.5°C global temperature compared to 2°C or higher, is likely to enhance the success and reduce the costs of EBA.

Payment for ecosystem services (PES), an economic adaptation option, provides financial incentives to land owners and natural resource managers to preserve environmental services and, when designed with a pro-poor focus, contribute to such as poverty reduction and livelihood security. Evidence from Costa Rica, with first experiences going back to the 1990s with, indicates neutral or positive impacts on livelihood outcomes (Locatelli et al. 2008; Arriagada et al. 2015) and rates of deforestation (Sánchez-Azofeifa et al. 2007; Arriagada et al. 2012). Similar dual synergies have been reported for Brazil (see Section 5.7.3.1, Box 5.2) and programs in other countries, although evidence of coupled adaptation-litigation benefits remains scarce (Samii et al. 2014; Börner et al. 2016) (Schwarzer et al. 2016). Higher synergies are achieved when there is local participation in the design, implementation and monitoring of PES programs (Wegner 2016) and when they are user-financed (voluntary) and locally-targeted and monitored (Wunder et al. 2008).

Long standing cultural adaptations to environmental change and uncertainty have enabled indigenous people to sustain themselves through generations (Armitage 2015; Apgar et al. 2015; Ford et al. 2016; Cobbinah and Anane 2016) (see also Chapter 4, Box 3.3 on Cold Regions). Building resilience through cultural adaptation enhances SDG2 (eliminating hunger), SDG6 (clean water and sanitation) and SDG10 (reduced inequalities), with evidence from initiatives that are community initiated and/or draw upon community knowledge or resources (Chief et al. 2016; Reid 2016; Berner et al. 2016; Murtinho 2016; Lasage et al. 2015; Regmi and Star 2015; Ayers et al. 2014; Chishakwe et al. 2012).

5.3.2 Trade-offs between Adaptation Response Options and Sustainable Development

Negative impacts for (trade-offs with) sustainable development have been observed across most adaptation categories (see Table SPM1, IPCC 2014b). In addition to sector-specific impacts, failure in streamlining adaptation into policy frameworks, private sector action, and institutional thinking and lack of attention to long-term effects increase the risk of maladaptation (Noble et al. 2014).

Agricultural response options may increase risk for health, oceans, and access to water if fertilizer and pesticides are used without regulation or irrigation competes over water (Shackleton et al. 2015a; Lobell and Tebaldi 2014; Campbell et al. 2016). Expanding farm land can have negative effects on biodiversity and on bioenergy production. Other adaptations such as crop insurance and climate services tend to overlook the poor and may increase inequality (Georgeson et al. 2017a; Dinku et al. 2014; Carr and Onzere 2016; Carr and Owusu-Daaku 2015). Changes in cropping patterns and timing may increase workloads, especially for women and changes in crop mix can result in loss of income or culturally appropriate food.

In the health sector, trade-offs occur when adaptation to heat stress takes the form of increased air conditioning, which leads to higher energy consumption and consequently higher emissions (Petkova et al. 2017). There is a direct negative implication for SDG13. Adaptation responses in one sector that lead to negative impacts in another sector (e.g. disaster risk from increased emissions or flood control by creating urban wetlands that breed mosquitoes) adversely affect SDG3 (Woodward et al. 2011; Smith et al. 2014a).

As EBA has become mainstreamed into adaptation, more evaluations of synergies and trade-offs with sustainable development are available (Conservation International 2016; Huq et al. 2017; Szabo et al. 2015). Trade-offs include loss of other economic land use types and resource extraction, tensions between biodiversity and adaptation priorities, lack of respect for local knowledge, and conflicts over governance across scales and land rights (Mercer et al. 2012; Ojea 2015; Wamsler et al. 2014). PES schemes that trade social outcomes for market-based business models risk perpetuating inequality and injustice (e.g. Fairhead et al. 2012; Muradian et al. 2013; Hahn et al. 2015; Calvet-Mir et al. 2015; Chan et al. 2017).

The concerns with cultural adaptation are more complex as traditional cultural adaptation is deemed to be slowly diminishing due to displacement, relocation, settlement schemes and other interventions by the Government (Maldonado et al. 2013; Warner 2015), which leads to traditional adaptations increasingly less resilient. Community-based adaptation that is grounded on community values, coping strategies and decision-making structures cannot operate exclusively at community level due to external factors that could increase community's vulnerability to climate change (Reid 2016; Jeans et al. 2014). Adaptation responses of climate change interventions, such as global expansion of biofuels, where land due to nationally driven policies is diverted from subsistence to commercial, could also have adverse negative impacts to achieving SDG10 (reducing inequality), for the local, indigenous as well as vulnerable groups due to dispossession of land, which affects their overall well-being physically, socially and culturally (Lunstrum et al. 2015).

However, not all adaptation options produce just synergies, or trade-offs. In reality, two-way relationships are common, as shown in the field of public health. On the one hand, effective adaptation measures for the near-term, in situations where basic needs are yet to be met, or resources are scarce, are programs that implement basic public health measures (Dasgupta 2016; Hess et al. 2012; Smith et al. 2014a). Adaptation needs are linked with existing adaptation deficits and there are many examples of where measures to reduce current adaptation deficits are important for tackling future climate change impacts (Woodward et al. 2011). On the other hand, specific and planned adaptation efforts are required in parallel for climatic events, such as recurrent flooding. This, however, can lead to erosion of household coping capacity over time (Webster and Jian 2011), damage to infrastructure, undermining of long-term adaptive capacity, and increases in cumulative risk (Tapsell et al. 2002). In this case, more of the same is not sufficient.

5.3.3 Sustainable Development Implications of Adaptation Pathways in a 1.5°C Warmer World

In a 1.5°C warmer world, adaptation response options will need to be intensified, accelerated, and scaled up. To ensure desirable outcomes for sustainable development and achieving the SDGs, above all eradicating poverty and reducing vulnerabilities and inequalities, the long-term goal will be to enhance known synergies and minimise negative impacts. This entails not only the right 'mix' of options (asking 'right for whom and for what?') but also a forward-looking and dynamic understanding of adaptation pathways, best understood as decision-making processes over sets of potential action sequenced over time (Wise et al. 2014; Câmpeanu and Fazey 2014). This challenge is compounded by the fact that responses to change, that is adapting to climate change, create new conditions and multiple possible and often interrelated pathways at different scales and for different groups of people; choices are shaped by uneven power structures and historical legacies and, in turn, create further change and the need for more or different responses (Fazey et al. 2016).

Pursuing a pathway approach to adaptation harbours the potential for significant positive outcomes, with synergies for well-being and dignified lives, and to 'leap-frog the SDGs' through inclusive adaptation planning (Butler et al. 2016b), in countries at all levels of development. It allows for identifying socially-salient and place-specific tipping points before they are crossed, based on what people value and trade-offs that are acceptable to them (Barnett et al. 2014, 2016; Tschakert et al. 2017; Gorddard et al. 2016a), sometimes contesting best science predictions and state adaption responses (Fincher et al. 2014; Fazey et al. 2016). Yet, emerging evidence also suggests significant and often hidden trade-offs that reinforce rather than reduce existing social inequalities and hence may lead to lock-in or poverty traps (Barnett et al. 2016; Nagoda 2015; Godfrey-Wood and Naess 2016; Pelling et al. 2016; Butler et al. 2016b) (see Figure 5.3).

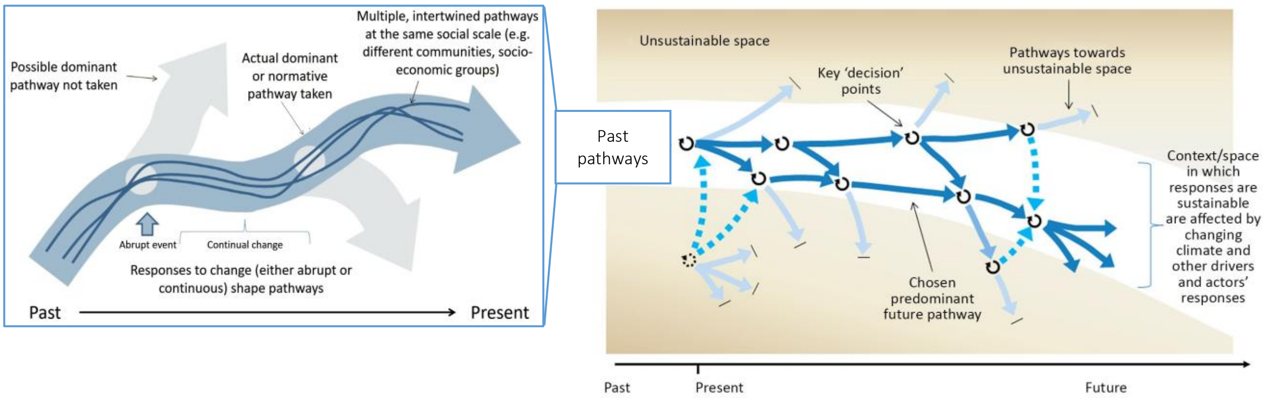

Figure 5.3: Adaptation pathways with possible routes, past-present-future (after Fazey et al., 2016)

Case studies in rural Rumania and the Solomon Islands illustrate how dominant or normative pathways validate the practices and visions of the more privileged members of a community, given their assets and long-standing power positions, while devaluing those of less well-off households, different ethnic groups, and other disenfranchised stakeholders, thereby exacerbating inequalities and pushing the most vulnerable toward lock-in situations with less and less capacity to navigate change (Fazey et al. 2016; Davies et al. 2014). Tensions between values and worldviews that influence adaptation pathway decisions, for instance individual economic gains and prosperity versus community cohesion and solidarity, further erode collective adaptive action; moreover, innovative actions that deviate from the dominant path are discouraged (Fazey et al. 2016). In the city of London, the dominant adaptation pathway and vision for disaster risk management adopts a discourse of resilience, albeit one embedded in national austerity measures; it increasingly emphasises self-reliance which, given the city's rising inequalities, intensifies the burden on low-income citizens and marginal populations such as the elderly and migrants and others who are unable to afford flood insurance or protect themselves against heat waves (Pelling et al. 2016). A climate adaptation and development pathway that enables subsistence farmers in the Bolivian Altiplano to become world-leading quinoa producers has led to reduced exposure and vulnerabilities and increased community resilience, but it has also triggered a series of new threats; these range from loss of ecosystem services to loss of social cohesion and traditional values to social exclusion and dispossession (Chelleri et al. 2016). These insights suggest that win-win outcomes, even via socially-inclusive adaptation pathway approaches to plan and prepare for 1.5°C global warming and higher local warming, will be exceedingly difficult to achieve without redistributive measures and built-in procedural justice mechanisms to meet the SDGs, particularly poverty eradiation and reducing inequalities.

5.4 Impacts of Mitigation on Sustainable Development

Mitigation response options and mitigative pathways, even more so than measures and trajectories on the adaptation side, are expected to have implications for sustainable development, poverty eradication, and inequalities, and the SDGs, across sectoral and regional contexts. These impacts will generate synergies and trade-offs. The literature on such impacts since the AR5 does often not directly refer to 1.5°C or higher temperature targets, yet it indicates mitigation options with high unrealised potential for accelerating the transition as well as side-effects. Aligning mitigation actions to sustainable developmental objectives can ensure public acceptance (IPCC 2014c) and enable policy design for fast actions (Lechtenboehmer and Knoop 2017). There is very high agreement in literature that pursuing stringent climate mitigation options generates multiple positive non-climate co-benefits that have the potential of reducing costs of achieving several sustainable development dimensions (Schaeffer et al. 2015b; Ürge-Vorsatz et al. 2014; Von Stechow et al. 2015; Singh et al. 2010; Ürge-Vorsatz et al. 2016; IPCC 2014c) (see also Table 5.1) and advancing multiple short-term tragets under the SDGs. However, the literature also suggests potential trade-offs between various mitigation measures and SD implications. An assement of trade-offs reveals what corrective measures can strengthen synergies and overcome trade-offs. The next two sub-sections assess such synergies and trade-offs. These sub-sections draw from the underlying literature summarised in Table 5.1 (see below), for individual mitigation options, by sector, and implications for the SDGs, with levels of confidence.

5.4.1 Synergies between Mitigation Options and Sustainable Development

Past IPCC assessment reports have examined mitigation strategies for specific sectors (energy supply, industry, buildings, transport, and AFOLU). Here, the focus is on mitigation action categories which need acceleration (IPCC 2014c) and simulatneous realisation, and their implications for the SDGs; yet, studies in this area are still limited. Hence, we draw predominantly on insights from the perspective of co-benefits or multiple benefits.

There is high agreement in the literature that, if each region and economic activity sector catch up with the best available technology for enhancing efficiency in resource use (energy, material) and waste reduction, realising the 1.5°C goal will be easier. In addition to such an ambitious mitigation goal, signifciant shifts in how nations organise economic activities are needed to enhance cross-sectoral exchanges. The exchanges can occur through symbiosis, consumer behaviour, product use efficiency, reduced demand, policy support, and modernisation of basic energy services across sectors towards low carbon or zero carbon or even carbon removal. Equally important is cross country collaboration. For deep and sustained emission reductions, a comprehensive package of mitigation options is necessary (Aamaas and Peters 2017), rather than pursuing them independently, which can lead to loss of livelihoods (Colenbrander et al. 2016).

5.4.1.1 Accelerating efficiency in resource use

The residential sector accounts for roughly one-third of total global final energy use (Lucon et al. 2014). Energy efficiency improvement in buildings across various countries has positive impacts on sustainable development, for example health, reduction in morbidity, cost savings, local employment, food security, women empowerment, reduced school absences, improved appearance, thermal comfort, pride in place and enhanced social status, improved indoor air quality, and energy savings. Clean cook-stoves enhance indoor air quality, especially in developing countries, improve health especially among indigenous and poor rural communities, less expenses for firewood, employment generation in the stove supply chain, food security, and women empowerment (synergies with SDGs 1, 3, 5, 7, 8 and 13). Industrial sector energy efficiency improvements generate synergies with SDGs 1, 3, 6, 7, 8, and 11. Estimates suggest that currently available and cost-effective measures can reduce transport GHG emissions by 40-50% compared to 2010 (Lah 2017). Transport sector efficiency improvements through congestion reduction, improvement in vehicle fleet usage in terms of passengers travelled, and higher comfort in public transportation systems contribute to SDGs 3, 7, 8, and 11.

5.4.1.2 Behavioural options

Technological improvements supplemented by behavioural responses help realising the full potential of energy efficiency improvements. Building technology and occupant behaviours interact to affect home energy consumption. Occupant habits sometimes cannot take advantage of the >50% of energy efficiency potential of a building. Synergies between changes in behavioural responses and SDGs 3, 7, 12, and 13 are expected. Individual behaviour change in distance (<100km) and frequency of travel, travel in non-motorised modes, public transport, two wheelers, car model choice and use patterns impact SDGs 8, 11 and 12. Individual automobile use behaviour change with appropriate incentives and awareness programs, policy interventions targeting restrictions on driving behaviour enhance SDG12. Changes in the tourism sector can provide promising mitigation in the transport sector while advancing SDGs 8 and 12 (Peeters and Dubois 2010).

5.4.1.3 Access to modern and reliable energy and fuel switch

Millions of people in the Global South are escaping poverty by accessing modern energy forms (Lloyd et al. 2017; Programme 2013). These systems are less carbon intensive and vital for advancing human development in rapidly growing countries like Vietnam, Brazil, India, South Africa, and poorest countries transitioning from agrarian to industrial societies (Mark et al. 2017; Dasgupta and Roy 2016). In the residential sector, switching to low-carbon energy fuels (e.g. cook stoves, modern appliances) results in energy savings, reduction in indoor pollution, sustainable consumption, human health and wellbeing, economic growth, sustainable communities, reduction in heating and cooling costs, energy justice, poverty reduction, and energy demand reduction, and lower risks for ecosystems. Creutzig et al. (2014) find that the 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. Renewable energies could potentially serve as the main source of meeting energy demand in rapidly growing cities of the Global South. Ali et al. (2015) estimated the potential of solar, wind and biomass renewable energy options to meet parts of the electrical demand in Karachi, Pakistan. Switching to low-carbon fuels in the residential sector enhances SDGs 3, 7, 11, and 13.

In the transport sector, the use of biodiesel, natural gas and electric vehicles (EVs) generates climate benefits and benefits for local air pollution, for instance through the Strategic Zero Carbon Transport Plan for the city of Athens is (Nanaki and Koroneos 2016). Electric vehicles are found to provide the largest number of SDG benefits (3,7,8,11,14,15). However, in some countries where electricity will be from fossil fuels the role of CCS will be important to be consistent with SDG7. Non-motorised transport like bicycles also satisfies multiple SDGs (3,8,10,11,12,15).

The response from the energy supply sector through phasing out of coal reduces adverse impacts of upstream supply-chain activities, in particular local air pollution, and coal mining accidents and risks for terrestrial ecosystems. Switching to natural gas is also expected to bring water benefits due to increasing power generation efficiency and reduced cooling water demands. Energy supply systems using modern biomass, nuclear, and renewables generate clear positive impacts for SDGs 1, 3,4,5,8,10,11,12, and17.

5.4.1.4 Cross-sector policy measures

New mitigation options that emerge from cross-sectoral efforts and new sectoral organisations based on the circular economy concept and multi-policy interventions that follow systemic approaches are showing higher synergies with SDGs.

In many newly industrialising countries, the dual problem of resource scarcity and environmental impacts of manufacturing processes can be addressed through adoption of operations that follow industrial symbiosis, industrial park/clusters or the circular economy concept. Studies show that such industrial operations improve the sustainable development ability by 33%, non-renewable inputs, imported resource inputs, and associated services could be saved by 99.71%, 25.64%, and 9.82% respectively, and the ratio of savings to the total GDP of the industrial park would be 29.71%. It helps in reducing the need for raw materials and energy consumption and improves the overall sustainability (Fan et al. 2017). Other benefits accruing through industrial parks in China are water savings, waste reduction and conversion to resources, resource savings through regenerative use of resources, sustenance of profitability, sustainable supply chain management, enhancing capability, ecosystem service value enhancement up to 27% (Zeng et al. 2017). Industries are becoming energy supplier for neighbouring towns. The use of waste heat, waste water, and industry roof tops for solar help meet neighbourhood urban energy demands. It creates a new opportunity for energy enhancing independency of specific regions, total energy demand reductions by towns, primary energy demand reduction and heating energy demand for towns beings met (Karner et al. 2015).

In the transport sector, the EU policy package of taxing fuels for private transportation, reducing taxes on electricity and increase in subsidies to renewable sources of electricity has been successful in simultaneously addressing SDGs 7 and 8 (Bartocci and Pisani 2013). Systemic policy targeting of mass transit systems, energy-efficient vehicles, stringent emission standards, and biofuel can have synergies with SDGs 3 and 12 (Aggarwal 2017). Integrated climate and air pollution target-oriented policies can enhance multiple SDGs (1,3,8,10,11, and 12) (Klausbruckner et al. 2016).

Most common SD benefits to communities are financial (although mostly benefitting the more powerful members), employment, infrastructure and technology transfer. One statistical study found correlation between high human development indicators and a high number of CDM projects/credits.

5.4.1.5 Land-based agriculture and forestry sector mitigation options

Land use, and especially forestry, plays a key role for emission reductions proposed by many countries to fulfil their NDCs and will be critical in longer-term strategies towards 1.5°C. In the land use related mitigation options, actions on the supply side reduce GHG emissions per unit of land per animal, or per unit of product and demand-side actions cover changing consumption patterns of food and other products, by reducing waste etc. (IPCC 2014c). One of the key UNFCCC and bilateral mechanisms promoting forestry is REDD+ (Reducing Emissions from Deforestation and Forest Degradation) which supports sustainable management, enhancement and conservation of forests and carbon stocks. Climate-smart agriculture mitigates GHGs through soil management, agricultural intensification, and waste reduction. Research on the sustainable development implications of both REDD+ and other land use measures has expanded considerably since the AR5. An analysis of first generation REDD+ pilot and demonstration activities by estimating smallholder opportunity costs of REDD+ in 17 sites in six countries (Brazil, Peru, Cameroon, Tanzania, Indonesia, and Vietnam) shows that poorer households face lower opportunity costs from deforestation and forest degradation in all the studied sites. This can lead to a situation where, in the case of flat payments, the poorest households would be the ones generating most of the emission reductions. This can have significant consequences on both equity and efficiency of REDD+ initiatives (Ickowitz et al. 2017). Agricultural intensification can promote conservation of biological diversity by reducing deforestation by rehabilitation and restoration of biodiverse communities on previously developed farm or pasture land. Reduction of waste in the food system generally benefits sustainable development. On the demand side, proposals to reduce methane and other GHG emissions by cutting livestock consumption can increase food security for some, if land grows food not feed.

5.4.2 Trade-offs between Mitigation Options and Sustainable Development

5.4.2.1 Accelerating efficiency in resource use

Complex interactions exist between resident behaviours and the built environment. Residing in energy efficient homes without adequate heating and ventilation strategies to minimise indoor dampness, for example, may increase the risk of adult asthma (Sharpe et al. 2015). In the extractive industries, water and energy efficiency targets are not always synergistic. These efficiency targets need to be addressed in a strategic and integrated way over the next decade to avoid industry level shortfalls (Nguyen et al. 2014).

5.4.2.2 Access to modern and reliable energy and fuel switch

Deep emission reductions through biofuel/biodiesel based transformations, if not managed carefully, can exacerbate food security and land use disputes in certain countries with disproportionate negative impacts upon rural poor and indigenous populations (Shi et al. 2017; Olsson et al. 2014; Aha and Ayitey 2017; Johansson et al. 2016) (Zhang & Chen 2015). Unjust and adverse outcomes have been documented amongst biofuel and hydropower projects in various developing countries, predominantly via the displacement and replacement of subsistence food economies, resulting in increased food insecurity and reduced access to fuel for the rural poor. Bioenergy may also increase irrigation needs and exacerbate water stress with negative associated impacts on multiple SDGs (e.g. 1, 6, 7, and 10). Achieving deep cut in emissions through CCS and nuclear options can also have significant adverse implications for health and water security (SDGs 3, 6), create lock-in to high carbon development trajectories (SDG13), and increase the societal costs and risks associated with the handling of waste and abandoned reactors (see SDG8) (see Table 5.1a and 5.1c available at the end of this Chapter).

Low-income populations in the Global North are often left out of renewable energy generation schemes, either because of high start-up costs or lack of home ownership (UNRISD 2016), while conservation efforts to enhance land and forest carbon sinks have excluded traditional owners and indigenous populations from efforts to manage natural resources, as in the case of Australia (Winer et al. 2012). Hence, trade-offs between renewable energy production and other environmental objectives need to be scrutinised for negative social outcomes. Deep cuts to emissions could impede development for certain regions, countries, and populations unless low carbon pathways and low cost energy are rapidly made available and implemented (Colenbrander et al. 2016).

5.4.2.3 Cross-sector policy measures

Despite multiple benefits of industrial parks, industrial symbiosis may result in loss of regulating and supporting services of the surrounding area and decrease the indirect economic value of these services in some cases (Shi et al. 2017).

It is unclear whether private finance can deliver the full range of actions required for a low carbon transition, or what role the public sector can and should play to mobilise these resources. Case of Kigali shows that governments in developing countries can lay the foundations for compact, connected low-carbon cities (Colenbrander et al. 2016). Identification of mitigation options with positive impacts on sustainable development may not be sufficient to deliver desired sustainable development objectives unless they are rightly valued and integrated into policy packages, supplemented by governance coordination across sectors and nations (Von Stechow et al. 2015), and ensure collaboration and dialogue between local communities and municipal bodies (Colenbrander et al. 2016; Ghosh et al. 2016). In rapidly devloping countries, efforts need to go beyond green growth indicators (Roy et al. 2016). Institutions that are effective, accountable, and transparent are needed at all levels of government to improve energy access, promote modern renewables, and boost energy efficiency.

In the AR5, assessments of the Clean Development Mechanism (CDM) revealed few pro-poor and sustainable development benefits (Olsson et al. 2014; Crowe 2012). Similar problems exist for the voluntary market, although some projects demonstrate strong social goals. Almost all research studies conclude that sustainable development is overlooked in such projects in the interests of emission reductions which generate market benefits for host countries and project developers. Some CDM projects have been shown to violate human rights by not consulting local people and creating land rights conflict and land grabs. CDM projects so far have been biased toward Asia and Latin America and renewables remain underrepresented.

Policy measures to improve energy standards may also produce contradictory outcomes for emission reductions if energy prices increase (e.g. increased electricity prices leading the poor to switch away from clean(er) fuels). Pro-poor mitigation policies are also needed to reduce climate change threats to poverty. Examples include investing in additional and better infrastructure by leveraging private resources, and using designs that account for future climate change and related uncertainties (Hallegatte et al. 2015). Mitigation responses are likely to produce differentiated opportunities and risks in the context of sustainable development when descaled to the regional/nation/local level. This is because social, economic, environmental and political contexts shape how mitigation opportunities, risks and costs manifest in specific places. For instance, the costs of mitigation vary significantly between regions, with aggregate relative costs typically lower in OECD and Latin American countries and higher in other regions (Clarke et al. 2014). Emission reduction costs associated with Nationally Determined Contributions (NDCs) also differ significantly between countries as a percentage of GDP (Akimoto et al. 2016).

5.4.2.4 Land based agriculture and forestry sector mitigation options

There are significant differences between countries and locations in terms of implementation of REDD+ policies due to biophysical conditions (e.g. carbon density per unit area), livelihood strategies, governance structures, and the integration of climate change mitigation into land use policies (Luttrell et al. 2013; Ravikumar et al. 2015; Di Gregorio et al. 2017a; Ickowitz et al. 2017; Loft et al. 2017). Studies on gender in first generation REDD+ pilots and demonstration activities show that women have been less involved in REDD+ initiative design decisions and processes than men (Brown 2011; Larson et al. 2014), and that implementation of REDD+ can perpetuate gendered divisions of labour (Westholm and Arora-Jonsson 2015). REDD+ projects have also been shown to negatively affect indigenous groups in some cases. Promoting land-use changes through planting monocultures on biodiversity hot spots can have adverse side-effects for biodiversity and local food security (IPCC 2014c). Mitigation policies implemented through a uniform global carbon price may also have negative effects on the agricultural sector. Poorer populations are more sensitive to price fluctuations, and the strongest decrease would occur for livestock product consumption in sub-Saharan Africa (Havlík et al. 2015). Proposals to reduce methane and other GHG emissions by cutting livestock consumption can also undermine livelihoods and the cultural identity of poor farming populations.

5.4.2.5 Temporal and spatial trade-offs and distributional impacts

Delaying action to reduce greenhouse gas emissions increases the risks associated with mitigation. Weak mitigation targets in the short term necessitate significant and rapid up-scaling of mitigation efforts in the medium term, with associated increased costs (Luderer et al. 2013; Schaeffer et al. 2015a) stranded coal assists (Johnson et al. 2015), job losses (Rozenberg et al. 2014) and risks associated with grid integration of fluctuating renewable energy (von Stechow et al. 2016). Delayed mitigation is also likely to constrain flexibility of future response options (von Stechow et al. 2015) and necessitate wide-scale deployment of negative emission technologies (Rogelj et al. 2015), thereby increasing the likelihood of negative trade-offs between energy, environmental and socio-economic objectives (von Stechow et al. 2016; Smith et al. 2016). Constraining technological options for mitigation requires significant up-scaling of other technological options, thereby increasing overall mitigation risks (von Stechow et al. 2016; Muratori et al. 2016). Restricted technological portfolios have also been shown to incur higher associated financial costs than unconstrained technological portfolios (Luderer et al. 2013; Jakob and Steckel 2016).

Future climate response options are expected to continue to impose differential regional impacts. For example, economies dependent upon fossil fuel-based energy generation and/or export revenue will be disproportionally affected by future efforts to restrict the use of fossil fuels via stranded assets and unusable resources (Johnson et al. 2015; McGlade and Ekins 2015). In turn, different climate response options will likely have regionally-differentiated implications for energy and food security. Cumulative oil imports as a percentage of oil consumption are projected to rise significantly for Asian and OECD nations under mitigation scenarios consistent with the 2°C warming target (Jakob and Steckel 2016). Alternatively, technological constrains are projected to significantly alter global energy trade patterns out to 2100 under 'full technology' and 'no CCS' scenarios (Muratori et al. 2016). Under the latter scenario, fossil fuels have been projected to virtually phase out by 2100, resulting in many Middle Eastern and African energy exporters becoming net energy importers by the end of the century while many North American and Eastern European nations become net exporters (see also Box 4.13 on solar radiation management).

Table 5.1: Impacts of mitigation options on specific targets of the 17 SDGs, for social (a), economic (b), and environmental (c) dimensions.

[Due to size, Table 5.1 is provided at the end of the chapter. A high resolution version of the table is available as a supplementary PDF (SR15_FOD_Chapter5_Table5_1.pdf) that can be downloaded with the chatper for review]

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

While previous sections have focused on the sustainable development and SDGs impacts of individual mitigation options, this section takes a systems perspective. Emphasis is on quantitative pathways depicting fundamental transformations and thus stringent mitigation policies consistent with 1.5°C and 2°C, and the differential synergies and trade-offs with respect to the various sustainable development dimensions.

As described in Chapter 2, achieving 1.5°C or 2°C requires deep cuts in GHG emissions and large scale changes of energy supply and demand as well as agriculture and forestry systems. Drawing upon comparative and multi-model pathways studies, we focus the assessment here on the aggregated impact of mitigation for the following SD-dimensions: air pollution & health, food security & hunger, energy access, biodiversity, water security, and poverty & equity (also see Sections 5.4.1 and 5.4.2). Emphasis is on multiregional studies, which can be aggregated to the global scale, and wherever possible we discuss also near-term implications in terms of the NDCs and SDGs.

[Studies that explore SD-climate policy linkages of mitigation and adaptation pathways, such as CD-LINKS (http://www.cd-links.org), are still in preparation. Updates to be made when model results are available]

5.4.3.1 Air pollution and health

Greenhouse gases and air pollutants are typically emitted by the same sources, such as power plants, cars, and factories. Hence, mitigation strategies that reduce the use of fossil fuels typically result in also cuts in emissions of pollutants, such as black carbon (BC), sulphur dioxide (SO_2), nitrogen oxides (NO_x), and other harmful species (Clarke et al. 2014; see Figure 5.4), causing adverse health and ecosystem effects at various scales (Bollen et al. 2009; Global Energy Assessment 2012; Markandya et al. 2009; Smith et al. 2009).

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). Recent multi-model comparisons indicate that mitigation pathways consistent with 1.5°C would result in considerably higher co-benefits for air pollution and health compared to pathways that stay below 2°C (see: CD-LINKS 2017 and Chapter 2 Scenario Database). The co-benefits for air pollution are the biggest in the developing world, particularly in Asia (see air pollution panel, Figure 5.4). The currently pledged NDCs lead in most countries to limited structural changes only. Hence, the co-benefits for air pollution is relatively small if compared to mitigation strategies consistent with 2°C and below (see air pollution panel, Figure 5.4).

5.4.3.2 Food security and hunger

Stringent climate mitigation strategies in line with 'well below 2°C' or '1.5°C' goals can rely on the deployment of large-scale land-related measures, like afforestation or bioenergy production (Creutzig et al. 2015a; Popp et al. 2014; Rose et al. 2014). These land-related measures can compete with food production and hence raise food security concerns (Smith et al. 2014b). Mitigation studies indicate that so-called 'single-minded' climate policy, aiming solely at limiting warming to 1.5°C or 2°C, can have negative impacts for global food security (Fujimori et al. forthcoming; Hasegawa et al. 2015). Impacts of 1.5°C mitigation pathways can be significantly higher than those of 2°C pathways (see Figure 5.4), particularly in Africa and parts of Asia. In these scenarios, mitigation policies worsen food security by more than doubling the number of people at risk of hunger in 2050 compared to a case without climate mitigation (Fujimori et al. forthcoming).

In order to avoid food-security trade-offs, mitigation policies need to be designed in a way so that they shield the population at risk of hunger from possible negative food price effects. Fujimori et al. (forthcoming) find that such policies can entirely eradicate the identified trade-off between climate mitigation and food security. The cost measured by welfare changes for these food security policy options are found to be low globally and significantly smaller than the mitigation costs of 2-6% that are associated with 1.5°C pathways (Rogelj et al. forthcoming).

5.4.3.3 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 South Asia where over 70% of the population relies primarily on solid fuels for cooking even today (Global Energy Assessment 2012; WB and IEA 2017). This has far reaching effects on health and wellbeing, in particular for the most marginalised including women and young children (Pachauri et al. 2012). One study quantifying the interactions between climate mitigation and energy access indicates that if climate change mitigation efforts increase energy costs, this could significantly slow down the transition to clean cooking fuels (Cameron et al. 2016). Under stringent mitigation pathways (e.g., 2°C Climate Policy Scenario), there could be up to 20% additional people without access to clean cooking in South Asia in 2030 (compared to Current Policies without stringent mitigation - see Figure 5.4) (Cameron et al. 2016). Perhaps most importantly, studies exploring the trade-offs between energy access and emissions mitigation policies show that redistributional measures, such as subsidies on cleaner fuels and stoves, could fully offset the negative effects on energy access. The climate policy design and the selection of the appropriate instrument will be critical thus for shielding the impoverished parts of the population against increasing fuel costs that may be spurred by climate policy. Within this context, studies indicate that the revenues from climate policy might potentially act as a means to help finance the costs for providing energy access to the poor (Cameron et al. 2016).

5.4.3.4 Water security (energy-related)

Transformations towards low-carbon energy and agricultural systems can have major implications for freshwater demand as well as water pollution. The up-scaling of renewables and energy efficiency as depicted by low emissions pathways will, 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. However, some low-carbon options such as bioenergy, nuclear and hydropower technologies could, if not managed properly, have counteracting effects that compound existing water-related problems in a given locale (see McCollum et al. forthcoming for a summar and Byers et al. 2014; Davies et al. 2013; Fricko et al. 2016; Fujimori et al. 2016; Hanasaki et al. 2013; Hejazi et al. 2013; Stewart et al. 2013; PBL 2012; Vidic et al. 2013).

Fricko et al. (2016) finds that on balance, the global energy-related water use and pollution of 1.5°C and 2°C mitigation pathways may result in adverse side-effects and thus trade-offs compared to fossil fuel-intensive baseline scenarios (Figure 5.4). The estimates across different assessments vary, however, significantly across scenarios. In addition, adaptation in power plant cooling technology can considerably reduce freshwater withdrawals as well as thermal pollution. Global freshwater consumption increases in 2°C scenarios primarily as a result of rapidly expanding electricity demand in developing regions and the prevalence of freshwater-cooled thermal power generation. Reducing energy demand emerges as a robust strategy for both water conservation and GHG emissions reductions. The results underscore the importance of an integrated approach when developing water, energy, and climate policy, especially in regions where rapid growth in both energy and water demands is anticipated.

5.4.3.5 Biodiversity

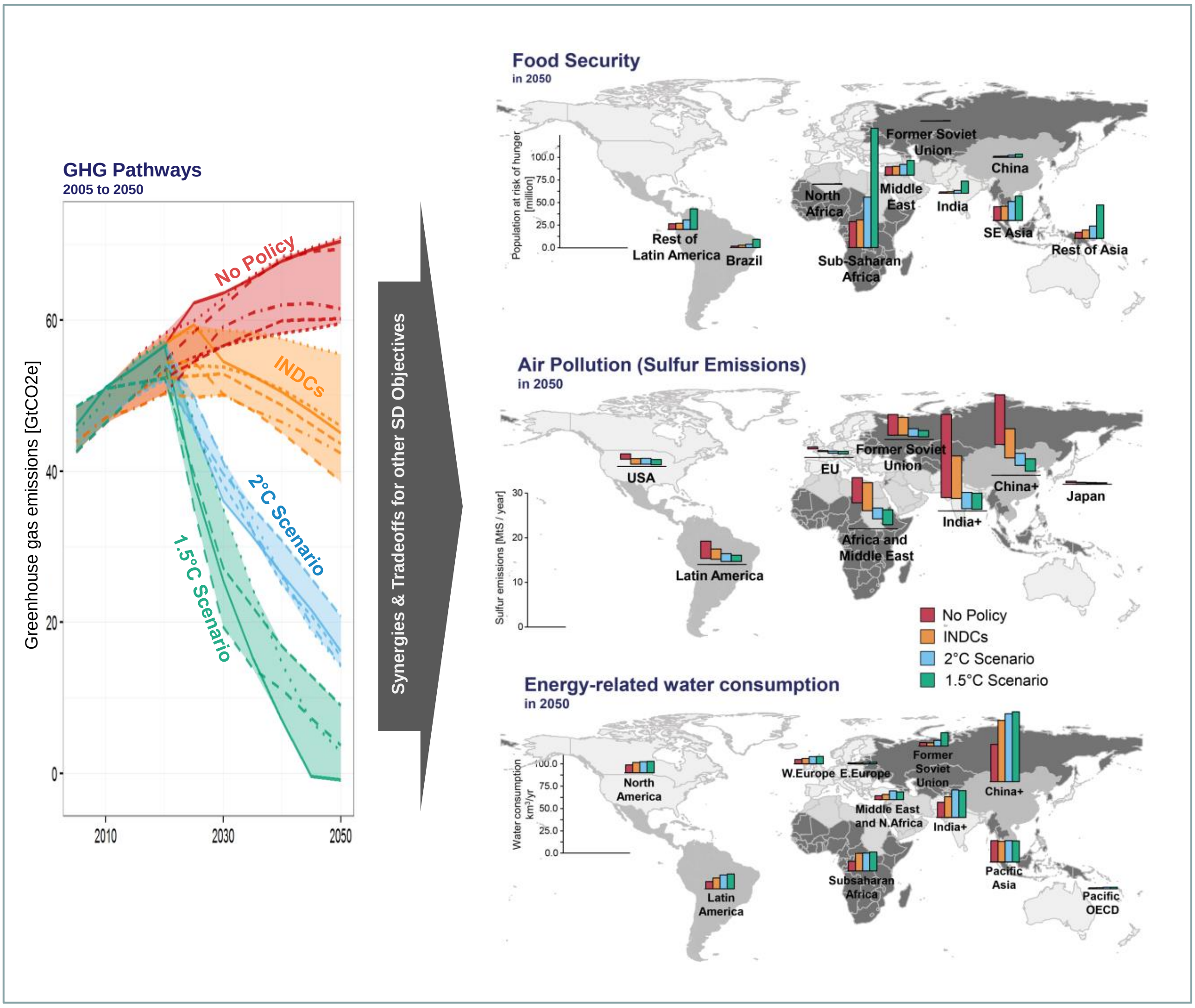

Figure 5.4: GHG emission pathways and associated regional synergies and trade-offs for food security, air quality, and energy-related water consumption. Climate policy baseline pathways (No-Policy) are compared with INDC, 2°C and 1.5°C mitigation pathways. Sources: Fujimori et al., forthcoming; Chapter 2 scenario database; CD-LINKS (2017).

[*Note that the Figure 5.4 shows preliminary data, and will be extended for other sustainability dimensions, such as energy access and biodiversity. In addition, we'll add uncertainty ranges, global aggregated panels, and information on costs of how to resolve possible trade-offs through redistribution measures.*]

In summary, the assessment of mitigation pathways shows that, in order to meet the 1.5°C target, a wide range of technological options, including large-scale deployment of negative emission technologies (e.g. BECCS) will likely be required (see Chapter 2). While pathways aiming at 1.5°C are associated with high co-benefits for some SD dimensions (such as health and air pollution), the rapid pace and magnitude of the required changes lead also to increased risks for adverse side-effects for a number of other SD dimensions (particularly risk of hunger, poverty, and basic needs, such as energy access). Reducing these risks requires smart policy designs and mechanisms that shield the poor and redistribute the burden, so that the most vulnerable are not affected. Recent scenario analyses show that this is in principle possible at relatively modest costs (see Fujimori et al. forthcoming). Demand-side measures, including efficiency and behavioural changes, can help to reduce the risk of potential trade-offs between mitigation and other sustainable development dimensions (von Stechow et al. 2015). Reliance on demand-side measures only, however, will not be sufficient for meeting stringent targets, such as 1.5°C and 2°C.

5.5 Development First: Implications for Reductions of Greenhouse Gas Emissions, Climate Vulnerabilities and Adaptive Capacities

Climate change mitigation and adaptation policies are becoming more systematically embedded within a larger framework of low-carbon development strategies and plans (Mitchell and Maxwell 2010; Mulugetta and Urban 2010; Von Stechow et al. 2015; Suckall et al. 2014a). This new context calls for a re-examination of the conventional 'climate-first' framing that addressed development as a co-benefit of climate stabilisation to adopt instead a 'development-first' approach, acknowledging that development drives emissions, not vice versa (Ürge-Vorsatz et al. 2014; Winkler et al. 2015; Stern 2007; Roman and Linner 2012). This shift of perspective is particularly significant given that development can be an important motivation for pro-environmental change, across diverse publics (Bain et al. 2016). Attention to development is also important in the context of 1.5°C global warming as such an ambitious climate goal will require a radical shift from business-as-usual development (Boucher et al. 2016; Griggs et al. 2013). However, not all sustainable development initiatives will facilitate rapid mitigation or a reduction in existing and future climate vulnerabilities. Approaching mitigation and adaptation policy through a development lens points to the need for governance structures that are flexible and reflexive over time and can address complex social factors and human behaviours (Sathaye et al. 2007; Stern et al. 2016).

5.5.1 Pursuing Development and Reaching Ambitious Emission Reductions

Pursuing sustainable development can be compatible with reaching ambitious climate objectives but may require selecting options that are not necessarily cost-effective from a narrow GHG emission mitigation perspective (Hildingsson and Johansson 2015; Delponte et al. 2017; van Vuuren et al. 2017). This section reviews the literature on how a sustainable development perspective changes the approach to mitigation policies, distinguishing cases where sustainability facilitates emission reductions (Section 5.5.1.1) and those where sustainability may hinder mitigation if specific conditions are not met (Section 5.5.1.2).

5.5.1.1 Sustainable development as a facilitator of mitigation

Several dimensions of sustainable development are synergetic with emission reductions so that strengthening action on the former automatically facilitates ambitious mitigation policies.

Protecting oceans and strengthening the health of coastal and marine ecosystems, including preserving ocean fauna, consistently appears to be a key enabler for strong emission reductions by enhancing carbon sinks (Singh et al. 2017; Atwood et al. 2015). Despite uncertainties, seagrasses, tidal marshes and mangroves are recognised as dense carbon sinks (Fourqurean et al. 2012; Lovelock et al. 2017; Lavery et al. 2013). Valuing 'Blue carbon' ecosystems can link local coastal management to the global debate on climate change (Huxham et al. 2015). Traditional knowledge and management systems from local communities also has a key role to play in preserving the long-term storage of blue carbon (Vierros 2017). Only strong mitigation action can ensure a sustainable use of the ocean (Lubchenco et al. 2016) and protect key marine and coastal organisms, ecosystems from the high risks they would face even under 2°C-compatible scenarios, hence maintaining the carbon sink capacity of the ecosystem (Gattuso et al. 2015; Magnan et al. 2016a).

Protecting health can also directly support emission reductions when development improves outdoor air quality by reducing pollutants from fossil fuel combustion (West et al. 2013; Yang and Teng 2016). Combining air pollution control and non-fossil energy targets also lowers the total cost of the coal-control policy (Wang et al. 2016). Health benefits can motivate public support for ambitious climate actions (Thurston 2013). Similarly, pursuing healthy diet trajectories to reduce the global incidence of illnesses (like type II diabetes, cancer and coronary heart disease or obesity) triggers significant decreases in GHG emissions (Tilman and Clark 2014; Springmann et al. 2016; Lowe 2014).

Public education can also support decarbonisation in fossil-producing economies by facilitating the redirection of a workforce away from low-skilled fossil fuel intensive work towards specialised skills in green projects; this is for example a key driver of China's 'new normal' (Tung 2016). In South Africa, successful education programs provide the enabling conditions to facilitate a shift away from unskilled employment in fossil fuel processes, notably coal, to new sectors (Altieri et al. 2016a).

Improved energy access through efficiency and decentralised energy is key to realising synergies across multiple sustainability objectives and climate mitigation (Von Stechow et al. 2015; Alstone et al. 2015). In fossil fuel importing countries, energy security is also a core condition for sustainable energy access and can be a core motivation to implement deep emission reductions (Oshiro et al. 2016). Changes in consumption and production towards more sustainable practices limiting energy use would also be highly correlated with ambitious mitigation (Druckman and Jackson 2016; Geels et al. 2015). Development policies favouring energy access in rural areas and maximising efficiency in urban zones are shown to reduce the social cost of carbon to meet a given climate target, compared to a climate-centric approach (Shukla et al. 2015).

Sustainable development partnerships between different constituencies, across a variety of governance scales and involving a range of actors, are also essential to achieve ambitious emission reductions (Anderson 2017). The coordination of international flows of finance and technology and of policies is key to reducing emissions, notably in energy-intensive industries (Denis-Ryan et al. 2016).

5.5.1.2 Conditional synergies between sustainable development and emission reductions

There is growing agreement in the literature that equitable development requires developed economies to reduce high energy consumption and production while enabling developing countries to pursue economic growth to achieve higher standards of living and wellbeing (dos Santos Gaspar et al. 2017; Barroso et al. 2016). The compatibility between sustained economic growth and ambitious emission reductions depends on the capacity to decouple economic growth and GHG emissions (Holden et al. 2016; Stern et al. 2016). The potential for decoupling is highly debated. The literature on de-growth argues that reliance on decoupling alone is not realistic and that ambitious climate goals also require a radical cut to energy demand and GDP growth, especially amongst developed states (Jackson and Senker 2011; Wiseman 2017; Weiss and Cattaneo 2017; Antal and Van Den Bergh 2016; Zhang et al. 2016). Others argue that economic growth can be compatible with decarbonisation and dematerialisation under specific conditions and well-designed policy settings which reorient growth patterns towards more efficient resources and energy use (Liu et al. 2017; Sheng and Lu 2015; Schandl et al. 2016). Emerging literature suggests ambitious emission reduction targets can unlock very strong decoupling potentials in industrialised fossil exporting economies (Hatfield-Dodds et al. 2015). Achieving inclusive, low-carbon growth depends on the capacity to mobilise finance for sustainable infrastructure, and the ability of carbon pricing schemes to close infrastructure access gaps (Bak et al. 2017; Bhattacharyya et al. 2016; Jakob et al. 2016). A major challenge in developing economies is to attain and sustain economic development without increasing GHG emissions, calling for specific strategies maximising the opportunities of the domestic context (Emodi and Boo 2015; Elum et al. 2017). Transitioning to low-carbon growth also requires progressive implementation measures to avoid serious immediate unemployment issues (Yuan et al. 2015), direct investment in key sectors for mitigation (Waisman et al. 2013), and opportunity to recycle the revenue from carbon pricing schemes to address inequalities and reduce unemployment (Combet 2013; Grottera et al. 2015).

Addressing inequality can enhance climate change mitigation efforts (Jorgenson 2015), but taking people out of poverty may also trigger additional energy demands and emissions (Chakravarty and Tavoni 2013; Ley 2017). Strategies exist that ensure that increased energy access can be compatible with emission reduction, like energy savings (François and Gavaldao 2017), the deployment of modern energies such as small-scale renewables (Sovacool and Drupady 2012), or off-grid solutions for people in remote areas (Sovacool 2012; Sanchez and Izzo 2017). The deployment of these low-carbon energy solutions requires adopting measures to overcome technology and reliability risks associated with large-scale deployment of renewables (Giwa et al. 2017) and adopting adequate economic incentives, particularly fossil fuel subsidy reforms (Jakob et al. 2015; Ouyang and Lin 2014; Rentschler and Bazilian 2016). Technological change combined with changes in consumption patterns raises questions about the potential for radical socio-cultural, technological and organisational innovation (Doyle and Davies 2013; Rourke and Lollo 2015; Mont 2014).

Considering effects associated with indoor air pollution by improving cook stoves efficiency can have a very significant positive effect on health while helping to reduce GHG emissions, notably in rural areas (Berrueta et al. 2017a). But health improvement strategies that shift from polluting stoves to fossil fuel create potential negative effects on emissions trends (Grieshop et al. 2011). A shift away from traditional cook stoves towards clean-burning cooking fuels may decrease public acceptability of mitigation policies if they trigger higher energy costs (Cameron et al. 2016). Synergetic approaches to policies for energy access, air pollution and climate change are required to avoid these side-effects (Rao et al. 2013a). Promoting low-emission options requires taking account of the cultural and social needs of users, such as recognising that stoves often serve as a gathering point for families (Bielecki and Wingenbach 2014). It also depends upon the articulation of new technology diffusion with other dimensions, like behaviour and lifestyle change (Jensen et al. 2016; Quam et al. 2017). Effective regional cooperation is key to promoting a synergetic approach between enhanced access to electricity, cooking energy, and emission reductions thanks to the deployment of renewables (Uddin and Taplin 2015).

Sustainable cities are usually defined as having lower emissions, but they have very significant embedded/imported emissions and managing sustainability has to consider global climate effects (World Bank 2010; Pancost 2016). Rapid urbanisation in the developing world is mainly due to rural-urban migration in parallel with economic growth, which increases energy consumption (Mjimba and Elum 2016). Managing this rapid urbanisation is key to achieving sustainable development and enabling alignment of urbanisation patterns and the requirements for ambitious mitigation (Cobbinah et al. 2015). Cities can contribute to climate change mitigation through an integrated approach involving low carbon development as part of a city's strategic planning. Cities have an opportunity to link climate change policies to local developmental priorities (Rescalvo et al. 2013), but there are wide variations in the type of strategies that can be used for reducing emissions in cities according to their characteristics (local climate, income, levels of industrial activity, urban form, and existing carbon intensity of electricity supply) (Kennedy et al. 2014). For example, water and sanitation services contribute to greenhouse gas emissions, and the choice of wastewater treatment technologies, improved pumping efficiency, use of renewable sources of energy, and within-system generation of energy can offer potential for reducing emissions (Howard et al. 2016).

Development of the land sector can contribute to ambitious mitigation objectives through the production of bioenergy (Rose et al. 2014). But large-scale biofuel is a sustainable use of land only if this production addresses issues posed by the competition for land. These issues include water, and other inputs which can affect land use dynamics and risks of increase emissions from deforestation and land use change from agricultural intensification (Acheampong et al. 2016). In addition, the overall result of biofuel emissions depends on complex interactions and trade-offs for example between water use, and soil (Macedo and Davidson 2014; Gao and Bryan 2017a). The land sector also offers a variety of cost-competitive mitigation options, and sustainability criteria are needed to guide development and implementation of AFOLU mitigation measures with context-specific application (Bustamante et al. 2014).

Similarly, carbon sinks in land and forests are key for ambitious mitigation (Rose et al. 2012) and smart, low-carbon agriculture addresses the difficult trade-offs between demands for food and energy, ecosystem services, soil carbon stocks, and land use (Mello et al. 2014). The feasibility of quantifying and verifying soil mitigation activities also remains an impediment to implementing sustainable land development (Paustian et al. 2016). Land management practices including carbon sequestration in agricultural soils, or deforestation (DeClerck et al. 2016a; Lal 2004), are also influenced by many other dimensions including the travel time to markets, in the case of the decision to cultivate upland rice in Thailand (Puri 2017) or development patterns affecting rice production in Mozambique (Roman and Hoffmaister 2012). This means that management practices in the land sector can support mitigation objectives if they are explicitly planned with decarbonisation policies (Boer et al. 2016).

5.5.2 Pursuing Sustainable Development, Reducing Vulnerabilities, and Enhancing Adaptive Capacities

Development can significantly influence adaptive capacity or the ability of institutions, people, systems and organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences (IPCC 2014b). Multiple lines of evidence since the AR5 confirm that development also significantly influences vulnerability (see definition in Glossary) *[to be available in SOD]* (Ayers et al. 2014; Forsyth 2013; Reed et al. 2015). Narrowly conceived development may create adverse responses to adaptation (Dilling et al. 2015), creating risks of exacerbated vulnerability and mal-adaptation over time (Juhola et al. 2016; Magnan et al. 2016b) while well integrated adaptation can support sustainable adaptation which is well integrated socially and environmentally (Smucker et al. 2015; Weisser et al. 2014; Aggarwal 2013; Adam 2015; Eakin et al. 2014). However, much development may only result in incremental adaptation where the central aim is to maintain the essence and integrity of a system or process at a given scale (AR5 Annex II: 1758) and, as such, may be insufficient in a rapidly warming world (Noble 2014: 836). For example, concern has been expressed that the rapid pace of global urbanisation has created significant pressures on resource use and consumption which may outpace incremental adaptive capacity (Doll and Puppim de Oliveira 2017; Thorne et al. 2017).

Since the AR5, new international agreements (Paris, Sendai, the New Urban Agenda) have positioned development in a new framework which focuses on sustainability, risk reduction, and inclusive/equitable urbanisation. Within this context, this section first reviews evidence about the extent to which sustainable development can promote *transformative* adaptation and significantly enhance a community's ability to meet its needs, and identify options within limits for a 1.5°C warmer world.

5.5.2.1 Sustainable development for transformative adaptation

The AR5 defined transformative adaptation as 'adaptation that changes the fundamental attributes of a system in response to climate and its effects' (IPCC 2014d: 1758). While sustainable development objectives can conflict with climate change adaptation, sustainable development is most likely to enable transformative adaptation when attention is paid to promoting equity, social justice and fairness, and participation in decision making, rather than addressing current vulnerabilities as stand-alone climate problems (Antwi-Agyei et al. 2017; Shackleton et al. 2015b; Mathur et al. 2014; Arthurson and Baum 2015). Recent literature also advances the analysis of AR5 which shifted focus away from major vulnerabilities and priority activities (hazard based approaches) *per se*, towards understanding the underlying causes of vulnerability, including insufficient information, social or institutional capacity, finance, or technology (Noble et al. 2014). Development that enables participation, by local people, is most effective when it addresses the wider socioeconomic and cultural processes that inhibit inclusive and equitable decision making (McCubbin et al. 2015; Nyantakyi-Frimpong and Bezner-Kerr 2015), and enables multi-scale planning strategies (Toole et al. 2016).

Investment in universal primary and secondary education around the world is an effective strategy for transforming vulnerabilities and significantly strengthening adaptive capacities (Striessnig et al. 2013; Muttarak and Lutz 2014; Striessnig and Loichinger 2015). Highly educated individuals and societies have better preparedness and responses to disasters, suffer less negative impacts, and are able to recover faster (Samir 2013; Sharma et al. 2013; Frankenberg et al. 2013). Education of policy makers about indigenous practices and the incorporation of local indigenous knowledge about, for example, weather, farming or seed resources, into decision making can also strengthen adaptive capacity (Nkomwa et al. 2014; Slegers 2008; Orlove et al. 2010; Sutcliffe et al. 2016).

Gender mainstreaming in development is also essential to ensuring that climate policies and programs are comprehensive, and that women and men are supported and empowered to take action on their own behalf (Alston 2014). The AR5 underscored that building women's capacity to contribute to sustainable development is important. There is growing evidence that, if development reinforces inequitable gender structures, it will undermine adaptive capacity in a changing climate (Bhattarai et al. 2015; Van Aelst and Holvoet 2016). Additional literature published since the AR5 emphasises that enhancing gender equity can advance opportunities enhancing collective problem-solving (Nilsson et al. 2016b; Makina and Moyo 2016; Ayers et al. 2014; Saito 2013; Uittenbroek et al. 2013; Cohen 2017; Pearse 2016; Mbow et al. 2015). Development is effective in promoting transformative adaptation where it addresses existing social exclusion and social inequalities including loss of women's rights to lands, across many parts of Africa. For example, a lack of access to farmlands by women and migrant farmers in Ghana predisposes these groups to climate change vulnerability by limiting the adaptation options available to them (Antwi-Agyei et al. 2015).

Economic growth and development can either transform vulnerability to climate change, for example through diversification away from climate-sensitive activities like agriculture or exacerbate community vulnerability, and climate exposure, for example through concentration of population in dense urban areas exposed to floods (Neumann et al. 2015; Zougmore et al 2016). This suggests economic growth *per se* does not automatically reduce or transform vulnerability, however, investment in skills and increased access to finance can indeed significantly reduce vulnerability to climate change (Bowen et al. 2012). However, unsustainable development can inhibit transformation; recent analysis of behaviour amongst high consumers in China (Wang 2017), Finland (Ala-Mantila et al. 2016), the United Kingdom (Butler et al. 2016a) and the United States (Dickinson et al. 2016) highlights the complex way motivations, values and social norms, together with household structures, opportunities to participate in new practices and household incomes can reinforce, undermine or lock-in, behaviours that strengthen climate adaptation over the short, medium and long term (Dilling et al. 2015).

Local and national institutions can be supported to address challenges posed by climate change (Agrawal 2010; Mubaya and Mafongoya 2017). The role of institutions is key for diffusion of technological innovation, helping to avoid the impacts of climate change in agriculture (Chhetri et al. 2012). Continuous and iterative learning processes are also vital aspects that enable adaptation and resilience to climate change (Tschakert and Dietrich 2010).

Addressing poverty which is endemic in many rural communities is significant for reducing the vulnerability of agrarian communities (Eriksen and O'Brien 2007). In Ghana, vulnerability of food production systems to climate change – in the form of drought – is strongly influenced by the socioeconomic conditions including poverty and literacy levels (Antwi-Agyei et al. 2012). It is important therefore, that sustainable development actions addressing climate change vulnerability can tackle the root causes of poverty in these communities in order to increase the adaptive capacity of such households.

Climate change-poverty linkages are complex, multifaceted, and context-specific (Leichenko and Silva 2014). There is broad agreement that low-income countries are more vulnerable to current climate variability and future climate change than rich countries (Schellnhuber et al. 2013). The 'adaptation' deficit – i.e. the fact that poorer countries have less ability to adapt – is one of the main explanations, and there is strong empirical evidence that lower demand for climate security at low income is a key driver of this deficit (Fankhauser and McDermott 2014). The support to reduce inequalities though transfers is therefore key to support global adaptation, but the transparency and accountability of these transfers matter, since intended effects of the funds in terms of climate-resilience may dissipate if development aid is administered in ways that ignore local priorities or undermine wider adaptation efforts (Eyckmans et al. 2016; Sovacool et al. 2017b).

Escaping poverty generally decreases people's vulnerability to climate change, and when done well, can be a highly effective form of climate adaptation (Hallegatte and Rozenberg 2017). Research in urban Brazilian municipalities suggest addressing income inequality is a key precursor to reducing vulnerability (Rasch 2017). However, there is disagreement about how poverty eradication should occur and little indication that many of the current policies are likely to achieve the transformational rates of poverty eradication required to protect vulnerable communities in a changing climate.

In summary, development can promote transformational adaptation; however, these approaches can be costly, and time-consuming, and without careful integrated planning, and attention to whose voices are heard in far reaching plans, development may exacerbate vulnerability, poverty, and inequity (Ojha 2016; Lonsdale et al. 2015). There is also some caution, in that development which addresses poverty may not necessarily always stimulate equivalent significant reduction in vulnerability, for example if households are unable or do not invest in related climate risk management strategies (Nelson et al. 2016). Resilience building cannot replace poverty reduction since the former does not exclusively apply to, or benefit, the poor (Béné et al. 2014). An integrated approach is key to address the societal dimensions that can exacerbate vulnerability because of mal-adaptation (Dilling et al. 2015). Reducing inequalities that cause vulnerability in Malawi is not prioritised in projects funded on the basis of climate-compatible development (Wood et al. 2016a).

5.6 Adaptation, Mitigation and Sustainable Development Integration: Opportunities and Challenges

This section examines opportunities and challenges associated with integrating adaptation, mitigation and sustainable development for 'triple-win' outcomes. Triple-wins refer to climate response measures and/or development initiatives that are capable of achieving adaptation, mitigation and sustainable development objectives together. Specifically, this section examines synergies and trade-offs between adaptation-mitigation-sustainable development objectives, key enabling conditions required for triple-win outcomes as well as key challenges, distributional implications of triple-win initiatives, and the potential for transformational adaptation to synergise climate and development objectives.

5.6.1 Integrated Approaches toward Climate and Development

Policy approaches that combine climate and development objectives has been put forward as an 'aspirational goal' for policy development (Denton et al. 2014). It has long been understood that adaptation and mitigation are interlinked, though not necessarily aligned (Klein et al. 2007; Moser 2012; Landauer et al. 2015); that effective climate responses involve a combination of both (Wilbanks et al. 2003; Swart and Raes 2007; Landauer et al. 2015); and that integrated adaptation-mitigation response options have the potential to deliver important co-benefits for development goals and vice-versa (Swart and Raes 2007; Di Gregorio et al. 2017; Suckall et al. 2015), particularly in developing countries (Dang et al. 2003; Swart and Raes 2007; Ayers and Huq 2009; Goklany 2007; Bizikova et al. 2007; Hallegatte et al. 2016a).

Increased understanding of the linkages between adaptation, mitigation and sustainable development has seen a proliferation of efforts to address climate and development objectives together. Various integrative frameworks now exist that promote policy coherence between these two domains (Di Gregorio et al. 2017b; Stringer et al. 2014; Suckall et al. 2014b; Goklany 2007), and a significant body of literature has begun to consider how climate policy can be mainstreamed in sustainable development policy (Ayers et al. 2014; Gwimbi 2017; Webber 2016). Recent adoption of the 2030 Agenda for Sustainable Development and the SDGs also underscores the need for integrated policy responses to address interlinked environment-development challenges (Boas et al. 2016; Nilsson et al. 2016a; International Council for Science 2017).

Standalone climate response options have the potential to produce a range of co-benefits and trade-offs with sustainable development goals and vice versa (see Sections 5.3, 5.4 and 5.5). Furthermore, as discussed in Chapter 2 and Section 5.4.3, limiting warming to 1.5°C will likely require a range of response options be deployed concomitantly. A major challenge for policy makers, then, is to identify strategies that enhance synergies between climate response options with development goals. This has led researchers to consider 'Climate Compatible Development' (CCD), defined as 'development that minimises the harm caused by climate change impacts while maximising the many human development opportunities presented by a low emissions, more resilient future' (Mitchell and Maxwell 2010: 1). A normative goal of policy coherence is to align climate and development objectives in order to maximise synergies and minimise trade-offs between them. It has been argued that such approaches have potential to achieve 'triple-wins' by leveraging opportunities for adaptation, mitigation and development concomitantly (Suckall et al. 2015).

Notable examples of triple-win measures include waste-to-compost projects in Bangladesh that reduce methane emissions, promote adaptive capacity via soil improvements, and contribute to sustainable development through the preservation of ecosystem services (Ayers and Huq 2009); as well as conservation projects that sequester carbon, reduce vulnerability to ecosystem services and contribute to rural livelihoods (Locatelli et al. 2015; Huxham et al. 2015). Climate-smart agriculture (CSA) has also been examined as an approach for transforming and reorienting agricultural systems to support local livelihoods and food security together with mitigation and adaptation with mixed outcomes (Lipper 2014; Stringer et al. 2012; Dyer et al. 2012; Kaczan et al. 2013; Bryan et al. 2013; Campbell et al. 2016). Analysis of the potential for policy frameworks and development strategies to deliver triple-win outcomes is also gaining prominence (Stringer et al. 2014; Sugar et al. 2013; Few et al. 2017; Tanner et al. 2014).

5.6.2 Achieving Triple-win Outcomes

Calls to integrate adaptation-mitigation-development have been criticised for being based-upon overly conceptual and optimistic assessments (Few et al. 2017), and for being disconnected from political and economic realities that shape on-the-ground implementation and associated equity and distributional outcomes (Moser 2012; Stringer et al. 2014; Few et al. 2017; Marino and Ribot 2012). It is clear, however, from the emerging empirical case study literature that various enabling conditions underpin triple-win outcomes, and that the presence of enabling conditions and constraints to adaptation, mitigation and sustainable development integration is unevenly distributed amongst regions, nations and communities.

5.6.2.1 Enabling conditions and challenges

Fragmented approaches to adaptation and mitigation increase the risk of trade-offs occurring between each other and broader development objectives, increasing the risk of mal-adaptation and mal-mitigation (Marino and Ribot 2012). Strong institutions, access to financial resources, strong partnerships and political will are central for the development of policy frameworks with high synergy potential, whereas weak institutions and poor institutional coordination tend to produce fragmented and disjointed policy responses (Di Gregorio et al. 2017b; Stringer et al. 2014; Duguma et al. 2014b; Kongsager et al. 2016). The following four attributes are recommended to advance triple-win outcomes at policy and project scales: a) institutional development at the national level; b) partnership development; c) learning and knowledge sharing through national and regional fora; and d) development of mechanisms that permit more equitable and transparent distribution of costs and benefits (Stringer et al. 2014). The significance of strong institutional linkages and multi-stakeholder partnerships across scales are also demonstrated in community-level development projects that align national and community climate and development objectives (Sanchez and Izzo 2017; Suckall et al. 2015). The absence of such multi-scale linkages may impede successful adaptation (Suckall et al. 2015).

Community-based case study evidence indicates that balancing stakeholders' immediate needs with longer-term global climate objectives produces synergies that enhance project effectiveness, development opportunities, and livelihood resilience (Sanchez and Izzo 2017; Suckall et al. 2015). Failure to do so has been shown to undermine adaptation, mitigation and development outcomes. For example, contestations over tenure and the meaning of land in community forestry projects have produced a range of social trade-offs that undermine livelihood resilience and exacerbate inequalities (Kongsager and Corbera 2015; Few et al. 2017). Participation of community members in the planning, implementation and monitoring of integrated climate-development projects has been shown to be a significant driver of triple-win outcomes by enhancing local empowerment, trust and collaboration, and social capital (Dyer et al. 2013; Sanchez and Izzo 2017).

Politics, actors, and institutions play an important role in enabling or frustrating the pursuit of integrated adaptation, mitigation and sustainable development measures towards triple-win outcomes. Analysis of energy system transformation in Kenya (Newell et al. 2014a), carbon forestry in Mozambique (Quan et al. 2014) and artisanal fisheries in Ghana (Tanner et al. 2014) show how powerful interests can inhibit the implementation of policies for triple-win outcomes, and shape how triple-wins are defined and for whom they are delivered. Insights from Malawi reveal how visible, hidden and invisible forms of power create barriers to procedural justice in climate-compatible development design, reducing the chance such projects can be contextually appropriate and have widespread stakeholder buy-in (Wood et al. 2016b). Successful implementation of development strategies capable of actualising triple-win outcomes therefore requires issues of power, justice and equity to be addressed, acknowledging that projects achieving triple-wins can also create auxiliary benefits and negative side-effects on different stakeholders and local people (Wood

2017). These trade-offs are best analysed in the light of wider national policy contexts as they strongly influence the prospects of achieving integrated climate policy and development goals in practice (Naess et al. 2015).

5.6.2.2 Distributional and dynamic dimensions of enabling conditions and constraints

Enabling conditions and constraints differ between regions, communities and groups of people; not all people have equal opportunities and capabilities to achieve triple-win outcomes. Assessment of national-level policy frameworks for policy coherence shows that enhancing synergy potential for triple-win outcomes remains challenging for many nations, particularly for those with weak and uncoordinated overarching governance for climate policy (Di Gregorio et al. 2017b; Stringer et al. 2014). In addition, systematic analysis of enabling conditions for synergies between adaptation and mitigation in low-income countries revealed that least-developed countries demonstrated the least synergy potential, thus suggesting higher relative likelihood of mal-adaptation and mal-mitigation in nations already experiencing relatively high levels of poverty and reduced development opportunities (Duguma et al. 2014b). An emerging literature on political instability highlights a growing concern about the impact of prolonged periods of violence and conflict on environmental degradation, de-forestation, loss of bio-diversity, failure of monitoring of conservation efforts, infrastructure and investment (Castro-Nunez et al. 2017) and the way conditions of peace encourage collective problem solving and long-term investment (Kester and Sovacool 2017).

Climate change impacts and climate response measures may also erode enabling conditions for triple-wins. First, worsening climate change may undermine enabling conditions and impose constraints upon the capabilities of vulnerable nations and communities to synergise adaptation, mitigation, and sustainable development. It is well understood that climate change will disproportionately affect the poorest and most vulnerable (see Section 5.2); may increase risk of violent conflict (Kelley et al. 2015; Adger et al. 2014); and undermine opportunities for sustainable development (Mugambiwa and Tirivangasi 2017). Furthermore, emerging evidence indicates that possibilities for achieving sustainable development goals and stringent mitigation will become increasingly restricted as global warming increases, particularly in countries with limited capacity to adapt (Mugambiwa and Tirivangasi 2017; Besada et al. 2015). Climate change will therefore interact with pre-existing vulnerabilities to further constrain the synergy potential of disadvantaged regions, nations and communities.

Second, climate response measures (or clusters of options) and development initiatives mapping onto current climate and socio-economic vulnerabilities affect future enabling conditions for triple-win outcomes. Forward-looking measures that anticipate the long-term and systemic effects of response measures adopted for mitigation, adaptation or development can facilitate the future attainment of triple-wins. For example, investments in transport infrastructure can increase emission reduction potentials, enhance resilience of the system to climate impacts and be part of the strategy towards sustainable cities (Hallegatte 2009; Creutzig et al. 2015b; Hallegatte et al. 2015). On the other hand, reactive coping strategies that enhance development outcomes in the short-term at the expense of adaptation and mitigation may degrade longer-term development opportunities and foreclose future response options (Suckall et al. 2014b; Thornton and Comberti 2017). Global-scale climate response options may also produce regionally differentiated outcomes that undermine adaptation, mitigation and sustainable development opportunities concomitantly. For example, large-scale deployment of BECCS and afforestation and reforestation (AR) has been projected to significantly decrease the amount of arable land available for food production (Smith et al. 2016), leading to potential food price increases (Muratori et al. 2016). Because agricultural prices are a significant driver of poverty (Hallegatte and Rozenberg 2017), and because synergy potential is strongly corrected with bio-capacity (Duguma et al. 2014b), countries with little bio-capacity and high poverty may have opportunities for triple-win outcomes significantly eroded as a consequence of BECCS and AR deployment.

Regions and communities featuring absent or weak enabling conditions that are also subject to high vulnerability to climate change and climate response measure risks are likely to encounter worsening trade-offs between adaptation, mitigation and sustainable development, here framed as ‘triple-losses’ in analogy to ‘triple-wins’ (see Figure 5.5). Triple-losses closely relate to ‘triple-injustices’, which occur when ‘green economy policies reproduce, or exacerbate inequalities and negative distributional consequences for already disadvantaged groups' (UNRISD 2016: 150). Emerging evidence indicates that the Tropics may be particularly vulnerable to triple-losses owing to low synergy potential (Duguma et al. 2014b), high incidence of fragile states (Fund for Peace 2017), high climate change impacts upon regional ecosystems and human wellbeing (Pecl et al. 2017; Harrington et al. 2016; Herold et al. 2017), and potentially high vulnerability to climate response measures that increase food prices and place additional stressors on poor and disadvantaged people (Hallegatte and Rozenberg 2017).

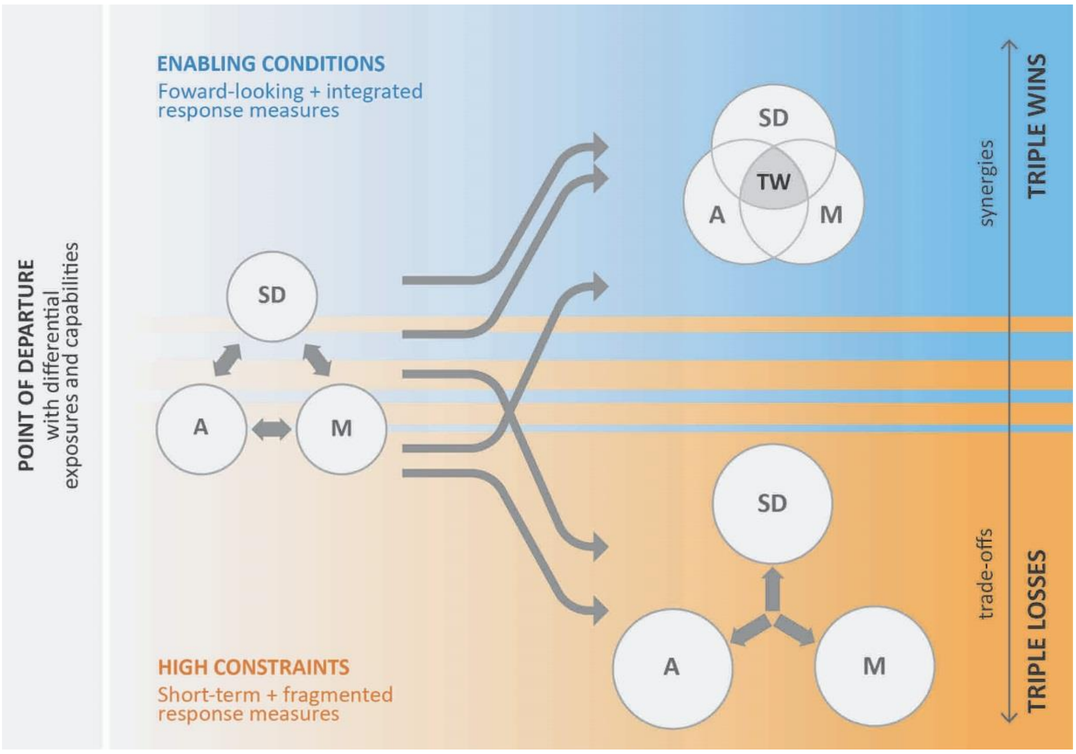

Figure 5.5: Conceptual model of triple-wins and triple-losses. Presence of high enabling conditions affords synergies between adaptation (A), mitigation (M) and sustainable development (SD) objectives, producing triple-win outcomes. Increasing constrains produce fragmented responses to A, M and SD, increasing the likelihood of undesirable trade-offs and triple-loss outcomes.

5.6.3 Governance to Strengthen Synergies for Transformation

Despite the growing interest in policies and programs for triple-wins, adaptation, mitigation and development continue to be addressed in isolation from each other in a majority of cases (Duguma et al. 2014b,a; Kongsager and Corbera 2015; Thuy et al. 2014; Di Gregorio et al. 2017b; Locatelli et al. 2016). The ability to capitalise upon adaptation-mitigation-development synergies is likely to be crucial for the capacity of nations and communities to achieve triple-win outcomes.

Trade-offs between adaptation, mitigation and sustainable development objectives occur within pre-existing development contexts (Thornton and Comberti 2017). This is because development contexts shape the range of options available to decision makers, as well as what is considered desirable, thus limiting the range of what is possible and desirable. For example, as discussed by Seto et al. (2016), technological, institutional and behavioural systems tend to interact through time to produce various forms of lock-in that are highly resistant to change and that can produce seemingly intractable trade-offs between climate and development objectives. Achieving synergies for triple-win outcomes within such contexts, therefore, has been argued to require holistic approaches to climate and development policy that consider interlinked ecological, economic and social factors (Duguma et al. 2014a; Kongsager and Corbera 2015), their dynamics over time (Tanner et al. 2014), as well as the transformation of development pathways (Thornton and Comberti 2017).

Transformation pathways were discussed in the AR5 as a way of achieving stringent emission reduction goals, acknowledging that trade-offs with other non-climate objectives are inherent to them (Clarke et al. 2014). However, as policy attention shifts towards integrated policy measures for triple-win outcomes, it is clear that the international community increasingly views trade-offs between climate and development goals as unacceptable. Furthermore, given the tight interconnections and feedbacks between adaptation, mitigation and sustainable development, emerging evidence indicates that integrated policy and program responses that address climate and development objectives concomitantly are more likely to achieve stringent climate targets than stand-alone measures. How to conceptualise and implement development pathways capable of delivering triple-win outcomes, with emphasis on equity and justice, is discussed in the subsequent section.

5.7 Climate-Resilient Development Pathways

5.7.1 Climate-resilient Development Pathways, Wellbeing, and Equity

Given this report's mandate to assess the knowledge on 1.5°C compatible pathways *in the context of* strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty, emergent insights on climate-resilient development pathways are of vital importance, even if the literature describes such development pathways often without explicit reference to specific degrees of global warming. Climate-resilient development pathways (CRDPs) are best understood as an extension to the AR5 climate-resilient pathways, foregrounding the tripartite emphasis on development, resilience, and transformation laid out in the Agenda 2030 – Transforming our World. These pathways are foremost development pathways that simultaneously promote climate resilience. Beyond 'triple-wins' (see 5.6), they emphasise equity, fairness, and justice and the potential to reduce societal vulnerabilities, address entrenched inequalities, and break the vicious circle of poverty through poverty eradication, combined with 'best' emission reduction and adaptation pathways (least trade-offs or negative side effects), to strive for a better future for all. The literature assessed in this section implies at least four key aspects (outcomes) of CRDPs: (i) enhanced adaptation and reduced vulnerabilities; (ii) stringent emission reduction; (iii) the promotion of equity, fairness and justice; and (iv) poverty eradication and improved wellbeing for people and ecosystems, with social learning and participatory governance as additional core attributes.

CRDPs (see Figure 5.1) go beyond best risk management practices and transformative adaptation pathways with built-in vulnerability reductions, as envisioned in the AR5. They are also distinct from most promising emission reduction and transition pathways that would limit global warming to 1.5-2°C above pre-industrial times. CRDPs emerge from the consideration of adaptation and mitigation pathways at different scales that may yield the highest synergies and least trade-offs. While some pathways focus on economically and technically feasible options, CRDPs entail what may be 'socially desirable and acceptable', acknowledging that the former may increase rather than decrease risks for already disadvantaged populations (von Stechow et al. 2016) or exacerbate inequalities. Mainstream biophysical, techno-economic, and socio-technical models tend to harbour 'overly optimistic techno-centric visions' (Rosenbloom 2017:46) and make unwanted assumptions about the ethicality and public acceptance of contentious approaches (Preston 2013; Gardiner 2013). Multi-scalar justice dilemmas are embedded in virtually all mitigation options and pathways (see 5.4.2-3), and an over-emphasis on emission reductions at national levels can obscure negative impacts on disadvantaged groups, including low-income communities and communities of colour in the Global North (Farrell 2012). Moreover, politics and power are often implicated in defining what is economically and technically feasible (Meadowcroft 2011; Haasnoot et al. 2013; Normann 2015; Patterson et al. 2016).

Identifying socially acceptable, inclusive, and equitable pathways for a 1.5°C warmer world in the context of a common global climate response and a broader pursuit of sustainable development, beyond 'triple-wins' and policy integration (see 5.6) is a challenging and contentious yet essential endeavour. It asks 'whose environed future are we pursuing and along which pathways?' (Gillard et al. 2016). People's preferences, choices, values and visions differ markedly within and between countries. These differences are underlain by vested interests and politics and power that perpetuate business-as-usual trajectories (O'Brien 2017). Therefore, even with the best intention, reconciling different visions for a future world and how those can be achieved can be fraught with complex moral, practical, and political difficulties. Each pathway involves trade-offs and has significant distributional consequences. CRDPs with the potential to limit global warming to 1.5°C will need to adopt stringent decarbonisation that does not exacerbate social injustices, locally and at national levels (Okereke and Coventry 2016) and engage with the politics of the sustainability and capabilities of everyday life (Agyeman et al. 2016; Schlosberg et al. 2017).

In order to explicitly highlight climate justice and equity in integrative approaches to mitigation, adaptation, and sustainable development (Moellendorf 2015), CRDPs incorporate conceptual advances regarding 'Common but Differentiated Responsibilities and Respective Capacities' (CBDR-RC) as well as lessons learned from community-level transformative change. Klinsky et al. (2016) stress the role of equity in pursuing low-carbon and climate-resilient development by deliberately focusing on well-being and strengthening the capabilities of those people who are typically excluded, marginalised, and most vulnerable. This implies choosing climate actions that create opportunities and benefits and allow people to live a life in dignity (following Sen and Nussbaum) while avoiding actions that undermine capabilities and erode well-being. This notion of CRDPs is in alignment with the 2030 Agenda of 'leaving no one behind', with the aim to preclude severe limitations in adaptive capacities and social and cultural losses. Enhancing capabilities of 'those who have least' entails an additional justice dimension to the premise of not exacerbating risk of those already most vulnerable. It is also in line with transformative social development (UNRISD 2016).

National-level metrics, based on human development, economic capacity, resilience to climate change impacts, governance capacity, and technical and innovation capacity, allow for assessing capabilities (Klinsky et al. 2017b) for countries at different stages of development trajectories. Evidence from CRDPs at the community level underscore the crucial roles of social equity, participatory governance, and social inclusion, as well as innovation, experimentation, and collective learning, together with systems thinking that entails longer time frames and feedbacks (MacKinnon and Derickson 2013; Burch et al. 2014; UNRISD 2016). Resilience and transformation are core elements of such pathways. The 2030 Agenda explicitly addresses transformation in its title, and resilience in SDG13 (climate action, target 13.1 – 'Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries') as well as in five other SDGs: poverty (1.5), hunger (2.4), industry, innovation and infrastructure (9.1), sustainable cities and communities (11 – resilient cities), and life below water (14.2). Climate resilience also overlaps with gender equality (target 5.4 unpaid and domestic care work), for instance in agriculture (Kanengoni 2015).

The section is structured as follows: it first summarises enabling conditions for CRDPs, focusing on social aspects and governance aspects. It then evaluates examples of CRDPs, from the national to the local level, and reviews the extent of these enabling conditions across scale and regions.

5.7.2 Enabling Conditions for Climate-Resilient Development Pathways

The feasibility of the 1.5°C target and synergies with the SDGs rest upon certain enabling conditions or perquisites being met. These conditions can be considered 'foundations' to CRDPs. They address the underlying social and governance/policy dimensions that need to be in place in order to ensure the synergies and trade-offs between technically and financially promising and socially desirable adaptation and mitigation pathways also fulfil the necessary equity and equality dimensions outlined in the 2030 Agenda (see Figure 5.1). There is growing evidence on these enabling conditions that can inform that so far limited literature on how to design, implement, and commit to CRDPs that are consistent with the 1.5°C target and the SDGs.

Understanding tensions between biophysical GHG trajectories (stabilisation targets for GHG concentration, i.e. the RCPs), techno-economic pathways (sequences of low-carbon technologies), socio-technical transitions (transition processes) and CRDPs requires attention to social and governance conditions. Although the Shared Socio-economic Pathways (SSPs) provide useful insight into socio-economic and policy parameters needed to achieve certain climate targets, for instance socially inclusive development, cross-sector and cross-level cooperation, and equality, they remain impractical for implementing CDRPs at different scales (see Box 1.1 on SSPs). Nascent efforts to downscale the global SSPs to the sub-national level (e.g. Absar and Preston 2015) are better able to assess the role of demographics and equity, public and private institutions, and civil society to achieve desirable sectoral results.

5.7.2.1 *Social enabling conditions*

Pathway thinking in line with CRDPs that goes beyond market-based approaches (e.g. carbon pricing) encompasses people's values, visions, and choices, necessitates public deliberation and participatory processes, and refrains from being policy neutral (Rosenbloom 2017). Pathways grounded in public visions for equitable, liveable, just, and low-carbon futures 'open up' alternatives by allowing the broader society, including those most affected, to analyse trade-offs and the structural conditions that perpetuate power imbalances, vulnerabilities, and patterns of exclusion (Stirling 2014; Leach et al. 2010). Realising alternative futures that are equitable and sustainable call for conscious social transformation (O'Brien 2017). Successful climate-resilience building requires equity, justice, and governance to be addressed, for instance in cities in Southeast Asia (Archer and Dodman 2015; Reed et al. 2015). Solution-driven approaches toward transformative change are successful when they adhere to strong social and right-based policies, particularly those that 'expand rights, increase equality and reduce power asymmetries', integrate economic objectives into social and environmental norms, and foster genuine participatory decision making (UNRISD 2016).

The social foundation that underpins human wellbeing in the ecologically safe and socially just space for humanity (Raworth 2017a, 2012; Dearing et al. 2014) is combined with the ecological ceiling of the planetary boundaries (Rockström et al. 2009; Steffen et al. 2015) (Figure 5.6). It highlights the regenerative and distributive transformations needed to 'bring humanity into the Doughnut' and avoid critical human deprivation (Raworth 2017b,a). The shortfalls in twelve dimensions below the social foundation (red inner segments in Figure 5.6), based on 1995-2016 data from UNESCO, WHO, UNICEF, WorldBank, ILO, FAO, UNODC, OECD, ITU, UN, and Gallup, show encouraging trends in population without access to improved drinking water and undernourished (9 and 11% shortfalls, respectively), but significant deprivations in peace and justice, gender equality, and political voice, and networks (Raworth 2017b). The latter are derived from data on population living in countries scoring high in corruption, voice, and accountability, gender gap in national parliament representation, and population without access to internet, with shortfalls 85-52% (Raworth 2017b). Tackling inequalities is paramount in order to overcome these social shortfalls, particularly resource inequalities in consumption and production (Raworth 2017a), while simultaneously eliminating ecological overshoots. The achievement of targets aimed at immediate human needs, alongside the planetary boundaries (Griggs et al. 2013) is not only in accordance with the SDGs but also with calls to conceive equity as tightly linked with human well-being, and pathways for well-being integral to CRDPs (Klinsky et al. 2017b).

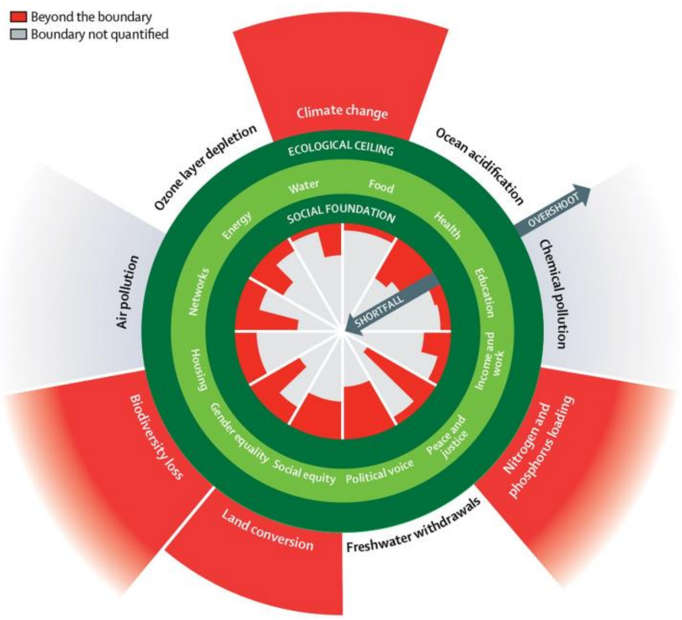

Figure 5.6: A safe and just space for humanity: Shortfalls on social foundations and overshoot beyond the ecological ceiling (Raworth 2017b).

Recent work draws attention to the social and climate policy arenas essential for generating transformative potential across the 17 SDGs (UNRISD 2016). Development pathways that commit to social policies, particularly those that adopt social and solidarity economies, are well positioned to overcome the social shortfalls, remove entrenched inequalities that *inter alia* drive risk to climatic hazards, and enable and expedite climate-resilient-development pathways. Social and solidarity economy (SSE) (see also Box 5.4) promotes cooperation, solidarity, democratic governance, collective action, active citizenship, and environmental stewardship (Bauhardt 2014; Wallimann 2014; Utting 2015). It understands ethics as a core ingredient of economic activity (Gibson-Graham 2008) and fosters economic and political empowerment (Agarwal 2015; Laville 2015; McMurtry 2013). This form of economy can break with unsustainable production and consumption patterns and exploitative social relations (United Nations Inter-Agency Task Force on Social and Solidarity Economy 2014; UNRISD 2016).

5.7.2.2 Governance and policy foundations

Literature since the AR5 identifies three dimensions of governance particularly relevant to CRDPs: the interconnected nature of complex problems, including power imbalances and inequitable resource distribution; the importance of transparent and participatory decision processes; and the need for iterative, adaptive planning (Naess et al. 2015; Sovacool et al. 2015; Dilling et al. 2015; Keohane and Victor 2016; Newell et al. 2014b).

First, a key challenge lies in the cross-sectoral nature and complex interlinkages between the sustainable development dimensions and climate change (Boas et al. 2016; Dimitrov 2016). A significant body of literature addresses this challenge through a ‘nexus’ approach to understanding complex connections, for example between climate, food, energy and water, and other development dimensions (Conway et al. 2015; Welsch et al. 2014; Rasul and Sharma 2016; Howarth and Monasterolo 2017; Keairns et al. 2016). The nexus approach is characterised by, ‘a holistic view of the world that surrounds society and interactions with a complex system of feedback loops, different sectors and natural resources’ (Howarth and Monasterolo 2017:104). A reductive focus on specific SDGs in isolation may undermine the long-term achievement of sustainable climate change mitigation (Holden et al. 2016).

Second, the AR5 also identified key unresolved issues, that is how to articulate both top-down and bottom-up planning approaches while engaging diverse communities across space and creating ‘procedurally equitable forms of decentralisation’ effective market mechanisms and government action (Fleurbaey et al. 2014: 287). Important literature since then has assessed mainstreaming climate policy in sustainable development policy, in ways that include a range of participants in the coproduction of policy, and legitimise the complex trade-off decisions and choices required to implement national goals for 1.5°C effectively and equitably (von Stechow et al. 2016; Clark et al. 2016; Maor et al. 2017; Ayers et al. 2014; Gwimbi 2017; Webber 2016). Climate policy can be more easily integrated where climate policies advance, ‘environmental protection, social and economic development and justice/participation’ (Rietig 2013; Cuevas et al. 2016; Cumming et al. 2017; Satyal et al. 2016). However a key challenge lies again in the cross-sectoral nature and complex interlinkages between the various sustainable development dimensions (Boas et al. 2016; Dimitrov 2016; Conway et al. 2015; Welsch et al. 2014; Rasul and Sharma 2016; Holden et al. 2016; Casado-Asensio and Steurer 2014). Given the pivotal role of local governments in fostering sustainability transitions, these issues are significant from the international to the local level as they link climate change policies to multi-scalar developmental priorities (Wamsler et al. 2014; Rescalvo et al. 2013).

Third, iterative decision making at all levels of governance helps to identify both the challenges and benefits inherent in simultaneously pursuing multiple priorities across multiple fora, in ways that can be flexible, innovative and responsive to the changing conditions and complex, ‘wicked’ climate problems (Shaw et al. 2014a; Termeer et al. 2016). While literature is divided about the trade-offs between participation and speed in climate decision making (Irvin and Stansbury 2004; Lubell et al. 2016; Howell 2013) iterative, transparent and inclusive, governance processes are more likely to be regarded as equitable and legitimate as they reduce compliance costs over time and enhance the ease of implementation, even in the absence of consensus or where decisions are controversial (Maor et al. 2017; DeCaro et al. 2017).

5.7.3 Evidence of Climate-Resilience Development Pathways: From Nation States to Communities

Emerging empirical evidence of CRDPs allows identifying context-specific ingredients for successes and challenges encountered, across a variety of scales. While the below insights from national and community level experiences (both communities of practice and place-specific communities) rarely make explicit reference to specific global warming levels or targets, they provide invaluable lessons for a 1.5°C warmer world. None of them reveals win-win (or triple-win) trajectories but instead complex trade-offs between 'socially acceptable' and 'market-oriented' pathways, highlighting the vital role of societal values, internal contestations, and political dynamics, all of which are not easily evaluated through scientifically and analytically rigorous analysis alone (Edenhofer and Minx 2014; von Stechow et al. 2016; UNRISD 2016).

5.7.3.1 Green economy pathways, green states, and implications for sustainable development

States play an important role in reconciling low-carbon pathways with sustainable development and ecological sustainability. Labels such as 'green economy', 'green growth', and 'green states' are increasingly used to describe nation-state strategies and policies for such dual commitment; yet, how states employ these concepts varies widely. Several typologies distinguish between green economy discourses and their potential for transformative change. Those discourses that align best with CRDPs are described as 'transformational' and 'strong' (Ferguson 2015). They include two important UN approaches: 1) the 2011 UNEP report 'Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication' where a green economy is defined as 'low-carbon, resource efficient and socially inclusive', leading to 'improved well-being and social equity, while significantly reducing environmental risks and ecological scarcities' (UNEP 2011: 9); and 2) the 2012 UNESCAP 'Green Growth, Resources and Resilience: Environmental Sustainability in Asia and the Pacific', with a strong focus on poverty reduction and resilience building (Georgeson et al. 2017b). Despite continuous reliance on market mechanisms and economic growth, and other areas of criticism (Wanner 2014; Brockington and Ponte 2015), the UN approaches appear best suited to integrate green economy pathways with sustainable development and the SDGs (Brown et al. 2014; Georgeson et al. 2017b).

Nonetheless, in promoting equity and social and environmental justice - core aspects of CRDPs - existing discourses fall short of their potential. An overemphasis on market and profit opportunities tend to trump environmental justice legislation and enforcement, and procedural justice policies appear more preoccupied with managing risks and controlling people and resistance rather than including and empowering affected citizens (Bell 2015). An alternative is a 'thick green' perspective that emphasises de-growth, democracy and empowerment of civil society, including marginalised groups, and justice that alters the global economy's very structure (Lorek and Spangenberg 2014; Ehresman and Okereke 2015).

Several countries from the Global South, including China, India, Brazil, and South Africa, are described as 'emerging green states' (Death 2015), despite concerns over lacking budgets, high unemployment or repressive regimes, and more urgent development priorities (Chandrashekeran et al. 2017). These 'emerging green powers' are juxtaposed with states from the Global North, especially the Scandinavian countries that rank top in the Global Green Economy Index/Social Progress Index (2016), having embraced the concept of 'green states' earlier on (Tienhaara 2014; Ferguson 2015; Duit et al. 2016; Bäckstrand and Kronsell 2015). A typology of green economy discourses targeted specifically toward the Global South (Death 2015) - green resilience, green growth, green transformation, and green revolution - suggests varying degrees of success and shortcomings across green interventions. Most national strategies are distinctly state-driven, ranging from Ethiopia's 'Climate-resilient Green Economy Strategy' and Mozambique's Green Economy Action Plan' to China's and India's technology and renewables pathways and ecosystem- and conservation-driven green transition paths adopted in Costa Rica and other Latin American countries (Death 2014, 2015, 2016; Weng et al. 2015; Kim and Thurbon 2015; Brown et al. 2014). Box 5.2 illustrates synergies, trade-offs, and dilemmas that such 'emerging green states' encounter as all trajectories embrace some elements of CRDPs, albeit with differential and incomplete results regarding poverty reduction, reducing inequalities, and equity.

Box 5.2: Successes and challenges of CRDPs in state-driven green economies

Brazil, South Africa, and South Korea represent examples of non-western ‘emerging green states’; they have demonstrated high-profile engagement and positioned themselves as green economy role models, stressing their assets as rising powers and respective capacities to become global leaders, despite major challenges (Death 2014, 2015; Han 2015; La Rovere 2015; Swilling et al. 2016). Such openings for low-carbon transitions may boost stronger efforts (Stern 2015) and provide vital lessons for CRDPs.

Brazil, an upper middle-income country, emphasised its leading role in ambitious climate action, based on low per-capita energy-driven GHG emissions, clean energy sources, and slowing rates of deforestation (Brown et al. 2014; La Rovere 2017). Enacting a ‘green growth’ discourse (Death 2015), the state has managed to create green jobs, boost renewables, and offer sustainable transportation, merged with social welfare programs (Brown et al. 2014). *Bolsa Verde*, established in 2011, combines a Payment for Ecosystem Services Program (*Bolsa Floresta*) with a social protection program (*Bolsa Familia*); the aim is to reduce extreme poverty in rural areas and conserve ecosystems. By 2015, >70,000 households received 300 reais/month (~$US125) and environmental training to engage in sustainable forest use practices (Cook et al. 2012; Coudel et al. 2015; OECD 2015; Schwarzer et al. 2016). *Bolsa Floresta*, the largest PES globally, operating across ~15 million ha in the State of Amazonas (Pinho et al. 2014), aims to reduce deforestation and improve the quality of life of traditional and indigenous peoples. It showed success in reducing deforestation trends, enhancing self-reported wellbeing, providing health and education services (Börner et al. 2013), and more equitable decision making with community participation (Gebara 2013). Yet, wider concerns remain relating to labour conditions in Brazil’s sugarcane ethanol sector, persistent inequalities, large-scale hydroelectric projects, monetisation of ecosystems, and lack of participation in green-style projects (Brown et al. 2014).

South Africa, also an upper middle-income country, draws heavily upon the green growth discourse, despite continued reliance on cheap, local coal as part of an entrenched minerals-energy complex, against the back-drop of high inequality, unemployment, and poverty rates (Cock 2014; Death 2014; Swilling et al. 2016; Chandrashekeran et al. 2017). While the state’s Green Economy Accord favours economic growth, green technology, carbon markets, and the commodification of ecosystem services (Death 2014), niche innovation in renewables and the creation of safe and decent green climate jobs represent encouraging efforts (Power et al. 2016; Swilling et al. 2016), the latter with support from civil society organisations and trade unions (Cock 2014). The Renewable Energy Independent Power Producers Procurement Programme (RE IPPPP) is lauded as a well-managed renewable electricity scheme that also meets community ownership and development criteria, including for Black Economic Empowerment (BEE) (Baker 2015; Power et al. 2016; Swilling et al. 2016). Alliances between the powerful albeit fragmented social and environmental justice movement and the labour movement, together with inclusive state-society deliberative processes are indicative of vital aspects of CRDPs, even if ineffectual policy implementation have so far hampered fundamental changes toward just transitions (Cock 2014; Chandrashekeran et al. 2017).

The Republic of South Korea, a high-income country and a ‘trendsetter’ in low-carbon green growth (Han 2015: 732) is committed to shifting from heavy reliance on fossil fuels to green-powered development, advocating for green urbanism and jobs in green industries, also housing the Global Green Growth Institute in Seoul (Death 2015). Various national strategies and stimulus packages help to demonstrate the country’s ambitions aspirations and capacities (Saxer 2013; Kim and Thurbon 2015; Brockington and Ponte 2015), supported by the former government’s green diplomacy and international recognition as an intellectual and market leader in green growth, despite lagging environmental performance at home, that is per capita CO_2 emissions (Han 2015). The state also encourages demand for green products and behaviour (Bell 2016). Nonetheless, the top-down approach could benefit from a stronger social base for innovations and more inclusive and participatory processes for decision making (Han 2015; Bell 2015).

5.7.3.2 *Climate-resilient development planning through state-NGO-community alliances*

Box 5.3: The Republic of Vanuatu– Enabling Resilient Communities

Vanuatu is a small island nation in the South Pacific with significant vulnerability to climate change. With a risk index of 36.28% and exposure to natural hazards of 63.66% the country is ranked one of the highest for risk and exposure to natural hazards in the world (United Nations University 2016). Despite rapid urbanisation (ADB 2013), ~80% of the population still reside in rural areas and depend on 'subsistence, rain-fed agriculture' on coastal plains together with coastal fisheries for food security (Sovacool et al. 2017a). Sea level rise, increased risk of prolonged drought, water shortages, intense storms and cyclone events and degraded coral reef environments are predicted to erode human security (Secretariat of the Pacific Community 2015; Aipira et al. 2017).

While Vanuatu faces severely constrained adaptive capacity (Secretariat of the Pacific Community 2015; Kuruppu and Willie 2015; Sovacool et al. 2017a), significant integrated planning efforts at multiple scales aim at increasing climate resilience, by supporting local coping capacities and iterative, inclusive processes of sustainable development and integrated risk assessment (Eriksson et al. 2017; Sovacool et al. 2017b; Granderson 2017; Aipira et al. 2017). These efforts include the 'Yumi stap redi long climate change'– or the Vanuatu NGO Climate Change Adaptation Program, a climate-resilient policy approach, founded in 2012 by a consortium of local and international NGOs to increase the resilience of local communities to the impacts of climate change (Sovacool et al. 2017b). The focus has been on equitable governance, with particular attention to supporting women's voices in decision making through allied programs addressing domestic violence and participation, together with rights-based education; addressing structural constraints on adaptive capacity that exacerbate social marginalisation and exclusion; engaging in institutional reforms for greater transparency and accountability (Ensor 2016; Davies 2015); and local participation in climate- smart agriculture (Ensor 2016; Sterett 2015). By 2014, 5400 women, men and young people in 30 communities in four provinces had participated in rights-based community wellbeing and climate awareness education (UN Women 2016). The aim is to limit external NGO influence to providing access to information so that communities are empowered to address structural and agency constraints, so local technical and decision making capacity is enhanced (Ensor 2016). Lessons learned from the program indicate that it is a valuable model for climate change action (Maclellan 2015) despite the ongoing challenges of power imbalances embedded in the political economy of development and climate finance programs that tend to marginalise the priorities of local communities (Sovacool et al. 2017b; Addinsall et al. 2016).

Given Vanuatu's long history of disasters, local and traditional adaptive capacity is assessed as relatively high, despite barriers of knowledge, lack of access to technology; low literacy rates and gendered challenges for example due to responsibilities within the home and caring for children (McNamara and Prasad 2014; Aipira et al. 2017; Granderson 2017). Climate-resilient planning aims to address vulnerability as a multiple interconnected issue, interacting with the lives of differently situated community members and reflecting their differing perceptions of risk and access to sustainable livelihoods and economic opportunities (Ensor 2016; Aipira et al. 2017). While relationships defined by power and cultural norms often continue to shape how local risks are understood, prioritised and managed (Kuruppu and Willie 2015), a focus on more equitable decision making has been identified as the basis for future adaptive actions that will benefit the whole community (Ensor 2016; Aipira et al. 2017). Climate resilience is also supported when decision making integrates ecosystem, community and social planning in resource management (Sterrett 2015; Sovacool et al. 2017a).

Regionally, related efforts to develop climate-resilient community planning frameworks have been established in Papua New Guinea, Timor Leste, and Vietnam (Sterrett 2015). The Pacific Risk Resilience Programme (PRRP) aims to integrate planning to reduce vulnerability and enhance climate change and disaster risk management in routine national and subnational planning processes, in a gender- and socially-inclusive manner (Selby and Jiwanji 2016). The achievement of risk resilience requires enabling measures such as improved urban governance arrangements, enhanced communication, and adequate human and financial resources (ADB 2013; Rey et al. 2017). However, in situations of constrained adaptation climate resilience planning for the short to medium term may not be able to cope with increasingly complex, severe climatic impacts over time (Dilling et al. 2015).

5.7.3.3 Alternative and bottom-up development paths

Box 5.4: CRDPs - Transnational Movements and Community Action

Agrarian and social and climate justice movements

Agrarian movements and social and climate justice movements across the Global South and Global North have converged over food sovereignty and climate justice as linked priorities. This convergence stems not only from realising the disproportional climate change impacts on poor communities and advocating just climate solutions and transitions, but also from contesting the market-driven ‘carbon complex’ including REDD+, climate-smart agriculture, Blue Carbon, and green growth that perpetuate rather than reduce injustice (Claeys and Delgado Pugley 2016) (Tramel 2016). Alternative ways of producing and delivering food, energy, and clean water are embedded in a vision of a better society that foregrounds redistribution, representation, and recognition of diverse identities (Scoones et al. 2017), with roots in environmental and food justice (Edelmann and Borras 2016; Alonso-Fradejas et al. 2015; Martinez-Alier et al. 2016) and social and solidarity economies (SSE) (UNRISD 2016; Avelino et al. 2016; Utting 2015; Chamorro and Utting 2015; Grasseni et al. 2013). Peasants, indigenous peoples, hunters and gatherers, family farmers, rural workers, herders and pastoralists, fisher folk and urban people (Global Convergence of Land and Water Struggles 2016) join efforts with movements such as *La Vía Campesina* and The World Forum of Fisher Folks (Tramel 2016) to align socially-desirable adaptation and mitigation pathways with transnational solidarity and wellbeing and justice for all. Landless peasant movements, such as the *Movimento dos Trabalhadores Rurais Sem Terra* (MST) in Brazil, have also played a major role in addressing social and climate justice with a commitment to sustainability through agroecological transitions in the communities that are formed through the process of direct political action aimed at reclaiming land for small-scale peasant farmers and families (Meek 2014, 2016; Pahnke 2015).

Latin American countries have been at the forefront of alternative development pathways rooted in an appreciation for peasant and indigenous lifestyles and values. These development pathways address social shortcomings (Raworth 2017b) as a prerequisite for CRDPs. *La Vía Campesina* is a transnational peasant movement that embraces a rights-based development approach centred on food sovereignty (largely self-reliance) and agroecology; it began in 1993, now counting >160 organisations in >70 countries and representing ~200 million small-scale producers (Claeys and Delgado Pugley 2016)**.** The movement aims to restructure the global food system (Desmarais et al. 2014; Agarwal 2014) and offer ‘peasant solutions’ to climate change to counter carbon trading, BECCS, and other ‘false solutions’ (Claeys and Delgado Pugley 2016) (McKeon 2015)**.** *Buen Vivir*, translated as ‘living well together’, with origin in the world-view of Quechua peoples, encapsulates the principles of a ‘good life’ based ecological sustainability, local trade systems, simplicity, solidarity, food sovereignty, and multiple ways of knowing (Bell 2016; McAfee 2016; Lang et al. 2013). It also rejects fossil-fuel reliance, overemphasis on economic growth, and green growth pathways (McAfee 2016), yet is not without critique (e.g. Cochrane 2014; Calisto Friant and Langmore 2015). The recent boom of quinoa, a nutritious and climate-variable crop, illustrates the prospects and pitfalls of ‘sustainable re-peasantisation’ in the Bolivian Altiplano as global food networks become accessible while conflicts over land and identity with returning migrants challenge collective decision making and harmony as pillars of *buen vivir* (Kerssen 2015)**.**

Transition Towns

The Transition Movement typifies local climate-resilient development pathways, combining adaptation, mitigation, and just transitions, mainly at the level of communities and towns. This grassroots movement began with Transition Towns (TTs) in the UK in 2005 (Hopkins 2008). It now has >1,300 registered local initiatives in >40 countries (Grossmann and Creamer 2017), although mostly in the UK, the US, and other countries in the Global North. TTs exemplify 'progressive localism' (Cretney et al. 2016), aiming to foster a 'communitarian ecological citizenship' that goes beyond changes in consumption and lifestyle (Kenis 2016). They promote equitable communities resilient to the impacts of climate change, peak oil, and unstable global markets; re-localisation 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 low-carbon living and economies, food self-sufficiency, energy efficiency through renewables, construction with locally-sourced material, and cottage industries, often in line with principles of de-growth (North and Longhurst 2013; Staggenborg and Ogrodnik 2015; Taylor Aiken 2016; Barnes 2015). Social and iterative learning through the collective involves dialogue, deliberation, capacity building, citizen science engagements, technical re-skilling to increase self-reliance, e.g. canning and preserving food and permaculture, future visioning, and emotional training to share difficulties and loss (Barnes 2015; Taylor Aiken 2015; Mehmood 2016; Grossmann and Creamer 2017; Kenis 2016).

Enabling conditions for successful transition groups include flexibility, participatory democracy, inclusiveness and consensus-building, assuming bridging or brokering roles, and community alliances and partnerships (North and Longhurst 2013; Feola and Nunes 2014; Aiken 2016; Mehmood 2016; Grossmann and Creamer 2017). Smaller scale rural initiatives allow for more experimentation (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 recognise the need to participate in policy making to overcome the 'post-political trap' (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 marginalised, non-white, non-middle-class community members (Evans and Phelan 2016; Grossmann and Creamer 2017; Nicolosi and Feola 2016). Expectations that niche innovates ought to grow in scale may undercut experimentation (Taylor Aiken 2015). Tension between targeted climate change action and efforts to appeal to more people have resulted in difficult trade-offs and strained member relations (Grossmann and Creamer 2017).

5.7.4 Lessons from Case Studies on Climate-resilient Development Pathways

As illustrated in the above case studies (Boxes 5.2-4), few of them exemplify all characteristics of CRDPs as described in Section 5.7.1. The empirical evidence indicates that such partial achievements are due to a number of factors: a) the intrinsic challenge of scoring on all fronts; b) the initial stages of the learning curve for many actors; c) climate change in general and the 1.5°C target specifically being only one of several objectives to be achieved; d) the lure of succumbing to normative pathways that fortify rather than rectify privileged positions; and 3) the temptation of shorter-term economic gains and power over longer-term and more far-reaching social and environmental justice solutions. Moreover, they are works-in-progress that embody aspects of resilience pathways, to be read within the context of treating interlinked adaptation-mitigation-development initiatives as ongoing processes and not outcomes (O'Brien et al. 2015). How to transform development and our societies while simultaneously addressing the climate change challenge and enhancing wellbeing for all is not yet well reflected in the literature, although evidence is growing. Lessons learned from the above and other case studies suggest the following three essential ingredients.

5.7.4.1 Social learning

Evidence across scales, from strategic new alliances in green states to Transition Towns re-skilling (Boxes 5.2-4) underscore the vital role of social learning for climate change action, including efforts to stay within the 1.5°C target and beyond. Given uncertainties in rate, timing and scale of impacts, potential consequences of higher rates of warming (overshoot), and multiple possible pathways as well as path dependencies, social, collective, and iterative learning allows to ramp up adaptive and mitigative management and foster deliberate processes that incorporate values, world views, and different types of knowledges in a more inclusive decision space (Butler et al. 2016b; Fook 2017; Cundill et al. 2014; Gorddard et al. 2016b; Fazey et al. 2016; Gillard et al. 2016). Knowledge co-production in climate resilience planning and implementation processes is a recognised mechanism for social learning, and extended learning cycles and iterative planning are necessary to address hidden, systemic drivers of transformation and uneven power dynamics (Ensor and Harvey 2015; Butler et al. 2016b; Ziervogel et al. 2016; Tschakert et al. 2016; Delgado-Serrano et al. 2017; Fook 2017; Turnheim et al. 2015; Bataille et al. 2016).

5.7.4.2 Equity, rights, and justice

Procedural and distributive justice, human agency, and rights, including rights to development, and what is fair and acceptable to the least privileged are core elements of CRDPs (Tanner et al. 2014; Fook 2017; Agyeman et al. 2016; Schlosberg et al. 2017). Yet, the large majority of case studies reveal dynamics that exacerbate existing vulnerabilities and inequalities and further undermine the rights and voices of the disadvantaged, often when market-based approaches trump human wellbeing and equity, poverty eradication, empowerment, and access to resources (Boxes 5.2-4). Power, knowledge, authority, and subjectivities all determine which pathways become dominant and normative and which get side-lined (Fazey et al. 2016; Ensor et al. 2015; Pelling et al. 2016; Tschakert et al. 2016; AMCOW et al. 2012; Wise et al. 2014; O'Brien et al. 2015), typically reinforcing the status quo rather than encouraging deep and radical transformational change. Procedural justice dimensions skewed toward exclusive participation and decision making form structural institutional barriers constraining the achievement of CRDPs (Reed et al. 2015; Shackleton et al. 2015a; Bedelian and Ogutu 2017; Simonet and Jobbins 2016; Barrett 2013).

5.7.4.3 Indicators, monitoring, and evaluation

Very limited literature currently exists regarding measures of success for CRDPs that review which criteria ought to be taken into account, whether these criteria are met, by whom, how, and over which time frames. Even less is known about the processes of identifying adequate metrics, particularly in contexts that aim for inclusiveness, iterative learning, and empowerment. Some early insights from Transition Towns recommend a small set of measurable indicators, e.g. percentage of food grown and consumed locally (Haxeltine and Seyfang 2009) while more recent experiences raise concerns about coercive and counterproductive requirements from funding bodies to measure and count (e.g. carbon saved through low-carbon lifestyles) that undermine local resilience building, social learning, and diverse ways of knowing (Taylor Aiken 2016). At the national level, progress in developing key capacities for resilience (Vaananen et al. 2017) as well as building transparency and accountability through tracking impacts of climate finance (Governance of Climate Change Finance Team (UNDP Bangkok Regional Hub) and Adelante 2015; Terpstra et al. 2015) contribute to the equity and effectiveness of CRDPs. Inadequate monitoring and regulatory measures though may hamper more fundamental transformations (Cock 2014; Chandrashekeran et al. 2017).

Important lessons can be learned from monitoring and evaluation (M&E), particularly in adaptation and development programs with a strong climate resilience focus. This includes context-specific and locally developed criteria for assessing climate-resilient livelihoods, for instance in Uganda (IFAD 2016) and frameworks for structured experimentation targeted at decision makers and practitioners (e.g. USAID 2014). These lessons underscore the crucial role of empowered local participation in the design, implementation and monitoring of programs and longer-term trajectories for social change; they also stress sufficient timeframes to allow for diverse alliances to emerge and detect steps in resilience building, critical social thresholds, and learning loops rather than a single focus on narrow carbon accounting (Burch et al. 2014; Mercy Corps 2015; O'Brien et al. 2015; Southern Voices on Adaptation 2016; Taylor Aiken 2016; Wegner 2016).

5.8 Synthesis and Research Gaps

This section concludes Chapter 5 as well as the entire Special Report. It summarises what is known about the linkages between sub-regional impacts of a 1.5°C warmer world, the positive and negative implications and distributional impacts of adaptation and mitigation response options and pathways toward this future reality, and the synergies and trade-offs between sustainable development, adaptation, and mitigation. It also outlines opportunities for climate-resilient development pathways that harbour the potential for re-orienting global society to limit the rise in global temperatures to 1.5°C above pre-industrial levels while achieving poverty eradication, reducing inequalities, and pursuing equity, in countries of all levels of development. This section closes the narrative arc introduced by Chapter 1. It ends with discussing major research gaps.

Moving towards sustainable and equitable futures in a 1.5°C warmer world is possible, and an ethical imperative in order to realise the dual objectives of limiting temperature increases and associated negative impacts, and achieving development and the SDGs, poverty eradication, equality, and equity, worldwide. Yet, it is also challenging as alternative pathways grounded in fairness and justice and embedded in integrated adaptation and mitigation approaches go hand in hand with conscious social transformations. This chapter and the preceding chapters have assessed the feasibility and challenges of ambitious actions, and the consequences of failing to do so, particularly with respect to inequalities and social, cultural, and biophysical losses. The findings underscore the numerous ethical dilemmas emerging from business-as-usual approaches and an entrenched binary logic that pits climate-first against development-first solutions. Climate-resilient development pathways, as partial and incomplete they may be to date, open up routes towards socially-desirable and co-constructed futures that are liveable, equitable, and justifiable to generations to come.

Knowledge on the linkages between a 1.5°C warmer world, including climatic impacts and those from response options, and future development pathways that address poverty eradication, equality, and distributive justice is growing. However, several gaps in the current literature have been identified:

- Limited evidence exists to date that explicitly examines or measures the implications of a 1.5°C warmer world (and overshoots) for sustainable development, poverty eradication, and reducing equalities, and the near-term goals of SDGs. So far, few projections exist that indicate how any degree of additional global warming will affect populations at the level of households, livelihoods, and communities, particularly those who are already disadvantaged. Equally little is known about how differentiated impacts will map onto future structural inequalities and poverty dynamics, in countries of all levels of development.
- The same research gaps exist for assessments of avoided impacts and development implications of 1.5°C versus 2°C and higher warming. Although proxies can be used to project differential impacts (e.g. the updated Reasons for Concern), these estimates are unable to reveal the embodied and emplaced implications of a 1.5°C warmer world in the context of pervasive power differentials that perpetuate or even exacerbate inequalities that, in turn, shape vulnerabilities, especially among the most marginalised.
- Some progress has been made in locating synergies and trade-offs associated with individual climate response options (adaptation and mitigation) and their implications for the SDGs, and vice versa. Yet, these positive and negative impacts need to be coupled with policy-relevant assessments. Only limited literature has considered the dynamics of clustered response options and their configurations in multiple, often competing pathways, and their implications for the dual objective imposed by the 1.5°C target.
- Limited literature exists that empirically investigates the effectiveness of integrated policy frameworks to deliver triple-win outcomes, the dynamics that produce such outcomes at the scale of implementation, and the anticipated winners. Even less is known about ‘triple-losses’ and the conditions that give rise to them. These include the combined effects of response measures and structural development deficiencies, including persistent poverty, across regions and sectors and among different groups of people.
- Emerging literature suggests key ingredients of climate-resilient development pathways that meet both development and justice priorities and stringent climate action. Case studies from the level of nation states to communities reveal opportunities and significant challenges to enable and sustain such pathways. Yet, it remains unclear what ‘socially desirable’ pathways mean for different groups of people and how tensions between socially-desirable and optimal pathways may be resolved. These constitute significant ethical and moral questions that climate science alone is ill equipped to solve. There is an urgent need for adequate and robust indicators of success that capture both the value of decision-making

and learning processes as well as outcomes, taking into consideration diverse types of knowledge and experiences.

Frequently Asked Questions

FAQ 5.1: Does the pursuit of sustainable development affect the capacity to reach ambitious climate goals like 1.5°C?

FAQ 5.2: Will stringent mitigation lead to a global warming limit of 1.5°C without exacerbating poverty?

FAQ 5.3: Is reducing inequalities a prerequisite for climate-resilient development pathways?

FAQ 5.4: Is it possible to simultaneously achieve sustainable development (incl. the SDGs) and the 1.5°C target?

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Table 5.1: Impacts of mitigation options on specific targets of the 17 SDGs, for social (a), economic (b), and environmental (c) dimensions

Table 5.1 shows Synergies (↑) and Trade-offs (↓) and undecided (~) relation between sectoral mitigation options and sustainable development dimensions as well as SDGs. Synergies and trade-offs or even undecided outcome of various mitigation options on SDGs arise due to multiple factors and nature of relation also vary. Brief description of those are given in following three tables based on assessment of the literature. Set of literature used so far based on current search are mentioned as well. Table 5.1a shows Social dimensions of SD along with relevant SDGs. Table 5.1b shows Economic dimensions of SD along with relevant SDGs. Table 5.1c shows Economic dimensions of SD along with relevant SDGs. We use various symbols for evidence (🕮), agreement (☺), confidence (★) and we use various strengths for each of these using following legends. Since variety of interactions among SDGs are possible following explanations from Nilsson et al. 2016 are used to indicate a score [] for showing interactions among SDGs.

Interaction score (Nilsson et al., 2016)

Interaction	Name	Explanation
+3	Indivisible	Inextricably linked to the achievement of another goal.
+2	Reinforcing	Aids the achievement of another goal.
+1	Enabling	Creates conditions that further another goal.
0	Consistent	No significant positive or negative interactions.
–1	Constraining	Limits options on another goal.
–2	Counteracting	Clashes with another goal.
–3	Cancelling	Makes it impossible to reach another goal.

LITERATURE AGREEMENT	EVIDENCE	CONFIDENCE
very high	very robust	***very high***
☺☺☺☺	🕮🕮🕮🕮	★★★★
high h	robust r	high
☺☺☺	🕮🕮🕮	★★★
medium m	medium m	***medium***
☺☺	🕮🕮	★★
limited l	low l	***low***
☺	🕮	★

[A high resolution version of the table is available as a supplementary PDF (SR15_FOD_Chapter5_Table5_1.pdf) that can be downloaded with the chatper for review]

Table 5.1a: Impacts of mitigation options on specific targets of the 17 SDGs, for social dimensions.

Mitigation option		SDG 1 (Interaction / Nilsson score / Evidence / Literature agreement / Confidence)	SDG 2	SDG 3	SDG 4	SDG 5	SDG 10	SDG 16	SDG 17
Industry demand res efficiency		**Reduces poverty** ↑ [+2] ★ [illegible] [illegible]		**air pollution reduction and better health** ↑ [+2] ★★ [illegible] [illegible]					
	Behaviour								
Industry fuel decarb Switch to low-carbon		**Reduce inequality (1.4)** ↑/↓ [+2,-1] ★ [illegible] [illegible]							
	CCS/CCU								
Residential demand behavior		**Poverty reduction via financial savings** ↑ [+2] ★ [illegible] [illegible]		**Improved warmth and comforts** ↑ [+2] ★★★ [illegible] [illegible]				**Environmental justice** ↑ [+2] ★ [illegible] [illegible]	
	efficiency	**Poverty and Development** ↑ [+2] ★★ [illegible] [illegible]	**Food Security** ↑ [+2] ★ [illegible] [illegible]	**Healthy lives and well-being for all at all ages** ↑ [+2] ★★★★ [illegible] [illegible]	**Reducing school absences** ↑ [+2] ★ [illegible] [illegible]	**Women empowerment** ↑ [+2] [illegible] [illegible]		**Energy justice** ↑ [+2] ★ [illegible] [illegible]	
Residential fuel decarb Switch to low-carbon		**Poverty reduction** ↑ [+2] ★★ [illegible] [illegible]							
Transport demand behavior				**Road Traffic Accidents (3.4/3.6)** ↑/↓ [+2,-1] ★★ [illegible] [illegible]			**Reduce inequality (10.2)** ↑ [+2] ★★ [illegible] [illegible]		
	efficiency			**Reduce illnesses from hazardous air, water and soil pollution (3.9)** ↑ [+2] ★★★ [illegible] [illegible]				**Ensure responsive, inclusive, participatory decision making (16.7)** ↑ [+2] ★★ [illegible] [illegible]	
Transport fuel decar Switch to low-carbon		**End Poverty in all its forms everywhere (1.3)** ↑/↓ [+2,-1] 📖📖 ●● ★★ Climate change threatens to worsen poverty, therefor 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. 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 (Hallegate et al, 2015); (Suckall, Tompkins, & Stringer, 2014)							
Phasing out coal supply-side, upstream-sector impacts				**Disease and Mortality (3.1/3.2/3.3/3.4), Air Pollution (3.9)** ↑ [+2] 📖📖📖 ●●● ★★★ Reduce adverse impacts of upstream supply-chain activities, in particular local air pollution, and coal mining accidents IPCC AR5 WG3 (2014); Koorneef et al. (2011); Singh et al. (2011); Hertwich et al. (2008); Veltman et al. (2010); Corsten et al.(2013); Ashworth et al. (2012); Einsiedel et al. (2013); IPCC (2005); Miller et al. (2007); de Best-Waldhober et al. (2009); Shackley et al. (2009); Wong-Parodi and Ray (2009); Waðöquist et al. (2009, 2010); Reiner and Nuttall (2011); Epstein et al. (2010); Burgherr et al. (2012); Chen et al. (2012); Chan and Griffiths (2010);					
Improving Access to Modern Energy modern biomass, nuclear, other renew		**Poverty and Development (1.1/1.2/1.3/1.4)** ↑ [+2] 📖📖📖 ●●● ★★★★ Access to modern energy forms (electricity, clean cook-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., in review) *McCollum et al. (in review)*; Bonan et al. (2014); Burlig and Preonas (2016); Casillas and Kammen (2010); Cook (2011); Kirubi et al. (2009); Pachauri et al. (2012); Pueyo et al. (2013); Rao et al. (2014)	**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 glo (Quote from McCollum et al., in review)bally, and thus reduced 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. *McCollum et al. (in review)*; Asaduzzaman et al. (2010); Cabraal et al. (2005); Finco and Doppler (2010); Hasegawa et al. (2015); Lotze-Campen et al. (2014); Msangi et al. (2010); Smith et al. (2013); Smith, P. et al. (2014); Sola et al. (2016); Tilman et al. (2009); van Vuuren et al. (2009)	**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., in review) *McCollum et al. (in review)*; Aranda et al. (2014); Lam et al. (2012); Lim et al. (2012); Smith et al (2013)	**Equal Access to Educational Institutions (4.1/4.2/4.3/4.5)** ↑ [+1] ★★ Access to modern energy ... well as modern information ... allows for studying after ... school enrollment rates ... [illegible] *McCollum et al. (in review)*; [illegible]	**Women's Safety & Worth (5.1/5.2/5.4) / Opportunities for Women (5.1/5.5)** ↑ [+1] ★★ [illegible] *McCollum et al. (in review)*; [illegible]		**Institutional Capacity and Accountability (16.1/16.3/16.6/16.7/16.8)** ↑ [+2] ★★★★ [illegible] *McCollum et al. (in review)*; [illegible]	
Deployment of Renewables modern biomass, other renewables (s		**Exposure and Vulnerability (1.5)** ↑ [+2] 📖📖📖 ●●● ★★★ 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. (Quote from McCollum et al., in review) *McCollum et al. (in review)*; Hallegatte et al. (2016); IPCC (2014); Riahi et al. (2012)		**Air Pollution (3.9)** ↑ [+2] 📖📖📖 ●●● ★★★★ Promoting most types of renewables and boosting efficiency greatly aid 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 centers 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. (Quote from McCollum et al., in review) *McCollum et al. (in review)*; Anenberg et al. (2013); Chaturvedi and Shukla (2014); Haines et al. (2007); IEA (2016); Kaygusuz (2011); Nemet et al. (2010); Rafaj et al. (2013); Rao et al (2013); Rao et al (2016); Riahi et al. (2012); Rose et al. (2014); Smith and Sagar (2014); van Vliet et al. (2012); West et al. (2013)			**Empowerment and Inclusion (10.1/10.2/10.3/10.4)** ↑ [+1] ★★ [illegible] *McCollum et al. (in review)*; [illegible]		**International Cooperation (all goals)** ↑/↑ [+2,0] ★★ [illegible] *McCollum et al. (in review)*; [illegible]
Subsidies for Renewables Energy Sou this category collects impacts that are		**Poverty and Development (1.1/1.2/1.3/1.4)** ~/↓ [0,-1] 📖📖📖 ●●● ★★★ 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 toward universal energy access and, by extension, counteract the fight to eliminate poverty. (Quote from McCollum et al., in review) *McCollum et al. (in review)*; Cameron et al. (2016); Casillas and Kammen (2012); Fay et al. (2015); Hallegate et al. (2016); Hirth and Ueckerdt (2013); Jakob and Steckel (2014)					**Empowerment and Inclusion (10.1/10.2/10.3/10.4)** ↑/↓ [1,-1] ★★★ [illegible] *McCollum et al. (in review)*; [illegible]		
Increased use of biomass			**Farm Employment and Incomes (2.3)** ↑/↓ [+2,-2] 📖📖📖 ●●● ★★★ Large-scale bioenergy production could lead to the creation of agricultural jobs, as well 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 labor. On the other hand, large-scale bioenergy production could alter the structure of global agricultural markets in a way that is, potentially, unfavorable to small-scale food producers. The distributional effects of bioenergy production are underexplored in the literature. (Quote from McCollum et al., in review) *McCollum et al. (in review)*; Balishter et al. (1991); Creutzig et al. (2013); de Moraes et al. (2010); Gohin (2008); Rud (2012); Satolo and Bacchi (2013); van der Horst and Vermeylen (2011); Corbera and Pascual (2012); Creutzig et al. (2013); Davis et al. (2013); van der Horst and Vermeylen (2011); Muys et al. (2014)						
Large-scale hydro									
Deployment of CCS in the power sector Either with fossil fuels or bioenergy (BECCS)				**Disease and Mortality (3.1/3.2/3.3/3.4)** ↓ [-1] 📖📖 ●●● ★★★ Adverse impacts of upstream supply-chain activities, risk of CO2 leakage IPCC AR5 WG3 (2014); Atchley et al. (2013); Apps et al. (2010); Siirila et al. (2012); Wang and Jaffe					
Nuclear energy				**Disease and Mortality (3.1/3.2/3.3/3.4)** ↓ [-2] 📖📖 ● ★★ Nuclear accidents and waste treatment, uranium mining and milling, increased occurrence of IPCC AR5 WG3 (2014); Cardis et al. (2006); Balonov et al. (2011); Moomaw et al. (2011a); WHO				**Reduce illicit arms trade (16.4)** ↓ [-1] ★★ [illegible]	
Improving energy efficiency general demand-side measures (where they cannot be specifically attributed to one sector)							**Empowerment and Inclusion (10.1/10.2/10.3/10.4)** ↑ [+1] ★★ [illegible] *McCollum et al. (in review)*; [illegible]		
AFOLU demand-side measures & dietary change	Reduced meat consumption	**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 SSA IPCC WGIII, 2014							
	Reduced food waste								
AFOLU supply-side measures	Increased efficiency of livestock systems								
	climate smart agriculture and Soil carbon sequestration	**Poverty and Development (1.1/1.2/1.3/1.4)** ~/↓ [0,-1] 📖📖 ●●● ★★ Mitigation policies implemented through a uniform global carbon price would have negative effects on agricultural production. Developing regions would be more affected than developed ones. (Quote from Havlik et al., 2015) Havlik et al. 2015							
	Enhanced Weathering, terrestrial								
	Forestry, Forest management , REDD+	**Poverty and Development (1.1/1.2/1.3/1.4)** ~/↓ [0,-1] 📖📖 ●● ★★ The distributional and equity impacts of REDD+ and similar measures are dependent on instrument design. If the poorest households have lowest opportunity costs, then in the case of flat rate payments they could be the ones generating most of the emission reductions. (Quote from Ickowitz Luttrell et al. 2013, Ravikumar et al. 2015, Di Gregorio et al. 2017, Ickowitz et al. 2017, Loft et al.				**Opportunities for Women (5.1/5.5)** ~/↓ [0,-1] ★ [illegible] [illegible]			
Non-CO2 mitigation	Methane removal								
Oceans/Water	Ocean iron fertilization								
	Blue carbon								
	Enhanced Weathering, ocean								

Table 5.1b: Impacts of mitigation options on specific targets of the 17 SDGs, for economic dimensions.

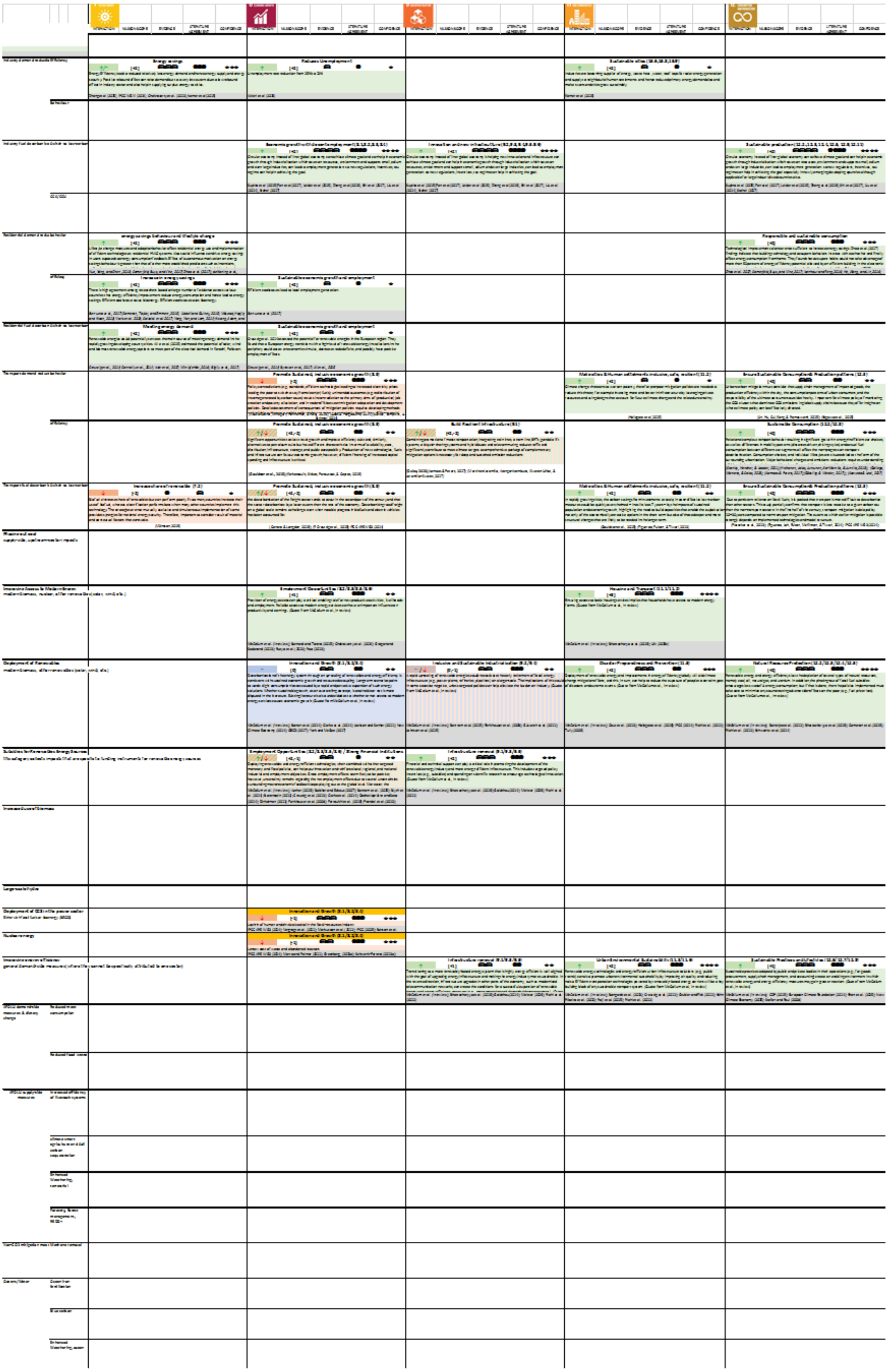

Table 5.1c: Impacts of mitigation options on specific targets of the 17 SDGs, for environmental dimensions.

		INTERACTION / NILSSON SCORE / EVIDENCE / LITERATURE AGREEMENT / CONFIDENCE	INTERACTION / NILSSON SCORE / EVIDENCE / LITERATURE AGREEMENT / CONFIDENCE	INTERACTION / NILSSON SCORE / EVIDENCE / LITERATURE AGREEMENT / CONFIDENCE
Industry demand reduction	**Efficiency**	**Water efficiency and pollution prevention (6.3/6.4/6.6)** ↑//~ [+2] 🕮🕮🕮 ☺☺☺ ★★★ 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 is trade off unless Vassolo and Doell (2005); Fricko et al. (2016); Holland et al. (2016);Nguyen et al (2014)		
	Behaviour	**Water efficiency and pollution prevention (6.3/6.4/6.6)** ↑ [+2] 🕮🕮🕮 ☺☺☺ ★★★ Behavioral 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 Doell		
Industry fuel decarbonization and cross sector collaboration	**Switch to low-carbon**	**Water efficiency and pollution prevention (6.3/6.4/6.6)** ↑ / ↓ [+2,-2] 🕮🕮🕮 ☺☺ ★★★ A switch to low-carbon fuels can lead to a reduction in water demand and wastewater 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 e.g., biofuel could increase water use compared to existing conditions if the biofuel comes from a water-intensive feedstock. Hejazi et al. (2015); Song et al. (2016); Fricko et al. (2016)		**Sustainable production (15.1,15.5,15.9,15.10)** ↑ / ↓ [+1,-1] 🕮 ☺ ★ Circular economy instead of liner global economy can achieve climate goal and can help in economic growth through industrialisation which saves on resources, enviornment and supports small, edium and even large industries, can lead to employment generation. so new regulations, incentives, tax regime can help in achieving the goal especially in newly emerging developing cpuntries although applicable for large indsutrialised countries also. Shi et al (2017)
	CCS/CCU	**Water efficiency and pollution prevention (6.3/6.4/6.6)** ↑ / ↓ [+1/-2] 🕮🕮🕮 ☺☺ ★★★ CCU/S requires access to water for cooling and processing which could contribute to localized water stress. CCS/U process can potentially be configured for increased water efficiency compared to a system without carbon capture via process integration. Meldrum et al. (2013); Fricko et al. (2016); Byers et al. (2016); Brandl et al. (2017)		
Residential demand reduction	**behavior**	**Water efficiency and pollution prevention (6.3/6.4/6.6)** ↑ [+2] 🕮🕮🕮 ☺☺☺ ★★★ Behavioral 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 wastewater, resulting in more clean water for other sectors and the environment. Bartos and Chester (2014); Fricko et al. (2016) Holland et al. (2016)		
	efficiecy	**Water efficiency and pollution prevention (6.3/6.4/6.6)** ↑ [+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 wastewater, resulting in more clean water for other sectors and the environment. Hendrickson et al. (2014); Bartos and Chester (2014); Fricko et al. (2016) Holland et al. (2016)		
Residential fuel decarbonization	**Switch to low-carbon**	**Water efficiency and pollution prevention (6.3/6.4/6.6)** ↑ / ↓ [+2,-2] 🕮🕮🕮 ☺☺ ★★★ A switch to low-carbon fuels in the residential sector can lead to a reduction in water demand and wastewater 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 e.g., biofuel could increase water use compared to existing conditions if the biofuel comes from a water-intensive feedstock. Hejazi et al.		
Transport demand reduction	**behavior**	**Water efficiency and pollution prevention (6.3/6.4/6.6)** ↑ [+2] 🕮🕮🕮 ☺☺☺ ★★★ Behavioral 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 wastewater, resulting in more clean water for other sectors and the environment. Vidic et al. (2013); Tiedemann et al. (2016); Fricko et al. (2016); Holland et al. (2016)		
	efficiency	**Water efficiency and pollution prevention (6.3/6.4/6.6)** ↑ [+2] 🕮🕮🕮 ☺☺☺ ★★★ Similar to behavioral 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 wastewater, resulting in more clean water for other sectors and the environment. Vidic et al. (2013); Tiedemann et al. (2016); Fricko et al. (2016); Holland et al. (2016)		
Transport fuel decarbonization	**Switch to low-carbon**	**Water efficiency and pollution prevention (6.3/6.4/6.6)** ↑ / ↓ [+2,-2] 🕮🕮🕮 ☺☺ ★★★ A switch to low-carbon fuels in the transport sector can lead to a reduction in water demand and wastewater 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 e.g., biofuel could increase water use compared to existing conditions if the biofuel comes from a water-intensive feedstock. Hejazi et al. (2015); Song et al. (2016); Fricko et al. (2016)		
Phasing out coal supply-side, upstream-sector impacts		**Water efficiency and pollution prevention (6.3/6.4/6.6)** ↑ [+2] 🕮🕮🕮 ☺☺☺☺ ★★★★ Phasing out coal in favour of other energy resources is anticipated to reduce water demands, if the alternative fuels have lower water intensity than coal. Most fuels do have a lower water intensity than coal. and switching to natural gas as a bridge to low-carbon societies is also expected to bring Webster et al. (2013); Zhang et al. (2014); Fricko et al. (2016); Wright et al. (2017)		**Healthy Terrestrial Ecosystems (15.1/15.2/15.4/15.5/15.8)** ↑ [+1] 🕮🕮 ☺☺☺ ★★★ Reduced impact from coal mining IPCC AR5 WG3 (2014); Adibee et al. (2013); Cormier et al. (2013); Smith et al. (2013), and reference cited therein: Palmer et al. (2010); Koorneef et al. (2011); Singh et al. (2011); Hertwich et al. (2008); Veltman et al. (2010); Corsten et al.(2013).
Improving Access to Modern Energy modern biomass, nuclear, other		**Access to improved water and sanitation (6.1/6.2)** ↑ / ↓ [+2,-1] 🕮🕮 ☺☺ ★★★ Access to modern forms of energy will enable water treatment and distribution. This will prevent water related human and environmental hazards. Transitioning away from non-commercial biomass is expected to avoid associated deforestation impacts on surrounding hydrology. However, if the transition to modern forms of energy results in the development of water-intensive energy resources, improved energy access could lead to increased water stresss. Rao and Pachauri (2017); Cibin et al. (2016); Fricko et al. (2016)		**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. (Quote from McCollum et al., in review) *McCollum et al. (in review);* Bailis et al. (2015); Bazilian et al (2011); Karekezi et al. (2012); Winter et al. (2015)
Deployment of Renewables modern biomass, other renewables (solar, wind, etc.)		**Water efficiency and pollution prevention (6.3/6.4/6.6) / Access to improved** ↑ / ↓ [+2,-1] 🕮🕮🕮 ☺☺☺ ★★★ 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 Bilton et al. (2011); Scott et al. (2011); Kumar et al. (2012); Kern et al. (2014); Meldrum et al. (2014); Fricko et al. (2016)	**Marine Economies (14.7) / Marine Protection (14.1/14.2/14.4/14.5)** ↑ / ↓ [1,-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., in review) *McCollum et al. (in review);* Buck and Krause (2012); Michler-Cieluch et al. (2009); WBGU (2013); Inger et al. (2009)	**Healthy Terrestrial Ecosystems (15.1/15.2/15.4/15.5/15.8)** ↓ [-1] 🕮🕮 ☺☺ ★★ landscape and wildlife impact for wind Wiser et al. (2011); Lovich and Ennen (2013); Garvin et al. (2011); Grodsky et al. (2011); Dahl et al. (2012); de Lucas et al. (2012); Dahl et al. (Dahl et al., 2012); Jain et al. (2011).
Subsidies for Renewables Energy Sources this category collects impacts that are specific to funding instruments for renewable energy sources		**Water efficiency and pollution prevention (6.3/6.4/6.6) / Access to improved** ↑ / ↓ [+1,-1] 🕮🕮🕮 ☺☺☺ ★★★ Subsidies for renewables are anticipated to lead to the benefits and tradeoffs outlined when deploying renewables. Subsidies for renewables could lead to improved water acccess and treatment if subsidies support projects that provide both water and energy services (e.g., solar desalination). Bilton et al. (2011); Scott et al. (2011); Kumar et al. (2012); Kern et al. (2014); Meldrum et al. (2014); Fricko et al. (2016)		

		↑ / ↓ [+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 fertilzer inputs, improving water quality. Hejazi et al. (2015), Bonsch et al. (2016), Cibin et al. (2016); Song et al. (2016); Gao et al. (2017); Taniwaki (2017); Woodbury et al. (2017); Griffiths et al. (2017); Ha et al. (2017)		~ / ↓ [0,-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. (Quote from McCollum et al., in review) *McCollum et al. (in review);* Smith et al. (2010); Smith et al. (2014)
Large-scale hydro		**Water efficiency and pollution prevention (6.3/6.4/6.6) / Access to improved** ↑ / ↓ [+2,-2] 📖📖📖📖 ☺☺☺☺ ★★★★ Developing dams to support reliable hydropower production can fragment rivers and alter natural Ziv et al. (2012); Grill et al. (2015); Grubert et al. (2016); Fricko et al. (2016); De Stefano et al. (2017)		**Healthy Terrestrial Ecosystems (15.1/15.2/15.4/15.5/15.8)** ↓ [-1] 📖📖 ☺☺ ★★ Habitat impact IPCC AR5 WG3 (2014); Kumar et al. (2011); Alho (2011); Kunz et al. (2011); Smith et al. (2013); Ziv et al.
Deployment of CCS in the power sector Either with fossil fuels or bioenergy (BECCS)		**Water efficiency and pollution prevention (6.3/6.4/6.6)** ↑ / ↓ [+1,-2] 📖📖📖 ☺☺ ★★★ CCU/S requires access to water for cooling and processing which could contribute to localized water Meldrum et al. (2013); Fricko et al. (2016); Byers et al. (2016); Brandl et al. (2017)		
Nuclear energy		**Water efficiency and pollution prevention (6.3/6.4/6.6)** ↑ / ↓ [+2,-1] 📖📖📖 ☺☺☺ ★★★ Nuclear power generation requires water for cooling which can lead to localized water stress and Webster et al. (2013); Fricko et al. (2016); Raptis et al. (2016); Holland et al. (2016)		**Healthy Terrestrial Ecosystems (15.1/15.2/15.4/15.5/15.8)** ↓ [-1] 📖📖 ☺☺ ★★ Safety and waste concerns, uranium mining and milling IPCC AR5 WG3 (2014); Visschers and Siegrist (2012); Greenberg (2013a); Kim et al. (2013); Visschers
Improving energy efficiency general demand-side measures (where they cannot be specifically attributed to one sector)		**Water efficiency and pollution prevention (6.3/6.4/6.6)** ↑ [+2] 📖📖📖 ☺☺☺ ★★★ As water is used to convert energy into useful forms, energy efficiency is anticipated to reduce water consumption and wastewater, resulting in more clean water for other sectors and the environment. Bartos and Chester (2014); Fricko et al. (2016) Holland et al. (2016)	**Ocean Acidification (14.3)** ↑ [+2] 📖📖📖 ☺☺☺ ★★★ Deployment of renewable energy and improvements in energy efficiency globally can reduce carbon dioxide emissions, and this, in turn, will slow rates of ocean acidification. (Quote from McCollum et al., in review) *McCollum et al. (in review);* Caldeira and Wicket (2003); Feely et al. (2009); Gruber (2011); Le Quére et al. (2009); The Royal Society (2005); WBGU (2013)	
AFOLU demand-side measures & dietary change	**Reduced meat consumption**	**Water efficiency and pollution prevention (6.3/6.4/6.6)** ↑ / ↓ [+2,-1] 📖📖📖 ☺☺☺ ★★★ Reduced meat consumption avoids direct water demand and wastewater for livestock and livestock feed products (e.g., crops), and avoids water used for energy supply by reducing agricultural energy inputs. However, switching diets could cause increased consumption of plant-based products that can also be water-intensive. Khan et al. (2009); Mekonnen et al. (2013); Bajzelj et al. (2014); Ran et al. (2016)		
	Reduced food waste	**Water efficiency and pollution prevention (6.3/6.4/6.6)** ↑ [+2] 📖📖📖📖 ☺☺☺☺ ★★★★ Reduced food waste avoids direct water demand and wastewater for crops and food processing, and avoids water used for energy supply by reducing agricultural, food processing and waste management energy inputs. Khan et al. (2009); Bajzelj et al. (2014); Ran et al. (2016); Villarroel Walker et al. (2014)		
AFOLU supply-side measures	**Increased efficiency of livestock 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 wastewater flows. However, efficiency measures that include agricultural intensification could increase water demands locally, leading to increased water stress if the intensification is mismananged. Mekonnen et al. (2013); Kong et al. (2016); Ran et al. (2016)		
	climate smart agriculture and Soil carbon sequestration	**Water efficiency and pollution prevention (6.3/6.4/6.6)** ↑ / ↓ [+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. Smith (2016)		**Conservation of Biodiversity (15.5/15.9)** ↑ / ↓ [+1,-1] 📖📖📖 ☺☺☺ ★★★ 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, IPCC WGIII, 2014
	Enhanced Weathering, terrestrial	**Water efficiency and pollution prevention (6.3/6.4/6.6)** ↓ [-1] 📖 ☺ ★ Weathering agents may end up in water bodies impacting their quality. Interactions with the water cycle are also anticipated but highly uncertain and under researched Taylor et al. (2015)		
	Forestry, Forest management , 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 Bonsch et al.		**Conservation of Biodiversity (15.2/15.3/15.4/15.5/15.9)** ↑ [+1] 📖📖📖 ☺☺☺ ★★★ Policies and programs for reducing deforestation and forest degradation, for rehabilitation and restorationof degraded lands can promote conservation of biological diversity IPCC WGIII, 2014
Non-CO2 mitigation measures	**Methane removal**	**Water efficiency and pollution prevention (6.3/6.4/6.6)** ↑ [+2] 📖📖📖📖 ☺☺☺☺ ★★★★ Methane removal from wastewater can be used to generate low-carbon energy. This energy can be used to offset increasing water treatment energy demands to ensure water quality objectives. Stillwell et al. (2010); McCarty et al. (2011); McDonald et al. (2016); Kavvda et al. (2016)		
Oceans/Water	**Ocean iron fertilization**	**Water efficiency and pollution prevention (6.3/6.4/6.6)** ↓ [-2] 📖 ☺ ★ Ocean iron fertilization involves changing the chemistry of ocean water bodies which will directly impact water quality, but these impacts are under researched. Koehler et al. (2013)		
	Blue carbon	**Integrated water resources management (6.3/6.5)** ↑ [+2] 📖 ☺ ★ Development of blue carbon resources (coastal and marine vegetated ecosystems) can lead to coordinated management of water in coastal areas. Vierros et al. (2013)		
	Enhanced Weathering, ocean	**Water efficiency and pollution prevention (6.3/6.4/6.6)** ↓ [-1] 📖 ☺ ★ Weathering agents are expected to impact water quality. Interactions with the water cycle are also anticipated but highly uncertain and under researched Taylor et al. (2015)		

References used in this assessment: Impacts of mitigation options on specific targets of the 17 SDGs, for social dimensions (Table 5.1a):

Altieri et al. 2016b; Casillas and Kammen 2012; Scott et al. 2014; Maidment et al. 2014; Berrueta et al. 2017b; Hallegatte et al. 2015; Suckall et al. 2014b; McCollum et al.; Bonan et al. 2014; Burlig and Preonas 2016; Casillas and Kammen 2010; Cook 2011; Kirubi et al. 2009; Pachauri et al. 2012; Pueyo et al. 2013; Hallegatte et al. 2016b; Riahi et al. 2012; Cameron et al. 2016; Fay et al. 2015; Hirth and Ueckerdt 2013; Jakob et al. 2014; IPCC 2014c; Havlík et al. 2015; Luttrell et al. 2013; Ravikumar et al. 2015; Di Gregorio et al. 2017b; Ickowitz et al. 2017; Loft et al. 2017; Asaduzzaman et al. 2010; Cabraal et al. 2005; Finco and Doppler 2010; Hasegawa et al. 2015; Lotze-Campen et al. 2014; Msangi et al. 2010; Smith et al. 2013; Sola et al. 2016; Tilman et al. 2009; van Vuuren et al. 2009; Balishter and Singh 1991; Creutzig et al. 2013; de Moraes et al. 2010; Gohin 2008; Rud 2012; Satolo and Bacchi 2013; van der Horst and Vermeylen 2011; Corbera and Pascual 2012; Davis et al. 2013; Muys et al. 2014; Xi et al. 2013; Zhang et al. 2015; Huebner et al. 2013; Yue et al. 2013a; Zhao et al. 2017; Willand et al. 2015; Wells et al. 2015; Cameron et al. 2015; Liddell and Guiney 2015; Sharpe et al. 2015; Derbez et al. 2014; Creutzig et al. 2012; Haines and Dora 2012; Saunders et al. 2013; Shaw et al. 2014b; Woodcock et al. 2009; Schucht et al. 2015; Figueroa et al. 2014; Peng et al. 2017; Klausbruckner et al. 2016; Koornneef et al. 2011; Singh et al. 2011; Hertwich et al. 2008; Veltman et al. 2010; Corsten et al. 2013; Ashworth et al. 2012; Einsiedel et al. 2013; Miller et al. 2007; de Best-Waldhober et al. 2009; Wong-Parodi and Ray 2009; Reiner and Nuttall 2011; Burgherr et al. 2012; Chen et al. 2012; Chan and Griffiths 2010; Asfaw et al. 2013; Aranda et al. 2014; Lam et al. 2012; Lim et al. 2012; Anenberg et al. 2013; Chaturvedi and Shukla 2014; Haines et al. 2007; IEA 2016; Kaygusuz 2011; Nemet et al. 2010; Rafaj et al. 2013; Rao et al. 2013a; Smith and Sagar 2014; van Vliet et al. 2012; West et al. 2013; Atchley et al. 2013; Apps et al. 2010; Siirila et al. 2012; Wang and Jaffe 2004; Cardis et al. 2006; Abdelouas 2006; Al-Zoughool and Krewski 2009; Schnelzer et al. 2010; Tirmarche et al. 2012; Brugge D. & Buchner 2011; Hiyama et al. 2013; Mousseau and Møller 2013; Møller and Mousseau 2011; Møller et al. 2012, 2011; von Stechow et al. 2016; Heinävaara et al. 2010; Kaatsch et al. 2008; Sermage-Faure et al. 2012; Lipscomb et al. 2013; van de Walle et al. 2013; Chowdhury 2010; Haves 2012; Matinga 2012; Pachauri and Rao 2013; Clancy et al. 2011; Dinkelman 2011; Köhlin et al. 2011; Brown 2011; Lucas and Pangbourne 2014; Cass et al. 2010; Cumbers 2012; Kunze and Becker 2015; Walker and Devine-Wright 2008; Jakob and Steckel 2014; Cayla and Osso 2013; Hult and Larsson 2016; Aggarwal 2013; AlSabbagh et al. 2017; Acemoglu 2009; ICSU and ISSC 2015; Tabellini 2010; Clarke et al. 2009; Eis et al. 2016; Montreal Protocol 1989; New Climate Economy 2015; O'Neill et al. 2017b; Ramaker et al. 2003; Riahi et al. 2015, 2017

References used in this assessment: Impacts of mitigation options on specific targets of the 17 SDGs, for economic dimensions (Table 5.1b):

Zhang et al. 2015; IPCC 2014c; Chakravarty and Tavoni 2013; Karner et al. 2015; Yue et al. 2013b; Zhao et al. 2017; de Koning et al. 2016; Isenhour and Feng 2016; van Sluisveld et al. 2016; Noonan et al. 2015; Allen et al. 2015; Jain et al. 2013; Hori et al. 2013; Sweeney et al. 2013; Webb et al. 2013; Huebner et al. 2013; Gyamfi et al. 2013; Berrueta et al. 2017b; Cameron et al. 2015; Liddell and Guiney 2015; McLeod et al. 2013; Noris et al. 2013; Salvalai et al. 2017; Yang et al. 2014; Kwong et al. 2014; Holopainen et al. 2014; Creutzig et al. 2014; Ali et al. 2015; Månsson 2016; Altieri et al. 2016b; Fan et al. 2017; Shi et al. 2017; Klausbruckner et al. 2016; Lucas and Pangbourne 2014; Suckall et al. 2014b; Gouldson et al. 2015; Carrara and Longden 2016; Bernard and Torero 2015; Chakravorty et al. 2014; Grogan and Sadanand 2013; Pueyo et al. 2013; Rao et al. 2013b; Bonan et al. 2014; Clarke et al. 2014; Jackson and Senker 2011; New Climate Economy 2014; OECD 2017; York and McGee 2017; McCollum et al.; Babiker and Eckaus 2007; Bertram et al. 2015; Blyth et al. 2014; Borenstein 2012; Creutzig et al. 2013; Dechezleprêtre and Sato 2014; Dinkelman 2011; Ferroukhi et al. 2016; Frondel et al. 2010; Gohin 2008; Guivarch et al. 2011; Johnson et al. 2015; He et al. 2016; Lin et al. 2015; Kagawa et al. 2015; Heinonen et al. 2013; Gallego et al. 2013; Aamaas and Peters 2017; Gössling and Metzler 2017; Figueroa et al. 2014; Banerjee et al. 2012; Bhattacharyya et al. 2016; Cameron et al. 2016; Riahi et al. 2012; Schwanitz et al. 2014; European Climate Foundation 2014; Khan et al. 2015; New Climate Economy 2015; Stefan and Paul 2008; Hallegatte et al. 2015; Figueroa et al. 2013; Daut et al. 2013; Tully 2006; Bongardt et al. 2013; Creutzig et al. 2012; Grubler and Fisk 2012; Kahn Ribeiro et al. 2012; Raji et al. 2015; Dulac 2013; Martínez-Jaramillo et al. 2017; Goldthau 2014; Meltzer 2016

References used in this assessment: Impacts of mitigation options on specific targets of the 17 SDGs, for environmental dimensions (Table 5.1c):

Vassolo and Döll 2005; Fricko et al. 2016; Holland et al. 2015; Nguyen et al. 2014; Hejazi et al. 2015; Song et al. 2016; Meldrum et al. 2013; Byers et al. 2016; Brandl et al. 2017; Bartos and Chester 2014; Hendrickson and Horvath 2014; Vidic et al. 2013; Tiedeman et al. 2016; Webster et al. 2013; Zhang et al. 2014; Wright et al. 2017; Rao and Pachauri 2017; Cibin et al. 2016; Bilton et al. 2011; Scott 2011; Kern et al. 2014; Bonsch et al. 2016; Gao and Bryan 2017b; Taniwaki et al. 2017; Woodbury et al. 2017; Griffiths et al. 2017; Ha and Wu 2017; Ziv et al. 2012; Grill et al. 2015; Grubert et al. 2014; De Stefano et al. 2017; Raptis et al. 2016; Khan and Hanjra 2009; Mekonnen and Hoekstra 2012; Bajželj et al. 2014; Ran et al. 2016; Walker et al. 2014; Kong et al. 2016; Smith 2016; Kavvada et al. 2016; Köhler et al. 2013; Vierros 2017; McCollum et al.; Buck and Krause 2012; Michler-Cieluch et al. 2009; WBGU 2013; Inger et al. 2009; Caldeira and Wickett 2003; Gruber 2011; The Royal Society 2005; Shi et al. 2017; IPCC 2014c; Smith et al.

2013; Koornneef et al. 2011; Singh et al. 2011; Hertwich et al. 2008; Veltman et al. 2010; Corsten et al. 2013; Bailis et al. 2015; Bazilian et al. 2011; Karekezi et al. 2012; Winter et al. 2015; Smith et al. 2010; Kim and Brownstone 2013