Chapter 5: Sustainable Development, Poverty Eradication and Reducing Inequalities

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Executive Summary

The final chapter in this Special Report assesses the knowledge on connections between sustainable development, poverty eradication, reducing inequalities, and pathways to limit global warming to 1.5°C above-preindustrial times. The UN 2030 Agenda for Sustainable Development established a set of 17 Sustainable Development Goals (SDGs) that seek to end poverty and hunger; reduce inequalities; ensure health; education; sustainable energy; water and work for all; and foster sustainable cities, consumption, ecosystems. SDG13 focuses on urgent action to combat climate change and its impacts. This chapter assesses 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 sustainable development and the SDGs. The chapter also explores the impacts of pursuing the SDGs on limiting warming to 1.5°C and on adaptive capacities, particularly for the most vulnerable populations. Finally, the chapter also assesses sustainable development pathways to 1.5°C, including climate-resilient development pathways that maximise synergies and minimise trade-offs between climate responses of mitigation and adaptation with sustainable development, especially poverty alleviation and reducing inequality. More research is needed to increase the confidence and breadth of understanding the specific links between limiting global warming to 1.5°C and achieving sustainable development, especially at the regional level.

Without consideration for equity and fairness, and concerted efforts from all countries as well as individuals, communities, and organizations, the dual goal of limiting global warming by the end of the 21st Century to 1.5°C compared to pre-industrial times, including temperature overshoots along the way, and achieving the SDGs by 2030 and beyond, inclusive of poverty eradication, will be exceedingly difficult to reach (*high confidence*).

As risks increase with every level of additional warming, a higher number of potentially adverse future impacts can be avoided when global warming is limited to 1.5°C rather than 2°C, with important benefits for poor and disadvantaged people. 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 (*medium evidence, high agreement*). Limiting global warming to 1.5°C versus 2°C will reduce the risks for livelihoods and for human, food, water, and ecosystem security through reduction of heat stress, more moderate impacts on agriculture and water, lower risks from extreme events, and reduced stress on unique and threatened systems, for instance those of high mountain areas, drylands, tropical coral reefs, and subsistence fisheries (*medium evidence, high agreement*) {5.2}. 1.5°C global warming will still have broad impacts and will disproportionately affect already disadvantaged and vulnerable populations, with more severe impacts expected in the case of temperature overshoot, particularly for indigenous people and systems in the Arctic, for agriculture- and coastal dependent livelihoods, and small-island developing states (SIDs) (*medium evidence, high agreement*) {5.2.1; 5.2.2}. Globally, the poorest people are projected to experience the impacts of 1.5°C global warming predominantly through increased food prices, food insecurity and hunger, income losses, lost livelihood opportunities, adverse health impacts and population displacements, for instance from increased heat stress and other extreme events such as coastal flooding, with more than 100 million additional people anticipated in poverty (*limited evidence, medium agreement*) {5.2.2}. Limits to adaptation and potential losses exist at every level of temperature increase (*medium confidence*), with place-specific implications, for example for Pacific Small Islands Developing States {5.2.3, 5.6.3}. Limiting global warming to 1.5°C is expected to make it easier to pursue sustainable development, with higher potential to eradicate poverty, reduce inequality, and foster equity than 2°C (*medium evidence, high agreement*). Limiting temperature to 1.5°C can reduce significantly the risks of failure in achieving certain SDGs, e.g. on poverty, health, and water and sanitation, although there will be differences between countries. Yet, the literature supporting this evidence remains scarce, particularly with respect to gender and inequalities (*limited evidence, medium agreement)* {5.2.4}.

Reducing climate vulnerability through adaptation is mostly consistent with achieving sustainable development in general, and the SDGs specifically (*high confidence*). Most adaptation strategies help meet the SDGs (known as synergies) but some generate negative consequences and make it more difficult to meet some SDGs (knowns as trade-offs) (*high confidence*). Transformative adaptation required to achieve sustainable development in a 1.5°C warmer world needs to address the root socio-

economic and cultural causes of vulnerability (*high confidence*).
Adaptation will be important in a 1.5°C warmer world to counter the anticipated impacts on human and natural systems around the world. Ensuring livelihood security, poverty alleviation, equity, and inclusion, support effectively the design of adaptation strategies that lead to the achievement of the SDGs, for climate-change affected communities but also more broadly (*high confidence*) {5.3.1, 5.3.2}. The extent of synergies between sustainable development and adaptation goals will vary by the development process adopted for a particular SDG (*high confidence*) {5.3.1}. There is a high potential for synergies between adaptation options and several sustainable development objectives, notably response options that reduce vulnerabilities in a way to support poverty reduction, elimination of hunger, clean water, and health (*very high confidence*) {5.3.2}. Negative outcomes (or trade-offs) can potentially occur either in the form of maladaptation or adverse consequences of particular adaptation strategy; this includes instances when the costs of adaptation increase poverty and debt, agricultural adaptation competes with protecting biodiversity or overlooks the poor and women, the expanded use air conditioning increases emissions, ecosystem-based adaptations conflicts with local rights, and migration increases cultural tensions (*high confidence*) {5.3.2}. Adaptation pathways that use a mix of adaptation options and maximise synergies and minimise trade-offs with sustainable development are successful when they follow inclusive, deliberative, and place-specific processes and procedural justice mechanisms; yet, persistent uneven power structures that dominate decision making reinforce existing social inequalities (*medium evidence, high agreement)* {5.3.3}.

Mitigation options compatible with 1.5°C warming can help meet sustainable development and the SDGs (synergies) but some generate negative consequences (trade-offs). Choices of mitigation options and policies will differentially affect people's lives and well-being, given different capacities and countries' positions on development trajectories. However, some of these risks can be reduced by policy designs and mechanisms at moderate cost (*high confidence*).
The choice of the portfolio of mitigation options and the policy instruments that are used for implementation will largely determine the overall synergies and trade-offs of 1.5°C mitigation pathways for sustainable development (*very high confidence*) {5.4.1,5.4.3, Figure 5.4.1, 5.4.2}. Mitigation actions in the energy demand sectors and behavioural response options with appropriate management of rebound effects can advance multiple SDGs simultaneously, more so than energy supply side mitigation actions (*very high confidence*) {5.4.1, Table 5.1 a-c, Figure 5.4.1}. Mitigation options that show higher synergies with SDGs are those that emerge from cross-sectoral efforts at city scale; new sectoral organisations based on the circular economy concept such as zero waste, decarbonisation and dematerialisation; and multi-policy interventions that follow systemic approaches. These synergies require governance coordination across sectors and nations, and collaboration and dialogue across scales (*medium evidence, high agreement*) {5.4.1.4}. A number of mitigation interventions in the AFOLU sector could help to deliver the SDGs, such as sustainable and climate-smart land/agricultural management, the shift toward sustainable healthy diets and reduction of food waste. Forestry mitigation options including reducing deforestation, afforestation, climate-smart sustainable forest management and multi-purpose systems for fibre, timber, and energy use- provide cost-effective measures and in many cases, negative emissions. Their appropriate design and implementation that take into account local people´s needs, biodiversity and other SD concerns can also provide large synergies with SDGs particularly within rural areas of developing countries (*high confidence*) {5.4.1.2, 5.4.1.5}. Mitigation pathways aiming at 1.5°C are in high synergies with health and air pollution. The nature of development patterns and the pursuit of sustainable development objectives affects the potential for ambitious mitigation and can reduce the social cost of reaching 1.5°C. Protection of oceans and marine ecosystems is a key enabler for ambitious mitigation, and the reduction of outdoor air pollution is a core motivation for public support for ambitious mitigation (*medium evidence, high agreement*) {5.4.1.5}. Economic growth and the reduction of inequalities can facilitate or hinder ambitious emission reductions depending on the strategy adopted to meet these sustainable development objectives (*medium evidence, medium agreement*) {5.4.1.4}. The rapid pace and magnitude of the required changes lead also to increased risks for trade-offs for a number of other sustainable development dimensions particularly risk of hunger, poverty, and basic needs, such as energy access. The negative impacts are more particularly for the poor populations without access to clean energy, employment and lead to overexploitation of some mineral resources required for renewable generation (medium confidence) {5.4.3, Figure 5.4.2}. 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 with focus on 1.5°C show that this is possible

at relatively modest costs (*high confidence*) {5.4.3, Figure 5.4.2}. For example, cash transfers, food subsidies and improvements in yields can reduce trade-offs of land-use change and bioenergy deployment which may threaten food and water security, cause biodiversity loss and competition for land, spikes in food prices, and lead to disproportionate consequences upon poor and indigenous populations (*high confidence*). Delaying actions to reduce GHGs increases risks of cost escalations, stranded assets, job loss, reduced flexibility in future response options in the medium to long-term. These may have trade-offs that increase uneven distributional impacts between countries at different stages of development (*medium evidence, high agreement*) {5.4.2}. 1.5°C pathways that feature very low energy demand show pronounced positive effects across multiple SDGs (*very high confidence*). Low-carbon and zero-carbon energy sources serve the dual goals of mitigation and improved access to modern and affordable energy, which is fundamental to human well-being and contributes to poverty reduction. But these transitions must be handled carefully to avoid trade-offs with sustainable development, notably upon poor and indigenous populations. They depend upon radical socio-cultural and organizational innovation, which can create challenges for social acceptability. For example, more electrification of transport sector can lead to rise in electricity prices and can adversely affect poor unless pro-poor redistributive policies are in place. Road infrastructure and city expansion can lead to eviction, bio energy can lead to land disputes unless appropriate strategies are built into the projects (*medium evidence, high agreement*) {5.4.1.3, 5.4.2.2, Table 5.1}. Economies dependent upon fossil fuel-based energy generation and/or export revenue will be disproportionally affected by restriction on the use of fossil fuels necessary for ambitious climate goal despite multiple other sustainable development benefits. There is a need for supplementary policies, including retraining, to ease job losses and the effects of higher energy prices, particularly in countries where the workforce is largely semi or unskilled (*very high confidence*) {5.4.1.3}.

While integrated approaches between mitigation, adaptation and sustainable development are possible, they will not be necessary, suitable or efficient for all situations. The efficiency of these integrated approaches to deliver triple-wins depends on the satisfaction of several enabling conditions (*medium evidence, high agreement*).
Comprehensive packages of adaptation and mitigation options supported by coordinated governance across sectors and nations can enhance sustainable development (*medium evidence, high agreement*) {5.3.1, 5.4.1}. Coherent and integrated institutions and governance, including on finance, is a key enabling condition for integrated approaches between mitigation, adaptation and sustainable development at the level of policies, programs and projects (*very high confidence*) {5.5.1}. The multi-level and multi-sector nature of integration inherently produce conflicting governing processes, actors and outcomes, raising issues of power, justice and political economy. The involvement of stakeholders though participatory mechanisms is a key condition for addressing these challenges in a way that ensures that the voices of the poor, disadvantaged and vulnerable populations are heard. Taking into account regional contexts and local knowledge is essential for maximizing the synergy potentials (*medium evidence, high agreement*) {5.5.2, 5.5.3}. Reconciling trade-offs between sustainable development, adaptation and mitigation towards a 1.5°C warmer world will require a dynamic view of the interlinkages between these three dimensions at different time horizons. This entails recognition of the ways in which development patterns shape the choices and effectiveness of interventions (*medium evidence, high agreement*) {5.5.4}.

Without strengthened contributions to decarbonization and commitment from countries, institutions, and communities to equity and fairness, pathways to 1.5°C will not allow to reach the Agenda 2030 objective to leave no one behind (*high confidence*). Sustainable development pathways, including climate-resilient development pathways, entail low-emissions trajectories that simultaneously promote fair and equitable climate resilience and effort sharing. These pathways take into account the following key aspects: the urgency of the 1.5°C target, the need to achieve global net zero emissions, the achievement of goals for sustainable development, the need to enhance capacity to adapt, the scale of societal transformation required, and the ethics, equity, and well-being implications of embarking on such substantial transformation {5.6.2}. The potential for such pathways differs between richer and poorer nations and regions (*very high confidence*), given different levels of development as well as differential responsibilities and capacities to cut emissions, eradicate poverty, and reduce inequalities and vulnerabilities. At the level of individuals, communities, and groups, emphasis on well-being, social inclusion, equity, and human rights helps to overcome limitations in capacity, as shown, for instance, in agrarian and social and climate justice movements in Latin America and Transition Towns predominantly in Europe and North America (*medium* *evidence, high agreement*) {5.6.2; 5.6.3}. Initial evidence of partially successful pathways points toward significant possibilities as well as inherent difficulties to the achievement of sustainable, robust and equitable climate-resilient development, including considerable albeit incomplete efforts in so-called emerging green states in the Global South and oil-producing countries in the Middle East and North Africa. Even at 1.5°C global warming, challenges in some parts of the world—for example in the Small Island Development States in the Pacific, despite ambitious and inclusive planning processes for climate resilience—will not prevent limits to adaptation and residual impacts. With appropriate policy support, community-led and bottom-up approaches offer potentials for climate-resilient development pathways at scale – as shown in farmer managed cropland management across drylands in sub-Saharan Africa and countries in South and Southeast Asia (*medium evidence; high agreement*) {5.6.2; 5.6.3}. Participatory governance and iterative social learning constitute key aspects to enable transformative social change in a 1.5°C compatible development pathway. Yet, dominant pathways and entrenched power differentials continue to undermine the rights, values, and priorities of disadvantaged populations in decision making. Very limited indicators and monitoring and evaluation systems currently exist that track multi-level progress toward equitable, fair, and socially desirable low-carbon futures (*high confidence*) {5.6.4}.

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 (*very high confidence*).
Limited evidence exists to date that explicitly examines 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. The assessments of avoided impacts and development implications of 1.5°C versus 2°C and higher warming often use proxies, which does not allow capturing the effects on inequalities that, in turn, shape vulnerabilities. Limited literature exists that empirically investigates the effectiveness of integrated policy frameworks to deliver triple-win (adaptation-mitigation-sustainable development) outcomes, the dynamics that produce such outcomes at the scale of implementation, and the anticipated winners and losers. More structured literature is needed on global trajectories compatible with 1.5°C warmer world and sustainable development that would emerge as a composite of local, regional, national pathways. Such studies would be directly policy-relevant at these scales of decision through quantification of the effects of different policy instruments on synergies and trade-offs, but would also inform on the related global trends characterizing the GHG emission objective and defining the global enabling conditions of change. Existing literature on development pathways that are sustainable and climate-resilient suggests inadequately demonstrate how governance structures enable or hinder different groups of people and countries at different levels of development, with different needs, rights, and capacities, to negotiate pathway options, values, and priorities, leaving significant ethical and moral questions unanswered. Methodologies of dialogues between different research communities, regarding processes of learning and deliberative decision making, and adequate and robust indicators, are needed to analyse the multiple dimensions of climate and development, overcoming persistent disciplinary knowledge fragmentation.

5.1 Scope and Delineations

This chapter assesses what is known about the connections between sustainable development and pathways to 1.5°C. It examines the impacts of keeping temperatures at 1.5°C global warming above preindustrial levels on sustainable development, compared to other scenarios, including 2°C, and examines the interactions between response measures of mitigation and adaptation and sustainable development. This chapter gives particular attention to synergies and trade-offs between 1.5°C and meeting the near term Sustainable Development Goals (SDGs) in the context of eradicating poverty and reducing inequality. The chapter builds on prior IPCC reports and assesses new literature. It offers insights into possible pathways and enabling conditions to achieve the 1.5°C goal and meet the SDGs with a particular focus on climate-resilient development pathways.

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

Chapter 1 provides an introduction of the concepts of sustainable development, equity and poverty as used in this report, as well as an overview of ethical issues and the Sustainable Development Goals (Box 5.1). The UN General Assembly views sustainable development as recognizing "that eradicating poverty in all its forms and dimensions, combating inequality within and among countries, preserving the planet, creating sustained, inclusive and sustainable economic growth and fostering social inclusion are linked to each other and are interdependent" (United Nations, 2015c). The scientific literature and development organizations define sustainable development in a variety of ways and see it as difficult to measure precisely but commonly see it as meeting environmental, social and economic goals (Bebbington and Larrinaga, 2014; Redclift and Springett, 2015). For some authors, sustainable development can also be assessed in terms of "well-being"; a subjective measure of satisfaction that can include happiness, social relationships, life expectancy, perception of environmental quality, and health (Barrington-Leigh, 2016; Helliwell et al., 2013; Schmoker, 2011).

The AR5 reported with *high confidence* that sustainable development is strongly connected to climate change and that disruptive levels of climate change would preclude reducing poverty (Denton et al., 2014; Fleurbaey et al., 2014). It also identified synergies and trade-offs in solving climate and development challenges and assessed literature that showed that the responses to climate change – mitigation and adaptation – could have significant positive and negative impacts and distributional implications for development. The UN underlined this interconnection in the 2030 Agenda for Sustainable Development "Climate change is one of the greatest challenges of our time and its adverse impacts undermine the ability of all countries to achieve sustainable development" (United Nations 2015, p5). The World Bank finds that climate change is a key obstacle to eliminating poverty and that climate change can reverse or erase improvements in living conditions and decades of development (Hallegatte et al., 2016a).Chapter 1 of this Special Report briefly discusses definitions of poverty (see Section 1.4.2), highlighting its multiple dimensions beyond low incomes, such as hunger, illiteracy, poor housing, lack of access to services, social exclusion and powerlessness. Given that reducing and eliminating poverty is a primary goal of sustainable development and the SDGs, this chapter pays particular attention to the implications of the 1.5°C target for various measures of poverty.

Chapter 1 highlights the importance of equity and ethics in the analysis of climate and sustainable development (see Section 1.4.1), noting the mention of equity in the Paris agreement and other documents, especially in relation to fairness and justice. It also makes the connection between the 1.5°C target and human rights (see Section 1.4.1). A principle of *equality* sees every human being as of equal worth, and argues that everyone should have the same opportunity and rights irrespective of origins. Climate change and climate policies can have unequal causes and consequences as a result of social and economic inequalities such as those in income or health. As noted in Chapter 1 (see Section 1.4.1), *equity* generally means treating everyone fairly and impartially, both in the distribution of responsibilities (distributive equity) and resources and in participation in decision making (procedural equity), and is often associated with concepts of justice (Fleurbaey et al., 2014). Equity and equality are discussed in the literature on climate justice which highlights the importance of structural and other inequalities between countries, communities, and people, the role of climate change in increasing inequality, the balance of co-benefits and trade-offs, and the need for equitable solutions to climate change (Holland, 2017; Okereke and Coventry, 2016; Klinsky et al., 2017; Lahn, 2017; Robiou et al., 2017; Caney, 2016; de Loma-Osorio, 2016; Moss, 2015; Caney, 2014; Gupta and Arts, 2017).

There is high agreement that individuals (and societies) often experience inequality and inequity through the intersection of multiple axes that include their gender, class, ethnicity, age, race, ability, and their relation to vulnerability and risk (Kaijser and Kronsell, 2014; Nightingale, 2011; Olsson et al., 2014; Thompson-Hall et al., 2016; Van Aelst and Holvoet, 2016; Vinyeta, Kirsten; Whyte, Kyle Powys; Lynn, 2015; Vinyeta et al., 2015). The UN Sustainable Development Goals (see below and Box 5.1) have a strong focus on reducing poverty and inequality: Goal 1 is to end poverty in all its forms everywhere, Goal 4 ensures equitable access to education, Goal 5 seeks gender equality, Goal 10 seeks to reduce inequality within and among countries, and other goals seek sanitation, water, healthy lives, energy, economic growth, and decent work "for all" (United Nations, 2016).

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: *ref*) and that multidimensional inequalities, often produced by uneven development processes, shape differential vulnerabilities to and risks from climate change (IPCC, 2014b).

Research shows that the responses to climate change interact in complex ways with goals of poverty reduction and equity. As we discuss in Sections 5.3 and 5.4 below, the benefits of adaptation and mitigation projects and funding may accrue to some and not others, responses may be costly and unaffordable to some people and countries, and projects may disadvantage some individuals, groups and development initiatives (Casillas and Kammen, 2012; Chen et al., 2016; Newell and Mulvaney, 2013; Schroeder and McDermott, 2014). One of the more challenging equity concerns arises if limits to adaptation produce significant residual impacts to some countries (Barnett et al., 2016a; Klein et al., 2014). The issue of loss and damage is addressed in the UNFCCC Warsaw International Mechanism and the Paris Agreement (Boyd et al., 2017; Mathew and Akter, 2017; Page and Heyward, 2017; Vanhala and Hestbaek, 2016) (see also Cross-Chapter Box 4.4).

5.1.2 Sustainable Development Goals

The 2000 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 greenhouse gas (GHG) emissions and thus to a trade-off between development and climate change (Janetos et al., 2012; United Nations, 2015b). Critics argued that the MDGs failed to address within country disparities and human rights, focused only on developing countries, did not address key environmental concerns, and had numerous measurement and attribution problems (Fukuda-Parr, Yamin, and Greenstein 2014; Langford, Sumner, and Yamin 2013).

The articulation of this new set of UN *Sustainable Development Goals* (see Chapter 1Box 1.2) 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), access to education (SDG4), achieving gender equality (SDG5), ensuring access to water and sanitation (SDG6) and energy (SDG7), promoting inclusive economic growth (SDG8), building resilient infrastructure and sustainable industrialisation (SDG9), reducing inequality (SDG10), making sustainable cities (SDG11) and ensuring sustainable consumption and production (SDG12), combating climate change (SDG13), conserving oceans and marine resources (SDG14) and protecting terrestrial ecosystems (SDG15), promoting peace and justice (SDG16), and strengthening partnerships (SDG17).

Figure 5.1 illustrates the current situation for a selection of development indicators for which comprehensive data is available. Several of these indicators are measures for both the MDGs and SDGs. Several patterns and challenges to sustainable development are evident. Low-income countries are on average less well-nourished and have much less access to electricity and sanitation. Upper-middle income and high-income countries have less poverty, hunger, child mortality and better access to water, sanitation and electricity. Sub-Saharan Africa is disadvantaged on most indicators. However, South Asia has higher average incomes, child survival and nourishment compared to their lack of sanitation and access to electricity. These indicators for 2013 are the result of progress that was made in recent decades on many of the measured and widely available development indicators, but there are still millions of people in extreme poverty and hunger, where many children die before the age of five, and where millions are without access to clean water, sanitation or electricity.

[INSERT FIGURE 5.1 HERE]

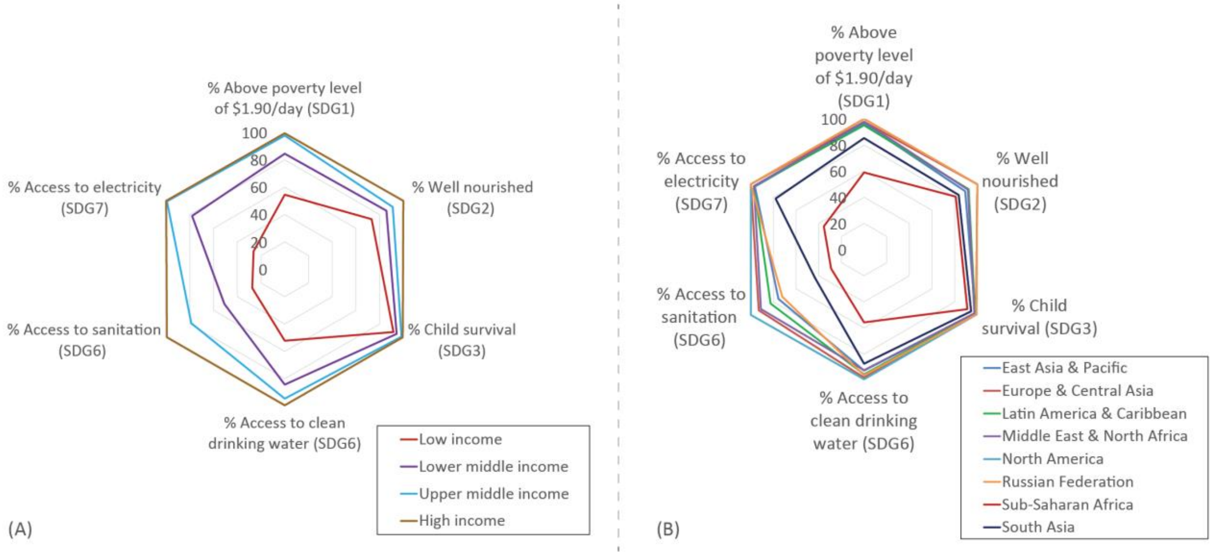

Figure 5.1: Sustainable Development indicators: Selected development indicators by (A) income group and by (B) world region for 2013. The income groups (low income, lower middle income, upper middle income and high income) are those used by the World Bank, as are the regional groupings. The indicators are associated with metrics used in the Sustainable Development Goals (SDGs) and include (i) the percent of the population living on more than $1.90/day at 2011 international prices (PPP), a poverty line defined by the World Bank and associated with SDG1 which seeks to eliminate poverty; (ii) the percent of population above the minimum level of dietary energy consumption (below which people are considered undernourished because their food intake is insufficient to meet dietary energy requirements) associated with SDG2 to eradicate hunger; (iii) the probability that a child will survive beyond the age of 5 measure as percent. It is based on the under-five mortality rate per 1000 babies born and is associated with SDG3 seeking healthy lives; (iv) the percentage of people using at least basic water services associated with SDG6 to ensure safe water. This indicator encompasses both people using basic water services as well as those using safely managed water services. Basic drinking water services is defined as drinking water from an improved source, provided collection time is not more than 30 minutes for a round trip. Improved water sources include piped water, boreholes or tube wells, protected dug wells, protected springs, and packaged or delivered water; (v) the percentage of the population using improved sanitation facilities. Improved sanitation facilities are likely to ensure hygienic separation of human excreta from human contact. They include flush/pour flush (to piped sewer system, septic tank, pit latrine), ventilated improved pit (VIP) latrine, pit latrine with slab, and composting toilet and are included in SDG6 to ensure safe water and sanitation; and (vi) the percentage of population with access to electricity. Electrification data are collected from industry, national surveys and international sources associated with MDG7 ensuring access to clean energy. All data is from the World Bank (http://databank.worldbank.org/).

Despite their ambitious and integrative vision, the 2030 Agenda has met with some scholarly criticism.

Some suggest the SDGs are too many and too 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 of the SGDs and the means of implementation; because implementation may requires some fundamental economic transformations beyond global partnerships and international trade, and will need to address the inequalities that have long contributed to unsustainable development (UNRISD, 2016).

[START BOX 5.1 HERE]

Box 5.1: Climate and the Sustainable Development Goals (SDGs)

Sustainable Development Goal 13 commits to 'Take urgent action to combat climate change and its impacts'(United Nations, 2015c). This goal recognises that climate change is one of the major threats to development and to success on the other 16 goals. The specific targets under the goal include targets to:

13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries
13.2 Integrate climate change measures into national policies, strategies and planning
13.3 Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning
13.4 Implement the commitment undertaken by developed-country parties to the United Nations Framework Convention on Climate Change to a goal of mobilizing jointly $100 billion annually by 2020 from all sources to address the needs of developing countries in the context of meaningful mitigation actions and transparency on implementation and fully operationalize the Green Climate Fund through its capitalization as soon as possible
13.5 Promote mechanisms for raising capacity for effective climate change-related planning and management in least developed countries and Small Island Developing States, including focusing on women, youth and local and marginalised communities

The targets acknowledge that the United Nations Framework Convention on Climate Change is the primary international, intergovernmental forum for negotiating the global response to climate change.

The indicators proposed so far (https://sustainabledevelopment.un.org/sdg13) include:
Indicator 13.1.1: Number of countries with national and local disaster risk reduction strategies
Indicator 13.1.2: Number of deaths, missing persons and persons affected by disaster per 100,000 people
Indicator 13.2.1: Number of countries that have communicated the establishment or operationalization of an integrated policy/strategy/plan which increases their ability to adapt to the adverse impacts of climate change, and foster climate resilience and low greenhouse gas emissions development in a manner that does not threaten food production (including a national adaptation plan, nationally determined contribution, national communication, biennial update report or other)
Indicator 13.3.1: Number of countries that have integrated mitigation, adaptation, impact reduction and early warning into primary, secondary and tertiary curricula
Indicator 13.3.2: Number of countries that have communicated the strengthening of institutional, systemic and individual capacity-building to implement adaptation, mitigation and technology transfer, and development actions
Indicator 13.a.1: Mobilised amount of United States dollars per year starting in 2020 accountable towards the $100 billion commitment
Indicator 13.b.1: Number of least developed countries and small island developing States that are receiving specialised support, and amount of support, including finance, technology and capacity-building, for mechanisms for raising capacities for effective climate change-related planning and management, including focusing on women, youth and local and marginalised communities

The goal will be reviewed at the UN High Level Political Forum in 2019. There is little research so far that explicitly assesses SDG 13, its progress or problems. The SDG Index and Dashboards report uses measures of CO_2 emissions per capita, imported CO2 emissions, climate change vulnerability, and effective carbon rate (Sachs et al., 2017). It is important to note that the SDGs have the short-term target of 2030, whereas the Paris Agreement focuses on 2100, with stocktakes every five years from 2023. The Paris Agreement does not set a date for limiting temperatures to 2°C or 1.5°C, achieving a global goal on adaptation, or mobilizing the $100 billion for responses. It establishes the aim to reach global peaking of greenhouse gases "as soon as possible" (United Nations, 2015a).

[END BOX 5.1 HERE]

5.1.3 Pathways to 1.5°C

This chapter seeks to identify the pathways and strategies through which the world could limit warming to 1.5°C while also achieving sustainable development, including meeting the SDGs of the 2030 Agenda. Chapter 1 identifies several categories of pathways to global mean temperature of 1.5°C including temperature stabilization pathways where temperatures rise and stabilise at 1.5°C, overshoot pathways where temperatures rise above 1.5°C before peaking and declining to or below 1.5°C and a continued warming pathway where 1.5°C is just a stage on the way to warming temperatures. Box 1.2 (Chapter 1, Section 1.2.4) introduces the concepts of scenarios and pathways, including development pathways that are sustainable and climate resilient.

This chapter focuses on the sustainable development implications of stabilizing at 1.5°C rather than higher temperatures and on the ways in which sustainable development can enable and motivate climate action. There is very little literature on the implications of overshoot pathways for sustainable development. There are reports such as AR5 or the World Bank report on 4°C (World Bank, 2012) that examine what a 2°C or higher temperature would mean for development but they do not discuss how development would be affected by a rise and then fall in temperatures over a particular time span.

The AR5 introduced the notion of '*climate-resilient pathways*', as "development trajectories that combine adaptation and mitigation to realise the goal of sustainable development. They can be seen as iterative, continually evolving processes for managing change within complex systems" (IPCC, 2014b). Climate-resilient pathways are built on the concept of *resilience*, defined in the 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'. Climate-resilient pathways rely on flexible, innovative, and participatory problem solving and may require transformational changes to reduce emissions and adapt to climate risks including transformation in social processes (Denton et al., 2014). 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 (Fazey et al., 2017; Pelling et al., 2015). Given the challenge of keeping temperatures under 1.5°C, in the context of sustainable development, and poverty eradication, and reducing inequalities, the pathways discussed in this report and this chapter demand greater emission reductions and more transformative changes and more attention to equity than those discussed in AR5.

The adoption of the SDGs and the efforts to achieve both sustainable development and the Paris Agreement, the word 'development' is combined with climate objectives through 'climate-resilient *development* pathways'. This implies 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, in the context of equity, fairness, and justice (Section 5.6).

5.1.4 Chapter Structure and Types of Evidence

The chapter proceeds as follows: Section 5.2 describes future impacts and risks of a 1.5°C warmer world for sustainable development, poverty eradication, reducing inequalities, and equity, including avoided impacts compared to a 2°C warmer world. It builds on the discussion of impacts in Chapter 3. Section 5.3 discusses evidence on how meeting the SDGs could enhance or limit the possibilities for adaptation, and assesses how adaptation response measures can have both synergies and trade-offs with sustainable development and the SDGs. Section 5.4 discusses connections between sustainable development and emissions reductions and examines the synergies and trade-offs between mitigation response measures and pathways and sustainable development. The sustainable development implications of Solar Radiation Management (SRM) are discussed in Cross-Chapter Box 4.2 (Chapter 4). Section 5.5 presents opportunities and challenges that result from the integration of adaptation, mitigation, and sustainable development, including distributional impacts. Section 5.6 summarises what is known about sustainable development pathways to 1.5°C and introduces climate-resilient development pathways. It examines emerging evidence of such pathways at different spatial scales, challenges encountered, and lessons learned. The chapter ends with a brief synthesis of findings and research gaps (Section 5.7), closing the arc of this Special Report 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 warming. We assess published literature, grey 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. While there is a scarcity of literature that explicitly links a 1.5°C target to sustainable development and the SDGs, we find relevant insights from many recent papers on climate and development, including work that examines trajectories to and beyond 1.5°C of warming. The chapter identifies a number of research gaps including the limited literature on a 1.5°C world and sustainable development, including the implications of overshoot scenarios, and the need for research on how integrated policy approaches, that include mitigation, adaptation and sustainable development, can be best developed.

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

5.2.1 Future Impacts and Risks from 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 gender, caste, 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 more difficult to measure, and identify, although not less real to the people who experience them. The latter include, for instance, loss of identity through displacement, culture, ecosystem security and migration (Adger et al., 2014; Barnett et al., 2016b; Serdeczny et al., 2017; Tschakert et al., 2017). Drawing attention to these less obvious impacts is compounded not only by scarce climate data and other observational records in the Global South poor countries (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 mostly in countries in the Global South, with highly different patterns of societal vulnerability (Aitsi-Selmi and Murray, 2016). Temperature overshoot toward 1.5°C at the end of the century (see Chapter 3, Section 3.6.1) is expected to be even more detrimental for certain populations and places for instance for Arctic systems, agriculture-dependent livelihoods as well as coastal-dependent livelihoods (O'Neill et al., 2017b); yet the literature is exceedingly scarce on implications for poverty reduction, inequalities, and equity. Inequality in general, and the gender aspects of inequality, are seldom addressed sufficiently in case studies on climate change (Djoudi et al., 2016).

This section focuses on future impacts and risks of 1.5°C and higher warming on dimensions of poverty, inequality, and equity at sub-regional levels (at a spatial level below the IPCC regions), such as from countries or groups of countries to households), complementing the Chapter 3 assessment at the regional and global level. It does so through the lens of livelihood, human, food, water, and ecosystem security, building on key risks (Oppenheimer et al., 2014). We acknowledge the difficulty in making visible the 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, 2015). The literature on such 1.5°C-specific 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). The literature on the links between poverty and inequality and climate change, however, is substantial and shows a detrimental relationship: the poor will experience climate change severely, and climate change will exacerbate poverty (Hallegatte et al., 2016b; O'Neill et al., 2017c; Olsson et al., 2014) (see also Chapter 3, Section 3.4.10) (*very high confidence*).

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 people, their livelihoods, and their ecosystems within the range of ~1.1–1.6°C global warming (O'Neill et al., 2017a) (see Chapter 3, Section 3.4). 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 methodological 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) (see Chapter 1, Box 1.2; and Chapter 2, Section 2.5.1), mainly due to increased food prices and health impacts. The same study projects most detrimental income losses for the poorest 20%, modeled for household data sets across 92 countries, suggesting that the already poor will get poorer and the poverty headcount will increase as a result of climate change. 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 labor 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 labor 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; Park et al., 2015; Sudarshan et al., 2015; Zivin and Neidell, 2010). Current productivity thus will likely be severely impacted by a higher global heat stress, projected to increase by 5.7 times with 1.5°C of warming, with cities such as Kolkata expected to experience record conditions every year (Matthews et al., 2017). By 2030, compared to 1961–1990 climate change could be responsible for an additional 38,000 annual deaths due to heat exposure among elderly people, 48,000 due to diarrhea, 60,000 due to malaria, and about 95,000 due to childhood undernutrition (WHO, 2014). There is an increased risk of undernutrition resulting from diminished food production in poor regions at warming greater than 1.5°C (see also Chapter 3, Section 3.4.7).

Health shocks and poor health already exacerbate poverty through income losses, health expenses, and care giver responsibilities (see also Chapter 3, Section 3.4.7); moreover, higher morbidity and mortality will slow down poverty reduction and increase inequality (Hallegatte et al., 2016a). 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).

There is a very high risk of displacement attributed to extreme climate events (floods, hurricanes) and increased sea level rise (Chapter 3, Section 3.3 and Section3.4), with temperature warming greater than 1.5°C by 2050 in low income and least developed countries is expected to result in high levels of poverty and inequality and low institutional capacity to respond to hazards (Aitsi-Selmi and Murray, 2016). This includes all small island developing states (SIDSs) in the Caribbean and the Pacific, and projections for the Bahamas, for example suggest annual average of 5.9% of displacements by tropical cyclones by 2050 (Aitsi-Selmi and Murray, 2016).

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). There is high confidence between the link of increased ocean acidification and temperature warming, and the reduction of coral reefs leading to reduced fish species and other resources important for livelihood security of around 500 million coastal people in tropical and subtropical regions (Gattuso et al., 2015; Cramer et al., 2014) (see also Chapter 3, Box 3.6). In Bangladesh, for example, projected loss of freshwater fish stocks by 2050 is expected to greatly impact livelihood and food security for poor households due to their lack of mobility, reduced access to land, and deep reliance on local ecosystems (Dasgupta et al., 2017). There is limited evidence but high agreement that the accelerated retreat of glaciers in high mountain regions such as the Tibetan plateau and countries like Bolivia will negatively impact the water and food security of the poor (Immerzeel et al., 2010). For instance, it is estimated that the food security of 4.5% of the total population in Asia river basins such as the Brahmaputra and Indus basins will be threatened as a result of reduced water availability and the Tibetan plateau retreat in these basins by 2050, with regional temperature increase greater than 1.5°C (Kraaijenbrink et al. 2017; Immerzeel et al. 2010) (see also Chapter 3, Section 3.4.5). Limited evidence but high agreement exists that impacts are likely to occur simultaneously across different levels of security, but the literature on interacting and cascading effects of climate change among multiple sectors and existing drivers of inequality remains scarce (Hallegatte et al., 2014; O'Neill et al., 2017b; Reyer et al., 2017b, a).

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 (see Chapter 3, Section 3.4). Yet, limited literature exists that assesses such avoided impacts regarding poverty eradication, inequalities, and equities. There is *high confidence* that limiting warming to 1.5°C would reduce the risks for unique and threatened ecosystems and associated risks with extreme weather events from High to Moderate/High transition (O'Neill et al., 2017b) (see also Chapter 3, Figure 3.17). This has implications for reducing risks on livelihoods, human, water, food and ecosystem security (O'Neill et al., 2017b).

For instance, risks for food, water, and ecosystem security particularly in subtropical regions such as Central America, and countries such as South Africa and Australia can be reduced in 1.5°C compared to higher risks posed at 2°C (Schleussner et al., 2016). There is *limited evidence* but *high agreement* that limiting temperature warming below 1.5°C will significantly reduce the population exposed to poverty in African and Asian countries (Byers et al.; Clements, 2009). For most of the African countries, twelve million people could be at risk from hunger at 1.5°C temperature warming compared to an additional 55 million people in 2°C warming scenario (Clements, 2009). In warming scenarios above 1.5°C Africa and Asia regions have higher fractions of the global exposed and vulnerable population to poverty, ranging from 8 – 21% at 1.5°C warming, to 29 – 54% at 3°C (Byers et al.).

Limiting warming to 1.5°C will reduce the total population exposed to droughts and heat waves from 455 million people at 1.5°C to 781 million people at 2°C, mainly in subtropical and tropical regions to more than one extreme drought event per year (Lange et al. submitted).Specifically, it will reduce the number of people in India and Australia exposed to heat waves by half relative to ~ 3 – 4°C in RCP8.5 by the mid-21st century(Mishra et al. 2017; King et al. 2017; Lange et al. submitted). For instance, in Mexico City, limiting the global temperature at 1.5°C will lead to reduced precipitation decline compared to 2°C reducing crop failures (Sosa-Rodriguez, 2014) and in the Northwest of USA, an increase in drier summers can be avoided by limiting the temperature target of 1.5°C (Karmalkar et al., 2017).

There is *high confidence* that maintaining levels of global warming at 1.5°C will reduce coral reefs mortality and safeguard livelihoods with some limited potential for adaptation at the lower warming level (Tschakert, 2015; O'Neill et al., 2017b; Reyer et al., 2017b; Magrin et al., 2014; Nurse et al., 2014; Hoegh-Guldberg et al., 2014; Schleussner et al., 2016) (see Chapter 3, Box 3.6). Specifically, 1.5°C limiting in temperature will reduce by 40% the exposure of coral reefs in the coast of Guyana, Suriname, and French Guiana to annual bleaching events until 2050 (in comparison to 2°C of warming) with implications for subsistence fisheries, tourism and protection from coastal storm surges (Reyer et al., 2017a).

Another way of assessing avoided impacts between 2°C and 1.5°C is to use, as a proxy, the AR5 WGII risk tables that were based on expert judgment. These tables suggest near-term (2030–2014) 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 shows three examples representing the range of avoided impacts relevant for poverty and inequality, with and without adaptation. For some areas (Figure 5.2a), the lower temperature target could result in risks reduced from very high (without adaptation) and high (with adaptation) under 2°C to low (with adaptation) under 1.5°C. For other areas (Figure 5.2c), no or very limited adaptation potential is anticipated, with the same negative impacts expected for both 1.5°C and 2°C (Figure 5.2c). The risk for other negative impacts to occur are projected to be medium under 2°C with further potential for reduction, especially with adaptation, to very low levels (Figure 5.2b). Context – and place – specific projections for the lives of poor and disadvantaged populations are not possible from these risk assessments.

[INSERT FIGURE 5.2 HERE]

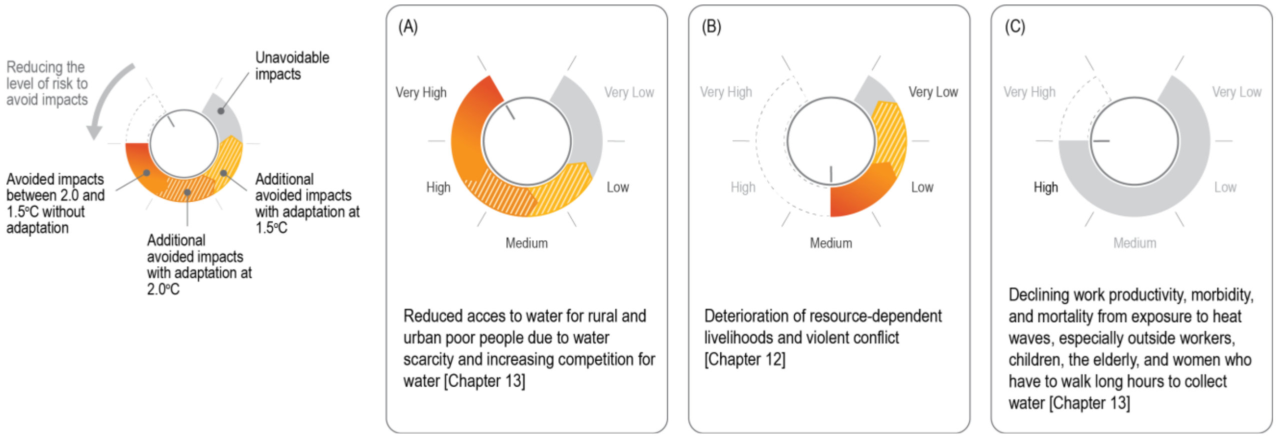

Figure 5.2: Reduced risk levels due to avoided impacts between 2°C and 1.5°C warming (in solid red-orange), additional avoided impacts with adaptation under 2°C (striped orange) and under 1.5°C (striped yellow), and unavoidable impacts with no or very limited potential for adaptation (grey), extracted from the AR5 WGII risk tables (Field et al., 2014, and underlying chapters). Risk levels for people and livelihoods associated with each of the two global warming levels range from very high to very low, with the potential for risk reduction through adaptation in addition to adaptation currently in place (expert judgement). The three examples (A-C, from left to right) illustrate the approximated range of possible avoided impacts (AR5 WGII chapter numbers in parenthesis).

5.2.4 Risks from 1.5°C Global Warming and the Sustainable Development Goals

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 well-being and sustainable development (Section 5.5 and 5.6). 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 (Section 5.4.2), hence constituting possibly double and triple injustices and losses (Section 5.5). As example, for health, there is no 'safe limit', as current impacts and risks from climate change and variability were already unacceptable, affecting people's health significantly and inequitably (Ebi and Bowen, 2016; Tschakert, 2015).

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 SDG 1 (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 well-being.

5.3 Climate Adaptation and Sustainable Development

Adaptation will be important in a 1.5°C warmer world since substantial impacts will be felt in various regions, human and natural systems (see Chapter 3, Section 3.3) (*robust evidence, high agreement*). Climate adaptation is the process of adjusting to actual or expected climate change (Agard et al., 2014) and adaptation options include structural, institutional, and social responses. Effective adaptation depends on the adaptive capacity of individuals and institutions including their ability to adjust to damage, seize opportunities and respond to consequences (Agard et al., 2014). Planning and policy implementation for adaptation includes enabling institutional action and financial investment (Betzold and Weiler, 2017; Sonwa et al., 2017; Sovacool et al., 2017b). Adaptation measures and options include structural and physical adaptations (coastal protection, water storage, plant breeding, transport and urban infrastructure, and ecosystem management), social adaptations (education, information, migration, social safety nets), and governance and institutional adaptations (insurance, land use regulation, water management, legal institutions and planning (see Chapter 4 and Table 14.1 in the WGII AR5 (Jha et al., 2017b; Maguire and McGee, 2017; Noble et al., 2014). Although engineering and technological measures currently dominate adaptation efforts, ecosystem-based, community-based, and institutional and social approaches are increasing (Chong, 2014; Munang et al., 2014; Reid, 2016).

This section investigates the interrelationships between adaptation response options and advancing sustainable development. Adaptation and development are to be best understood as having a two-way relationship. On the one hand, adaptation can assist in meeting long-term development goals (Klein et al., 2014). On the other hand, development affects the adaptive capacity of social and natural systems to cope with the negative impacts of climate change while reducing poverty and improving well-being (Castellanos-Navarrete and Jansen, 2015; Lee et al., 2014). This section assesses how prioritizing sustainable development enhances or impedes climate adaptation efforts (Section 5.3.1), and how climate adaptation measures create synergies and trade-offs with sustainable development and the SGDs, including poverty eradication and reducing inequalities (Section 5.3.2). Subsequently, the section discusses the sustainable development implications of adaptation pathways towards a 1.5°C warmer world (Section 5.3.3).

5.3.1 Sustainable Development in Support of Climate Adaptation

Making sustainable development a priority, and meeting the 2030 SDGs, is mostly consistent with efforts to adapt to climate change. Other international programs for sustainable development such as the UN Sendai Framework for Disaster Risk Reduction and the New Urban Agenda of UN Habitat highlight the importance of risk reduction and equitable, inclusive, and accountable approaches that are consistent with reducing climate vulnerabilities and adapting to climate change (Kelman, 2017; Roberts et al., 2015; Satterthwaite, 2017; Schlosberg et al., 2017).

Multiple lines of evidence confirm that sustainable development significantly influences vulnerability and adaptive capacity (Ayers et al., 2014; Forsyth, 2013; Reed et al., 2015). The process of development is more effective in supporting adaptive capacities if it considers not only major vulnerabilities and priority activities (hazard-based approaches) *per se*, but also the root causes of vulnerability, including insufficient information, social or institutional capacity, finance, or technology (Abel et al., 2016; Colloff et al., 2017; Mapfumo et al., 2017; Noble et al., 2014). Transformative adaptation, defined as ‘adaptation that changes the fundamental attributes of a system in response to climate and its effects'(IPCC 2014d: *ref*) has the potential to be strongly impacted by the type of development pursued. Four significant dimensions by which sustainable development can lead to effective adaptation, transformative and incremental, are discussed below.

Firstly, the literature suggests that sustainable development will enable transformative adaptation when attention is paid to reducing poverty and promoting equity, social justice and fairness in climate adaptation decision making, rather than addressing current vulnerabilities as stand-alone climate problems (Antwi-Agyei et al., 2017b; Arthurson and Baum, 2015; Mathur et al., 2014a; Shackleton et al., 2015a). The overarching development goals of zero poverty, good health, and gender equality contribute to reducing climate vulnerabilities associated with low incomes, poor health, or gender differentials (Blau, 2017; Lemos et al., 2016).

Ending poverty in its multiple dimensions (SDG1) is a highly effective form of climate adaptation (Hallegatte and Rozenberg, 2017; Leichenko and Silva, 2014) with poor countries having less ability to adapt than richer countries (Fankhauser and McDermott, 2014). Addressing income inequality and poverty is a key precursor to reducing vulnerability in urban municipalities (Colenbrander et al., 2017; Rasch, 2017)and in agrarian communities (Eriksen and O'Brien, 2007; Hashemi et al., 2017). However, reducing poverty alone is not enough and complementary measures are needed to ensure that increased household wealth is channelled into risk reduction and risk management strategies enhancing adaptive capacities (Nelson et al., 2016).

Secondly, participation by local people is most effective for enabling effective adaptation 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).Sustainable development can also advance local participation in multi-scale planning strategies (Toole et al., 2016). It is particularly effective in advancing public engagement in planning when it is associated with peace building (Gupta and Arts, 2017b; Holden et al., 2016).The incorporation of local indigenous knowledge about, for example, weather, farming or seed resources, into decision making can also facilitate and significantly strengthen adaptive capacity (Nkomwa et al., 2014; Orlove et al., 2010; Slegers, 2008; Sutcliffe et al., 2016). Recent analyses 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) highlight the complex way in which motivations, values and social norms, together with household structures, opportunities to participate in new practices and household incomes, reinforce, undermine or lock-in behaviours that strengthen climate adaptation over the short-, medium- and long-term (Dilling et al., 2015).

Thirdly, development is effective in promoting transformative adaptation when it addresses existing social exclusion and social inequalities (see also Section 5.6.2 and Section 5.6.4 for a discussion on equity and justice as enabling conditions for achieving climate resilient development pathways). Several goals for sustainable development, including access to education, gender equality and partnership, support values and behaviors that promote transformative adaptation (Fazey et al., 2017; O'Brien, 2016; O'Brien et al., 2015). For example, SDG 5 on gender equality and empowering women supports climate adaptation measures that include women's input, seek to reduce women's vulnerabilities and ensure that women benefit from adaptation actions (Bhattarai et al., 2015; Cohen, 2017; Mbow et al., 2015; Nilsson et al., 2016; Pearse, 2016; Van Aelst and Holvoet, 2016). This includes addressing the loss of women's rights to lands, as shown, for instance, in the case of women and migrant farmers in Ghana (Antwi-Agyei et al., 2015). Gender is particularly important given the disproportionate risk burden in climate adaptation which women and children continue to bear (Cutter, 2016). New gender responsive national adaption plans are being developed (Cutter, 2016; Doze and Dekens, 2017) but knowledge gaps in gender and climate research remain (Schipper et al., 2017). Emerging research suggests the Green Climate Fund may help bridge this gap (Ihalainen et al., 2017). SDG 4 seeks inclusiveness and equality in access to education. Highly educated individuals and societies have better preparedness and responses to disasters, suffer less negative impacts, and are able to recover faster (Frankenberg et al., 2013; Samir, 2013; Sharma et al., 2013). Investment in universal primary and secondary education levels around the world, and improving literacy is, therefore, an effective strategy for transforming and significantly strengthening adaptive capacities (Antwi-Agyei et al., 2012; Muttarak and

Lutz, 2014; Santos et al., 2016; Striessnig et al., 2013; Striessnig and Loichinger, 2015). Investment in equal and inclusive skills and increased access to finance can also reduce vulnerability to climate change (Bowen et al., 2012) as envisioned in SGD17 which seeks strong partnerships. For example, partnerships for climate finance alongside carbon taxation have been identified in the emerging literature as strategies to reduce inequalities (SDG 10) and advance climate mitigation and adaption (Chancel and Picketty, 2015). Local and national institutions for adaptation can be supported through the strong institutions sought under SDG 16 (Agrawal, 2010; Mubaya and Mafongoya, 2017). The role of institutions (SDG 16) and financial partnerships (SDG 17) is also key for diffusion of technological innovation and building resilience for example in agriculture (Chhetri et al., 2012; Halonen et al., 2017; Nhamo, 2016).

Fourth and finally, concrete actions on specific development goals are supportive of enhanced adaptive capacities. For example, SDG 11 seeks resilient and sustainable cities and settlements and is particularly important for the achievement of effective adaptation (Satterthwaite, 2017). The SDG targets of reducing disaster losses in cities and of increasing the number of cities implementing policies for climate adaptation are directly supportive of climate adaptation (Depietri and McPhearson, 2017; Klopp and Petretta, 2017; Parnell, 2017). Significant pressures on resource use and consumption created by rapid urbanisation can also outpace adaptive capacity if adaptation is based on an incremental vision (Bren d'Amour et al., 2016; Doll and Puppim de Oliveira, 2017; Thorne et al., 2017), for instance, in the case of rapid concentration of populations in dense urban areas exposed to floods (Neumann et al., 2015; Zougmore et al, 2016; Kelman, 2017). Ensuring water and sanitation for all (the goal of SDG 6) has strong synergies with climate adaptations that seek to increase water and health security. Developing reliable sources for safe drinking water is an important option for adapting households to drought, as are increases in water-use efficiency and cooperation in the management of transboundary water resources (Bhaduri et al., 2016; Olmstead, 2014; Rasul and Sharma, 2016a; Rouillard et al., 2014). Appropriate water management is crucial for ensuring water resource quantity and quality, and for tackling increase in urban wastewater production from population outburst and extreme weather conditions (Kumar et al., 2017; Ware, 2016; Zouboulis and Tolkou, 2015). For instance, wastewater reuse will be necessary as part of climate change adaptation measure (Hiremath et al., 2016; Trinh et al., 2013; Valipour and Singh, 2016). In water-stressed countries and in countries vulnerable to water-borne diseases, ensuring access to adequate and safe water is critical for health sector adaptation (Dasgupta, 2016; Ebi, 2016). SDG 2, which seeks zero hunger, has targets that include increasing agricultural productivity and incomes, implementing resilient agricultural practices, and maintaining genetic diversity – all strategies that are also those for adapting agricultural and food systems to climate change (Lipper et al., 2014). SDG3 for good health and well-being sets out to reduce maternal and infant mortality, reduce infectious disease, provide health cover, and increase health finance – also consistent with adaptation strategies to reduce the impacts of climate on health.

Reducing climate vulnerability through adaptation is mostly consistent with achieving sustainable development in general, and the SDGs specifically (*medium evidence, high agreement*).Amongst available mechanisms, those that preserve and ensure livelihood security are most effective for designing adaptation strategies that lead to achievement of the SDGs. This holds true for climate-change affected communities but also more broadly (*medium evidence, high agreement*). Transformative and context-specific adaptation, takes into consideration root socio-economic and cultural causes of vulnerability, including poverty and existing inequalities, and local specificities, including indigenous knowledge (*medium evidence, high agreement*). This constitutes an adaptation pathway that facilitates achievement of the SDGs in a 1.5°C warmer world (*medium evidence, high agreement*).

5.3.2 Synergies and Trade-offs between Adaptation Response Options and Sustainable Development

There are synergies and trade-offs between the dual goal of keeping temperatures below 1.5°C global warming and achieving sustainable development, in the short and the long term. The extent of synergies between development and adaptation goals will vary by the development process adopted for a particular SDG (*medium evidence, high agreement*). This section focuses on the implications of adaptation response options for sustainable development. It highlights synergies and trade-offs between adaptation and sustainable development for some key sectors and approaches to adaptation (see Figure SPM 2 and Table 1 in WGII AR5for details on the relevance of the risks arising in these sectors for different regions in the world). An assessment of evidence and agreement on these indicates that 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. Converging examples show that well integrated adaptation supports sustainable development (Adam, 2015; Aggarwal, 2013; Eakin et al., 2014; Smucker et al., 2015; Weisser et al., 2014). However, there are also trade-offs between adaptation measures and sustainable development across many adaptation measures. Most robust evidence of positive synergies stems from the agricultural and health sectors, and from ecosystem-based and cultural-based adaptation particularly among indigenous peoples.

Agricultural adaptation: In the agricultural sector, the most direct synergy is between SDG2 (eliminating hunger) and adaptation in cropping, livestock and food systems designed to maintain or increase production and SDG2 (eliminating hunger) (Rockström et al., 2017; Lipper et al., 2014; Neufeldt et al., 2013). Evidence indicates that farmers with adaptation strategies have higher food security levels and experience lower levels of poverty(Ali and Erenstein, 2017). Vermeulen et al. (2016) report strongly positive returns on investment across the world from agricultural adaptation with side benefits for environment and economic well-being. Well adapted agricultural systems contribute to safe drinking water, health, biodiversity and equity goals (DeClerck et al., 2016; Myers et al., 2017). Similar synergies were observed for water resources adaptation, specifically SDG6 on clean water and when attention is paid to local needs and governance (Bhaduri et al., 2016; Schoeman et al., 2014). Insurance and climate services are additional options that suggest synergies in terms of protecting incomes and livelihoods (Carter et al., 2016; Linnerooth-Bayer and Hochrainer-Stigler, 2015; Lourenço et al., 2015). Climate-smart agriculture (CSA) is a systematic approach to agricultural development intended to address synergies between food security and climate change adaptation and mitigation spanning from field management to national policy (see also Section 5.3.2, Section 5.4.2 and Section 5.5.2). While some scholars see CSA as an excellent option for adaptation, others are concerned that climate-smart agriculture is biased to technological solutions and may not be gender sensitive (Altieri and Nicholls, 2017; Lipper et al., 2014).

Agricultural response options increase risk for health, oceans, and access to water if fertiliser and pesticides are used without regulation or irrigation competes for water (Campbell et al., 2016; Lobell and Tebaldi, 2014; Shackleton et al., 2015a). 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 thereby increase inequality (Carr and Onzere, 2016; Carr and Owusu-Daaku, 2015; Dinku et al., 2014; Georgeson et al., 2017a). For example, agricultural insurance, can have 'maladaptive' outcomes. Although there is mixed evidence in the literature on whether insurance increases or decreases fertiliser and pesticide use, but in the cases where it does increase the usage of such agrochemical inputs, it has negative effects on ground water (SDG 6), biodiversity SDG 15 and human health (SDG 3) under certain conditions (Müller, Johnson, & Kreuer, 2017).

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 (Bryan et al., 2017; Carr and Thompson, 2014; Thompson-Hall et al., 2016). Cradle-to-grave evaluations help delineate trade-offs and complementarities between agricultural yields, biodiversity protection, and human nutrition (Kanter et al., 2016). Transformational agricultural adaptation requires careful interactions with broader political and cultural environments as costs and benefits can extend far beyond the local farm system (Rickards and Howden, 2012).

Health adaptation: Adaptation responses in the health sector will reduce morbidity and mortality in countries at all stages of development (Arbuthnott et al., 2016; Ebi and Del Barrio, 2017). Early warning systems help lower injuries, illnesses, and deaths during heat waves and other extreme and weather events and during outbreaks of infectious diseases, with positive impacts for SDG3 (good health and well-being) and SDG13 (climate action). Better institutions for sharing information, additional indicators for detecting climate sensitive diseases, improved provision of basic health care services and coordination with other sectors also improve risk management, thus reducing adverse health outcomes (Dasgupta et al., 2016; Dovie et al., 2017).

In the health sector, trade-offs occur when, for example, increased use air conditioning to enhance resilience to heat stress leads to higher energy consumption and, depending on the energy source, higher greenhouse gas emissions (Petkova et al., 2017). This is a direct negative implication for SDG13. Adaptation responses in one sector can lead to negative impacts in another sector. An example is the creation of urban wetlands through flood control measures which can breed mosquitoes, adversely affecting SDG3 (Smith et al., 2014a; Woodward et al., 2011).

However, not all adaptation options produce just synergies, or trade-offs. In reality, two-way relationships are common, as in 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 deficits in health systems and there are many examples of where measures to reduce current 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. Such events 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.

Ecosystem-based adaptation (EBA): EBA includes ecological restoration (e.g., of wetlands and floodplains), afforestation, fire management, and green infrastructure, and is found to yield mostly positive benefits for sustainable development (Brink et al., 2016; Butt et al., 2016; Jones et al., 2012; Munang et al., 2013a; Ojea, 2015), although there are research and data gaps that make assessments 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 (Daigneault et al., 2016; Estrella et al., 2016; Ojea, 2015). 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 increase, compared to 2°C or higher, is likely to enhance the success and reduce the costs of EBA.

As EBA has become mainstreamed into adaptation, more evaluations of synergies and trade-offs with sustainable development and agreements such as the Convention on Biological Diversity are available (Conservation International, 2016; Huq et al., 2017; Morita and Matsumoto, 2015; 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).

Coastal adaptation: Coastal adaptation to a range of global average temperatures and sea level rise has strong synergies with sustainable development objectives. Recent work indicates that adaptation to sea-level rise remains essential in coastal areas even under climate stabilization scenarios (1.5°C and 2°C) underlining the promotion of long-term adaptation and adaptation pathway approaches for coastal areas (Nicholls et al. In Press).Adaptation options that include building resilient infrastructure such as coastal defences are consistent with the SDGs on resilient infrastructure and sustainable cities as well as the Sendai framework for disaster risk reduction. Such so called 'hard' adaptation options may involve trade-offs when they have high costs and divert resources from other development priorities or if they impact on coastal ecosystems. Coastal adaptation options that are based on restoring ecosystems such as mangrove forests are more consistent with goals for life on land and in oceans (SDG 14) and can increase food security in sheltering fisheries. Coastal adaptation that involves land use control or relocation of coastal communities may be more or less consistent with development goals depending on whether decisions are participatory and the new settlements are designed for equity and sustainability (Chow, 2017; Dulal et al., 2009; Fletcher et al., 2016; Gibbs, 2016; Jobbins et al., 2013; Paprocki and Huq, 2017; Serrao-Neumann et al., 2014; Szabo et al., 2015;

Voorn et al., 2017).

Community-based adaptation: Community-based adaptation involves local people in a participatory and collaborative manner through the merging of scientific and local knowledge to improve resilience and ensure sustainability of adaptation plans (Fernandes-Jesus et al., 2017; Ford et al., 2016; Grantham and Rudd, 2017; Gustafson et al., 2016, 2017). However, community based adaptation has also been criticised for not always representing vulnerable people fairly or for failing to build long-term social resilience (Ensor, 2016; Forsyth, 2013; Taylor Aiken et al., 2017). Evidence from climate change-affected communities indicates that community based adaptation provides benefits by increasing local adaptive capacity in order to improve livelihood assets and security as well as addressing inequalities, gender biases, at the local level, in providing synergies with SDG 5 and SDG10 (Vardakoulias and Nicholles, 2014). Still, challenges of such adaptation are observed in mainstreaming into national and local planning, upholding principles of equity, justice and ensuring access to information that is fair for all, in a manner that enhances SDG 5 (gender equality), SDG10 (reducing inequality), SDG 16 (peace, justice and strong institutions) (Archer et al., 2014; Cutter, 2016; Kim et al., 2017; Reid and Huq, 2014).

Community based adaptation that is grounded on community values, coping strategies and decision-making structures cannot work in isolation at the community level since factors beyond the control of the community scale, such as governance and policy context, affect their vulnerability to climate change (Reid, 2016; Jeans et al., 2014; Tschakert et al., 2016). Adaptation responses induced by climate change interventions, such as global expansion of biofuels, where land is diverted from subsistence to commercial use due to nationally driven policies, could also have adverse negative impacts on achieving SDG10 (reducing inequality), for the local, indigenous as well as vulnerable groups, arising from the resultant dispossession of land, which affects their overall well-being physically, socially and culturally (Chambwera et al.; Dasgupta et al., 2014; Lunstrum et al., 2015). Other examples observed, moving the flood defenses inland as part of a managed realignment project resulted in taking agricultural land out of production, in which will affect farmers' livelihoods (Van de Noort, 2013). Focus on protection strategies in responding to coastal issues (i.e., dykes) lead to path dependencies and reduce local adaptive capacity for self-determinism in adaptation processes (Smith et al., 2013b).

Traditional knowledge-based adaptation: Long standing traditional knowledge systems have enabled indigenous people to sustain themselves against environmental change and uncertainty through generations (Armitage, 2015; Apgar et al., 2015;Whyte, 2015; Ford et al., 2016; Cobbinah and Anane, 2016; CTKW, 2015;Ani, 2013) (see also Chapter 4, Cross-Chapter Box 4.3). Building resilience through traditional knowledge and social cohesion 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 (Ayers et al., 2014; Berner et al., 2016; Chief et al., 2016; Chishakwe et al., 2012; Lasage et al., 2015; Murtinho, 2016; Regmi and Star, 2015; Reid, 2016). However, traditional knowledge is diminishing due to displacement and relocation of indigenous communities (Ensor, 2016; Maldonado et al., 2013; Villamizar et al., 2017; Warner, 2015; Williams and Hardison, 2013), thus multiple forms of knowledge should be incorporated to complement adaptation processes in achieving sustainable development (Ani, 2013; Ataur Rahman and Rahman, 2015; Enqvist et al., 2016; Tengö et al., 2014). The resilience of traditional knowledge is also threatened by a history of exploitation, a lack of recognition and respect for indigenous people values and rights, and a lack of safeguards for the control and proper use of their knowledge (Ensor, 2016; Villamizar et al., 2017; Williams and Hardison, 2013).

Migration as adaptation: Empirical evidence indicates that decisions about migration are inextricably linked to a host of socio-economic, political and institutional conditions (see for instance Waldinger and Frankhauser ,2015), including job availability, skill and educational levels, environmental changes, climate and health hazards (Suckall et al., 2017). However, the extent to which it succeeds as an adaptation option depends also on several factors, including prevailing differentials in income and socio-economic status and access to information among migrants. Temporary migration is a centuries old strategy for adapting to extreme events amongst pastoralists and seasonal agricultural workers (Keshri and Bhagat, 2013). Many climate change-affected communities have already been using migration as a means to adapt to and withstand the challenges to their livelihoods and security (Jha et al., 2017a; Marsh, 2015) and its success lies in having appropriate adaptation measures in destination areas and strengthening existing protections for all migrants (Entzinger and Scholten, 2016; McNamara, 2015). There are sustainable development impacts in both the sending and receiving regions when migration is used as an adaptation option (Fatima et al., 2014). For example, those left behind may be vulnerable women and the elderly without sustainable livelihoods and migration can be culturally disruptive (Islam and Shamsuddoha, 2017; Wilkinson et al., 2016). When migrants end up in refugee camps. they may experience poor health and hunger and may increase pressure on water and energy resources at their destination (McMichael, 2015; Patrozou, 2015).

Payment for ecosystem services (PES), is an innovative means of facilitating adaptation and has been increasingly advocated for ecosystem based adaptation in particular. It provides incentives to land owners and natural resource managers to preserve environmental services and, when designed with a pro-poor focus, contributes to poverty reduction and livelihood security. Evidence from Costa Rica, with first experiences going back to the 1990s, indicates neutral or positive impacts on livelihood outcomes (Arriagada et al., 2015; Locatelli et al., 2008) and rates of deforestation (Arriagada et al., 2012; Sánchez-Azofeifa et al., 2007). Similar dual synergies have been reported for Brazil (see Section 5.6.3) and programs in other countries, although evidence of coupled adaptation-mitigation benefits remains scarce (Samii et al. 2014; Börner 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).

There is robust evidence of the potential for synergy between adaptation responses and several SDGs, such as poverty reduction, elimination of hunger, clean water, and health (*robustevidence, high agreement*). However, negative outcomes (or trade-offs) can also potentially occur across sectors either in the form of maladaptation or adverse consequences of particular development or adaptation strategies (*medium evidence, high agreement)*. Examples of such instances include conservation of biodiversity and agricultural expansion, resilience to heat stress and energy consumption, land rights and biofuel programs, high cost adaptation options in resource constrained situations. More research is required to understand how trade-offs and synergies will intensify or reduce, differentially across geographic regions and time, under a 1.5ºC world as compared to higher temperatures.

5.3.3 Sustainable Development Implications of Adaptation Pathways toward 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 (see Chapter 1, Section 1.2.4, Box 1.2), best understood as decision-making processes over sets of potential action sequenced over time (Câmpeanu and Fazey, 2014; Wise et al., 2014). This challenge is compounded by the fact that responses to change, that is, adapting to the local realities of a 1.5°C global warming, create new and unknown conditions. Hence, multiple and often interrelated pathways become possible, at different scales and for different groups of people. Choices between possible pathways 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; Lin et al., 2017; Murphy et al., 2017; Bosomworth et al., 2017).

Pursuing a pathway approach to place-specific adaptation harbors 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 (*medium evidence, high agreement*). 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, 2016b; Gorddard et al., 2016a; Tschakert et al., 2017), sometimes contesting best science predictions and state adaption responses (Fincher et al., 2014; Fazey et al., 2016; Murphy et al., 2017). Yet, emerging evidence also suggests significant and often hidden trade-offs that reinforce rather than reduce existing social inequalities and hence may lead to poverty traps (Barnett et al., 2016; Nagoda, 2015; Godfrey-Wood and

Naess, 2016; Pelling et al., 2016; Butler et al., 2016b; Murphy et al., 2017) (*medium evidence, high agreement*).

Dominant or normative pathways tend to validate the practices, visions, and values of existing governance regimes and 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, as shown in case studies from Romania, the Solomon Islands, and Australia (Fazey et al., 2016; Davies et al., 2014; Bosomworth et al., 2017). 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; Davies et al., 2014; Bosomworth et al., 2017). In the city of London, UK, the dominant adaptation and disaster risk management pathway 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). A narrow view of decision making, for example focused on technical feasibility and cost-benefit analyses, tends to crowd out more participatory and inclusive processes that foreground collective learning and wider consultation (Lawrence and Haasnoot, 2017; Lin et al., 2017) and obscure contested values and power asymmetries in governance (Bosomworth et al., 2017).

A situated and context-specific understanding of place that brings to the fore multiple knowledges, values, and contested politics helps to overcome dominant path dependencies, challenge scientific options detached from place, and advance joint place making (Murphy et al., 2017; Wyborn et al., 2015). 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 a commitment to inclusiveness, place-specific trade-off deliberations, redistributive measures, and procedural justice mechanisms to facilitate equitable transformation while meeting the SDGs, particularly poverty eradiation and reducing inequalities (*medium evidence, high agreement*).

5.4 Mitigation and Sustainable Development

Mitigation response options and mitigation pathways are expected to have synergies and trade-offs for sustainable development, poverty eradication, and inequalities, and the SDGs, across sectoral and regional contexts. The literature assessed in this section, although each one of them does not always directly refer to 1.5°C, but writes about the mitigation options that are crucially needed to accelerate the reductions of emission and to deepen them and are critical for 1.5°C pathways (see also Chapter 2, Section 2.3, and Chapter 4, Section 4.3). Aligning mitigation actions to sustainable development objectives can ensure public acceptance (IPCC, 2014c) since development can be an important motivation for pro-environmental change, across diverse publics (Bain et al., 2016;Roy et al,. 2016). Attention to development is particularly 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). Maximizing the synergies between mitigation and sustainable development enables policy design for fast actions (Lechtenboehmer and Knoop, 2017) and advance debate about ways and means to achieve just and fair approaches to achieving the 1.5°C degree target, (Mary Robinson Foundation, 2015; Gupta and Arts, 2017; Holz et al., 2017; Winkler et al., 2017, UNEP, 2017) . Section 5.4.1 assesses such synergies and trade-offs between mitigation options and sustainable development goals. It also presents how a sustainable development approach can help in accelerating mitigation actions. Section 5.4.2 presents short assessment of what are the distributional impacts of delayed mitigation actions. Section 5.4.3 presents sustainable development implications of 1.5°C and 2°C mitigation pathways and the corrective measures that can strengthen synergies.

5.4.1 Synergies and Trade offs between Mitigation Options and Sustainable Development

Past IPCC assessment reports have examined mitigation strategies for specific sectors (energy supply, industry, buildings, transport, and agriculture, forestry and land use (AFOLU)). In this section, the focus is on comprehensive assesment of the interaction of diverse mitigation option categories for sustainable development including dimensions of poverty and inequality. *There is very high agreement* in the 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 (IPCC, 2014c; Schaeffer et al., 2015b; Singh et al., 2010; Ürge-Vorsatz et al., 2014, 2016; von Stechow et al., 2015) (see also Table 5.1 and Figure 5.3) and advancing multiple short-term tragets under the SDGs. However, the literature also suggests potential trade-offs (Table 5.1 and Figure 5.3). Understanding of this two way interaction is key for selecting mitigation options that are not necessarily cost-effective from a narrow GHG emission mitigation perspective, but maximise the synergies between mitigation and development (Delponte et al., 2017; Hildingsson and Johansson, 2015; van Vuuren et al., 2017).

5.4.1.1 Accelerating Efficiency in Resource Use

There is very high confidence in the literature that accelerating energy efficiency improvement in all end use energy demand sectors has strong synergies with large number of SDGs (Figure 5.3, Table 5.1). The residential sector accounts for roughly one-third of total global final energy use (Lucon et al., 2014). A study in Canada shows that efficient lighting, efficient furnaces, and high efficiency appliances can be achieved at the lowest cost (Subramanyam et al., 2017). Accelerating energy efficiency improvement by removal of local barriers (Lucon et al., 2014; Mata et al., under review) in buildings across various countries has positive impacts on sustainable development and connects with large number of SDGs (Table 5.1, Figure 5.3). *There are robust evidence* that they generate health benefits, 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, local sourcing of materials (Berrueta et al., 2017; Cameron et al., 2015; Casillas and Kammen, 2012; Derbez et al., 2014; Fay et al., 2015; Hallegatte et al., 2016a; Hirth and Ueckerdt, 2013; Kusumaningtyas and Aldrian, 2016; Liddell and Guiney, 2015; Maidment et al., 2014; McCollum et al., 2017; Scott et al., 2014; Sharpe et al., 2015; Wells et al., 2015; Willand et al., 2015). The industrial sector generate synergies with all the economic dimensions of sustainable developmental goals by accelerating energy efficiency improvements through removal of barriers especially in many developing countries (Apeaning and Thollander, 2013; Fischedick et al., 2014). It creates decent jobs, training of youths and technical and managerial skills, which in turn help in sustaining the efficient manufacturing practice management, help in reducing poverty, lead to water savings. Energy efficiency of tourism transport can help in reducing rising energy consumption and emission from tourism transport (Shuxin et al., 2016).

There is *high agreement* in literature that to actualize the full potential of energy savings, the managing rebound effect must be managed strategically (Altieri et al., 2016; Chakravarty and Tavoni, 2013; IPCC, 2014c; Karner et al., 2015; Zhang et al., 2015). 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).

5.4.1.2 Behavioural Options

Consumption perspective strengthens the environmental justice discourse while possibly increasing an individualised environmental discourse (Hult and Larsson, 2016). Behavioural responses and right incentive design help realising the full potential of intermittent renewable energy (Nyholm et al., 2016) and energy efficiency improvements (Chakravarty and Roy, 2016). Complex interactions exist between resident behaviours and the built environment. Building technology and occupant behaviours interact to affect home energy consumption (Zhao et al., 2017). Echegaray (2016) discusses, based on urban sample survey in Brazil, subjective preference for new products. Declaration of premature obsolescence for appliances act as barrier to sustainability. Longer life for goods and services is important to reduce demand and industrial emission (Fischedick et al., 2014).At the same time Liu et al. (2016b) suggest that there is need to go beyond individualist and structuralist perspectives to analyse sustainable consumption. Inertia in the occupant behaviour to change habits quickly sometimes cannot take advantage of more than 50% of energy efficiency potential of an efficient building (Zhao et al., 2017).

There is high agreement in literature that synergies between efficiency improvement and changes in behavioural responses in residential sector can help achieve multiple SDGs across all three dimensions of sustainable development (Aydin et al., 2015; Berrueta et al., 2017; Cameron et al., 2016; Fay et al., 2015; Hallegatte et al., 2016c; Ismailos and Touchie, 2017; Jakob and Steckel, 2014; Maidment et al., 2014; McCollum et al., 2017; Scott et al., 2014) and also to large extent SDG 7 if rebound effect can be managed appropriately. Behaviour to adjust thermostat help in energy saving, building survey and monitoring also have positive impact (Song et al., 2016). Adoption behaviour of smart meters and smart grids which can happen through community based social marketing, participatory behaviour change programmes and help in reduction in peak demand, expansion of innovation and infrastructure for energy savings (Anda and Temmen, 2014). Promoting low-emission options for households 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). Profound changes in energy uses, like the ones required to take people out of poverty, provide energy access and reduce GHG emissions, require a combination of changes in technologies and consumption patterns which in turn depend upon radical socio-cultural, technological and organisational innovation (Doyle and Davies, 2013; Mont, 2014; Rourke and Lollo, 2015). User behaviour plays a much more important role toward decarbonization in transport sector (Mattauch, Ridgway, & Creutzig, 2016). Individual behaviour change towards increased physical activity in short distances in non-motorised modes, public transport, two wheelers, car model choice and use patterns generate health benefits (Chakrabarti and Shin, 2017; Shaw et al., 2014b) help reducing inequality in access (Kagawa et al., 2015; Lucas and Pangbourne, 2014), sustainable infrastructure growth in human settlements (Kagawa et al., 2015; Lin et al., 2015) but public policy intervention is needed to reduce risks of road accidents for pedestrians (Hwang et al., 2017; Khreis et al., 2017) and increase safety on the road (SDG 16)Partnership on Sustainable Low Carbon Transport, 2017). Individual automobile use behaviour change with appropriate incentives and awareness programs, policy interventions targeting restrictions on driving behaviour enhance SDG12, choice of sustainable lifestyle (Creutzig et al., 2016; Kagawa et al., 2015; Lin et al., 2015).

There is robust evidence and high agreement that in the AFOLU sector, behavioural change leading to dietary change toward global healthy diets and waste reduction could reduce emissions (Bajželj et al., 2014; Garnett, 2011; Hiç et al., 2016; Kummu et al., 2012; Tilman and Clark, 2014), whilst also contributing predominantly to SDGs 2, 3 and 13, with additional contributions to SDGs 6, 12, 14 and 15. Encouraging responsible sourcing of forest products enhances economic benefits by creating decent jobs, helps innovation and upgrading of technology, encourages responsible decision making and enhances trade (Bartley, 2010; Hejazi et al., 2015; Huang et al., 2013).

5.4.1.3 Access to Modern and Reliable Energy and Fuel Switch

There is *robust evidence and agreement* that millions of people in the global south are escaping poverty by accessing modern energy forms (Lloyd et al., 2017) which are fundamental to human development (Anenberg et al., 2013; Bonan et al., 2014; Burlig and Preonas, 2016; Casillas and Kammen, 2010; Chowdhury, 2010; Clancy et al., 2012; Cook, 2011; Dinkelman, 2011; Haves, 2012; Kaygusuz, 2011; Kirubi et al., 2009; Köhlin et al., 2011; Matinga, 2012; McCollum et al., 2017; Pachauri et al., 2012; Pode, 2013; Pueyo et al., 2013; Rao et al., 2014; Zulu and Richardson, 2013). Aggressive efficiency improvement with low carbon generation sources has potential to offset increased demand in residential sector (Reyna and Chester, 2017). The systems that are less carbon intensive and vital for advancing human development, resolve energy access and energy poverty issues in rapidly growing countries like Vietnam, Brazil, India, South Africa, and poorest countries transitioning from agrarian to industrial societies (Dasgupta and Roy, 2017; Mark et al., 2017). In Africa in crowded cities informal transport, high cost of commuting limits access to jobs (Lall et al., 2017). In Latin American cities, triple informality (transport, jobs, housing) is leading to low productivity and living standards (CAF Corporacion Andina de Fomento, 2017), poor road infrastructure reduces safety in cities and by increasing risks of road accidents (Vasconcellos and Mendonça, 2016). However, in cities such infrastructure expansion need to include pro-poor strategies into construction and operation as sometimes such constructions lead to eviction from informal settlements (Colenbrander et al., 2016). Electric vehicles using electricity from renewables or low carbon sources need to be combined with e-mobility options such as trolley buses, metros, trams and electro buses, as well as promote walking and biking, especially for short distances (Ajanovic, 2015).

Effective regional cooperation in renewable energy is key to promoting a synergetic approach between enhanced access to electricity, cooking energy, and emission reductions (Uddin and Taplin, 2015).The deployment of small-scale renewables (Sovacool and Drupady, 2012), or off-grid solutions for people in remote areas (Sanchez and Izzo, 2017; Sovacool, 2012) has strong potential for synergies with access to energy but requires adopting measures to overcome technology and reliability risks associated with large-scale deployment of renewables (Giwa et al., 2017; Heard et al., 2017). Development of baseload energy sources from renewable like geothermal, biomass or hydro power ensure reliability of energy supply with low-carbon options (Matek, 2015; Matek and Gawell, 2015). Renewable energies could potentially serve as the main source of meeting energy demand in rapidly growing cities of the Global South with multiple sustainable development benefits. 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. 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).

Incentive design to addressing the behaviourial response through rebound effect need to keep in view the differential magnitudes and welfare implications in the context of developed and developing countries especially in the latter where energy access is limited and unmet demand is high (Aydin et al., 2015; Chakravarty et al., 2013; Santarius et al., 2016). In developing countries higher rebound effect help in achieving affordable access to energy (SDG 7.1) faster, so rebound supressing policies such as carbon price/carbon tax can harm disproportionately consumers with energy poverty and need to be regionally differentiated (Kriegler et al., under review) and be made revenue neutral to avoid trade off even in developing country context (Saunders, 2011;Combet, 2013; Grottera et al., 2015;Winkler 2017). In cases where higher energy costs make the shift towards clean-burning cooking fuels less acceptable (Cameron et al., 2016) synergies in policies for energy access, air pollution and climate change are required (Rao et al., 2013).

In the transport sector, fuel use such as use of sustainable biodiesel, natural gas, electric vehicles (EVs) are considered for deep decarbonised transport system and climate benefits with benefits for local air pollution (Alahakoon, 2017; Nanaki and Koroneos, 2016; Sundseth et al., 2015) but for electric vehicles environmental benignity will depend on electricity generation mix (Ajanovic, 2015; Wolfram and Wiedmann, 2017; Xylia and Silveira, 2017) to be consistent with SDG7. Social acceptance is a determining factor for the large-scale deployment of bioenergy solutions in a way that maximises the synergies with sustainable development objectives, in turn depending upon a complex set of socioeconomic, local and market dimensions (Fytili and Zabaniotou, 2017). With more electrification of transport sector electricity price can go up and adversely affect poor unless pro-poor redistributive policies are in place (Klausbruckner et al., 2016). Improving and Promoting public transport system makes cities sustainable (Song et al., 2016).

Outdoor air quality improves due to reduction of pollutants from fossil fuel combustion (West et al., 2013; Yang et al., 2016). The health benefits can motivate public support for ambitious actions that also have the benefit fo reducing GHG emissions (Thurston, 2013). This is for example the case of transport solutions improving air quality at street and pedestrian level in cities and contributing to lower emission intensity of transport activities, through inter-city passenger transport management (Ren et al., 2016) or actions on urban transport (Creutzig et al., 2015a).

For energy intensive processing industries (EPI), which account for most of the 30% global emissions share of the total industry sector, have an urgent need for zero carbon energy sources (Åhman et al., 2017; Denis-Ryan et al., 2016). This calls for a change in user behaviour, culture, policy, corporate innovation strategy, infrastructure besides radical technology change along with ongoing energy efficiency improvements and low carbon fuel transitions (Lechtenboehmer and Knoop, 2017; Wesseling et al., 2017). Study in EU energy intensive processing industries (EPI) shows need for radical technology innovation through maximum electrification, hydrogen use or biomass, integration of CCS and innovations for CCU. However, strong synergies with multiple SDGs due to progressing decoupling , innovation, scope of cross sectoral, supranational partnership, scope for sustainable production need to be strengthened by attending to the trade off due to risks of CCS based carbon leakage, higher need electricity and price impacts through careful regulatory mechanisms (Wesseling et al., 2017).

Phasing out of coal and fast deployment of renewables like solar and wind, hydro, modern biomass in energy supply sector do enhance health goal by reducing air pollution. It also advances SDGs 1 and 10, 11,12(Chaturvedi and Shukla, 2014; Haines et al., 2007; IEA, 2016; McCollum et al., 2017; Riahi et al., 2015, 2017; Rose et al., 2014a; Smith and Sagar, 2014; West et al., 2013) Rao et al (2016). However, some conflict with SDGs can emerge from offshore installations with SDG 14 based on local context (Inger et al., 2009; McCollum et al., 2017; Michler-Cieluch et al., 2009; WBGU, 2013) Buck and Krause (2012); and also with SDG 15 due to landscape and wild life from wind, large hydro and large biomass installations (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), and habitat impact (Smith et al. 2014). But, trade-offs between renewable energy production and other environmental objectives need to be scrutinised for negative social outcomes. Shifts towards domestically-produced renewable energy enhance energy security in fossil-importing economies (Oshiro et al., 2016).

Achieving deep cut in emissions through CCS and nuclear options can also have significant adverse implications for health and water security (SDGs 3, 6) and increase the societal costs and risks associated with the handling of waste and abandoned reactors (see SDG8) (see Table 5.1a and d and Figure 5.3).

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). 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 (UNEP 2017). Switching to natural gas to replace coal is also expected to bring water benefits due to increasing power generation efficiency and reduced cooling water demands.Combining air pollution control and non-fossil energy targets lowers the total cost of the coal-control policy (Wang et al., 2016). Literature also suggests that ambitious emission reduction targets can unlock very strong decoupling potentials in industrialised fossil exporting economies (Hatfield-Dodds et al. 2015).

There is *high agreement* in the literature based on *robust evidence* that economies dependent upon fossil fuel-based energy generation and/or export revenue will be disproportionally affected by future needs to restrict the use of fossil fuels via stranded assets, unusable resources under the ground, lower capacity use, early phase out of large infrastructure already under construction under stringent cimate goals and higher carbon prices (Johnson et al. 2015; McGlade and Ekins 2015, UNEP 2017) (see Section 5.1, Box 5.2). Despite global climate goals investment in coal continues to be attractive in many countries as it is a mature technology, provides cheap energy supply, access and energy security (Jakob and Steckel, 2016) which make it politically attractive (Vogt-Schilb and Hallegatte, 2017) under such circusmtances there is *high agreement* in literature that besides sustainable development benefits there is need for supplementary policies to ease job losses, relatively higher prices of alterantive energy, (Garg et al., 2017; High-Level Commission on Carbon Prices, 2017; Jordaan et al., 2017; OECD, 2017; Oei and Mendelevitch, 2016; Oosterhuis and ten Brink, 2014; UNEP, 2017). Research on historical transitions shows that managing the impacts on workers through retraining programs are a key condition to align the phase down of mining industry, required for meeting ambitious climate targets, and the objectives of a 'just transition' (Caldecott et al., 2017; Galgóczi, 2014; Healy and Barry, 2017). This aspect is even more important in developing countries where the mining workforce is largely semi or unskilled (Altieri et al., 2016; Tung, 2016).

5.4.1.4 Cross-sector Response Options

Mitigation efforts that emerge from cross-sectoral efforts at city scale, new sectoral organisations based on the circular economy concept (Preston and Lehne, 2017) and multi-policy interventions that follow systemic approaches are showing higher synergies with SDGs.

The UNFCCC recognises that equitable development requires enabling developing countries to pursue economic growth to achieve higher standards of living and well-being and reduced inequalities (Barroso et al., 2016; dos Santos Gaspar et al., 2017). The compatibility between this and ambitious emission reductions depends on the capacity to decouple economic growth and GHG emissions (Holden et al., 2016; Stern et al., 2016) and on the promotion of measures addressing inequality while enhancing climate change mitigation efforts (Chakravarty and Tavoni, 2013; Jorgenson, 2015; Ley, 2017b). The potential for decoupling economic growth and GHG emissions 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 (Antal and Van Den Bergh, 2016; Jackson and Senker, 2011; Weiss and Cattaneo, 2017; Wiseman, 2017; 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; Schandl et al., 2016; Sheng and Lu, 2015).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.

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 (Elum et al., 2017; Emodi and Boo, 2015). This also calls for specific measures to manage the transitioning to low-carbon growth through progressive implementation measures to avoid serious immediate unemployment issues (Yuan et al., 2015), direct investment in key sectors for mitigation (Waisman et al., 2013). Adopting adequate economic incentives, particularly fossil fuel subsidy reforms, can also be a key driver of this shift to low-carbon energy for taking people out of poverty (Jakob et al., 2015; Ouyang and Lin, 2014; Rentschler and Bazilian, 2016).

Development policies, can enhance synergies with energy efficiency and deployment of decentralised renewable energy, sustainable consumption and production practices (Alstone et al., 2015; Creutzig et al., 2016; Druckman and Jackson, 2016; Geels et al., 2015; von Stechow et al., 2015)and reduce the social cost of carbon compared to a narrowly focused climate-centric approach (Shukla et al., 2015)

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. Such industrial operations improve the sustainable development ability by reducing non-renewable inputs, imported resource inputs, and associated services and the ratio of savings to the total GDP of the industrial park is also positive. 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 (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). However, elctrification of transport sector unless supplemented by increasing deacrbonisation of electricity cannot deliver desired climate goal (Ajanovic, 2015; Wolfram and Wiedmann, 2017).

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 Kolkata 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) as an instrument for emission trading and sustainable development benefits are given. While some literature criticises the CDM for limited sustainable development benefits (Crowe, 2012; Olsson et al., 2014), the bulk of the literature finds that the CDM has been instrumental in mobilizing mitigation in developing countries, especially from renewable energy (see overview of CDM-related literature in(Michaelowa, 2015; Stavins et al., 2014). While initially, CDM activities focused on Asia and Latin America, the programmatic approach introduced from 2007 onwards led to Africa having a share of 30% in such programmatic activities (Michaelowa et al., 2015). If demand of emission credits increased in the future, market mechanisms like the CDM could play an important role in reducing mitigation cost, thus leading to higer ambition and an increased likelihood to reach the 1.5°C target of the Paris Agreement (Bodnar et al., In Press)

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). Fujimori et al. (2016a) also show that NDC cost differs across countries. At the same time, the emissions trading system can reduce the mitigaion cost largely by 80%.

5.4.1.5 Land-based Agriculture, Forestry and Ocean: Response Options

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). Land-use options, 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 (Smith et al., 2014b). For forestry, key mitigation options include avoiding deforestation, afforestation and reforestation, climate-smart forest management, as well as integrated systems such as agroforestry, biochar and sustainable use of wood products for long-term use and wood residues for energy

(Griscom et al., 2017; Siagian et al., 2016). Negative emissions (i.e., a carbon sink) can be achieved with afforestation programs, sustainable forest management that increases biomass productivity and carbon in soils, and by using wood products for energy that substitutes fossil fuels. Implementation of mitigation in forest sector through REDD+ (Reducing Emissions from Deforestation and Forest Degradation) not only contributes to emissions reductions, but also contributes to biodiversity conservation and climate change adaptation (Bustamante et al., 2014; Morita and Matsumoto, 2018). 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 in the case of flat payments, the poorest households would be the ones generating most of the emission reductions, with significant consequences on both equity and efficiency of REDD+ initiatives (Ickowitz et al., 2017). 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; Nobre et al., 2016, 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). 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).

Supply side actions reduce GHG emissions per unit of land per animal, or per unit of product while demand-side actions cover changing consumption patterns (Bajželj et al., 2014; Bellarby et al., 2013; Garnett, 2011)of food and other products, by reducing waste, and so on (Fuss et al., 2014; Ingram, 2011; Siagian et al., 2016). Climate-smart agriculture mitigates GHGs through soil management, sustainable agricultural intensification, and waste reduction (Bennetzen et al., 2016; Branca et al., 2011; Lipper et al., 2014), though measures require close scrutiny (Frank et al., 2017; Neufeldt et al., 2013). Sustainable intensification (Smith, 2013) can promote conservation of biological diversity by reducing deforestation by rehabilitation and restoration of biodiverse communities on previously developed crop or pasture land (Lamb et al., 2016), though rebound effects need to be considered, and land spared may not be of equivalent status for delivering the SDGs. Reduction of waste in the food system generally benefits sustainable development (Kummu et al., 2012). 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 (Schader et al., 2015; Muller et al., in press).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 could also undermine livelihoods and the cultural identity of poor farming populations (Herrero et al., 2016), if implemented without due consideration of these issues. Many Short-Lived Climate Pollutant mitigation measures (SLCP) like provision of cleaner fuel and devices for rural households are synergistic to SDGs 3,4,5,15 (Griggs et al., 2014), transport fuel and small industrial fuels, banning the open burning of biomass and waste in urban areas are synergistic to multiple SDGs, 2,3,7,11,12 (UNEP 2017).

Deep emission reductions through biofuel/biodiesel based transformations, if not managed carefully, can exacerbate food security and land use disputes with disproportionate negative impacts upon rural poor and indigenous populations (Aha and Ayitey, 2017; Johansson et al., 2016; Olsson et al., 2014; Shi et al., 2017)(Zhang and Chen, 2015). Unjust and adverse outcomes have been documented amongst biofuel and large 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 (Table 5.1, Figure 5.3, Grill et al., 2015; Grubert et al., 2014; Fricko et al., 2016; De Stefano et al., 2017). Dedicated crop for bioenergy may also increase irrigation needs and exacerbate water stress with negative associated impacts on multiple SDGs (e.g., 1, 6, 7, and 10).

Large-scale mitigation efforts may also produce negative spillovers that inhibit the capacity of poor and vulnerable groups to produce triple wins. A large body of literature now exists documenting the negative impacts of bio-carbon sequestration and other mitigation measures upon vulnerable groups via processes of land appropriation and dispossession (Cavanagh and Benjaminsen, 2014; Corbera et al., 2017; Fairhead et al., 2012; Hunsberger et al., 2014; Work, 2015). Emerging evidence indicates that future mitigation efforts required to reach stringent climate targets, particularly those associated with Carbon Dioxide Removal (e.g., BECCS and afforestation and reforestation), may also impose significant constraints upon poor and vulnerable communities via increased food prices and competition for arable land (Burns and Nicholson, 2017; Muratori et al., 2016; Smith et al., 2016) and the adoption of policy frameworks for the management of the supply chain (Fajardy and Mac Dowell, 2017).

Ocean Iron Fertilisation (OIF) can increase food availability for fish stocks leading to increased yields but potentially at the cost of reducing the yields of fisheries outside the enhancement region by depleting other nutrients Maintaining mangrove, Seaweed aquaculture, greening of aquaculture can not only help sequestration but also employment generation (Table 5.1, Figure 5.3).

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 (Atwood et al., 2015; Gattuso et al., 2015; Magnan et al., 2016a; Singh et al., 2017b). Despite uncertainties, richness of seagrasses, tidal marshes and mangroves are recognised as dense carbon sinks (Fourqurean et al., 2012; Johannessen and Macdonald, 2016; Lavery et al., 2013; Lovelock et al., 2017). 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.

Detailed assement of synergies and trade-offs of mitigation options with SDGs (Table 5.1a–d, Figure 5.3) clearly reveals that synergies of mitigation response options in near term are far more than tradeoffs. Mitigation actions in energy demand sectors and behaviourial response options can advance multiple SDGs simultaneously far more compared to energy supply side mitigation actions. Corrective measures and choice of options in mitigation portfolio based on immediate synergies and in some instances sustainable development approach can overcome trade-offs to further strengthen the synergies (*robust evidence, high agreement*).

[INSERT FIGURE 5.3 HERE]

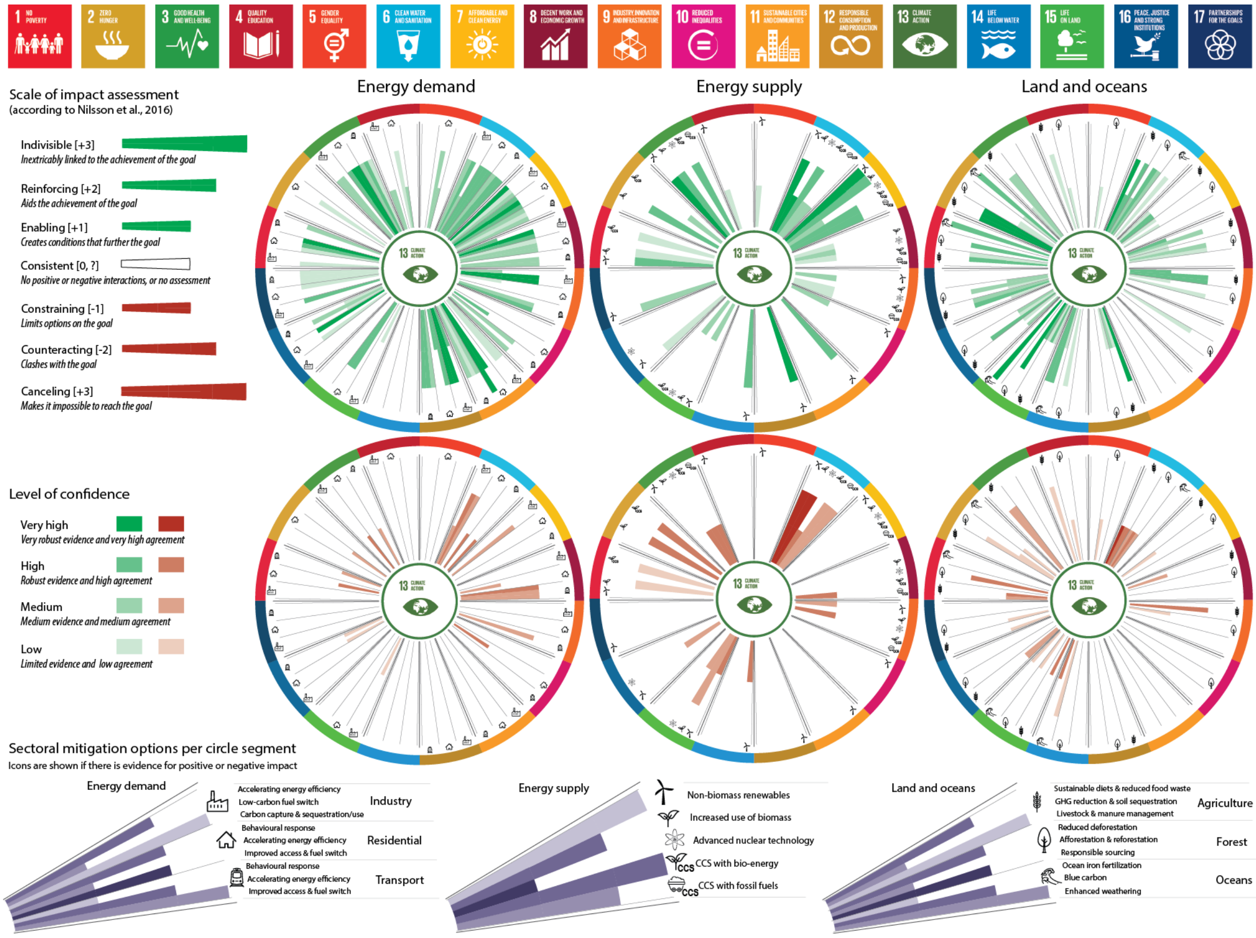

Figure 5.3: Synergies and trade-offs between mitigation options and SDGs.
Top three wheels are representing synergies and bottom three wheels show trade -offs. Colours on the border of the wheels correspond to the SDGs listed above. Here SDG 13 climate action is at the centre because the figure shows if mitigation actions (climate action) in various sectors are taken then what do they interact with the 16 SDGs. Vertically starting from the first left side pair of wheels correspond to synergies (Top) and tradeoffs (Bottom) of three mitigation actions undertaken in each of the energy demand sectors (Industry, Residential and Transport sectors). Middle pair of wheels vertically shows the synergies (Top) and tradeoffs (Bottom) with SDGs of the five mitigation actions taken in the energy supply sector. Right most pair, shows synergies (top) and tradeoffs (bottom) with SDGs of three types of mitigation actions in each of the sectors Agriculure, Forestry and Oceans. Length of the coloured bars show the strength of the synergies or tradeoffs. Longer the bar higher is the strength. Shade of the color represent level of confidence based on evidence and agreement in the literature. Darker the shade higher is the confidence and lighter the shade confidence level is lower. White within wheels show no interaction between the corresponding mitigation action sand the SDG, Grey within the wheels show knowledge gap. Bottom panel shows various mitigation actions in each sector and corresponding symbols.

5.4.2 Temporal and Spatial Trade-offs and Distributional Impacts

Delaying action to reduce greenhouse gas emissions increases the risks associated with mitigation (*very high confidence);* however, these risks are not uniform for all mitigation options, or for different regions and groups (*medium evidence; medium agreement*). Weak mitigation targets in the short term necessitate significant and rapid up-scaling of mitigation efforts in the future if stringent climate targets are to be met (Gambhir et al., 2017; van Soest et al., 2017). The rapid scale-up of future mitigation efforts presents various potential risks, including increased mitigation costs (Luderer et al., 2013; Schaeffer et al., 2015a) stranded coal assets (Gambhir et al., 2017; Johnson et al., 2015), job losses (Rozenberg et al., 2014), risks associated with grid integration of fluctuating renewable energy (von Stechow et al., 2016), and increased inter-generational and inter-regional inequities (Liu et al., 2016a; Mary Robinson Foundation: Climate Justice, 2015). 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 (Fujimori et al., 2016b; Rogelj et al., 2015), thereby increasing the likelihood of negative trade-offs between energy, environmental and socio-economic objectives (Fujimori et al., 2015; Smith et al., 2016; von Stechow et al., 2016). Constraining technological options for mitigation requires significant up-scaling of other technological options, thereby increasing overall mitigation risks (Muratori et al., 2016; von Stechow et al., 2016). Restricted technological portfolios have also been shown to incur higher associated financial costs than unconstrained technological portfolios (Jakob and Steckel, 2016; Luderer et al., 2013).

Future climate response options are expected 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) (see Box 5.2). 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 constraints 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 be largely phased 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.

[INSERT TABLE 5.1 HERE]

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

[Due to size, Table 5.1.a–d is provided at the end of the chapter, page 114. A high resolution version of the table is available as a supplementary PDF (SR15_SOD_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 individual mitigation options and their interaction with sustainable development and SDGs and distributional aspects, this section takes a systems perspective. Emphasis is on quantitative pathways depicting path depednent evolutions of the system over time. Specifically, the focus is on 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 (Section 2.3), achieving 1.5°C or 2°C targets require deep cuts in GHG emissions and large scale changes of energy supply and demand as well as agriculture and forestry systems. For the assessment of the sustainable development implications, we draw upon comparative and multi-model pathways studies, for example, (CD-LINKS 2017; Krey et al. submitted), which have assessed the aggregated impact of mitigation for multiple sustainable development dimensions and across multiple integrated assessment modelling (IAM) frameworks (eg, IMAGE, REMIND-Magpie, MESSAGE-GLOBIOM, AIM, WITCH, GCAM, E3MG, and others). Often these tools are linked to disciplinary models covering specific SDGs in more detail (see eg Cameron et al, 2015; Rao et al, 2017 or for multiple models Krey et al, submitted). Unsing multiple IAMs and disciplinary models are important for a robust assessment of the sustainable development implications of different pathways. The recent literature on 1.5°C mitigation pathways has begun to provide estimations of different sustainable development dimensions, including particularly air pollution and health, food security and hunger, energy access, biodiversity, water security, and poverty and equity (also see Sections 5.4.1 and 5.4.2). Furthermore, emphasis is on multi-regional 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.

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, factories, agriculture, forest and peatland fires. Hence, mitigation strategies that reduce GHGs or the use of fossil fuels typically also reduce emissions of pollutants, such as particulate matter (PM2.5 and PM20), 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; GEA, 2012; Kusumaningtyas and Aldrian, 2016; 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; Shindell et al., 2017, Klimont et al., 2017). Recent multi-model comparisons indicate that mitigation pathways consistent with 1.5°C would result in higher co-benefits for air pollution and health compared to pathways that stay below 2°C (see Figure 5.4, panel a and b), reducing the number of premature deaths by about 0.2 million by 2050 (Krey et al., submitted; and Chapter 2 Scenario Database). The co-benefits for air pollution are the biggest in the developing world, particularly in Asia. The currently pledged NDCs lead in most countries to limited structural changes and therefore the health co-benefits of NDCs are comparatively small, (Krey et al., submitted). While the quantitative modelling literature focuses primarily on air pollution, the systemic implications of joint mitigation and well-being strategies on health go beyond air pollution, with potentials to address both chronic lifestyle conditions and mental health issues through a re-orientation of values, beliefs and norms across societies (Bhaskar et al., 2010).

5.4.3.2 Food Security and Hunger

Stringent climate mitigation strategies in line with ‘well below 2°C’ or ‘1.5°C’ goals do rely often on the deployment of large-scale land-related measures, like afforestation and/or bioenergy production (Creutzig et al., 2015b; Popp et al., 2014; Rose et al., 2014b). 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 without concurrent measures in the food sector, can have negative impacts for global food security (Fujimori et al. submitted; Hasegawa et al. 2015; Krey et al. submitted). 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 “single-minded” scenarios, mitigation policies worsen food security and may increase the number of people at risk of hunger significantly compared to a case without climate mitigation, between about 0.2 to 1.2 billion people at risk of hunger (Fujimori et al.; Hasegawa et al., 2015; Krey et al., submitted) (Figure 5.4, panels a and b).

An important driver of the food security impacts in these scenarios is the increase of food prices and the effect of mitigation on disposable income and wealth due to GHG pricing. On aggregate the price and income effects on food are found to be bigger than the effect due to competition over land between food and bioenergy (Hasegawa et al., 2015)(Fujimori et al., submitted). In this context, a recent study shows that on balance, limiting bioenergy may have a negative effect on food security, since the associated negative effects of the increased GHG prices (assuming that such prices are also applied to non-CO_2 emissions associated with food production) will more than offset the positive effects of reduced land competition (Hallegatte et al., 2016b).

(Grubler et al. submitted) show that 1.5°C pathways without reliance on BECCS can be achieved through a fundamental transformation of the service sectors which would significantly reduce energy and food demand. Such low energy demand (LED) pathways would result in significantly reduced pressure on food security, lower food prices, and less people at risk of hunger.

In order to fully eradicate food-security trade-offs, however, mitigation policies need to be designed in a way so that they shield the population at risk of hunger. Krey et al. (submitted) and Fujimori et al. (submitted) find that relatively simple complementary measures, such as food price support, may entirely eradicate the identified trade-off between climate mitigation and food security. The costs measured by welfare changes for these complementary food security policies are found to be low globally and much smaller than the associated mitigation costs of 1.5°C pathways of 2– 6% of total GDP (Rogelj et al. forthcoming). Food subsidies are not the only measures that are available for eradicating food security concerns. Other measures may include, for example, direct cash transfers, improvements of agricultural productivity and yields (Frank et al., 2017; Valin et al., 2013), or programs focusing on forest land-use change (Havlík et al., 2014) to mention a few.

Importantly, the food security trade-offs will also be reduced by the avoided impacts in the agricultural sector due to the reduced climate change of the 1.5°C pathways (see Chapter 3, Section 3.5, and Section 3.6).

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 (GEA, 2012; WB and IEA, 2017). Scenario studies which quantify the interactions between climate mitigation and energy access, indicate that the increase of energy costs due to stringent climate policycould significantly slow down the transition to clean cooking fuels (Cameron et al. 2016; Krey et al. submitted).

Estimates across five different models (AIM, IMAGE, WITCH, REMIND, and MESSAGE-Globiom; Krey et al. submitted) indicate that in absence of compensatory measures the number of people without access to clean cooking may increase by 2050 from 1.6–3 billion in baseline scenarios to about 2.7–3.6 billion in 1.5°C pathways (Figure 5.4, panel a). Redistributional measures, such as subsidies on cleaner fuels and stoves, could fully offset the negative effects of mitigation on energy access. Costs of the redistributional measures are estimated to be modest, about an order of magnitude smaller than the mitigation costs of 1.5°C pathways (Krey et al. submitted). The recycling of revenues from climate policy might 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

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 (Byers et al., 2014; Davies et al., 2013; Fricko et al., 2016; Fujimori et al., 2017; Hanasaki et al., 2013; Hejazi et al., 2013; McCollum et al., 2017; PBL, 2012; Stewart et al., 2013; Vidic et al., 2013; Wang et al., 2017).

Under stringent mitigation efforts, the demand for bioenergy can result in a substantial increase of water demand for irrigation, thereby potentially contributing to water scarcity in water-stressed regions (Berger et al., 2015; Bonsch et al., 2016; Gerbens-Leenes et al., 2009, 2012; Jägermeyr et al., 2017) However, by prioritizing rain-fed production of bioenergy this risk can be limited (Bonsch et al., 2016; Hayashi et al., 2015).

Reducing energy demand emerges as a robust strategy for both water conservation and GHG emissions reductions (Von Stechow et al. 2015; Grubler et al. submitted). 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 (Parkinson et al. submitted).

Comparing estimates across different models (Krey et al. submitted), the overall signal in terms of water-related synergies and trade-offs of 1.5°C mitigation pathways are relatively ambiguous. Some pathways show positive co-benefits while others indicate increases of water use due to mitigation (Figure 5.4, panels a and b). The signal depends on the adopted specific policy implementation or mitigation strategies and technology portfolio. Mitigation options in the electricity sector exist with potentially higher (e.g., nuclear, carbon capture and storage) or lower (solar PV, wind) water use than conventional fossil power options. A number of adaptation options exist (eg, dry cooling), which can effectively reduce electricity-related water trade-offs (Fricko et al., 2016). Similarly, irrigation water use will depend on the regions where crops are produced, whether they are irrigated, the sources of bioenergy (e.g., agriculture vs. forestry) and dietary change induced by climate policy.

5.4.3.5 Biodiversity

Stringent mitigation pathways reaching 2°C or 1.5°C are often associated with large-scale land-use changes due to afforestation and/or bioenergy deployment (Popp et al. 2017; Rogelj et al. submitted).

The bioenergy deployment in these scenarios may be confronted by substantial concerns for competition over land with potentially high biodiversity impacts (see Fuss et al. (2014) for a review and (Edenhofer et al., 2013; Haberi, 2015; Robledo-Abad et al., 2017; Smith et al., 2013a; Williamson, 2016). In addition, the reclamation of so-called marginal land for biomass for energy which is often associated with detrimental impact on biodiversity (Dale et al., 2010; Shaw et al., 2014a; Wiens et al., 2011). Specific options, however, allow for biodiversity preservation, or positive contribute to biodiversity (Fuss et al. submitted).

As summarised by (Fuss et al. submitted), comprehensive review of the effect of afforestation and reforestation on biodiversity is lacking at the moment. Nonetheless, afforestation using native species is generally regarded as superior compared to plantations (Hall et al 2012, McKinley et al 2011); and although they may perform less well in terms of carbon sequestration, diverse afforestation plots are less vulnerable also to climatic perturbations (Locatelli et al., 2015) and provide a greater variety of subsistence products and services, enhancing local management and acceptability (Locatelli et al., 2015) (Díaz et al 2009, Venter et al 2012).

Recent estimates across a range of different 1.5°C and 2°C pathways from six different IAM models (Krey et al. submitted) indicate that biodiversity loss of mitigation activities may be substantial (see Figure 5.4, panel b). Biodiversity loss in 1.5°C pathways is estimated to be 0.5–3% by 2050 (measured as the fraction of species whose future potential distribution area changes by more than 50%), which compares to 0.4–1.6% in 2°C pathways and 0.2–0.3% in the baseline (without new mitigation policies) (see Figure 5.4, panel a).

[INSERT FIGURE 5.4 HERE]

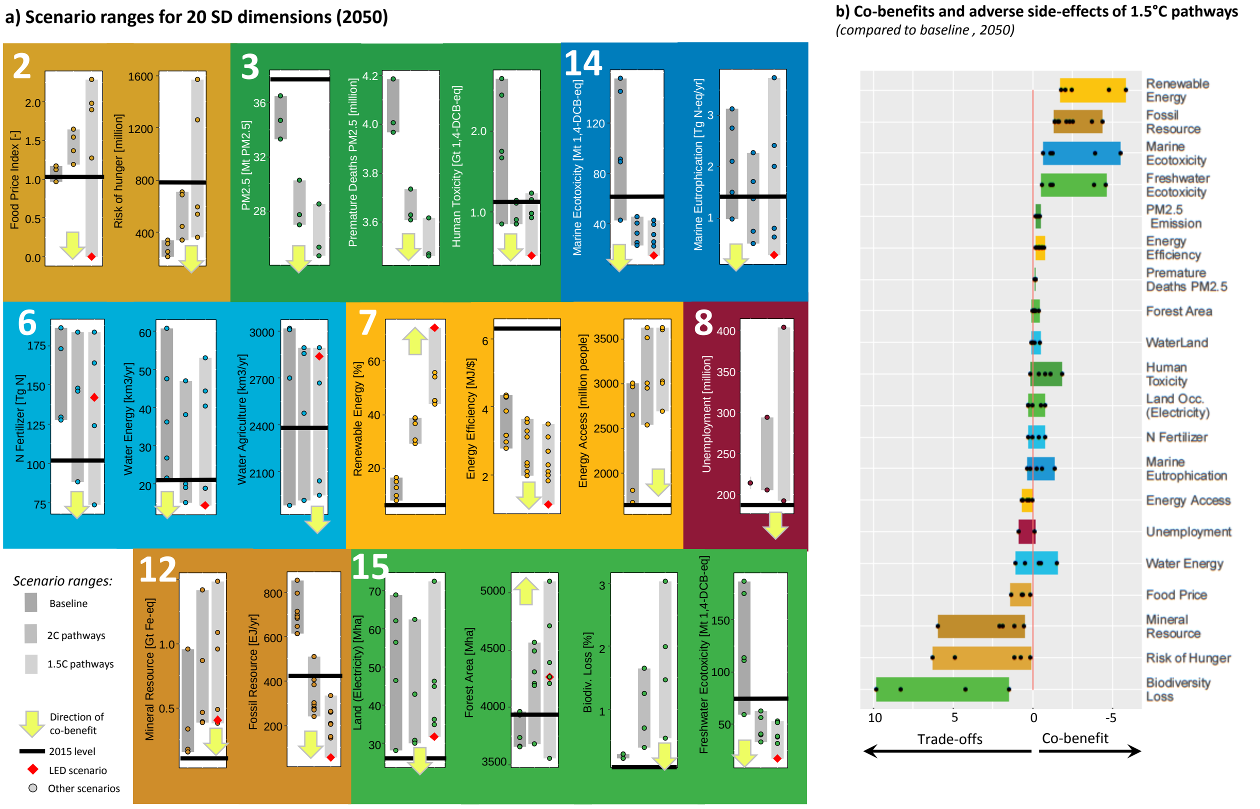

Figure 5.4: Sustainable development implications of 1.5°C pathways. Panel (a) shows ranges for 1.5°C pathways for 20 different sustainable development dimensions compared to ranges of 2°C pathways and baselines scenarios. The ranges depict quantifications of up to six different integrated assessment models, which were coupled to disciplinary models for the assessment of distributional and local effects for eg air pollution and health implications, biodiversity, employment, energy access and many other sustainable development implications (covering SDG 2, 3, 6, 7, 8, 12, 14, 15) Panel (b) presents the resulting co-benefits and trade-offs of 1.5°C pathways compared to middle-of-the-road baseline scenarios. Each figure in panel (a) shows the underlying data for one corresponding 1.5°C bar in panel (b). All estimates are for the year 2050. Note that sustainable development effects are estimated for the effect of mitigation and do not include benefits from avoided impacts (see Chapter 3, Section 3.5). Red dots denote estimates from a pathway with extremely low energy demand (LED) reaching 1.5°C without BECCS. Sources: (Fujimori et al.; CD-LINKS 2017; Krey et al. submitted), (Gruebler et al, submitted).

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, Section 2.3 and Section 2.4). While pathways aiming at 1.5°Care associated with high co-benefits for some sustainable development dimensions (such as human health and air pollution, forest preservation, fossil resource use, and human-, marine-, and eco-toxicity; see Figure 5.4, panel a and b), the rapid pace and magnitude of the required changes lead also to increased risks for adverse side-effects for a number of other sustainable development dimensions (particularly risk of hunger, food security, biodiversity, and mineral resources for renewables; Figure 5.4, panel a and b) . 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 associated costs for eradicating the trade-offs for eg food and energy access to be modest and significantly lower than the costs of mitigation (see Krey et al, submitted; Fujimori et al., submitted). Fundamental transformation of demand, including efficiency and behavioural changes, can help to significantly reduce the reliance on risky technologies, such as BECCS, and thus reduce the risk of potential trade-offs between mitigation and other sustainable development dimensions (Grubler et al, 2015 and 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 (Clarke et al, 2014).

5.5 Integrating Adaptation, Mitigation and Sustainable Development: Challenges and Enabling Conditions

The purpose of this section is to assess integrated approaches to climate and development, outlining key enabling conditions and constraining factors affecting the integration of adaptation, mitigation and sustainable development at policy and community levels. Although little literature has examined integrated approaches in the context of 1.5°C global warming, the adoption of the Paris Agreement and the 2030 Agenda for Sustainable Development underscore the need for integrated responses to interlinked climate and development challenges given the close synergies between ambitious mitigation to 1.5°C, the feasibility of effective adaptation to the changes already locked into the climate system and poverty reduction (Boas et al., 2016; ICSU, 2017; Nilsson et al., 2016).

Climate response options for adaptation and mitigation interact with each other (see Chapter 4, Section 4.5) and with other development goals, producing separately a complex assemblage of synergies and trade-offs with attendant effects on poverty, equity and sustainable development (see Sections 5.3 and 5.4.). In practice, the three dimensions are closely interlinked such that concrete decision-making requires an integrated vision of mitigation, adaptation and sustainable development (Nunan, 2017). This integrated approach cannot be built by simply adding a development perspective on top of existing climate policy initiatives, but requires significant shifts in institutional approaches to environmental policies and regulation at all scales (Ficklin et al., 2017). The AR5 identified the integration of adaptation and mitigation response options within the broader context of sustainable development as an 'aspirational goal' for climate policy (Denton et al., 2014). In turn, analysis of the potential for policy frameworks and development strategies to deliver integrated outcomes is gaining prominence (Di Gregorio et al., 2017a; Duguma et al., 2014b; Few et al., 2017; Northrop et al., 2016; Stringer et al., 2014; Sugar et al., 2013; Tanner et al., 2017).

Climate Policy Integration (CPI), a variant of the Environmental Policy Integration (EPI) literature, proposes a conceptual framework for thinking about policy integration, which argues that climate concerns should be 'mainstreamed' into existing policy fields (Jordan and Lenschow, 2010). Recent literature has started to investigate what, beyond the conceptual discussion, can be learnt to inform policymakers striving to design policies that integrate climate objectives, notably when considering the relationship with sustainable development (Adelle and Russel, 2013). In the European Sustainable Development Strategy, four criteria are identified for climate legislation to contribute to sustainable development in a way that can be evaluated at the policy proposal stage: policy integration and coherence, environmental protection, social and economic development and justice/participation (Rietig, 2013). But, the basic factors that can make the promises of climate policy integration work in practice are still not clearly defined (Runhaar et al., 2014). Integrated strategies can be useful as policy documents, but they cannot replace more focused strategies that adopt a narrower, sectoral basis (Casado-Asensio and Steurer, 2014).

The climate-compatible development (CCD) literature adopts a donor perspective aimed at fostering 'triple wins' in individual project, that is, delivering synergies between simultaneously reaching low emissions, building resilience and promoting development (Bickersteth et al., 2017; Mitchell and Maxwell, 2010). The literature on CCD consists essentially of empirical analysis of how CCD has been operationalized, how triple-wins can be achieved (Ellis et al., 2013; Nunan, 2017; Stringer et al., 2014; Suckall et al., 2014a) and what are the potential missing links and challenges revealed by concrete implementation (Antwi-Agyei et al., 2017a; Kalafatis, 2017). Robust criteria to evaluate triple-wins do not exist (Suckall et al., 2015). The operationalization of CCD shows the existence of multi-level and multi-sector trade-offs with 'winners' and 'losers' across governance levels and (spatial and temporal) scales (Ficklin et al., 2017; Wood, 2017).

Integrated approaches are possible but are often difficult to achieve and not always ideal, and integration will not be necessary, suitable or efficient for all situations. For example, broad analyses of adaptation, mitigation and development interactions have been conducted for climate-smart agriculture and carbon-forestry projects highlighting the potential for integration (Bryan et al., 2013; Campbell et al., 2016; Dyer et al., 2012; Kaczan et al., 2013; Lipper, 2014; Stringer et al., 2012). But there is little empirical evidence of triple wins being achieved in climate-smart projects, and there is even risk that the search for triple wins leads to the adoption of less effective policies if they don't take into account the local and external constraints like skills, knowledge or funding (Nunan, 2017) (see also Chapter 4).

A major challenge for governments, communities and other stakeholders, then, is to identify the enabling conditions that manage trade-offs and enhance synergies across adaptation, mitigation and sustainable development objectives at the level of policies, programs and projects in the pursuit of the 1.5°C target and the SDGs.

5.5.1 Coherent and Integrated Institutions and Governance

Strong institutions, effective cross-institutional partnerships, and multi-level governance are central for the development policy frameworks with high synergy potential at the national level (Di Gregorio et al., 2017a; Duguma et al., 2014b; Somorin et al., 2015) and at the scale of community and project interventions (Dyer et al., 2013; Kongsager et al., 2016; Sánchez and Izzo, 2017; Suckall et al., 2015). Low-carbon and adaptation objectives can be more easily aligned at the project level than at the aggregate and macroeconomic level where the consistency of low-carbon and climate resilient patterns of growth is less clear and vary on a geographical basis (Pye et al., 2010). This stresses the importance of internal and external climate policy coherence, of vertical policy integration to mainstream climate change into sectoral policies and of horizontal policy integration to ensure cross-sectoral coordination (Di Gregorio et al., 2017b; Rietig, 2013). The absence of strong institutions and weak institutional co-ordination can undermine integration potential, with 'institutional tussles' (Stringer et al., 2014), the reluctance of ministries to cede power (Di Gregorio et al., 2017a), and weak institutional oversight and corruption (Tanner et al., 2017) inhibiting integrative efforts.

Enhancing synergy potential remains challenging for many nations, particularly for those with weak and uncoordinated overarching governance for climate policy (Di Gregorio et al., 2017a; Stringer et al., 2014). Environmental governance is achieved between and among different levels of government, civil society and the private sector (Dyer et al., 2013). Significant challenges relate to limited coordination among institutions and agencies, limited institutional capacity and a lack of resources in ensuring coherence, which is particularly important for climate-sensitive sectors such as agriculture, energy, water, forest and wildlife (Antwi-Agyei et al., 2017a). The production, framing, communication and use of climate knowledge is also hampered by inadequate coordination that limit the capacity to inform complex multi-staged decision-making (Tàbara et al., 2017a).

Conventional funding mechanisms like CDM are shown to exacerbate existing inequalities and hence fail to fill the energy access gap in a number of LDCs like Tanzania, demonstrating the need for innovative energy funding schemes (Wood et al., 2016b). Access to external funding is often required to achieve triple wins (Sánchez and Izzo, 2017; Wood, 2017), but it can effective to reach this objective only if financing and implementing entities and the local governance structures in place ensure that projects meet the triple objective, as shown on the example of Decentralised renewable energy in Central America (Ley, 2017a). Even when integration between adaptation and mitigation is practical, effective or desirable, it can be facilitated or disabled by project financing structures (Locatelli et al., 2015), international donors who hold a lot of power over aid-dependent countries (Ficklin et al., 2017; Phillips et al., 2017; Schipper et al., 2017) by the national and international policy settings (Kongsager et al., 2016), by the nature of multilevel engagement with the private sector (Leventon et al., 2015). Lack of additionality and validation problems also constrains the capacity of programs to deliver triple wins (Kongsager and Corbera, 2015; Ley, 2017b). The case of micro-hydropower systems in the Dominican Republic shows that access to finance and education and alignment of community needs and national policy objectives are key enabling factors for synergistic adaptation, mitigation and sustainable development outcomes for local communities (Sanchez and Izzo, 2017). In developing countries, it is also essential to ensure that enough finance is directed towards the necessary capacity-building needs and enabling factors, which requires strong connections with national planning processes (Boyle et al., 2013).

5.5.2 Participatory Processes to Address Issues of Power and Justice

The multi-level and multi-sector nature of integration inherently produce conflicting governing processes, actors and outcomes (Ficklin et al., 2017). Issues of power and justice affect the pursuit of integrated adaptation, mitigation and sustainable development measures, which calls for accounting for political economy dimensions in the design of integrated approaches (Nunan, 2017). Evidence of actualising integration outcomes underscores the need to address power, justice and equity, acknowledging that integration of mitigation, adaptation and development can also create auxiliary benefits and negative side-effects on different stakeholders and local people an (Nunan, 2017; Wood, 2017). The plurality of values and interests that coexist and conflict mean that there is no universal standard of distributive justice, which should instead be negotiate between these interests (Fisher, 2015). In particular, given the objective to reduce the vulnerabilities of local people, their voices should be heard to avoid the risk of perpetuating local inequalities and providing least benefit to underprivileged households (Mathur et al., 2014b; Wood et al., 2017). These trade-offs should be considered within wider national policy contexts, as shown, for example, in Kenya, where renewable energy, such as grid connected geothermal power and off-grid solar home systems, is judged as a cost-competitive option for achieving triple wins, but trade-offs arise because of high interest in utilizing the country’s fossil fuel reserves for energy security (Naess et al., 2015).

Analyses of carbon forestry in Mozambique (Quan et al., 2017), energy system transformation in Kenya (Newell et al., 2014b), and artisanal fisheries in Ghana (Tanner et al., 2017) show how powerful interests can inhibit synergistic policy implementation, 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 (Barrett, 2013; Wood et al., 2016a), which, in turn, perpetuate local inequalities (Wood, 2017). Power asymmetries and various forms of injustice may also exacerbate local inequalities, as discussed in the context of climate-smart agriculture (Neufeldt et al., 2013; Taylor, 2017a), carbon offsets (Cavanagh and Benjaminsen, 2014) and CCD (Ficklin et al., 2017; Phillips et al., 2017; Stringer et al., 2017). However, analyses may overlook or downplay trade-offs, value conflicts and power asymmetries (Chandra et al., 2017; Neufeldt et al., 2013; Taylor, 2017b). One of the principal areas of contestation around climate-smart agriculture relates to equity, including who wins and who loses, who is able to participate, and whose knowledge and perspectives count in the process (Karlsson et al., 2017).

The involvement of stakeholders though participatory mechanisms is a key condition for addressing these challenges to support sustainable climate policy integration (Rietig, 2013). For instance, participation of community members in the planning, multi-stakeholder partnerships, implementation and monitoring of integrated climate-development projects enhances local empowerment, trust and collaboration, and social capital (Dyer et al., 2013; Sanchez and Izzo, 2017). In contrast, contestations over land in community forestry projects have produced a range of social trade-offs that undermine livelihood resilience and exacerbate inequalities (Few et al., 2017; Kongsager and Corbera, 2015). Taking into account regional contexts and local knowledge is essential for maximizing the synergy potentials, in contrast to top-down approaches which may lead to undesired trade-offs, as shown in the example of the water–energy nexus of irrigation modernization in China (Cremades et al., 2016).

5.5.3 Accounting for Local Circumstances and Unequal Opportunities

Even when integration between adaptation, mitigation and development is effective and desirable, not all people and places have equal opportunities to achieve it, with least-developed countries demonstrating the least potential (Duguma et al., 2014b). Low-emission, climate-resilient development plans are still developed in a growing number of least developed economies with an emphasis on different aspects of the low-carbon resilient agenda, according to a country’s circumstances (Fisher, 2013a). This is done by adopting an holistic vision of development (White, 2010) that goes beyond economic factors and carbon emissions to assess the tradeoffs in integrated approaches, and capture issues such as quality of life, cultural significance and social cohesion (Ficklin et al., 2017). Within a country, people and individuals have different opportunities to benefit from integrated approaches because the space available for synergies between adaptation, mitigation and sustainable development depends on their situation. Mitigation or adaptation interventions stand to create multi-level patterns of both benefits and negative side-effects that may have diverse consequences for individuals and groups (Tompkins et al., 2013).

Climate change impacts will disproportionately undermine the capacities of poor and vulnerable populations to achieve triple wins by restricting development opportunities, economic growth and adaptive capacities (Hallegatte et al., 2016b; IMF, 2017; Olsson et al., 2014; Reyer et al., 2017b; UN-OHRLLS, 2009). Moreover, climate shocks and stressors have been shown to negatively affect some CCD projects by undermining the synergistic potential of planned interventions (Kongsager and Corbera, 2015) and producing negative side effects in some cases (Wood, 2017). Vulnerable and disadvantaged communities experiencing multiple stressors (including climate change) with few livelihood alternatives – women and the elderly in particular – may either not have the resources and skills to pursue integrated objectives (Sietz and Van Dijk, 2015), and this may not be the most effective way to address their most pressing concerns.Indigenous populations are disproportionately exposed to climate change impacts, which may cause an adaptation-mitigation disconnect hindering the benefits of integrated strategies for transformational changes when indigenous knowledge and adaptive capacities are ignored in adaptation planning (Thornton and Comberti, 2017).

5.5.4 Towards a Systemic and Dynamic Approach for Integration

The enabling conditions and challenges discussed in previous sections evolve over time and the capacity to implement integrated approaches to mitigation, adaptation and sustainable development feature path dependencies. Uneven starting conditions increase the risk of maladaptation (see Section 5.3.2) (Juhola et al., 2016; Magnan et al., 2016b), and the risk of negative effects of mitigation responses on the poor and vulnerable groups (see Section 5.4) (e.g., through processes of land appropriation and dispossession) (Cavanagh and Benjaminsen, 2014; Corbera et al., 2017; Fairhead et al., 2012; Hunsberger et al., 2014; Work, 2015) or increased food prices and competition for arable land (Burns and Nicholson, 2017; Muratori et al., 2016; Smith et al., 2016).

Furthermore, reinforcing mechanisms known as poverty traps (see Haider et al., 2017) may further erode the capabilities and capacities of already disadvantaged and marginalised groups. Vulnerable and disadvantaged communities experiencing multiple stressors (including climate change) with few livelihood alternatives may employ short-term maladaptive coping strategies that lock communities into high-carbon development pathways, in turn undermining their long-term socio-economic development and adaptive capacities (Ehara et al., 2016; Suckall et al., 2014b; Tanner et al., 2017; Thornton and Comberti, 2017), thus further entrenching poverty and community disadvantages.

Regions, nations and communities with weak or absent enabling conditions may be subject to vicious circles like poverty traps, and are likely to encounter worsening trade-offs between adaptation, mitigation and sustainable development over time. This is what happens when poorly designed and implemented development interventions impose significant costs and constrain alternative low-carbon and climate-resilient development trajectories for local communities over the longer-term.The Tropics is emerging as a region prone to such situation due to high vulnerability to climate risks (Harrington et al., 2016; Herold et al., 2017; Pecl et al., 2017), susceptibility to climate response spillovers (Muratori et al., 2016), prevalence of fragile states (Fund for Peace, 2017) and un-coordinated policy contexts (Duguma et al., 2014b).

Nonetheless, the improvements of enabling conditions can enhance the opportunities for integrated approaches. Balancing stakeholders' immediate needs with longer-term global climate objectives may produce synergies that enhance project effectiveness, development opportunities, and livelihood resilience (Sanchez and Izzo, 2017; Suckall et al., 2015). Pursuing big wins or 'low hanging fruit' options in the short-term might prioritise actions that are easier to measure and execute but prevent the search for longer-term projects with synergies or win-wins across climate and development objectives (Fisher, 2013a). This is notably true for community-based integrated policy might be more likely to trigger the transformational changes called by integrated strategies if it employs a longer time horizon, recognition of adaptability and feedbacks, integrated decision making, and systems thinking (Burch et al., 2014).

Ultimately, reconciling trade-offs between local development needs and global emission reductions towards a 1.5°C warmer world will require a more dynamic view of the interlinkages between adaptation, mitigation and sustainable development (Nunan, 2017). This entails recognition of the ways in which development contexts shape the choice and effectiveness of interventions, limit the range of responses afforded to communities and governments, and potentially impose injustices upon vulnerable groups (Thornton and Comberti, 2017; UNRISD, 2016). In situations where trade-offs appear intractable, for example where indigenous communities are exposed to extreme or rapid climate change, considering alternative development pathways that open up novel possibilities for equitable responses will become essential (Thornton and Comberti, 2017). Such climate-resilient development pathways are discussed in the next section.

5.6 Sustainable Development Pathways to 1.5°C

This final section assesses what is known in the literature on development pathways that are sustainable and climate resilient and relevant to a 1.5°C warmer world. It builds on insights from approaches that integrate adaptation, mitigation, and sustainable development (Section 5.5) but takes a more dynamic view, based on the notion of pathways. Box 1.2 (Chapter 1, Section 1.2.4) describes pathways in two broad ways: as temporal evolution of a set of scenario features, such as GHG emissions and socioeconomic development, largely quantitative; and as solution-oriented trajectories and decision-making processes about transitions from today's world to achieving a set of future goals, typically more qualitative. Both are relevant for understanding short-term actions that enable long-term transformations and are examined in Section 5.6.1 and Section 5.6.2, respectively.

Limiting global warming to 1.5°C above pre-industrial times and ensuring well-being among human populations and ecosystems in a 1.5°C warmer world require ambitious and well-integrated adaptation-mitigation-development pathways that deviate fundamentally from high-carbon, business-as-usual futures (Arts, 2017; Gupta and Arts, 2017a; Okereke and Coventry, 2016; Sealey-Huggins, 2017). Well-being for all is at the core of an ecologically safe and socially just space for humanity (Dearing et al., 2014; Raworth, 2012, 2017b; Rockström et al., 2009a), highlighting the relational and subjective dimensions of being and social interactions (White, 2010). These integrated pathways address the urgency and unprecedented scale of emission reductions necessary to remain within a 1.5°C target (Chapter 2, Section 2.4), the transformational changes needed to overcome the path dependencies that cause current unsustainable trajectories and undesirable lock-in patterns (Chapter 4, Section 4.5), and the ethics and equity dimensions associated with ambitious decarbonization and society-wide transformation across scales and regions (Chapter 5, Sections 5.6.1–5.6.4). These pathways also entail a collective, value-driven reflection about the desirable futures we want (Bai et al., 2016; Gillard et al., 2016; Tàbara et al., 2017b).

5.6.1 Sustainable Development Pathways

This section focuses on the growing body of literature on pathways exploring linkages between mitigation, adaptation and sustainable development. It presents, to a large extent, insights from systems approaches to development pathways relevant to a 1.5°C warmer world, and how to get there.

Identifying "enabling" conditions under which integration of sustainable development with adaptation and mitigation can be achieved is critical for the design of transformation strategies that maximise synergies and avoid potential trade-offs (see Section 5.5). Full integration across all sustainable development dimensions is, however, challenging, given the diversity of sustainable development dimensions and the need for high temporal, spatial, and social resolution to tackle local effects of sustainable development, including heterogeneity that is critically important for understanding poverty and equity implications (von Stechow et al. 2015; Johnson et al. submitted). While quantitative systems models can be helpful in identifying how to address these trade-offs, the analysis of sustainable development pathways often requires improved representation of sustainable development drivers as well as further integration through, for example, bridging and linking of different analytical approaches that can complement each other (Rao et al., 2017; Johnson et al., submitted; Geels et al., 2016; Turnheim et al., 2015).

Generally, available research on long-term climate change mitigation and adaptation scenarios has covered individual SDGs to different degrees. An initial understanding of the interactions between climate and other SDGs has developed in the areas of health (SDG3), energy (SDG7), economic growth (SDG8) and, increasingly, hunger (SDG 2), as well as the sustainable use of water (SDG6), land (SDG15) and oceans (SDG14) (e.g., Vuuren et al. (2012); McCollum et al. (2013); Clarke et al. (2014); von Stechow et al. (2016); Krey et al.(submitted)). Key areas such as poverty (SDG1), inequality within and between countries (SDG10), the role of education (SDG4), gender (SDG5) sustainable communities and cities (SDG11) or institutions (SDG16) are largely underexplored territory for integrated long-term scenarios (see also Section 5.4.3).

Many pathways studies have focused predominantly on one-directional interactions across a limited set of sustainable development dimensions. Being more limited in scope, these studies often take one or more SDGs as an entry point for reaching broader societal objectives. For example, Abel et al. (2016) show how universal education (SDG 4) would fundamentally change the role of woman in society and by extension result in reduction of fertility in the developing world, ultimately reducing population growth significantly. A smaller population may lead to reduced emissions (O'Neill et al., 2010) and thus support reaching stringent climate targets such as 1.5°C. Higher income due to education may, at the same time, however, increase emissions. The balance of the two effects is not well understood. Another example for a sectoral study is the Global Energy Assessment (Riahi et al., 2012), illustrating how a fundamental energy transformation (SDG7), if managed appropriately, can result in multiple societal benefits for health, security, affordability, access and reliability of energy services.

Recent pathways studies exploring sustainable development have broadened their scope, given particularly the growing recognition of the many interactions inherent in the management of water, energy, and land-related SDGs and that these interdependencies could fundamentally alter the adopted transition strategies (Arent, 2014; Bierbaum and Matson, 2013). In this context,"nexus" refers to a sub-set of sustainable development dimensions that are investigated together because of their particularly close relationships. Examples of a "nexus" approach include (Parkinson et al., 2016; Conway et al., 2015; Welsch et al., 2014; Rasul and Sharma, 2016; Howarth and Monasterolo, 2017; Keairns et al., 2016). While such a nexus approach foregrounds interactions and feedbacks from a complex systems perspective (Howarth and Monasterolo, 2017), assemblage approaches focus on continuously changing relations between human and non-human actors and constructive tension as opportunities for change (Gillard et al., 2016). Given these interdependencies, the concept of nexus thinking (Fricko et al., 2016) has gained traction within the IAM community and work has begun to improve the representation of nexus linkages within individual models and to develop integrated nexus frameworks that endogenously consider the trade-offs and synergies among water, food, and energy supply systems (Johnson et al., submitted).

A key challenge of the nexus approach lies in the cross-sectoral nature and complex interlinkages between advancing sustainable development and addressing climate change (Boas et al., 2016; Dimitrov, 2016). Networked governance can assist complex climate decision making (Tosun and Schoenefeld, 2017).However a reductive focus on specific SDGs in isolation may undermine the long-term achievement of sustainable climate change mitigation (Holden et al., 2016).

Nexus assessments are particularly needed in the context of the Sustainable Development Goals (SDGs) where an integrated framework would be useful to identify strategies for addressing multiple goals while avoiding efforts that are counterproductive from a holistic perspective (van Vuuren et al., 2015; Weitz, 2015; Zhou and Moinuddin, 2017). In this context, an early pioneering study by PBL (Vuuren et al., 2012) extended the boundary conditions of pathways to explore also the sustainability of land use, and identify strategies for eradicating hunger and maintaining stable and sufficient food supply while conserving biodiversity. A more recent example of pathways of how water, energy and climate SDGs (6,7,13) interact (Parkinson et al, submitted) calls for integrated water-energy investment decisions in order to manage the transition of these strongly connected sectors. An important option in this context is the provision of bioenergy, which can help mitigate climate change and alleviate energy security concerns, but can have negative impacts on food security, water use, and biodiversity (Bonsch et al., 2016; Chaturvedi et al., 2013; Lotze-Campen et al., 2014; Secretariat of the Convention on Biological Diversity, 2009).Despite these trade-offs, many synergies among solutions exist. Foremost,policies that improve the resource use efficiency of land, energy, and water may have synergistic benefits for the other supply systems given that each system relies on resources from the others (Bartos and Chester, 2014).

Importantly, there is an increasing body of literature exploring the effect of mitigation pathways (and SDG13 on climate) for sustainable development and other SDGs, going beyond the energy-water-land nexus (Krey et al.,; Bertram et al.; Grubler et al.,) (Humpenoeder et al., 2017). These studies take decarbonization as an entry point and try to understand implications for sustainable development. (Bertram et al. submitted) emphasise the importance of the mitigation portfolio, and show how choices of mitigation technologies can help in designing mitigation portfolios that would maximise synergies with sustainable development and help avoid trade-offs. (Krey et al. submitted) present a recent modeling comparison experiment on how mitigation affects 21 selected sustainability dimensions, ranging from ecosystem impacts (e.g., biodiversity and afforestation) to health implications, food security, water, employment, to name just a few. A keyconclusion from the study is that major synergies between 1.5°C pathways and sustainable development exist and that in most areas where trade-offs between mitigation and sustainable development can be avoided through appropriate policy design (see also Section 5.4.3). Regulation in specific areas may complement price-based instruments to avoid trade-offs due to high carbon pricing of 1.5°C pathways. Such combined policies generally lead also to more early action maximizing synergies and avoiding some of the adverse climate effects for sustainable development (Bertram et al., submitted).

A more comprehensive analysis of climate change in the context of sustainable development will be dependent on defining suitable reference scenarios that lend themselves to broader sustainable development considerations. The Shared Socioeconomic Pathways (SSPs) (O'Neill et al., 2017; Riahi et al., 2017) (see Chapter 1,Box 1.2) provide a tool-box for integrated assessment of climate-development linkages and constitute thus an important first step in this direction (Ebi et al., 2014). Their underlying narratives (O'Neill et al., 2017a) map well into some of the key SDG dimensions. For example, SSP4 describes a world with highly unequal investments in human capital across the world combined with increasing disparities in economic opportunity and political power leading to increasing inequality and stratification, both within and across countries. In contrast, SSP1 describes a reference world that shifts towards a more sustainable path of inclusive development that respects environmental boundaries compared to historical patterns (van Vuuren et al., 2017). Comparing transition dynamics from such very different reference worlds and studying the co-benefits and risks at the climate-SDG nexus is crucial and thus an important gap that the new scenario framework can fill. The SSPs will need to be linked also to non-SSP pathways approaches, like (Shukla and Chaturvedi, 2013) and other studies, exploring the sustainability implications on regional and global levels.

The narratives and quantifications of the SSPs have been used so far primarily around mitigation and adaptation. The global mitigation dimension has been assessed relatively comprehensively (Riahi et al., 2017; Rogelj et al., submitted; Bauer et al., 2017; Popp et al., 2017; van Vuuren et al., 2017). Recently, also SSP-based work focusing on adaptation and impacts and applying the framework to different other sustainable development dimensions has become more widespread (Byers et al. submitted; Parkinson et al. submitted; Blanco et al. 2017; Hasegawa et al. 2014; Ishida et al. 2014; Arnell et al. 2015; Bowyer et al. 2015; Burke et al. 2015; Hallegatte and Rozenberg 2017; Lemoine and Kapnick 2016; O'Neill et al. 2017; Rozenberg and Hallegatte 2016; Rutledge et al. 2017). So far these activities have resulted in an ensemble of mitigation scenarios, comprehensively covering the entire SSP-RCP matrix. An important finding of the SSP-based mitigation analyses is that the socioeconomic storyline (SSPs) affects mitigation costs almost as much as the choice of the forcing target (RCPs). Perhaps equally important, the mitigation scenarios clearly illustrate how specific socio-economic conditions (e.g., as described by SSP3) might render specific climate forcing targets unattainable (such as 2.6 or 1.9 W m^{-2}) (Riahi et al. 2017; Rogelj et al. submitted) (Fujimori et al, 2017). The multiple pathways of the SSP-RCP framework lend itself thus for the systematic exploration of uncertainties and the extent of development-climate synergies or possible trade-offs.

Harnessing the full potential of the SSP framework to inform sustainable development requires (1) further elaboration and extension of the current SSPs to explicitly cover sustainable development objectives, and (2) the development of new or variants of current narratives that would facilitate more SDG-focused analyses with climate as one objective (among other SDGs) (Riahi et al., 2017). Initial work in this direction comprises the development of SSP-based inequality and poverty projections (Rao et al, submitted), which have been downscaled to sub-national rural and urban as well as spatially explicit levels (Gidden et al. submitted). The high granularity of the datasets has enabled advanced assessments of local vulnerabilities impacts, and sustainable development effects based on the SSPs (Byers et al. submitted). The explicit representation of poverty and inequality constitutes thus a major advancement of the SSPs compared to earlier community scenario sets, such as the RCPs (van Vuuren et al., 2011) or the SRES (Nakicenovic et al., 2000). A major conclusion from the SSP-based inequality assessments is that aggressive reductions in between-country inequality may decrease the emissions intensity of global economic growth (Rao and Min, In Press). This is due to the higher potential for decoupling of energy from income growth in lower income countries, which would be critically important for reaching 1.5°C climate targets in a socially and economically equitable world.

Scenarios in major international research collaborations, for example under the umbrella of IPBES (Intergovernmental Platform on Biodiversity and Ecosystem Services) or “The World in 2050” (www.TWI2050.org) increasingly build upon the SSPs as a starting point in order to explore conditions under which the SDGs can be achieved. Particularly the TWI2050 has been established to provide the framework for the scientific community to explore so-called Sustainable Development Pathways (SDPs). The TWI2050 framework is designed to allow modeling groups, using for example Integrated Assessment Models (IAM) and Earth system models (ESM), and other models, to identify and explore pathways to achieve all SDGs on a stable and resilient Earth system (Griggs et al., 2013; Rockström et al., 2009b; Steffen et al., 2015). In addition, the SDPs share some elements with the so-called CDRPs (see Section 5.6.2), going beyond modelling and including a narrative where required governance and institutional changes would help addressing critical societal goals related to, eg, poverty, vulnerability and inequality. The framing is set to explore pathways to reach the SDGs by 2030, continue to deliver on social and economic aspirations in an expanding world by 2050, and to do so within the biophysical safe operating space of a stable and resilient Earth system. Main components of TWI2050 framework includes the development processes for the SDP narrative which would expand beyond the SSP1 sustainability narrative (O’Neill et al., 2017a; van Vuuren et al., 2017); and two target spaces of indicators that provide the first step to allow modeling groups and other research communities to use backcasting approaches to analyse pathways from 2050 (and in some cases 2100) to the present. At the moment, the pathways are under development as part of the TWI2050 community process with a first report scheduled for 2019 to inform the High Level Political Forum on the SDGs.

5.6.2 Climate-resilient Development Pathways

This section assesses literature that adopts the second notion of pathways as solution-oriented trajectories and decision-making processes toward achieving a set of future goals to be considered for a 1.5°C warmer world. It introduces climate-resilient development pathways (CDRPs) as a conceptual and aspirational notion of pathways that are socially desirable, taking into account individual and collective values and socio-cultural, place-specific preferences, fair and equitable, and compatible with 1.5°C trajectories (Figure 5.5; FAQ 2). CRDPs are best understood as an extension to climate-resilient pathways (Denton et al., 2014) and transformation (emission reduction) pathways (Clarke et al., 2014), as defined in the AR5, as well as earlier advances in the domain of climate-compatible development (Maxwell, 2016; Mitchell and Maxwell, 2010; Stringer et al., 2014; Wood et al., 2016a, 2017) and triple-wins (see Section 5.5). They are based on a growing, yet dispersed literature following the 2015 Paris Agreement and the Agenda 2030 – Transforming our World, including the triple emphasis on development, resilience, and transformation as laid out in the latter.

[INSERT FIGURE 5.5 HERE]

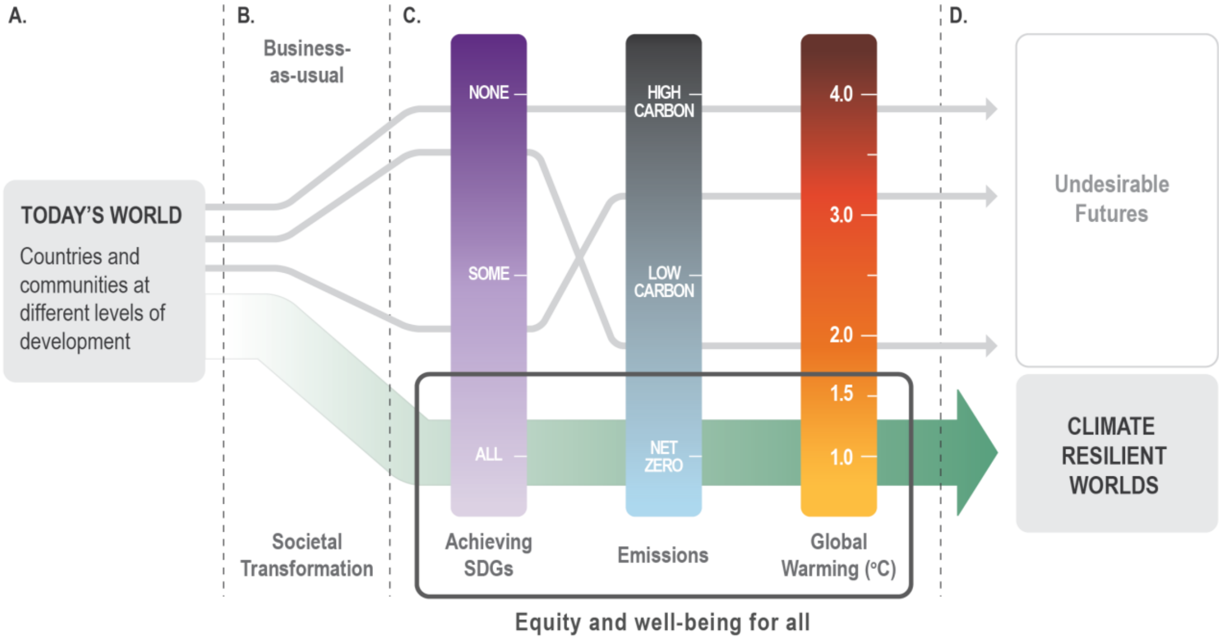

Figure 5.5: Climate-resilient development pathways (CRDPs) (green thick arrow) between our current world in which countries and communities exist at different levels of development, with various adaptation and mitigation measures available to them (A) and future worlds that are climate-resilient (bottom), undesirable (top), or somewhere in between (D). CRDPs emerge when aligned with societal transformation rather than business-as-usual policies and approaches (B). Pathways that achieve the SDGs by 2030 and beyond, strive for net zero emissions by mid- or later 21st century, and stay within the global 1.5°C warming target by the end of the 21st century, while ensuring equity and well-being for all, are considered as CRDPs (C).

5.6.2.1 Transformations, Well-being, and Equity

The notion of development pathways that are simultaneously climate resilient, as suggested by emerging literature, delineates a future in which easy wins, minor trade-offs, and space for inaction are waning while low-carbon trajectories are taken up across societies, in alignment with the UNFCCC premise of "common but differential responsibilities and respective capacities" (CBDR/RC). For CRDPs to attain the anticipated *transformations*, within a small window of time, all countries, independent of their income level or development status, as well as non-state actors, will need to strengthen their contributions, through bolder and more committed effort-sharing (Ekwurzel et al., 2017; Frumhoff et al., 2015; Holz et al., 2017; Millar et al., 2017; Rao, 2014; Shue, 2017) (*medium evidence, high agreement*). Sustaining decarbonization rates at a level compatible with the 1.5°C target would be 'historically unprecedented' (Millar et al. 2017: *ref*) and not possible without rapid transformations to a net-zero-emissions global economy by mid-century (Rockström et al., 2017a) or the later half of the century (Granoff et al., 2015). Such efforts would entail overcoming entrenched barriers such as technical, infrastructural, institutional, and behavioral carbon lock-in, within and across states and sectors (Pfeiffer et al., 2016; Seto et al., 2016), as well as defeating the path dependencies of poverty dynamics (so-called poverty traps) at the level of households, communities and nations (Boonstra et al., 2016; Enqvist et al., 2016; Haider et al., 2017; Lade et al., 2017) (*medium evidence, high agreement*).

Well-being for all(Dearing et al., 2014; Raworth, 2012, 2017b; Rockström et al., 2009a) appears as one of the core yardsticks for CRDPs. It includes peace and justice, social equity, gender equality, political voices, and networks, in addition to education, income and work, health, food, water, energy, and housing, as illustrated in the 'Doughnut' of social and planetary boundaries (Raworth, 2012). The fundamental social condition to enable well-being for all is to address entrenched inequalities within and between countries, especially those that show continuous shortfalls below the social foundations (e.g., peace and justice, gender equality, and political voice) while eliminating ecological overshoots (Raworth, 2017a, b), analogue to the

Agenda 2030 premise to 'leaving no one behind', including no place and no ecosystem. This entails transforming economies and overcoming uneven consumption and production patters to avoid critical human deprivation (Dearing et al., 2014; Häyhä et al., 2016; Raworth, 2017b) and moving toward development as well-being rather than growth (Gupta and Pouw, 2017).

Equity, fairness, and climate justice constitute the other essential yeardstick for these pathway endeavours (Caney, 2012; Klinsky et al., 2017a; Moellendorf, 2015; Roser and Seidel, 2017; Sealey-Huggins, 2017; Shue, 2014a; Thorp, 2014) (*medium evidence, high agreement*). Consideration for what is equitable and fair in the pursuit of 1.5°C suggests the need for stringent decarbonization that does not exacerbate social injustices, locally and at national levels (Okereke and Coventry, 2016), is 'socially desirable and acceptable' rather than merely economically and technically feasible (Rosenbloom, 2017; von Stechow et al., 2016), and makes visible vested interests implicated in defining what is considered feasible (Gardiner, 2013; Haasnoot et al., 2013; Meadowcroft, 2011; Normann, 2015; Patterson et al., 2016; Preston, 2013). Pathways compatible with 1.5°C warming are not merely 'possible futures' but their development, deliberation, and implementation entail societal values and a 'new politics of anticipation' (Beck and Mahony, 2017: *ref*), including attention to politics and power that perpetuate business-as-usual trajectories (O'Brien, 2016), the politics of the sustainability and capabilities of everyday life (Agyeman et al., 2016; Schlosberg et al., 2017), and the deep-seated inequities built into uneven development and uneven climate ambitions (CSO Review, 2015; Holz et al., 2017)(*medium evidence, high agreement*).

Identifying socially acceptable, inclusive, and equitable pathways for a 1.5°C warmer world that take into account differential responsibilities and capacities is a challenging yet essential endeavour, fraught with complex moral, practical, and political difficulties (*very high confidence*). It asks 'whose vision of a climate compatible [and resilient] future is being pursued and along which pathways?' (Gillard et al., 2016:*ref*). Hence, equity- and urgency-driven pathways toward livable, just, and low-carbon futures and conscious social transformation necessitate public deliberation and participatory processes, including from those most affected (Leach et al., 2010; O'Brien, 2016; Rosenbloom, 2017; Stirling, 2014; Tàbara et al., 2017a). Meeting the social and governance conditions that enable CRDPs is a prerequisite for their feasibility, yet how to do so remains insufficiently addressed in most pathways literature (see Chapter 1,Cross-chapter Box 1.1). Vital lessons emerge from lived experiences with and tensions within climate-compatible and climate-resilient development approaches (e.g., Baker et al., 2014; Archer and Dodman, 2015; Reed et al., 2015; Swilling et al., 2016; Arent et al., 2017; Brown et al., 2017) (see Section 5.5).

5.6.2.2 Development Trajectories, Responsibilities, and Capacities

The potential for embarking on and realistically pursuing development pathways that are sustainable and climate-resilient differs between nations at different levels of development (*very high confidence*). The associated equity challenges are made explicit through the 'Common but Differentiated Responsibilities and Respective Capacities' (CBDR-RC), as defined in the UNFCCC. There is a growing literature on various effort- or burden-sharing approaches to climate stabilization among all countries, predominantly at the level of nation states(Baer et al., 2008; Okereke and Dooley, 2010; Okereke and Coventry, 2016; Anand, 2017; du Pont et al., 2017; Bexell and Jönsson, 2017; van den Berg et al., under review). Different principles and methodologies result in different levels of responsibilities and capacities (Skeie et al., 2017), with some, however, systematically biased against poorer countries and those with low emissions (Kartha et al. forthcoming). The disparity between nations, their respective opportunities and challenges, and the position they occupy on current development trajectories, as highlighted in the 2017 SDG Dashboard, determine to a large extent the countries' uneven potential for pursuing CRDPs in a 1.5°C warmer world. For the developing world, achieving the 1.5°C goal also means potentially severely curtailed development prospects (Okereke and Coventry, 2016) while not meeting the 1.5°C will also have implications. Successfully navigating CRDPs will go hand in hand with countries' efforts to ensure inclusive societies, development as well-being, and green economies, and honour their obligations to human rights, as outlined in the SDGs and the Paris Agreement, in alignment with the Right to Promote Sustainable Development (Gupta and Arts, 2017a; Gupta and Pouw, 2017).

Recent advances in the scientific literature address notions of fair shares at the level of nation states in their attempt to limit global warming to 1.5°C (CSO Review 2015;du Pont et al. 2017; Holz et al. 2017; Winkler et al. 2017). These efforts build on the AR5 'responsibility-capacity-need' assessment (Clarke et al., 2014), complement other proposed national-level metrics for capabilities, equity, and fairness (Fuglestvedt and Kallbekken, 2016; Heyward and Roser, 2016; Klinsky et al., 2017b) and fall under the wider umbrella of fair share debates on responsibility, capability, and right to development in climate policy (Fuglestvedt and Kallbekken, 2016). In the (I)NDCs, the large majority of nations (>90%), including Least Developed Countries (LDCs), Small Island States (SIDs) and other countries in the global South, considered fairness and equity largely through the lenses of a country's vulnerability and/or their small shares of global emissions, compared to OECD countries (<10%), with only limited reference to 1.5°C overall (Winkler et al., 2017). Such scientific literature contributes to the understanding of the ethical premises and consequences of the relative fairness in countries' pledges and actions, without being policy-prescriptive (Kartha et al., under review).

Recent literature suggests that a 'justice-centred implementation of 1.5°C compliant mitigation' (Holz et al. 2017:xx), based on a country's responsibility and capacity, requires both ambitious domestic emission reductions and committed international cooperation whereby wealthier countries support poorer ones, technically, financially, and otherwise, to mitigate their fair share (Okereke and Coventry, 2016). Such an approach also takes into account the differential costs of implementing mitigation (Akimoto et al., 2016; Clarke et al., 2014; Hof et al., 2017; Maljean-Dubois, 2016; Williams and Montes, 2016) (*medium evidence, medium agreement*). Figure 5.6 depicts these 'dual obligations' by highlighting high and low ambition fair share emission reductions. Data are extracted from the Climate Equity Reference Framework (CERF), the successor to the Greenhouse Development Rights framework (Baer et al., 2008), a well-known, justice-based effort-sharing scheme, and summarised by Holz et al. (2017): high-income countries are typically less vulnerable to climate change, externalise many of the costs of their domestic development (high international 'spill-overs'), and have pledged NDCs that, on average, are significantly lower than the fair share of emission reductions as assessed through the CERF. Poorer countries, by contrast, tend to be more vulnerable, generate low spillovers, and yet may have to do more than their fair share, conditional upon adequate external support (Holz et al., 2017).

[INSERT FIGURE 5.6 HERE]

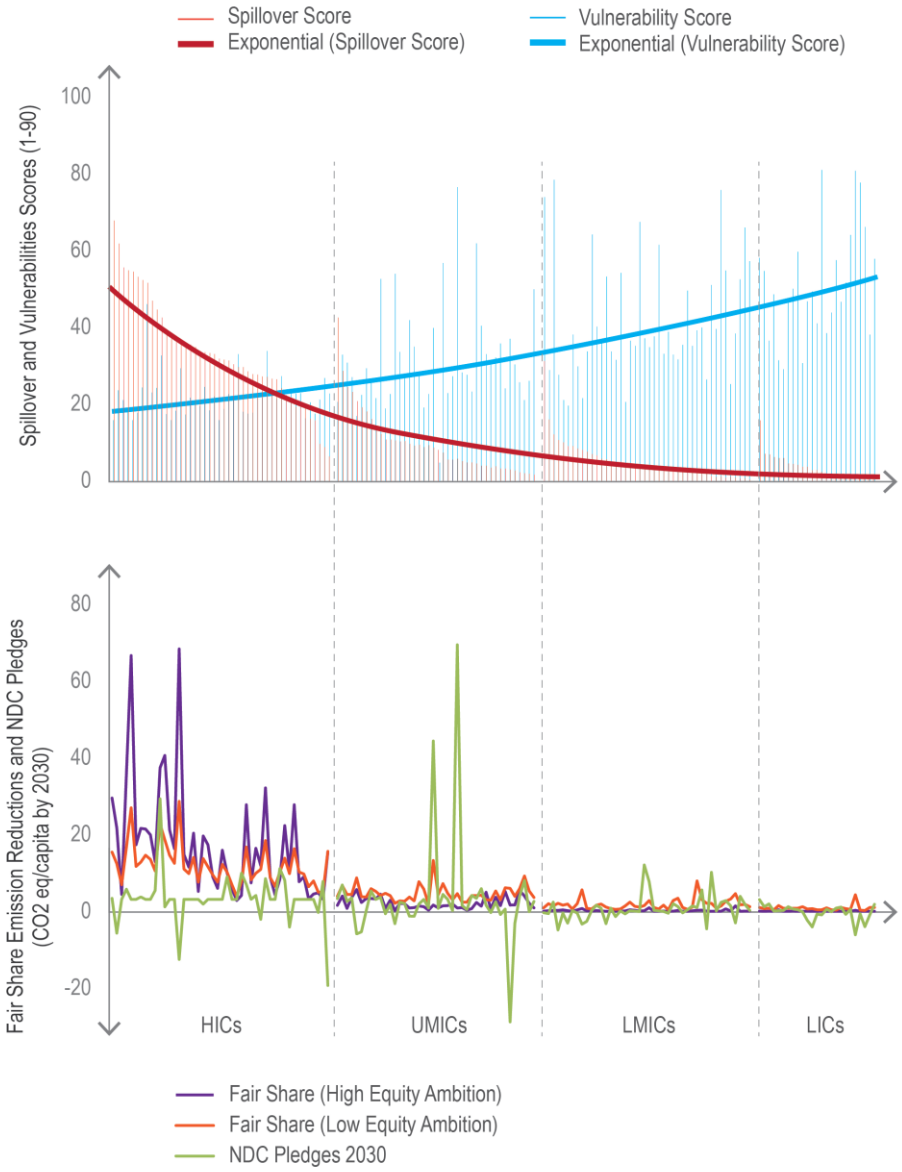

Figure 5.6: Common but Differentiated Responsibilities and Respective Capacities between high-, middle-, and low-income countries. The figure shows countries' vulnerability to climate change (blue), international spillovers (red), two 2030 'mitigation fair shares' for a 1.5°C consistent pathways (purple and orange line, respectively) and submitted Nationally Determined Contributed [NDC] pledges (lower ambition/unconditional) for 2030 (green line). Vulnerability and Spillover scores are shown along the left axis (0–90), with higher scores indicating higher vulnerability to climate change and higher international spillovers. The Vulnerability Score is a measure of a country's overall vulnerability to climate change, averaging the combined scores of the normalised Climate Change Vulnerability Index (Sachs et al., 2017), based upon HCSS, 2015) and the Notre Dame Global Adaptation Index (ND-GAIN, 2017). The Spillover Score is the degree to which development undertaken by one country negatively affects or forecloses development opportunities in other countries, that is, a measure of externalizing the costs of development, averaging nine normalised spillover indices grouped within three themes: environmental, finance and security (see Sachs et al., 2017). The blue and red dotted lines across the data set indicate trend lines (exponential) for the vulnerability score and spillover score, respectively, across the four income groupings. The Fair Share Emission Reduction Scores and NDC Pledges are shown on the right axis and are expressed in ktonnes CO_2 equivalent per capita ($ktCO_2$-eq/cap) against baseline, based on Holz et al. (2017) supplementary data, and the Climate Equity Reference Calculator (CERC, 2017). The 'high equity ambition' fair share score (most progressive) (purple line) is calculated using 1980 as the historical start

date, a development threshold of US$7,500, a luxury threshold of $50,000 (progressive between thresholds), and a 50:50 ratio between Responsibility and Capacity. The 'low equity ambition' fair share score (least progressive) (orange line) is calculated using 1990 as the historical start date, no development threshold and no luxury threshold, and a 50:50 ratio between Responsibility and Capacity. The NDC pledges for 2030 emission reductions (green line) are expressed in t/capita CO_2eq of mitigation below baseline, under the low ambition case Holz et al. (2017). Countries are grouped along the horizontal axis according to the World Bank 2017 income levels: High-Income Countries (HIC), Upper Middle-Income Countries (UMIC), Lower Middle-Income Countries (LMIC) and Low-Income Countries (LIC).

Recent literature suggests important contributions to climate change from non-state actors such as cities (Bulkeley et al., 2013, 2014b; Byrne et al., 2016), businesses (Frumhoff et al., 2015; Heede, 2014; Shue, 2017) and transnational initiatives (Andonova et al., 2017; Castro, 2016) and their responsibilities toward those affected by the damages (*medium evidence*, *medium agreement*). Strikingly, the contributions of 90 industrial carbon producers to the rise in atmospheric CO_2 (~57%), global mean surface temperature (~42–50%), and global sea level (~26–32%) over 1880–2010 (with two thirds of these during 1980–2010) has been highlighted (Shue, 2017; Heede, 2014; Ekwurzel et al., 2017). Hence, non-state actors, especially businesses, shape the potential of countries and citizens to pursue CRDP and, in turn, are shaped by the environment that determines their capacity to adopt low-carbon and climate-resilient trajectories and embark on transition pathways (see Chapter 4, Section 4.5).

At the level of groups and individuals, equity in pursuing low-carbon and climate-resilient development means deliberately focusing on well-being and strengthening the capabilities of people who are typically excluded, marginalised, and most vulnerable (Byrnes, 2014; Klinsky et al., 2017b; Tokar, 2014). Community-level CRDPs that focus on capabilities and capacities can provide an important complement to national trajectories, flagging potential negative impacts of state-level commitments on disadvantaged groups, such as low-income communities and communities of colour (Baer et al., 2008; Caney, 2009; Farrell, 2012; Rao et al., 2014). They underscore the crucial roles of social equity, participatory governance, social inclusion, and human rights, as well as innovation, experimentation, and collective learning (*medium evidence, high agreement*) (see emerging case studies and lessons learned in Section 5.6.3 and Section 5.6.4). This approach to CBDR-RC 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 (Klinsky et al. 2016). It is in alignment with transformative social development (UNRISD, 2016) and the 2030 Agenda of "leaving no one behind", aiming to preclude severe limitations in adaptive capacities while supporting transformation and strengthening resilience.

5.6.3 Emerging Country and Community Experiences with Climate-Resilient Development Pathways

Literaturedepicting different notions of sustainable development trajectories that are consistent with CRDPs as outlined above, degrees of global warming. Nonetheless, examples from case studies suggest four key aspects (outcomes), albeit not necessarily all at once: (i) enhanced adaptation and reduced vulnerabilities; (ii) stringent emission reduction; (iii) the promotion of equity, fairness and justice; and (iv) poverty eradication and improved well-being for people and ecosystems.

This section provides insights from regional-, national- and community-level policy and planning efforts and experiences consistent with CRDPs and their core dimensions. Through the case studies that follow, it is possible to identify context-specific ingredients for successes and challenges encountered, across a variety of scales, and hence provide invaluable lessons for a 1.5°C warmer world. None of these examples reveals win-win (or triple-win) trajectories but instead complex trade-offs along a continuum of '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; UNRISD, 2016; von Stechow et al., 2016).

5.6.3.1 Regional and State-led Efforts Toward Climate-resilient Development Pathways: Green States, Low-carbon Economies, and National Planning and Partnerships

Various development models and pathways exist, known under various lavels (e.g., green growth, inclusive growth, de-growth, post-growth, and developemt as well-being rather than growth) as well as region-speficic pathway planning and partnership approaches. States play an important role in reconciling low-carbon pathways with sustainable development and ecological sustainability. This section offers two examples.

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). Important insights stem from 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 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 criticism (Brockington and Ponte, 2015; Wanner, 2014), 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 poverty eradication, 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). States from the Global North, especially the Scandinavian countries that rank top in the Global Green Economy Index/Social Progress Index (2016), have embraced the concept of 'green states' earlier on (Tienhaara, 2014; Ferguson, 2015; Duit et al., 2016; Bäckstrand and Kronsell, 2015; Han, 2015; Bell, 2015; Kim and Thurbon, 2015; Bell, 2016), yet several high-income countries also show high spill-over effects due to the out-sourcing of their emissions (Holz et al., 2017) (see Figure 5.6). An alternative is a 'thick green' perspective that emphasises equitable de-growth beyond GDP reduction, democracy and empowerment of civil society, including marginalised groups, and justice that alters the global economy's very structure (Buch-Hansen, 2018; Ehresman and Okereke, 2015; Lorek and Spangenberg, 2014; Schneider et al., 2010) (see also Chapter 4, Section 4.5).

Several countries from the Global South, including China, India, Brazil, and South Africa, have been described as 'emerging green states' (Death 2014; Death 2015), despite concerns over lacking budgets, high unemployment or repressive regimes, and more urgent development priorities (Chandrashekeran et al., 2017; Brockington and Ponte, 2015; Cock, 2014). Brazil, for instance,has 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, coupled with the creation of green jobs, a boost in renewables and sustainable transportation (Brown et al., 2014; La Rovere, 2017) and social welfare programs tied to payment for ecosystem services (e.g., the now discontinued *Bolsa Verde*). The latter demonstrated success in poverty reduction, sustainable forest use practices, and more equitable decision making with community participation (Cook et al., 2012; Coudel et al., 2015; OECD, 2015; Schwarzer et al., 2016; Pinho et al., 2014; Börner et al., 2013; Gebara, 2013). Yet, wider concerns remain relating to Brazil's persistent inequalities, large-scale hydroelectric projects, monetisation of ecosystems, and lack of participation in green-style projects (Brown et al., 2014) as well as the labour conditions in the country's Brazil's growing sugarcane ethanol sector and associated potentials for displacement (McKay et al., 2016).

Such openings for low-carbon transitions in non-OECD countries, even if contradictory and incomplete, may boost stronger efforts (Stern, 2015) and provide vital lessons for CRDPs. Most national strategies are distinctly state-driven, ranging from Ethiopia's 'Climate-resilient Green Economy Strategy' and Mozambique's Green Economy Action Plan' to ecosystem- and conservation-driven green transition paths adopted in Costa Rica and other Latin American countries to China's and India's technology and renewables pathways (Brown et al., 2014; Chen et al., 2015; Death, 2014, 2015, 2016; Khanna et al., 2014; Kim and Thurbon, 2015; Wang et al., 2015; Weng et al., 2015). Reconciling low-carbon pathways with inclusive development in oil-producing countries provides complex economic and ethical challenges, due to stranded assets (e.g., Caney, 2016; Bos and Gupta, 2017)(see Box 5.2). Experiences with low-carbon resilient development approaches in Least Development Countries (LDCs) highlight the crucial role of identifying synergies across scale, removing institutional barriers, and ensuring equity and fairness in distributing benefits as part of the right to development (see also Section 5.5) (Fisher, 2013b; Rai and Fisher, 2017).

[START BOX 5.2 HERE]

Box 5.2: Low-Carbon Pathways in Oil-Producing Countries

The Gulf Cooperative Council (GCC) region is characterised by high aridity, vast low costal lands, and fragile ecosystems as well as high dependency on hydrocarbon resources (natural oil and gas), which together make the region vulnerable to both the physical impacts of climate change and the socioeconomic impacts of policies and response measures to address climate change. The region is vulnerable to water stress (Evans et al., 2004; Shaffrey et al., 2009), desertification (Bayram and Öztürk, 2014), sea level rise, and high temperature and humidity with future levels potentially beyond human adaptability (Pal and Eltahir, 2016). Economically, the region is vulnerable to the negative impacts of climate change response measures on the global demand and price of hydrocarbons, given that oil and gas revenues accounted for ~70% of government budgets and contributed > 35% to the region's GDP in 2010 (Callen et al., 2014). The region is projected to face the highest costs from global GHG emission reduction pathways consistent with 2°C stabilization, regardless of the policy design, with average loss > 10% in present value consumption from business-as-usual scenarios compared to a world average cost of 1.5% (Leimbach et al., 2010; Massetti and Tavoni, 2011), with even higher losses expected under a 1.5°C compatible trajectory.

A low-carbon pathway that manages climate-related risks within the context of sustainable development and 1.5°C warming requires an adaptation approach that jointly addresses both types of vulnerabilities (Al Ansari, 2013; Babiker, 2016; Griffiths, 2017; Lilliestam and Patt, 2015). Rising per-capita GDP, energy and CO_2 intensities, and large carbon footprints (Babiker, 2010; Babiker and Fehaid, 2011) suggest difficult trade-offs between mitigation measures and economic development. Yet, there are emergent opportunities for energy price reforms, energy efficiency, turning emissions in valuable products, and deployment of renewables and other clean technologies, if accompanied with appropriate policies and in the context of economic diversification (Atalay et al., 2016; Luomi, 2014; Griffiths, 2017a; Griffiths, 2017b). The offered INDCs for GCC countries identified energy efficiency, deployment of renewables, and technology transfer to enhance agriculture, food security, protection of marine, and management of water and costal zones (Babiker, 2016). The renewables deployment potentials in the region are large, including the "Estidama" Initiative and Abu Dhabi'2 Plan 2030, and UAE 2050 Strategy for UAE; and Vision 2030 for Saudi Arabia (IRENA, 2016), yet their exploitation is currently limited by economics and structural challenges (Griffiths, 2017; Lilliestam and Patt, 2015). The deployment of renewables in planned mostly for electricity generation, ranging from 5% by 2030 for Bahrainto 25% by 2030 and 75% by 2050 for UAE (Griffiths, 2017).

The United Arab Emirates (UAE) is at the forefront among the GCC and Middle East and North African (MENA) countries in the development and deployment of renewable energy. UAE hosts the flagship renewables development project "Masdar" intended to be "The world's most sustainable eco-city" featuring a global clean technology hub, the world's first carbon-neutral zero waste city, and recently became the headquarter of the International Renewable Energy Agency (Angelidou, 2017; Cugurullo, 2016; IRENA, 2016). Masdar, inspired by the UAE Vision 2030, is a commercially driven, international renewable energy and sustainability company that advances solutions in energy, water, urban development and clean technologies in and outside the UAE (Cugurullo, 2013, 2016). Masdar city is a $20 billion emerging global clean-technology cluster that places its resident companies in the heart of the global renewable energy industry (Cugurullo, 2016). "Mubadala", a renewables company under Masdar, is advancing the development, commercialization and deployment of renewable energy solutions and clean technologies, establishing Abu Dhabi as a global centre of excellence in the renewable energy and clean technology sector

(Masdar, 2017). Under Masdar, "Shams1" is the largest concentrated solar power (CSP) plant in the region with a capacity of 100 MW developed through a BOO (Build Operate and Own) contract to feed the emirate of Abu Dhabi (Cugurullo, 2013; Masdar, 2017). UAE has the best frameworks in place for renewable energy deployment in the GCC and MENA context (Mondal et al., 2016) and is known for innovative pricing and methods of financing, for instance power auctioning, with Dubai leading in utility-scale solar PV auctions (Griffiths, 2017). The Power Purchase Agreement (PPA) for Dubai's first phase of renewable energy solar park of 200 MW was auctioned at a record low price of $0.0584 per kWh in March 2015. The auction for the third phase of the park in 2016 resulted in the lowest ever bid for solar PV of $0.0299 per kWh (Griffiths, 2017).

[END BOX 5.2 HERE]

The example of Small Pacific Island Development States (PSIDS) highlights other vital aspects of regional- and state-level planning and partnership efforts consistent with core dimensions of CRDPs. For most PSIDS, climate change poses a severe risk to sustainable development (*medium evidence, high agreement*). Since the AR5 – IPCC (2014), emerging literature has examined opportunities for PSIDS to coordinate national adaptation planning to advance the 2030 Agenda for Sustainable Development, respond to global climate change objectives of Paris and reduce the risk of disasters in line with the Sendai targets (FRDP, 2016; McCubbin et al., 2015; Nunn and Kumar, 2017; Shultz et al., 2016).

The SAMOA Pathway: SIDS Accelerated Modalities of Action (United Nations, 2014a) prioritised partnerships for adaptation to climate change as the immediate and urgent global priority for SIDS, considering their special needs and vulnerabilities to climate change, complex risks and the potential of climate change to adversely affect their efforts to achieve sustainable development (Steering Committee on Partnerships for SIDS and UNDESA, 2016). There is agreement that developing and enhancing the resilience of national economies and communities to climate change is a priority for most Pacific Island Countries (PIC) (Government of Kiribati, 2012, 2016; Lefale et al., 2017; MELAD, 2012).

However, PSIDS have varied access to human, institutional, social and financial resources at the national, island/provincial, and village/local community, particularly in small states like Kiribati, Nauru, and Tuvalu, to meet obligations under the UNFCC and achieve and maintain sustainable, resilient development (Barnett and Walters, 2016; Cvitanovic et al., 2016; Hemstock, 2017; Michalena and Hills, 2018).

Pacific Island communities have different approaches to the application and integration of 'resilience' and 'development' in national planning contexts as a result of differing social contexts and experiences of economic development and access to human, technical, institutional and financial resources including regional and international support (Aipira et al., 2017; Bell et al., 2016; Buggy and McNamara, 2016; Cabezon, 2015; Janif et al., 2016; McNamara and Buggy, 2017; Robinson and Dornan, 2017).

Climate resilience planning for the short to medium term may be insufficient to address increasingly complex, severe climatic impacts over time (Dilling et al., 2015). However. regionally related efforts to develop and implement climate-resilient community planning frameworks have been established in Papua New Guinea, Timor Leste, and Vietnam (Sterrett, 2015a). The Pacific Risk Resilience Programme (PRRP) also aims to provide guidance and advice to Fiji, Solomon Islands, Tonga and Vanuatu on ways 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 (UNDP, 2016). The Republic of Vanuatu is leading the PSIDS to develop a national plan coordinated across government departments and other sectors (MCCA, 2016)(see Box 5.3).

[START BOX 5.3 HERE]

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

The Republic of Vanuatu has developed a national response to climate-resilient development in the context of high exposure to hazard risk (UNU-EHS, 2016). Despite rapid urbanisation (ADB, 2013), an estimated 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 (Aipira et al., 2017; Gov of Vanuatu, 2015).

While Vanuatu faces severely constrained adaptive capacity (Gov of Vanuatu, 2015; Kuruppu and Willie, 2015; Sovacool et al., 2017a), it has developed a national level sustainable development plan for 2016 to 2030, also referred to as the People’s Plan (Republic of Vanuatu, 2016). This overarching national plan of action on economy, environment, and society aims to build adaptive capacity and resilience to climate change and disasters. It emphasises the importance of a single focal institutional point, coordinating an inclusive planning response that considers the rights of all Ni-Vanuatu including women, youth, the elderly and vulnerable groups are promoted in relevant institutions (Nalau et al., 2016). Vanuatu has also developed a Coastal Adaptation Plan (Republic of Vanuatu, 2016) and an integrated Climate Change and Disaster Risk Reduction Policy (2016–2030) that sets out directives for the implementation of CC and DRM initiatives. The first South Pacific national advisory board on Climate Change & Disaster Risk reduction (NAB) at a national level was established in Vanuatu in 2012 (UNDP, 2016). This is the policy making and advisory body for all disaster risk reduction and climate change programs, projects, initiatives and activities.

Vanuatu’s National efforts aim to integrate planning at multiple scales, and increase climate resilience by supporting local coping capacities and iterative, inclusive processes of sustainable development and integrated risk assessment (Aipira et al., 2017; Eriksson et al., 2017; Granderson, 2017; Sovacool et al., 2017b). Climate resilient development is also supported by non-state partnerships for example 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 (Davies, 2015; Ensor, 2016; UN Women, 2016); and local participation in climate- smart agriculture (Ensor, 2016; Sterrett, 2015b). The aim is to limit external NGO influence to providing access to information so that communities are empowered to address structural and agency constraints, and local technical and decision making capacity is enhanced (Ensor, 2016; Maclellan, 2015).

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 barriers to women’s participation (Aipira et al., 2017; Granderson, 2017; McNamara and Prasad, 2014). The experience of the low death toll after Cyclone Pam, despite significant infrastructure damage suggests absence of storm surge flooding combined with effective use of local knowledge in planning and early warning climate can support resilient development pathways in a 1.5°C warmer world (Handmer and Iveson, 2017). Yet, ongoing power imbalances embedded in the political economy of development and climate finance programs also tend to marginalise the priorities of local communities(Addinsall et al., 2017; Baldacchino, 2017; Sovacool et al., 2017b).

Relationships defined by power and cultural norms often continue to shape how local risks are understood, prioritised and managed (Kuruppu and Willie, 2015). However a focus on more equitable decision making has been identified as the basis for future adaptive actions that will benefit the whole community (Aipira et al., 2017; Ensor, 2016). Climate resilience is also supported when decision making integrates ecosystem, community and social planning in resource management (Sovacool et al., 2017a; Sterrett, 2015a). The serious damage of Cyclone Pam 2015 highlights the benefits and limits of resilient development effort by individual SPIDS (Ensor; Handmer and Iveson, 2017) .

[END BOX 5.3 HERE]

5.6.3.2 Community-led And Bottom-up Approaches to Climate-resilient Development Pathways

Communities – both communities of practice and place-specific communities – also play an important role regarding pathways to low-carbon, sustainable development trajectories that simultaneously promote fair and equitable climate resilience. Their efforts reveal different angles to CRDPs, equally partial and incomplete, just as those at the level of countries and regions. The two case studies below depict examples from the perspective of alternative development pathways, with experiences from Latin America (Box 5.4), and community- and ecosystem-based practices in drylands, mainly from Africa (Box 5.5). A third case study on Transition Towns is presented in the Cross-Chapter Box 5.1.

[START BOX 5.4 HERE]

Box 5.4: Alternative Development Pathways and Transnational 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., 2017a), with roots in environmental and food justice (Agyeman et al., 2016; Alonso-Fradejas et al., 2015; Edelmann and Borras, 2016; Martinez-Alier et al., 2016) and social and solidarity economies (SSE) (Avelino et al., 2016; Chamorro and Utting, 2015; Grasseni et al., 2013; UNRISD, 2016; Utting, 2015). 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 well-being 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, 2017a) and reveal culturally-appropriate opportunities to foster resilience to climate and other disturbances (Sietz and Feola, 2016), important prerequisites 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 (Agarwal, 2014; Desmarais et al., 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; Gupta and Pouw, 2017; McAfee, 2016; PWGAD, 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)**.**

[END BOX 5.4 HERE]

The second example illustrates community-based drylands practices at scale, as an illustration of a transition toward CRDPs. Drylands, comprising heterogenous agroecological zones, are climate change hotspots (see Chapter 3, Section 3.3.15) where the protracted climate stress encountered is particularly challenging for building resilience (Fuller and Lain, 2017). Small-scale farmers in drylands are important agents of change in transforming food systems to efficiency and climate resilience (IRP, 2016); their role will be crucial in a 1.5°C development pathway. Cases of ecosystem- and community-based practices at scale that bring together adaptation, mitigation and development provide insights for achieving climate resilience in these vulnerability hotspots. Examples include: (i) farmer managed natural regeneration of trees in cropland (FMNR) in sub-Saharan Africa, and (ii) catchment rehabilitation using a range of sustainable land-water management practices in India and Ethiopia (see Box 5.5). With appropriate policy support, fostering enabling conditions, such as those which strengthen community land and forest rights farmer managed systems have the potential to spread (Stevens et al., 2014, Vermuelen et al., 2015), become pathways to resilience and serve as loci for transformation to CRDPs.

These cases embody enabling conditions required for CRDPs in including adaptive planning and management and ongoing learning (Gray et al., 2016); giving greater voice to women and to marginalised groups (Dumont et al., 2017); and the important role of social learning (Coe et al., 2014; Dumont et al., 2017; Epule et al., 2017; Isaac et al., 2007). Social learning is linked with building adaptive capacity (see Section 5.6.4), and is the primary mechanism for scaling up community-based successes and building a grassroots movement to focus on mindset change and agency (Binam et al., 2017; Dumont et al., 2017; Reij and Winterbottom, 2015).

An ongoing multi-institution project in East Africa and the Sahel (Ethiopia, Niger, Mali, Tanzania and Kenya), promotes nested communities of practice at different scales that include farmers, facilitators, extension, research, development and governance institutions, to facilitate an iterative co-learning cycle of action research (Coe et al., 2014; Sinclair, 2016). The role of social learning in FMNR indicates an evolution towards a promising CRDP, in which the politics of producing knowledge are opened up through the process of knowledge co-production. However, more evidence is needed on the impacts of FMNR on social equity, soils, water, non-economic livelihood benefits, microclimate, carbon sequestration, as well as on enabling governance frameworks (Francis et al., 2015; Weston et al., 2015).

The policy environment conditions the diffusion and scaling-up of the community-based approaches to climate-resilient development. Policy recognition and support to holistic agroforestry and farmer managed natural systems creates enabling conditions and provides the needed resources for the diffusion and spread of community based CRDPs. This is seen for some countries, such as in the case of Kenya's low carbon CRDP (Government of Kenya, 2012). In the case of MERET, its mainstreaming into the larger Sustainable Land Management Programme (SLMP) and other programs implies that MERET's community-driven triple-win approach has become the corner-stone of Ethiopia's ambitious drive for building a climate-resilient and a green middle-income economy within a decade, as envisioned in the country's NDC and national strategies. The National Mission for a Green India, as a mission under the National Action Plan on Climate Change, focuses on multiple ecosystem services along with carbon sequestration, and envisages a key role for local communities as it seeks to reach various targets such as social forestry/agroforestry over 3 million hectares and the NDC commitment of enhancing the carbon sink substantially by 2030 (Ministry of Environment and Forests).

Current constraints to these community-based practices at scale as the basis for CRDPs in different dryland regions include inadequate attention to socio-technical processes of innovation, as well as to beyond-farm elements of the farming system (Grist et al., 2017; Scoones et al., 2017b), and contestations with the prevalent agricultural modernisation paradigm in Africa (Coe et al., 2017; Reij and Winterbottom, 2015); there remain also uncertainties about the impact of climate change on agroforestry systems; institutional inability to deal with long term climate risk at local scale by farmers (Singh et al., 2017a) and in case of MERET, matching of specific practices with agro-ecological conditions and complementary modern inputs (e.g., Kassie et al., 2015; Kato et al., 2011; Gebremedhin and Swinton, 2003). In general, the social, equity and governance dimensions and barriers of community-based practices at scale are not well documented and analysed. Policy support to overcome some of these constraints, creation of enabling conditions and support to research-in-development approaches to increase the evidence basis (Coe et al., 2014), would assist these community-based, large scale initiatives to transformation into climate-resilient development pathways in drylands.

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Box 5.5: Cases of Ecosystem- and Community-based Practices in Drylands

FMNR is practised in 18 countries across Sub-Saharan Africa, Southeast Asia, Timor-Leste, India and Haiti. Using community-based FMNR, farmers have restored over five million hectares of land in the Sahel (Bado et al., 2016; Haglund et al., 2011; Niang et al., 2014). In Ethiopia, the Managing Environmental Resources to Enable Transitions (MERET) programme entails community-based watershed rehabilitation to address the root causes of vulnerability and food insecurity, including soil and water conservation, afforestation and water harvesting – thus a 'triple win' approach of enhancing resilience, climate mitigation potential (e.g., through increased forest cover), and productivity of rural landscapes (Gebrehaweria et al., 2016; Haileslassie et al., 2008). During 2012–2015, MERET supported around 648,000 people, resulting in the rehabilitation of 400,000 hectares of land in 72 severely food insecure districts across Ethiopia.

In India, meta-analysis of 311 watershed case studies from different agro-ecological regions has revealed that watershed programmes have benefited farmers through enhanced irrigated areas by 33.5%, increased cropping intensity by 63%, reducing soil loss to 0.8 t/ha and runoff to 13%, and also improved groundwater availability. The watershed programmes were reported to be beneficial and viable with a benefit–cost ratio of 1: 2.14 and an internal rate of return of 22% (Joshi et al., 2005). In a recent study, (Agoramoorthy and Hsu, 2016) reported climate adaptive and mitigating outcomes of small check dams in some dryland districts in India, namely, Dahod in Gujarat and Jhalawar and Banswara in Rajasthan and opined that scaling up such interventions will be a win-win strategy for farming communities in terms of increase agricultural output and reduction in local climate change consequences. The adoption of conservation agriculture as a climate adaptation strategy in rainfed agroecosystems by farmers increased production by 200% in Central India's tribal belt (Pradhan et al., 2018).

These low-cost, flexible community-based practices at scale have been adopted by tens of thousands of resource-poor, risk-averse farmers, and positively assessed as low-regrets adaptation strategies (across the globe) (Francis et al., 2015; Niang et al., 2014; Weston et al., 2015). Evidence suggests that elements of supportive enabling environments include developing agroforestry value chains and markets (Reij and Winterbottom, 2015), and implementing sequenced integrated landscape management approaches (Gray et al., 2016).

Mitigation benefits have been quantified (Weston et al., 2015); in Niger, these include sequestration of an estimated 25–30 Mtonnes of carbon over the past 30 years by the 5 million hectares of still immature trees under FMNR (Stevens et al., 2014). In Ethiopia, an impact evaluation indicated that nearly two-thirds of all MERET households stated that they had successfully escaped from poverty during the previous ten years, while less than half of non-MERET households stated the same (WFP, 2012). While few scientific studies have directly evaluated the environmental impacts of MERET, studies assessing the program's core attributes, that is, soil and water conservation and other community-driven environmental rehabilitation efforts find significant impacts of MERET-related interventions on productivity and resilience (e.g., Kato et al., 2011; Kassie et al., 2015).

Social, economic and environmental benefits achieved through FMNR encompass a number of the attributes of emerging CRDPs, including strengthened ecosystem resilience and biodiversity, increased agricultural productivity and food security for poor households, a range of psycho-social benefits including joy and peace of mind, improved health, livelihood diversification and reduced poverty, enhanced agency and social capital through collaborative communities of practice, and reduced time spent by women in gathering firewood (Bado et al., 2016; Dumont et al., 2017; Francis et al., 2015; Mbow et al., 2015; Niang et al., 2014; Pye-Smith, 2013; Reij and Winterbottom, 2015; Weston et al., 2015).

[END BOX 5.5 HERE]

[START CROSS-CHAPTER BOX 5.1]

Cross-Chapter Box 5.1: Cities and Urban Transformation

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Global Urbanisation in a 1.5°C Warmer World

Increasing urbanisation will be a key global trend in the next several decades as the world moves toward a 1.5°C increase in global temperature. It is estimated that there will be approximately 70 million additional urban residents every year through the mid part of this century (United Nations, 2014b). The vast major of the new urbanisation will be in small and medium sized cities in low- and middle-income countries that typically have limited capacity to adapt and mitigate climate change (Birkmann et al., 2016; Grubler et al., 2012a). Different regions of the world will experience different rates of increased urbanisation. The urbanisation rate in African countries will be especially high (Dodman et al., 2017; Gore, 2015). The new built environment and urban infrastructure being constructed, especially in the Global South, holds the potential to anticipate climate change but also raises significant questions of path dependency (Seto et al., 2014).

The process and character of urbanisation significantly influences cities' capacity to respond to climate change. Increase in urban population and urban land are associated with heightened resource demand driven by economic development (Huang et al., 2010). Resource demands on adjacent peri-urban areas and more distant locations (i.e., where critical resources are extracted and transported to cities) result in significant negative and positive impacts on rural economics, lifestyles, and territorial development (McGregor et al., 2006). Peri-urban zones, particularly those in low- and middle-income countries, will face the greatest demands given the simultaneous high rates of ongoing urbanisation(Dos Santos et al., 2017; Tian et al., 2017). The high level of people living under conditions of informality in these cities, limits the reach of formal governance and policy instruments. At the same time, growth in productivity driven by urbanisation and spatial development provides the economic and employment momentum to help finance climate resiliency and climate mitigation (Chu et al., 2017).

Multiple Interactions of Urbanisation and Environmental Change

Urbanisation is a significant driver of local, regional and global environmental change (Grimm et al., 2008; Marcotullio and McGranahan, 2007; Seto et al., 2014). At the local scale, urbanisation leads to a variety of ecological and environmental stresses and crises associated with environmental degradation and enhanced vulnerability, risk and impacts (Elmqvist et al., 2013). Urban and peri-urban dwellers most affected by environmental degradation often are vulnerable to climate change impacts, especially those living in informal settlements and conditions of informality (Revi et al., 2014). Conversely, urban densities present many opportunities for enhanced resource and energy use efficiency not available in lower-density population settings (Grubler et al., 2012b; Seto et al., 2014). Rural-to-urban migrants take advantage of these efficiencies as they adopt urban lifestyles (Nguyen et al., 2017; Shen et al., 2017).

The full complement of urban contexts including rural-to-urban linkages, through which migrants, resources and waste products flow and circulate, can be understood as a set of multiple, interlocking complex systems

(Dasgupta et al., 2014; Grimm et al., 2008; Revi et al., 2014). Urbanisation-focused systems include sociocultural-economic interactions (e.g., concerning class, gender [Chant et al. (2017)] race, ethnic and religious identities), governance structures (e.g., at the local, regional, and national scales – see Section 4.4.1 that deals with multi-level governance), urban infrastructure (e.g., the built environment including food, energy, waste, and water supply systems), and the interactions between the private and public, and formal and informal spheres.

Scalar Interactions of Governance, Resource and Waste Flow, and Economic Development

The structure and character of an individual city provide an urban metabolism and opportunities for reducing carbon and fostering resilience through adaptation (Carreón and Worrell, 2017). Rural-to-urban natural resource and waste flows connect higher density urban centres and extended metropolitan areas with their hinterlands bioregions. These links can enable opportunities for decarbonizing power and transport sectors, and creating adaptive responses to climate change (Newman et al., 2017). Governance of these resource and waste links also influence the rate of economic growth and equity, and how environmental stresses and risks are managed (Hughes et al., 2018).

At the international scale, the force of economic globalization significantly affects cities. These shifts result in changes in urban spatial development, income growth and inequities, and environmental stresses. Economic globalization is now continuing throughout much of the Global South and has implications for energy, transport, and water system infrastructure path dependency and the limiting of capacity to make mitigation and adaptation adjustments.

The Paris Climate Agreement NDCs will be promulgated at least in part through central governments to urban regions and local communities (Betsill et al., 2015). At the same time, the Agreement recognises the role of non-state actors in providing climate change solutions. Transnational coalitions of cities are at the forefront of climate solutions discussions and connect with national government policies and take part in international debates on climate change (Betsill et al., 2015; Bulkeley et al., 2014a; Hughes et al., 2018). Cities increasingly are connected with each other via bi-lateral or multi-lateral agreements and networks (Bouteligier, 2012). These linkages provide opportunities for advanced and accelerated collaborative learning and problem solving and emphasizing a city dimension in climate change negotiations (Johnson, 2018). Many networks have adopted or specifically focus on sustainability themes, and on climate adaptation and mitigation issues specifically (Fünfgeld, 2015).

Urban Transformations – Connections of Adaption and Mitigation and Emerging Climate-Resilient Development Pathways

City governments, non-governmental organizations, enterprises, and residents understand the effects climate change has on everyday life in their city (Bouteligier, 2015). At the same time, urban populations recognise the many other urban challenges, such as economic stagnation, social inequity, poverty, marginality, insecurity, and violence, and environmental pollution. Climate change interacts with and exacerbates many of the other stresses and crises in urban areas. For example, urban resource shortages (e.g., water), climate-triggered stress (e.g., extreme events) and social inequity are increasingly intertwined (Birkmann et al., 2016; Garschagen and Romero-Lankao, 2015). Conversely, climate mitigation including the advance of lower carbon-emitting transit options has immediate positive local impacts on urban air quality.

Cities have the potential for transformational adaptation and mitigation in part due to the concentration of economic activity and population, dense social networks, human resource capacity, high levels of investment in infrastructure and buildings, relatively nimble local governments, close connection to surrounding rural and natural environments, and a tradition of innovation. Local governments are closer to citizens and citizens' needs than central government. In addition, urban spaces offer a physical arena where local issues and solutions can be discussed and addressed (see case study on Transitions Towns below). The disruptive innovations of rooftop solar and other small-scale local technology for water and waste are happening in growing cities and can be used to leapfrog into a decarbonized, resilient and inclusive future, especially in slum renewal (see case study on Addis Ababa below). Electric vehicles and IT services are fast emerging solutions that contribute to city decarbonisation and enhanced air quality and life quality. Bringing financial and administrative resources from outside the city from regional, national and international sources also provides advantages for cities (Colenbrander et al., 2016). Overall, cities are increasingly key sources of solution-based policy transitions required to address the global challenge of the Sustainable Development Goals (SDGs) and promote opportunities for the climate-resilient, sustainable development pathways.

Transition Towns (TTs) represent one example of how urban communities have begun to experiment with putting aspects of climate-resilient sustainable development pathways into practice. The grassroots TT movement (begun in the UK in 2005) combines adaptation, mitigation, and just transitions, mainly at the level of communities and towns. It now has >1,300 registered local initiatives in >40 countries (Grossmann and Creamer, 2017), although mostlyin 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 (Evans and Phelan, 2016; Feola and Nunes, 2014; 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 (Barnes, 2015; North and Longhurst, 2013; Staggenborg and Ogrodnik, 2015; Taylor Aiken, 2016). Social and iterative learning through the collective involves dialogue, deliberation, capacity building, citizen science engagements, technical re-skilling to increase self-reliance, 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 (Nicolosi and Feola, 2016; North and Longhurst, 2013). Increasingly, TTs recognise the need to participate in policy making to overcome the 'post-political trap' (Barnes, 2015; Kenis and Mathijs, 2014).

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). In the UK, expectations of innovations growing in scale (Taylor Aiken, 2015) and carbon accounting methods required by funding bodies (Taylor Aiken, 2016) undermine local resilience building. Tension between explicit engagements with climate change action and efforts to appeal to more people have resulted in difficult trade-offs and strained member relations (Grossmann and Creamer, 2017). In the rapidly growing cities of South Asia and Africa, it is not yet clear that TTs are able to address the need for bulk infrastructure, shelter, clean energy and mobility that underpin climate change vulnerability (van Noorloos and Kloosterboer, 2017; Wachsmuth et al., 2016). Some of the coping strategies forged by citizens of developing countries, in the absence of public urban services, share attributes of flexibility, brokering, and partnership with TTs, and efforts have been able to harness low-carbon energy, sanitation and waste management technologies (Brown and McGranahan, 2016). There is no guarantee, however, that these strategies will evolve and cohere into the type of service delivery and climate governance system that prevails in many more developed cities (Jaglin 2014).

Transformations in informal settlements and urban slums illustrate a different set of opportunities and challenges, seen through the lens of contributions to the SDGs. Addis Ababa, for instance, like many developing country cities, has a high level of informal settlements (up to 80%) (Assefa and Newman, 2014). The question facing many such cities is how these informal settlements can be upgraded to achieve a reduction in GHG emissions (SDG 13) while enabling economic and social goals to be achieved as set out in the other SDGs (United Nations, 2015c).

Two approaches are at play in Addis Ababa. One is urban renewal based on slum clearance and transfer to high rise dwellings; the other is urban regeneration based on in situ upgrading of infrastructure using solar energy and other community-based distributed infrastructure (OECD, 2011; Satterthwaite, 2016). Data from three existing slums have been compared to two urban renewal high-rise complexes in Addis Ababa, where residents were transferred from slums (Teferi submitted).

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

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

[END CROSS-CHAPTER BOX 5.1]

5.6.4 Sustainable and Climate-resilient Development Pathways: Enabling Conditions and Lessons Learned

The broader empirical evidence, including the above case studies (Boxes 5.2 – 5.5), shows that few resilience pathways initiatives exemplify all characteristics of CRDPs as described in Section 5.6.2, due to a number of factors: (a) the complexity of the task; (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 (e) the temptation of shorter-term economic gains and power relations over longer-term and more far-reaching social and environmental justice solutions. Thus, 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). There is limited but growing evidence on how to transform development and societies while simultaneously addressing the climate change challenge and enhancing well-being for all.

Emerging evidence suggests that far reaching transformation to address climate change challenges and enhance well-being is more likely to be regarded as legitimate by local populations when it pays attention to just outcomes for those negatively affected by change (Cervigni and Morris, 2016; Dilling et al., 2015; Keohane and Victor, 2016; Naess et al., 2015; Newell et al., 2014a; Sovacool et al., 2015). However, it should be noted that there is not consensus on the direction of social transformation to address climate change. Lessons learned from the empirical evidence and emerging literature suggest four wider enabling conditions may advance CRDPs, these are: inclusive governance, social learning; equity and justice, and monitoring and evaluation.

5.6.4.1 Inclusive Governance

Emerging literature since AR5 and empirical evidence highlight the importance of inclusive governance in achieving CRDPs. Robust institutions, cross-institutional partnerships, and multi-scale communication can also help facilitate the development of policy pathways for transformation in complex decision making contexts (Di Gregorio et al., 2017a; Duguma et al., 2014a; Somorin et al., 2015). The growing role of citizens, cities, businesses, labour movements, governments, non-governmental organizations and international agencies in promoting climate policy transformation has also led to more co-production of policy, and a need for governance approaches at national, regional and international levels that can coordinate, and monitor multi-scale policy actions and trade-offs in the course of implementing national goals for 1.5°C (Ayers et al., 2014; Clark et al., 2016; Gwimbi, 2017; Hale, 2016; Hayward, 2017; Maor et al., 2017; Roger et al., 2017; von Stechow et al., 2016; Webber, 2016). Local governments also play a pivotal role in linking climate change policies to other multi-scalar developmental priorities (Rescalvo et al., 2013; Wamsler et al., 2014).

At the national level, progress in developing key capacities for resilience (Väänänen et al., 2017) as well as building transparency and accountability through support for and tracking of impacts of climate finance (Governance of Climate Change Finance Team (UNDP Bangkok Regional Hub) and Adelante, 2015; Terpstra et al., 2015) can contribute to the equity and effectiveness of sustainable development pathways toward a 1.5°C warmer world and CRDPs. Inadequate monitoring and regulatory measures though may hamper more fundamental transformations (Chandrashekeran et al., 2017; Cock, 2014). Inclusive decision making can reduce compliance costs over time and enhance the ease of implementation, even in the absence of consensus or where decisions are controversial (DeCaro et al., 2017; Maor et al., 2017). At the same time, deliberative governance models that allow space for transformational agency, creative friction, and agitative actors may harbor greater potential for overcoming inertia and engendering far-reaching change (Evans and Reid, 2014; Gillard et al., 2016; Westley et al., 2013).

Solution-driven approaches rather than top-down steering have shown to reduce inequalities, advance well-being and distributive justice, and foster transformative change across the17 SDGs, operationalized best at regional levels (Hajer et al., 2015). Approaches with such transformative potential are expected to be 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 2016:10). Examples include social policies that adhere to principles of social and solidarity economy (SSE) and promote cooperation, solidarity, democratic governance, collective action, active citizenship, and environmental stewardship (Agarwal, 2015; Bauhardt, 2014; Laville, 2015; McMurtry, 2013; Utting, 2015; Wallimann, 2014) (see also Box 5.4).

5.6.4.2 Social Learning

Evidence across scales, from strategic new alliances in green states to Transition Towns re-skilling (Boxes 5.2–5.4) underscore the vital role of social learning for climate resilient development, including efforts to stay within the 1.5°C target and beyond. Given uncertainties in the 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 can facilitate accelerated adaptive management of adaptation-mitigation-development processes, and foster deliberate processes that incorporate values, world views, and different types of knowledges in a more inclusive decision space (Cundill et al., 2014; Butler et al., 2016b; Fazey et al., 2016; Gillard et al., 2016; Gorddard et al., 2016b; Fook, 2017). Knowledge co-production in climate resilience planning and implementation processes is a recognised mechanism for social learning, important in blending indigenous, local and scientific knowledge to support climate resilient development processes; 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; Harvey et al., 2017; Turnheim et al., 2015; Bataille et al., 2016). The link between social learning and building adaptive capacity is recognised in the literature, and studies increasingly explore tools for, monitoring of and the impact of social learning in complex inter-linked challenges such as climate resilient development processes; accomplished facilitation and recognising social difference to prevent co-option by more powerful actors are central to a successful outcome (Ensor and Harvey, 2015). (Lotz-Sisitka et al., 2015) highlight the potential for social learning to enable a transgressive approach to prevent resilience of unsustainable systems that could be maladaptive; such an approach could be important in enabling transformative social change in a 1.5°C pathway. 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 (Aipira et al., 2017; Ensor, 2016).

5.6.4.3 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; Agyeman et al., 2016; Fook, 2017; Schlosberg et al., 2017). Yet, the large majority of case studies reveal wider dynamics can exacerbate existing vulnerabilities and inequalities and further undermine the rights and voices of the disadvantaged, often when market-based or development approaches marginalise local experiences of human well-being and equity, poverty eradication, empowerment, and access to resources (Boxes 5.2–-5.4). Power, knowledge, authority, and subjectivities all determine which pathways become dominant and normative and which get side-lined (AMCOW et al., 2012; Wise et al., 2014; Ensor et al., 2015; O'Brien et al., 2015; Fazey et al., 2016; Pelling et al., 2016; Tschakert et al., 2016), as well as which actors determine the meaning of transformational change (Winkler and Dubash, 2016). Failure to attend to underlying or new inequalities during times of change can reinforce the status quo or create new injustices rather than encouraging far reaching and equitable transformational change (Buggy and McNamara, 2016; Cervigni and Morris, 2016). Procedural justice dimensions skewed toward exclusive participation and decision making reinforce structural institutional barriers constraining the achievement of CRDPs (Barrett, 2013; Reed et al., 2015; Shackleton et al., 2015a; Simonet and Jobbins, 2016; Bedelian and Ogutu, 2017).

5.6.4.4 Indicators, Monitoring, and Evaluation

Strengthening the evidence base and improving monitoring for sustainable development pathways to 1.5°C and CRDPs will allow for greater effectiveness through enhanced adaptive management and will promote procedural and distributive justice, including gender equity (Bryan et al., 2017; Fuller and Lain, 2017; Wood et al., 2017)While very limited literature currently exists on evaluating emerging CRDPs, important lessons can be gleaned from growing M&E of existing resilience, adaptation and development and triple-win programs (e.g.,Fuller and Lain, 2017; Mukute et al., 2017). Pertinent issues are what criteria are used, how they are identified, by whom, how, and over which time frames, particularly with the aims of inclusiveness, iterative learning, and empowerment (Atteridge and Remling, 2017; Fuller and Lain, 2017). Some positive examples include context-specific, participatory and locally developed criteria for assessing climate-resilient livelihoods (Fuller and Lain, 2017; IFAD, 2016), impact evaluation given that long-term results need to be assured (Lain, 2017), and frameworks for structured experimentation targeted at decision makers and practitioners (e.g., USAID 2014). 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; Mukute et al. 2017). Additionally, monitoring and evaluation programmes need to incorporate composite measures and coupled, non-linear effects of response diversity and connectivity as key resilience factors shaping sustainable development pathways for 1.5°C and CRDPs (Sietz and Feola, 2016; Speranza et al., 2014), to enhance the capacity of a socio-ecological system to withstand disturbance or to transform and enter a new, more sustainable development trajectory.

For a full understanding of equity and effectiveness of resilience pathways initiatives, qualitative as well as quantitative indicators are required, such as those tracking social and institutional capability (Fuller and Lain, 2017; Lain, 2017)agency and capacity for learning and knowledge sharing and management (Mukute et al., 2017; Speranza et al., 2014), and experimentation and innovation (Lain, 2017; Speranza et al., 2014); effective feedback loops are necessary between bottom-up and top-down monitoring and reporting frameworks (Fisher and Karani, 2015; Mukute et al., 2017; Speranza et al., 2014). At the municipal level, early insights from Transition Towns recommend a small set of measurable indicators, for example 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). In Mozambique and Uganda, participatory development of national standard climate indicators that were context- and gender-sensitive led to transformation of governance systems (Mukute et al., 2017). Meta-analyses have indicated that most M&E frameworks for adaptation do not adequately track maladaptation potential (Atteridge and Remling, 2017); this is an important gap that emerging monitoring and evaluation processes for climate-resilient development pathways will need to fill.

5.7 Synthesis and Research Gaps

This section concludes Chapter 5 as well as the entire Special Report. It summarises what is known about the 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 discusses the enabling conditions and challenges arising from the interactions between these factors over time for re-orienting global society towards sustainable and climate-resilient development pathways. These pathways harbour the potential for limiting the rise in global temperatures to 1.5°C above pre-industrial levels while achieving sustainable development objectives, poverty eradication and reducing inequalities, 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 given the consequences of failing to do so, particularly with respect to inequalities and social, cultural, and biophysical losses. The two objectives of limiting temperature increases and associated negative impacts, and achieving development and the SDGs, poverty eradication and reduction of inequalities worldwide are mutually reinforcing. Reducing climate impacts through ambitious mitigation and effective adaptation is a key condition for meeting sustainable development objectives, and sustainable development patterns are the key enablers for effective actions for limiting climate impacts. Yet, it is also challenging as these alternative pathways, grounded in fairness and justice and embedded in integrated adaptation and mitigation approaches, go hand in hand with conscious social transformations.

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. The transformations towards the dual goal of sustainable development and 1.5°C involve profound changes of development patterns at all scales, and require taking into account the specific circumstances of each context and the articulation over time between short-term actions and longer-term objectives. This chapter and the preceding chapters have assessed the challenges of implementing these transformations and enabling conditions. 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 ethical, liveable, equitable, and justifiable to generations to come.Emerging literature on development pathways that are sustainable and climate-resilient suggests key ingredients that meet both development, equity, and well-being priorities as well as ambitious climate action. Case studies from the level of nation states to communities reveal opportunities and significant challenges to enable and sustain such pathways, particularly within the mandate of the 2030 Agenda to 'leave no one behind'.

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. More studies are needed to investigate and quantify the synergies and trade-offs for a 1.5°C warmer world, specific to regional, national and sub-national levels. Quantitative assessments of policy instruments to enhance synergies on mitigation options and sustainable development dimensions in a cost-effective manner can inform decision makers more concretely to take action. 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. More literature is needed to treat SDGs in general and as a nexus and consider their implications for climate change adaptation (and mitigation). In addition, the global level conclusion that adaptation will be lower in a 1.5°C world because higher levels of mitigation will have been achieved has no supporting literature and comes as a deductive reasoning which is insufficient to understand the interplay with sustainable development.
- Limited literature exists that empirically investigates the effectiveness of integrated policy frameworks to deliver triple-win (adaptation-mitigation-sustainable development) outcomes, the dynamics that produce such outcomes at the scale of implementation, and the anticipated winners. 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.
- The question of sustainable development and 1.5°C climate goal poses an issue of multi-scale articulation. The implementation challenges of sustainable development, adaptation and mitigation measures are often more precisely understood at the local scale but the 1.5°C goal and several key enabling conditions of change (e.g., finance, technology) require a global-scale perspective. These two scales of analyses are largely investigated in disconnected bodies of literature. More structured literature is needed, that investigate the specificities of each local, regional, national context, to be directly policy-relevant at these scales of decision, but that allows also to build a global trajectory emerging as a composite of these local visions.
- Emerging literature suggests key ingredients of climate-resilient development pathways that meet both development and justice priorities and stringent climate action. It remains unclear how governance structures enable or hinder different groups of people and countries at different levels of development, with different needs, rights, and capacities, to negotiate pathway options, values, and priorities. There is also a significant knowledge gap regarding possible benefits and negative side-effects from a range of pathway choices and path dependencies along the spectrum of socially desirable to technically and economically feasible. These gaps in knowledge constitute significant ethical and moral questions that climate science alone is ill equipped to solve. There is an urgent need for adequate and robust monitoring and indicators of success for such development pathways that take into consideration diverse types of knowledge and experiences regarding a range of enabling conditions and challenges (geophysical and environmental-ecological, technological and economic, and cultural, social and institutional), in a way that enables exchanges between the different research communities to overcome disciplinary fragmentation.
- More research is needed to adequately capture the value of iterative learning, resilience building, and deliberative decision-making in climate-resilient development pathways and possibilities for scaling-up emerging success stories, as well as stringent outcomes of zero-emission trajectories that are compatible with a commitment to sustainable development and poverty eradication in a fair and equitable 1.5°C warmer world.

Frequently Asked Questions

FAQ 5.1: What are the interactions between sustainable development and limiting global warming to 1.5°C?

Summary:
The UN Sustainable Development Goals (SDGs) aim to enhance global development in ways that meet the needs of the present without compromising the needs of future generations. Sustainable development is closely linked with climate change. Limiting the world to 1.5°C warming will have impacts on sustainable development and, similarly, pursuing sustainable development will influence emissions and impacts. Responses to climate change in the form of adaptation and mitigation will also interact with sustainable development. These impacts may work together and be positive, resulting in a synergy, or work against each other in a negative way, known as a trade-off. Maximising synergies and limiting trade-offs is the goal when planning future actions to reduce climate change and to pursue sustainable development.

For more than 25 years, the United Nations (UN) and other international organizations have embraced the concept of sustainable development, understood as the ambition to meet the needs of the present without compromising future generations. This concept spans economic, social and environmental objectives including poverty and hunger alleviation, equitable economic growth and access to resources, and the protection of water, air and ecosystems.

Recent decades have seen big improvements in sustainable development. There have been reductions in poverty, hunger and child mortality, as well as greater access to clean water and sanitation. But more is needed to achieve sustainable development for all. The UN Sustainable Development Goals (SDGs), endorsed in 2015 as part of the 2030 Agenda for Sustainable Development, apply to all countries and cover ambition in seventeen key areas(*refer to FAQ Figure*). These are: to eliminate extreme poverty and hunger; to ensure health, education, peace, safe water and clean energy for all; to promote inclusive and sustainable cities, consumption, infrastructure and economic growth; to reduce inequality, including gender inequality; to combat climate change, and to protect the oceans and terrestrial ecosystems.

[***Figure Suggestion:*** *The official UN figure of 17 Sustainable Development Goals (SDGs)*]

The link between climate change and sustainable development is complex. Previous IPCC reports have found that climate change undermines sustainable development, and that well-designed responses to climate change in the form of both adaptation and mitigation can promote more sustainable and equitable societies.

Limiting global warming to 1.5°C requires international, national, community and individual adaptation and mitigation actions that are not just limited to technology and infrastructure, but that also cover policy design, implementation and behavioural changes. Most actions in these areas will have some impacts on sustainable development. This can happen in a positive way where sustainable development is strengthened, known as a *synergy*, or in a negative way, where sustainable development is hindered or reversed, known as a *trade-off*.

For example, sustainable forestry management illustrates the synergies between climate change mitigation and sustainable development. Well-managed and protected forests can prevent emissions from deforestation as well as absorb carbon, reducing warming at reasonable cost. Sustainable forests can take into account the needs of local people, protect watersheds and enhance biodiversity. Achieving synergies requires coordination across sectors and nations, as well as collaboration at local to international scales.

Pursuing climate mitigation compatible with a 1.5°C warmer world, if poorly designed or implemented, can lead to negative trade-offs with some dimensions of sustainability. An example of such trade-offs are the negative impacts of changing how land is used from natural forests, indigenous ownership, or agriculture to plantations for bioenergy production. This can threaten food and water security, create conflict over land rights, cause biodiversity loss, and increase food prices. Another trade-off can occur for some countries and workers if a switch is made from fossil fuels to other energy sources without adequate planning for a transition. Many trade-offs can be minimised if effectively managed, however. For example, maximising the efficiency of bioenergy crops to reduce land-use change, or providing retraining for employees of sectors in transition.

In general, progress made to reduce poverty and gender inequalities, and to enhance food, health and water security will likely help adaptation and reduce vulnerability to climate change. Similarly, the protection of oceans, marine and coastal ecosystems can reduce the impacts of climate change on these systems. The sustainable development goal of affordable and clean energy recognises the need for better access to electricity and the role of renewable energy, behavioural change, and energy efficiency in reducing the carbon intensity of energy and meeting ambitious climate goals. The Sustainable Development Goals for peace, justice, strong institutions and partnerships can all contribute to limiting warming to 1.5°C. These are all supported explicitly within SDG 13, which targets climate action consistent with the Paris Agreement.

Yet, there are some risks that making sustainable development the priority can undermine climate adaptation and mitigation goals if, for example, people escaping from poverty and hunger consume more energy or land, or goals for economic growth and industrialization drive increased fossil fuel consumption. The challenge is to implement sustainable development policies that improve well-being, reduce deprivation, poverty and ecosystem degradation at the same time as reducing emissions, limiting climate impacts and facilitating adaptation.

Good governance and strong partnerships when planning climate change adaptation and mitigation actions can help strengthen synergies and minimise trade-offs. While it is unlikely that all trade-offs can be avoided or minimised, corrective measures in the near term could at least help to create conditions that enable sustainable development in the long term.

FAQ 5.2: What are the pathways to achieving poverty reduction and reducing inequalities while reaching the 1.5°C world?

Alternative suggestion: What role do equity and justice play in pathways to limit warming to 1.5°C?

Summary:
Issues of equity, fairness and justice have long been central to climate change and sustainable development. Climate-related risks are unevenly distributed and the impacts of 1.5°C global warming will disproportionately affect disadvantaged populations. A number of pathways exist that could limit warming to 1.5°C at the same time as promoting sustainable development. These are where a mix of adaptation and mitigation measures are designed in a way that reduces emissions and enables adaptation while contributing to poverty eradication and reducing inequalities. Such transformative trajectories include 'Climate-Resilient Development Pathways' (CRDPs). They will differ across regions, and flexible governance will be needed to ensure they are inclusive, fair, and successful. While challenges would remain in some parts of the world, 1.5°C-compatible development pathways generate more benefits than those that reach 2°C warming or higher.

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

These concepts are, and have always been, strongly intertwined with climate change and sustainable development. The text of the Paris Agreement states that it "will be implemented to reflect equity… in the light of different national circumstances" and calls for "rapid reductions" of greenhouse gases to be achieved "on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty". Similarly, the Sustainable Development Goals (SDGs) include goals to reduce poverty and inequalities and ensure equitable and affordable access to health, water and energy for all.

These principles are important for considering pathways that limit warming to 1.5°C in a way that is liveable for every person and species. These pathways recognise the uneven development status between richer and poorer nations, the unevenly distributed impacts from climate change including impacts on future generations, and the uneven capacity of different nations and people to respond to climate risks. This is particularly true for those who are highly vulnerable to climate change people such as indigenous communities in the Arctic, people whose livelihoods depend on agriculture, coastal and marine ecosystems, and inhabitants of small-island developing states. The poorest people will experience a world that is 1.5°C warmer than pre-industrial levels mainly through higher food prices and hunger, but also through loss of income and livelihood opportunities, adverse health effects, and displacement.

Well-planned adaptation and mitigation measures are essential to avoid exacerbating inequalities or creating new injustices. Pathways exist that limit global warming to 1.5°C and incorporate mitigation and adaptation that reduces inequalities in terms of who benefits, who pays the costs, and who is affected by synergies and trade-offs. Attention to equity ensures that disadvantaged peoples can secure their livelihoods and live in dignity and that those who experience costs for mitigation or adaptation have financial and technical support to enable fair transitions.

*Climate-resilient development pathways (CRDPs)*illustrate ways of limiting warming to 1.5°C that incorporate efforts towards strengthening sustainable development and eradicating poverty. These trajectories simultaneously promote fair and equitable climate resilience and responses, by taking into account the following key aspects: the potential to limit warming to 1.5°C, the need to achieve global net zero emissions, the achievement of goals for sustainable development, the scale of societal transformation required, the need to build resilience and capacity to adapt, and attention to ethics, equity, and well-being. Additionally, they emphasise the potential for, and commitment to, reducing societal vulnerabilities, addressing inequalities, and alleviating poverty (*refer to FAQ Figure*).

*[**Figure Suggestion:** Schematic showing the key aspects and goals of climate-resilient development pathways – based on Figure 5.5 in the chapter]*

The characteristics of CRDPs will differ across communities and nations, and each will have different implications, distributional consequences, and criteria for success. Flexible governance can help support iterative and continuous learning that creates equitable and robust pathways toward socially- desirable, just, and low-carbon futures. There will still be significant challenges in some parts of the world where residual impacts will occur, but 1.5°C-compatible CRDPs generate more benefits than those that reach 2°C warming or higher temperatures.

There are few examples so far that meet all the criteria for sustainable and climate-resilient development pathways that reduce poverty and inequality, but there are good examples that illustrate the potential for implementing CRDPs. For instance, some countries have fostered clean energy and sustainable transportation while creating green jobs and supporting social welfare programs to reduce domestic poverty. Yet, persistent inequalities, committed paths to high-carbon energy infrastructure, and weak institutions can hamper progress toward climate resilience. Other examples include development paradigms inspired by community values, such as *Buen Vivir* and the Transition Movement. *Buen Vivir* is a Latin American concept based on indigenous ideas of communities living in harmony with nature, aligned with peace, diversity, solidarity, rights to education, health, and safe food, water, and energy, and well-being and justice for all. The Transition Movement, with origins in Europe, promotes equitable and resilient communities through low-carbon living, food self-sufficiency, and citizen science albeit achieving inclusive participation can remain a challenge.

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[Due to size, Table 5.1.a–d is provided here. A high resolution version of the table is available as a supplementary PDF (SR15_SOD_Chapter5_Table5_1.pdf) that can be downloaded with the chatper for review]

Chapter 5 Table 5.1

Table of Contents

Panel A Part 1

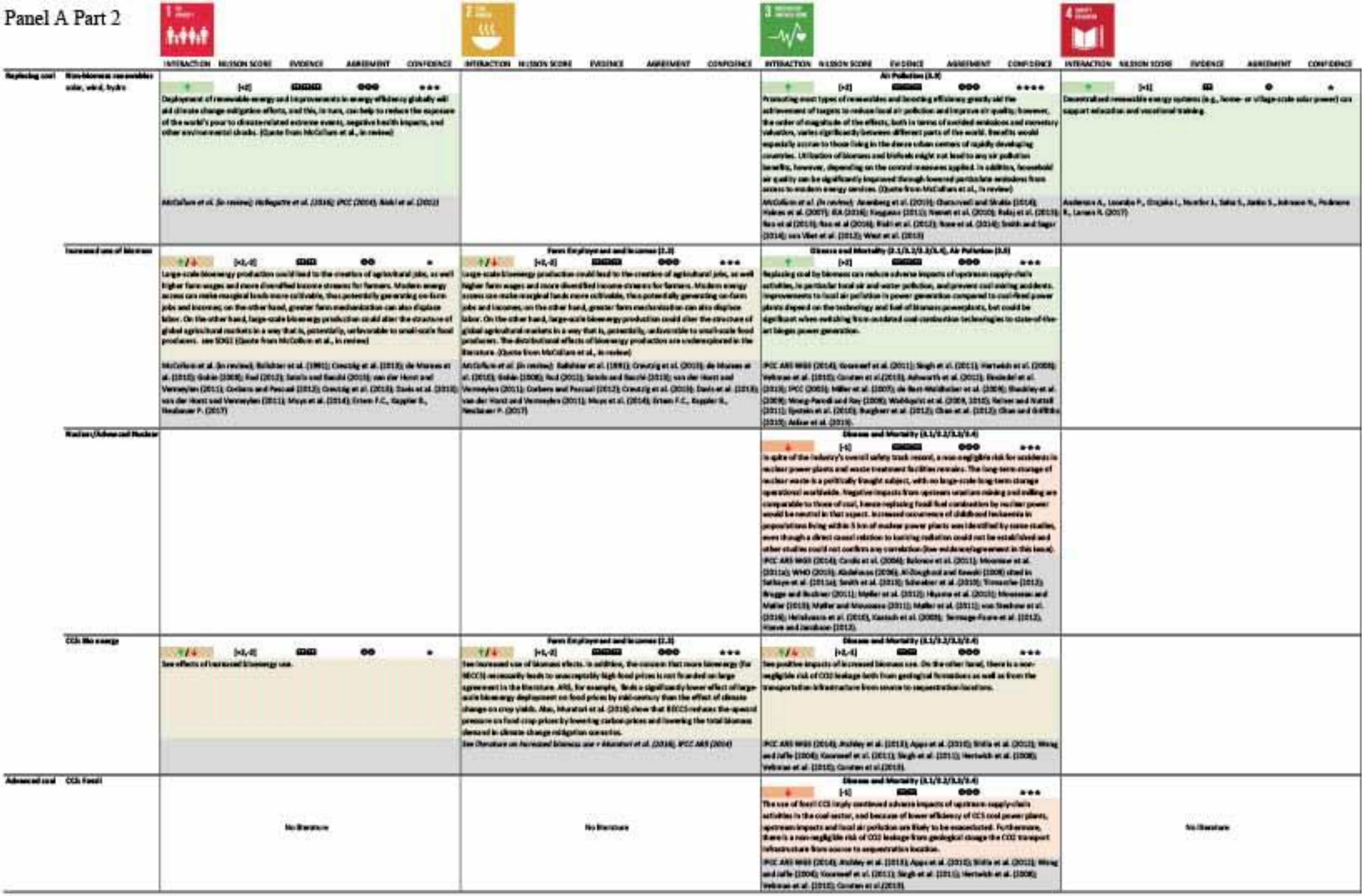
Sector	Mitigation option	SDG 1 (Interaction / Mission score / Evidence / Agreement / Confidence)	SDG 2 (Interaction / Mission score / Evidence / Agreement / Confidence)	SDG 3 (Interaction / Mission score / Evidence / Agreement / Confidence)	SDG 4 (Interaction / Mission score / Evidence / Agreement / Confidence)
Industry	Accelerating energy efficiency improvement	Reduce poverty; [+2]; % of people living below poverty line declines from 49% to 18% in south african context; Altieri et al (2016)	[0] No direct interaction, No literature	Air pollution reduction and better health (3.9); [+2]; People living in the deprived communities feel positive and predict considerable financial savings. [illegible]; Ji et al (2013), Zhang et al (2015), Vassolo and Döll (2005); Fricko et al. (2016); Holland et al. (2016); Nguyen et al (2014)	Technical education, vocational training (4.3, 4.4, 4.5); [+1]; Awareness, knowledge and technical and managerial capability are closely linked, energy audit, information for trade unions; Fernando et al (2016), Apeaning and Thollander (2013)
	Low-carbon fuel switch	[0] No direct interaction, No literature	[0] No direct interaction, No literature	Water and air pollution reduction and better health (3.9); [+2]; Industries are becoming supplier of energy, waste heat, water, roof tops for solar energy generation and hence helping in improving air and water quality; Vassolo and Doll (2005); Fricko et al. (2016); Holland et al. (2016); Nguyen et al (2014); Karner et al (2015)	Technical education, vocational training (4.4); [+1]; New technology deployment creates demand for awareness, knowledge with technical and managerial capability otherwise acts as barrier for rapid expansion; Fernando et al (2016), Apeaning and Thollander (2013)
	Decarbonisation/CCS/CCU	[0] No direct interaction, No literature	[0] No direct interaction, No literature	Disease and Mortality (3.1/3.2/3.3/3.4); [-1]; There is a risk of CO2 leakage both from geological formations as well as from the transportation infrastructure from source to sequestration locations; IPCC AR5 WGIII (2014); [illegible]	
Residential	Behavioural response	Poverty reduction via financial savings (1.2); [+2]; People living in the deprived communities feel positive and predict considerable financial savings; Scott, Jones, and Webb (2014)	[0] No direct interaction, No literature	Improved warmth and comforts; [+2]; Home occupants reported warmth as the most important aspect of comfort which were largely temperature related and low to energy costs. Residents living in the deprived areas expect improved warmth in their properties after energy efficiency measures are employed; Scott, Jones, and Webb (2014); Huebner, Cooper, and Jones (2013); Yue, Long, and Chen (2013); Zhao et al. 2017	
	Accelerating energy efficiency improvement	Poverty and Development (1.1/1.2/1.3/1.4); [+2,-1]; Energy efficiency interventions lead to cost savings which are realised due to reduced energy bills that further lead to poverty reduction. [illegible] (Quote from McCollum et al., in review); Maidment et al. (2014); Scott, Jones, and Webb (2014); Berrueta et al. (2017); McCollum et al. (in review); [illegible]	Food Security; [+2]; Using the improved stoves supports food security [illegible] (Berrueta et al. 2017); Berrueta et al. (2017)	Healthy lives and well-being for all at all ages (3.2, 3.9); [+2]; Efficient cookstove improves health especially for indigenous and poor rural communities. [illegible]; Berrueta et al., 2017; Maidment et al., 2014; [illegible]	Reducing school absences; [+2]; Household energy efficiency measures reduce school absences for children with asthma; Maidment et al. (2014)
	Improved access & fuel switch to modern low-carbon energy	Poverty and Development (1.1/1.2/1.3/1.4); [+2]; Access to modern energy forms (electricity, clean cook-stoves, high-quality lighting) is fundamental to human development [illegible] (Quote from McCollum et al., in review); McCollum et al. (in review); [illegible]	Food Security and Agricultural Productivity (2.1/2.4); [-1/+1]; Modern energy access is critical to enhance agricultural yield/productivity [illegible]; McCollum et al. (in review); [illegible]	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 [illegible] (Quote from McCollum et al., in review); McCollum et al. (in review); [illegible]	Equal Access to Educational Institutions (4.1/4.2/4.3/4.5); [+1]; Access to modern energy is necessary for schools to have quality lighting and thermal comfort, as well as modern information and communication technologies. [illegible] (Quote from McCollum et al., in review); McCollum et al. (in review); [illegible]

D

1 Panel A Part 1

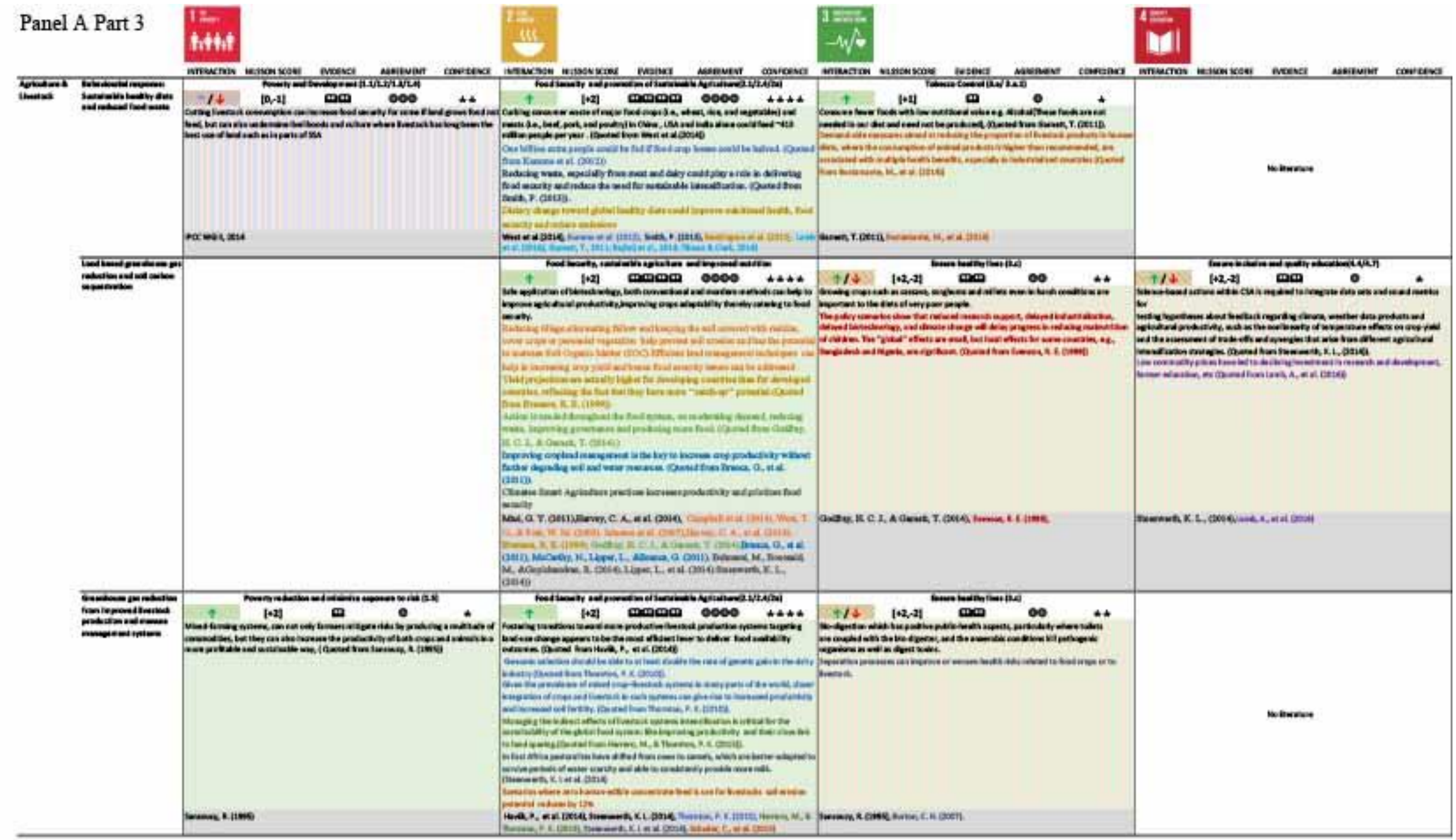
Transport	Behavioural response			**Road Traffic Accidents (3.4/3.6)** ↑/↓ [+2,-1] ▪▪▪ ●●● ★★ Active travel modes' (such as walking and cycling) represent strategies not only for boosting energy efficiency but also, potentially, for improving health and well-being (e.g., lowering rates of diabetes, obesity, heart disease, dementia, and some cancers). However, a risk associated with these measures is that they could increase rates of road traffic accidents, if the provided infrastructure is unsatisfactory. Overall health effects will depend on the severity of the injuries sustained from these potential accidents relative to the health benefits accruing from increased exercise. (Quote from McCollum et al., in review) McCollum et al. (in review); Creutzig et al. (2012); Haines and Dora (2012); Saunders et al. (2013); Shaw et al. (2014); Woodcock et al. (2009), Shaw et al (2017),Chakrabarti and Shin (2017), Huang et al (2017)	
	Accelerating energy efficiency improvement			**Reduce illnesses from hazardous air, water and soil pollution (3.9)** ↑ [+2] ▪▪▪ ●●● ★★★ Locally relevant policies targeting traffic reductions and ambitious diffusion of electric vehicles results in measured changes in non-climatic population exposure included ambient air pollution, physical activity, and noise. The transition to low-carbon equitable and sustainable transport can be fostered by numerous short- and medium-term strategies that would benefit energy security, health, productivity, and sustainability. Evidence-based approach that takes into account greenhouse gas emissions, ambient air pollutants, economic factors (affordability, cost optimization), social factors (poverty alleviations, public health benefits), and political acceptability is needed tackle these challenges. (Schucht et al., 2015)(Figueroa, Lah, Fulton, McKinnon, & Tiwari, 2014) (Peng, Yang, Wagner, & Mauzerall, 2017), (Klausbruckner et al., 2016)	
	Improved access & fuel switch to modern low-carbon energy	**End Poverty in all its forms everywhere (1.1,1.4,1.a, 1.b)** ↑/↓ [+2,-1] ▪▪▪ ●●● ★★★ Climate change threatens to worsen poverty, therefore pro-poor mitigation policies are needed to reduce this threat; for example investing more and better in infrastructure by leveraging private resources and using designs that account for future climate change and the related uncertainty. Communities in poor areas cope with and adapt to multiple-stressors including climate change. Coping strategies provide short-term relief but in the long-term may negatively affect development goals. And responses generate a trade-off between adaptation, mitigation and development . African cities with dense and due to high commuting costs many walk to work places which limit access. In Latin america tripple informality leading to low productivity and living standards. In Sweden decarbonization of public bus is receiving attention more than efficiency improvement. With more electrification electricity price goes up and affordability can worsen for poor unless redistributive policies are in place. *(Hallegatte et al. 2015); (Suckall, Tompkins, & Stringer, 2014); Lall, Henderson, & Venables, 2017, (Corporación Andina de Fomento, 2017), Xylia et al (2017), Klausbruckner, Annegarn, Henneman, & Rafaj, 2016*	**Ensure Access to Food Security (2.1, 2.3, 2.a, 2.b,2.c)** ↑ [0] ▪ ● ★ 21 Projects aiming at resilient transport infrastructure development to improve access (e.g. C40 Cities Clean Bus Declaration, UITP Declaration on Climate Leadership, Cycling Delivers on the Global Goals, Global Sidewalk Challenge) do not substantially contribute to realizing the (indirect) transport targets with mostly a rural focus: Agricultural Productivity (SDG 2) and Access to Safe Drinking Water (SDG 6) *Partnership on Sustainable Low Carbon Transport, 2017*	**Reduce illnesses from hazardous air pollution (3.9)** ↑ [+2] ▪ ● ★ Projects aiming at resilient transport infrastructure development (e.g. C40 Cities Clean Bus Declaration, UITP Declaration on Climate Leadership, Cycling Delivers on the Global Goals, Global Sidewalk Challenge) are targeting at reducing airpollution, Electric vehicles using electricity from renewables or low carbon sources combined with e-mobility options such as trolleybuses, metros, trams and electric buses, as well as promote walking and biking, especially for short distances need consideration *Partnership on Sustainable Low Carbon Transport, 2017, Ajanovic (2015)*	

Panel A Part 1


Panel A Part 2
INTERACTION
CONFIDENCE
No literature

Do N


Panel A Part 2



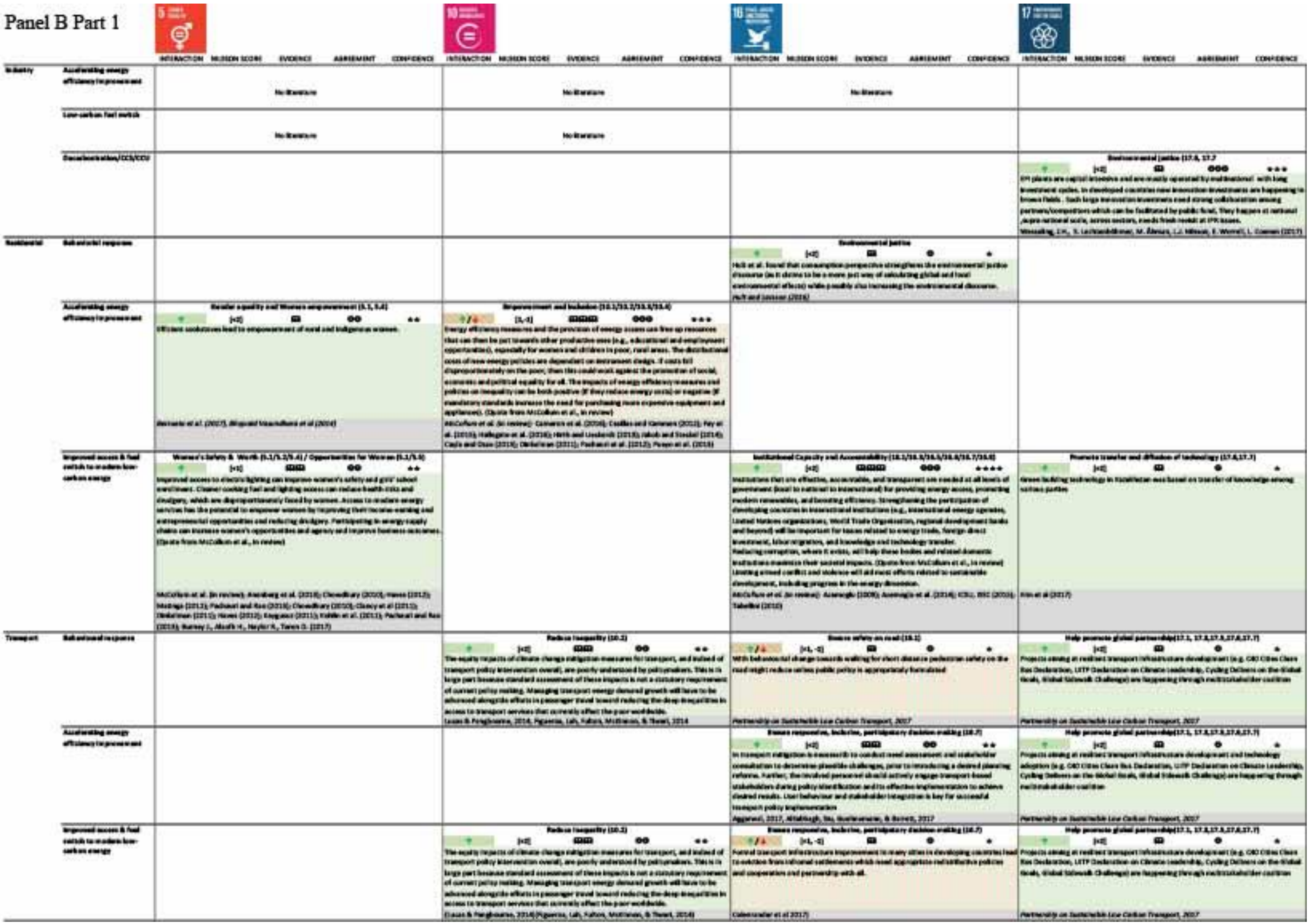
Panel A Part 3

		SDG 1: INTERACTION / NILSSON SCORE / EVIDENCE / AGREEMENT / CONFIDENCE	SDG 2: INTERACTION / NILSSON SCORE / EVIDENCE / AGREEMENT / CONFIDENCE	SDG 3: INTERACTION / NILSSON SCORE / EVIDENCE / AGREEMENT / CONFIDENCE	SDG 4: INTERACTION / NILSSON SCORE / EVIDENCE / AGREEMENT / CONFIDENCE
Agriculture & Livestock	Behavioural response: Sustainable healthy diets and reduced food waste	Poverty and Development (1.1/1.2/1.3/1.4) ↑/↓ [0,-1] ◘◘ ●●● ★★ Cutting livestock consumption can increase food security for some if land grows food not feed, but can also undermine livelihoods and culture where livestock has long been the best use of land such as in parts of SSA IPCC WG3, 2014	Food Security and promotion of Sustainable Agriculture(2.1/2.4/2a) ↑ [+2] ◘◘◘◘ ●●●● ★★★★ Cutting consumer waste of major food crops (i.e., wheat, rice, and vegetables) and meats (i.e., beef, pork, and poultry) in China, USA and India alone could feed ~413 million people per year. (Quoted from West et al.(2014)) One billion extra people could be fed if food crop losses could be halved. (Quoted from Kummu et al. (2012)) Reducing waste, especially from meat and dairy could play a role in delivering food security and reduce the need for sustainable intensification. (Quoted from Smith, P. (2013)). Dietary change toward global healthy diets could improve nutritional health, food security and reduce emissions West et al.(2014), Kummu et al. (2012), Smith, P. (2013), [illegible]	Tobacco Control (3.a/ 3.a.1) ↑ [+1] ◘ ● ★ Consume fewer foods with low nutritional value e.g. Alcohol(These foods are not needed in our diet and need not be produced), (Quoted from Garnett, T. (2011)). Demand-side measures aimed at reducing the proportion of livestock products in human diets, where the consumption of animal products is higher than recommended, are associated with multiple health benefits, especially in industrialised countries (Quoted from Bustamante, M., et al. (2014)) Garnett, T. (2011), Bustamante, M., et al. (2014)	No literature
	Land based greenhouse gas reduction and soil carbon sequestration		Food Security, sustainable agriculture and improved nutrition ↑ [+2] ◘◘◘◘ ●●●● ★★★★ Safe application of biotechnology, both conventional and modern methods can help to improve agricultural productivity,improving crops adaptability thereby catering to food security. [illegible] Yield projections are actually higher for developing countries than for developed countries, reflecting the fact that they have more "catch-up" potential (Quoted from Evenson, R. E. (1999)) Action is needed throughout the food system, on moderating demand, reducing waste, improving governance and producing more food. (Quoted from Godfray, H. C. J., & Garnett, T. (2014)) Improving cropland management is the key to increase crop productivity without further degrading soil and water resources. (Quoted from Branca, G., et al. (2011)). Climate Smart Agriculture practices increases productivity and prioritises food security [illegible], Harvey, C. A., et al. (2014), [illegible] Evenson, R. E. (1999), Godfray, H. C. J., & Garnett, T. (2014), Branca, G., et al. (2011), McCarthy, N., Lipper, L., Branca, G. (2011), [illegible] Lipper, L., et al. (2014) Stanworth, K. L., (2014))	Ensure healthy lives (3.c) ↑/↓ [+2,-2] ◘◘ ●● ★★ Growing crops such as cassava, sorghums and millets even in harsh conditions are important to the diets of very poor people. The policy scenarios show that reduced research support, delayed industrialization, delayed biotechnology, and climate change will delay progress in reducing malnutrition of children. The "global" effects are small, but food effects for some countries, e.g., Bangladesh and Nigeria, are significant. (Quoted from Evenson, R. E. (1999)) Godfray, H. C. J., & Garnett, T. (2014), Evenson, R. E. (1999),	Ensure inclusive and quality education(4.4/4.7) ↑/↓ [+2,-2] ◘◘ ● ★ Science-based actions within CSA is required to integrate data sets and sound metrics for testing hypotheses about feedback regarding climate, weather data products and agricultural productivity, such as the nonlinearity of temperature effects on crop yield and the assessment of trade-offs and synergies that arise from different agricultural intensification strategies. (Quoted from Steenwerth, K. L., (2014)). Low commodity prices have led to declining investment in research and development, farmer education, etc (Quoted from Lamb, A., et al. (2016)) Steenwerth, K. L., (2014), Lamb, A., et al. (2016)
	Greenhouse gas reduction from improved livestock production and manure management systems	Poverty reduction and minimize exposure to risk (1.5) ↑ [+2] ◘ ● ★ Mixed-farming systems, can not only farmers mitigate risks by producing a multitude of commodities, but they can also increase the productivity of both crops and animals in a more profitable and sustainable way, (Quoted from Sansoucy, R. (1995)) Sansoucy, R. (1995)	Food Security and promotion of Sustainable Agriculture(2.1/2.4/2a) ↑ [+2] ◘◘◘◘ ●●●● ★★★★ Fostering transitions toward more productive livestock production systems targeting land-use change appears to be the most efficient lever to deliver food availability outcomes. (Quoted from Havlik, P., et al. (2014)) Genomic selection should be able to at least double the rate of genetic gain in the dairy industry (Quoted from Thornton, P. K. (2010)). Given the prevalence of mixed crop-livestock systems in many parts of the world, closer integration of crops and livestock in such systems can give rise to increased profitability and increased soil fertility. (Quoted from Thornton, P. K. (2010)). Managing the indirect effects of livestock systems intensification is critical for the sustainability of the global food system, like improving productivity and their close link to land sparing (Quoted from Herrero, M., & Thornton, P. K. (2013)). In East Africa pastoralists have shifted from cows to camels, which are better adapted to survive periods of water scarcity and able to consistently provide more milk. (Steenwerth, K. L et al. (2014)) Scenarios where zero human-edible concentrate feed is use for livestock soil erosion potential reduces by 13% Havlik, P., et al. (2014), Steenwerth, K. L. (2014), Thornton, P. K. (2010), Herrero, M., & Thornton, P. K. (2013), Steenwerth, K. L et al. (2014), Schader, C., et al. (2015)	Ensure healthy lives (3.c) ↑/↓ [+2,-2] ◘◘ ●● ★★ Bio-digestion which has positive public-health aspects, particularly where toilets are coupled with the bio digester, and the anaerobic conditions kill pathogenic organisms as well as digest toxins. Separation processes can improve or worsen health risks related to food crops or to livestock. Sansoucy, R. (1995), Burton, C. H. (2007).	No literature

Panel A Part 3

Forest	Reduced deforestation, REDD+		Food Security and promotion of Sustainable Agriculture(2.1/2.4/2a) ↑/↓ [+1,-2] Food security, may lead to the conversation of productive land under forest, including community forests, into agricultural production. In a similar fashion, the production of biomass for energy purposes(SDG 7) may reduce land available for food production and/or for community forest activities (Quoted from Katila, P., et al. (2017)). [illegible] (Quoted from Katila, P., et al. (2017)); [illegible]		Ensure inclusive and quality education(4.4/4.7) ↑ [+1] Local forest users learn to understand laws, regulations and policies which facilitate their participation in the society. Education and capacity building provide technical skill and knowledge. (Quoted from Katila, P., et al. (2017)) (Quoted from Katila, P., et al. (2017))
	Afforestation and reforestation	Poverty and Development (1.1/1.2/1.3/1.4) ↑/↓ [+2,-2] CDM-AR can have different implications on local community livelihoods. [illegible] Zomer, R. J., Trabucco, A., Bossio, D. A., & Verchot, L. V. (2008); [illegible]	Food Security (2.1) ↑/↓ [+1,-1] CDM-AR can have different implications on local to regional food security and local community livelihoods. Zomer, R. J., Trabucco, A., Bossio, D. A., & Verchot, L. V. (2008).		Promote knowledge and skill to promote SD (4.7) ↓ [-1] Most landholders reported having low levels of knowledge about tree planting for carbon sequestration-particularly available programmes, prices and markets, and government rules and regulations (Quoted from Schirmer, J., & Bull, L. (2014)) Schirmer, J., & Bull, L. (2014)
	Behavioural responses (responsible sourcing)				
Oceans	Ocean iron fertilization		Food Security (2.1/2.3) ↑/↓ [+1,-1] OIF can have different implications on fish stocks and aquaculture, it might actually increase food availability for fish stocks (increasing yields) but potentially at the cost of reducing the yields of fisheries outside the enhancement region by depleting other nutrients. Smetacek and Naqvi (2008), Lampitt et al. (2008), Williamson et al. (2012)		
	Blue carbon	Poverty and Development (1.1/1.2/1.5) ↑ [+3] avoiding loss of mangroves and maintaining the 2000 stock could save a value of ecosystem services from mangroves in Southeast Asia of approximately US$2.16 billion until 2050 (2007prices), with a 95% prediction interval of US$1.58–2.76 billion (case study area South East Asia); Seaweed aquaculture will enhance carbon uptake and provide employment; traditional management systems provide benefits for blue carbon and support livelihoods for local communities; Greening of aquaculture can significantly enhance carbon storage; PES schemes could help capture the benefits derived from multiple ecosystem services beyond carbon sequestration; Zomer, R. J., Trabucco, A., Bossio, D. A., & Verchot, L. V. (2008); Schirmer, J., & Bull, L.	Food Production (2.3/2.4) ↑ [+3] avoiding loss of mangroves and maintaining the 2000 stock could save a value of ecosystem services from mangroves in Southeast Asia including fisheries; Seaweed aquaculture will provide employment; traditional management systems provide livelihoods for local communities; Greening of aquaculture can increase income and well being; Mariculture is a promising approach for China; Brander et al. (2012); Sondak et al. (2017); Vierros (2017); Ahmed et al. (2017a); Ahmed		
	Enhanced Weathering				

Panel A Part 3



Panel B Part 1
INTERACTION
EVIDENCE
AGREEMENT
CONFIDENCE
Industry
Accelerating energy efficiency improvement
No literature
Low-carbon fuel switch
Decarbonisation/CCS/CCU
Environmental justice (17.6, 17.7
Residential
Behavioural response
Environmental justice
Transport

Panel B Part 2

		SDG 5	SDG 10	SDG 16	SDG 17
		INTERACTION / NILSSON SCORE / EVIDENCE / AGREEMENT / CONFIDENCE	INTERACTION / NILSSON SCORE / EVIDENCE / AGREEMENT / CONFIDENCE	INTERACTION / NILSSON SCORE / EVIDENCE / AGREEMENT / CONFIDENCE	INTERACTION / NILSSON SCORE / EVIDENCE / AGREEMENT / CONFIDENCE
Replacing coal	Non-biomass renewables solar, wind, hydro	↑ [+1] ▬ ● ★ Decentralized renewable energy systems (e.g., home- or village-scale solar power) can reduce the burden on girls and women of procuring traditional biomass. Schwerhoff G., Sy M. (2017)	Empowerment and inclusion (10.1/10.2/10.3/10.4) ↑ [+1] ▬▬ ●● ★★ Decentralized renewable energy systems (e.g., home- or village-scale solar power) can enable a more participatory, democratic process for managing energy-related decisions within communities. (Quote from McCollum et al., in review) McCollum et al. (in review); Cass et al. (2010); Cambers (2012); Kunze and Becker (2015); Walker and Devine-Wright (2008)	Energy justice ↑ [+2] ▬ ● ★ The energy justice framework serves as an important decision-making tool in order to understand how different principles of justice can inform energy systems and policies. Islar et al. (2017) states that off-grid and micro-scale energy development offers an alternative path to fossil-fuel use and top-down resource management as they democratize the grid and increase marginalized communities' access to renewable energy, education and health care. Islar et al. (2017)	International Cooperation (all goals) ↑/↓ [+2,0] ▬▬ ●● ★★ International cooperation (in policy) and collaboration (in science) is required for the protection of shared resources. Fragmented approaches have been shown to be more costly. Specific to SDG7, to achieve the targets for energy access, renewables, and efficiency, it will be critical that all countries: (i) are able to mobilize the necessary financial resources (e.g., via taxes on fossil energy, sustainable financing, foreign direct investment, financial transfers from industrialized to developing countries); (ii) are willing to disseminate knowledge and share innovative technologies between each other; (iii) follow recognized international trade rules while at the same time ensuring that the least developed countries are able to take part in that trade; (iv) respect each other's policy space and decisions; (v) forge new partnerships between their public and private entities and within civil society; and (vi) support the collection of high-quality, timely, and reliable data relevant to the furthering their missions. There is some disagreement in the literature on the effect of some of the above strategies, such as free trade. Regarding international agreements, ""no regrets options"", where all sides gain through cooperation, are seen as particularly beneficial (e.g., nuclear test ban treaties). (Quote from McCollum et al., in review) McCollum et al. (in review); Clarke et al. (2009); [illegible] et al. (2016); Montreal Protocol (1989); New Climate Economy (2015); O'Neill et al. (2017); Ramaker et al. (2009); Riahi et al. (2015); [illegible] et al. (2017).
	Increased use of biomass				
	Nuclear/Advanced Nuclear			Reduce illicit arms trade (16.4) ↓ [-1] ▬▬ ●● ★★ Continued use of nuclear power poses a constant risk of proliferation. IPCC AR5 WGIII (2014); von Hippel et al. (2011, 2012); Sagan (2011); Yim and Li (2013); Adamantiades and Kessides (2009); Rogner (2013).	
	CCS: Bio-energy		No literature		
Advanced coal	CCS: Fossil	No literature	No literature	No literature	

Do N

Panel B Part 2

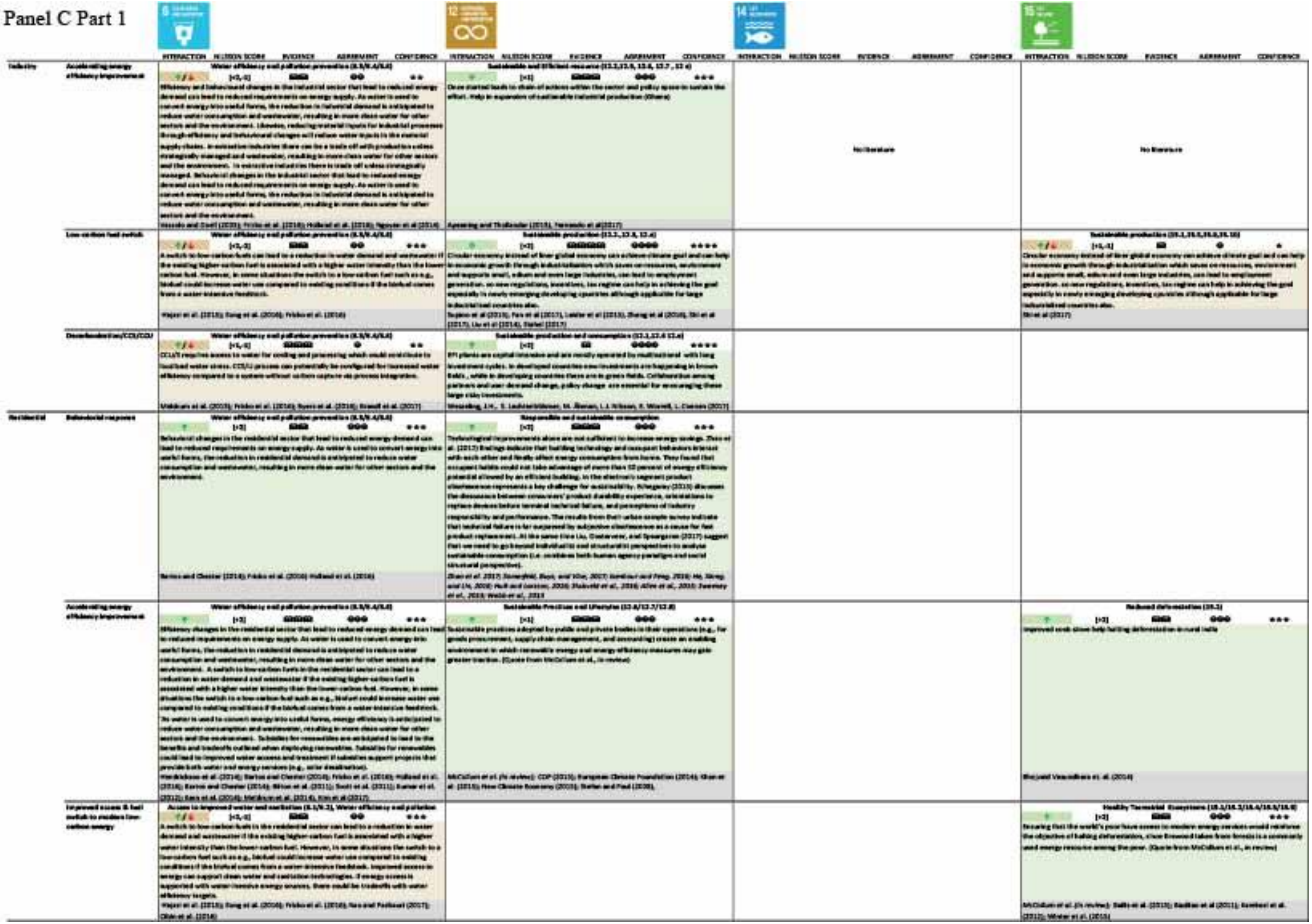
Panel B Part 3

		SDG 5 [Gender equality]	SDG 10 [Reduced inequalities]	SDG 16 Peace, justice and strong institutions	SDG 17 Partnerships for the goals
		INTERACTION / NILSSON SCORE / EVIDENCE / AGREEMENT / CONFIDENCE	INTERACTION / NILSSON SCORE / EVIDENCE / AGREEMENT / CONFIDENCE	INTERACTION / NILSSON SCORE / EVIDENCE / AGREEMENT / CONFIDENCE	INTERACTION / NILSSON SCORE / EVIDENCE / AGREEMENT / CONFIDENCE
Agriculture & Livestock	Behavioural response: Sustainable healthy diets and reduced food waste	No literature	No literature	**Strong and effective institutions and responsive decision making (16.6/ 16.7 / 16.a)** ↑/↓ | [+1,-1] | ▭▭▭▭ | ●● | ★★ Appropriate incentives to reduce food waste may require some policy innovation and experimentation, but a strong commitment for devising and monitoring them seems essential. (Quoted from Bajželj et al (2014)) [illegible] [illegible] [illegible] Bajželj et al (2014), [illegible]	**Resource mobilization and Strengthen Partnership (17.1/17.16)** ↑/↓ | [+1,-1] | ▭▭ | ● | ★ Decision makers should try to integrate agricultural,environmental and nutritional objectives through appropriate policy measures to achieve sustainable healthy diets coupled with reduction in food waste. [illegible] Garnett, T. (2011), [illegible]
	Land based greenhouse gas reduction and soil carbon sequestration	No literature	No literature	**Build effective, accountable and inclusive institutions (16.6/ 16.7/16.8)** −/↓ | [0,-1] | ▭▭▭▭ | ●● | ★★ Action is needed throughout the food system for improving governance and producing more food. (Quoted from Godfray, H. C. J., & Garnett, T. (2014)). [illegible] [illegible] [illegible] Godfray, H. C. J., & Garnett, T. (2014), [illegible]	**Resource mobilization and Strengthen multi-stakeholder Partnership** ↑ | [+2] | ▭▭▭▭ | ●●● | ★★★ Climate Smart Agriculture requires more careful adjustment of agricultural practices to natural conditions, a knowledge-intensive approach, huge financial investment, and policy and institutional innovation, etc. Besides private investment quality of public investment is also important. (Quoted from Behnassi, M., Boussaid, M., Gopichandran, R. (2014)). [illegible] [illegible] Behnassi, M., Boussaid, M., Gopichandran, R. (2014), [illegible]
	Greenhouse gas reduction from improved livestock production and manure management systems	No literature	No literature	**Responsible decision making (16.7)** ↑ | [+1] | ▭ | ● | ★ To minimize the economic and social cost, policies should target emissions at their source—on the supply side—rather than on the demand side as supply-side policies have lower calorie cost than demand-side policies.The role of livestock system transitions in emission reductions depends on the level of the carbon price and which emissions sector is targeted by the policies (Quoted from Havlík, P., et al. (2014)) Havlík, P., et al. (2014)	**Improve domestic capacity for tax collection (17.1)** ↑ | [+2] | ▭▭▭ | ●● | ★★ The role of livestock system transitions in emission reductions depends on the level of the carbon price and which emissions sector is targeted by the policies (Quoted from Havlík, P., et al. (2014)) [illegible] Havlík, P., et al. (2014), Herrero, M., & Thornton, P. K. (2013)

1 Panel B Part 3

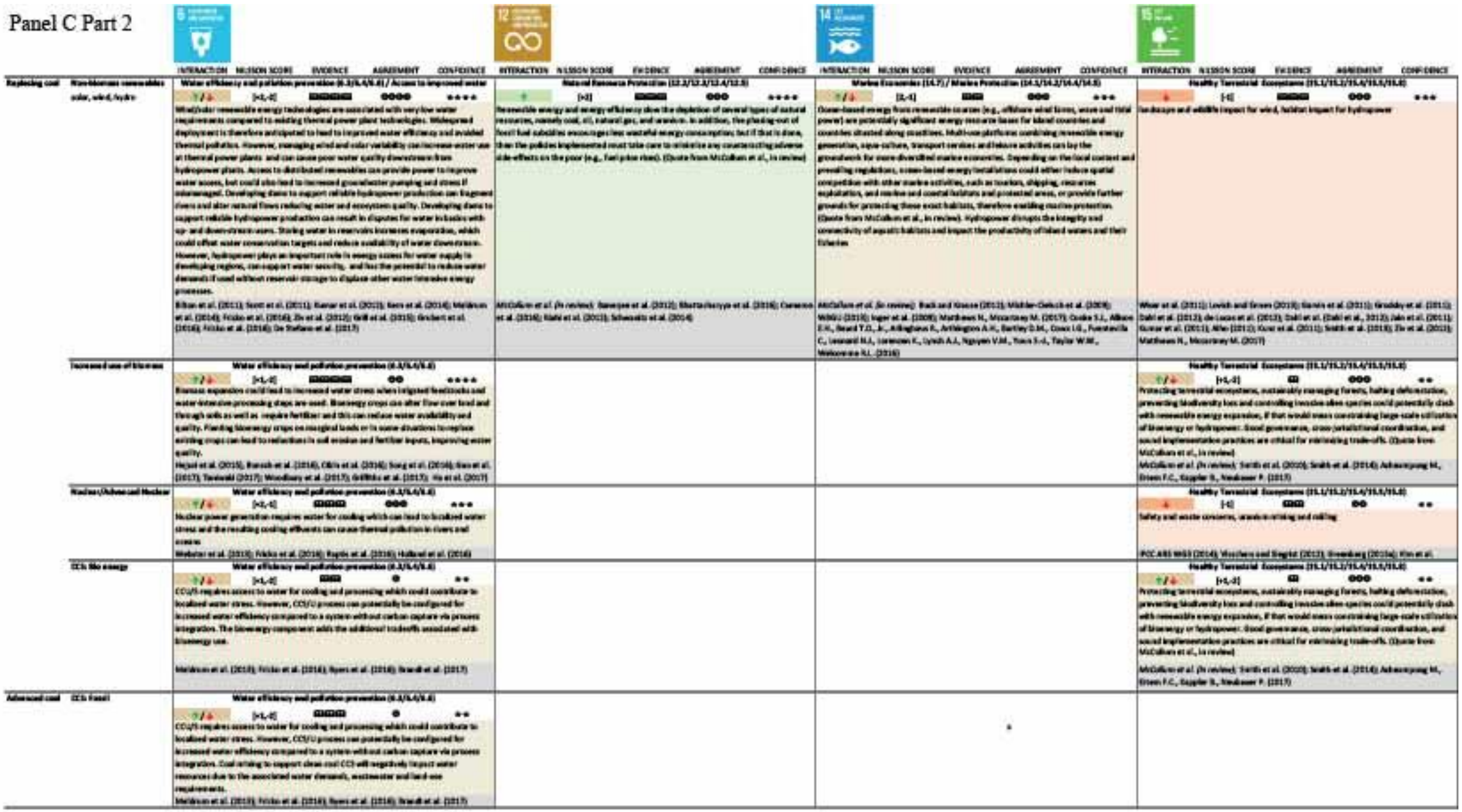
Forest	Reduced deforestation, REDD+	**Opportunities for Women (5.1/5.5)** ↑/↓ [+1,-1] Women have been less involved in REDD+ initiative (pilot project) design decision and processes than men. Girls and women have an important role in forestry activities, related to fuel-wood, forest-food and medicine. Their empowerment contributes to sustainable forestry as well as reducing inequality (Quoted from Katila, P., et al. (2017)) Brown 2011, Larson et al. 2015, (Quoted from Katila, P., et al. (2017))	**Reduced inequality, empowerment and inclusion (10.1/10.2/10.3/10.4)** ↑ [+2] Urges developed country to support, through multilateral and bilateral channels, the development of REDD+ national strategies or action plans and implementation (Quoted from Lima, M. G. B., Kissinger, G., Visseren-Hamakers, I. J., Brana-Varela, J., & Gupta, A. (2017)). Girls and women have an important role in forestry activities, related to fuel-wood, forest-food and medicine. Their empowerment contributes to sustainable forestry as well as reducing inequality (Quoted from Katila, P., et al. (2017)) (Quoted from Lima, M. G. B., Kissinger, G., Visseren-Hamakers, I. J., Brana-Varela, J., & Gupta, A. (2017)), (Quoted from Katila, P., et al. (2017))	**Build effective, accountable and inclusive institutions, Responsible decision making (16.6/16.7/16.8)** ↑ [+2] Institutional building (National Forest Monitoring Systems, Safeguard Information Systems, etc.), with full and effective participation of all relevant countries (Quoted from Lima, M. G. B., Kissinger, G., Visseren-Hamakers, I. J., Brana-Varela, J., & Gupta, A. (2017)). REDD+ actions also deliver non-carbon benefits (e.g. local socioeconomic benefits, governance improvements) (Quoted from Lima, M. G., et al. (2015)) Forest governance is another central aspect in recent studies, including debate on decentralization of forest management, logging concessions in public owned commercially valuable forests, and timber certification, primarily in temperate forests. (Quoted from Bustamante, M et al. (2014)) (Quoted from Lima, M. G. B., Kissinger, G., Visseren-Hamakers, I. J., Brana-Varela, J., & Gupta, A. (2017)), Lima, M. G., et al. (2015), Bustamante, M et al. (2014)	**Resource mobilization and Strengthen multi-stakeholder Partnership (17.1/17.3/17.9/17.17)** ↑/↓ [+1,-1] To provide finance and technology to developing countries to support emissions reductions. Be supported by adequate and predictable financial and technology support, including support for capacity-building. (Quoted from Lima, M. G. B., Kissinger, G., Visseren-Hamakers, I. J., Brana-Varela, J., & Gupta, A. (2017)). Partnerships in the form of significant aid money from, e.g., Norway, other bilateral donors, and the World Bank's Forest Carbon Partnership Facility (FCPF) are forthcoming (quoted from Andrew, D. (2017)) [illegible] (Quoted from Miles, L. & Kapos, V. (2008)) Forest governance is another central aspect in recent studies, including debate on decentralization of forest management, logging concessions in public owned commercially valuable forests, and timber certification, primarily in temperate forests. (Quoted from Bustamante, M et al. (2014)) (Quoted from Lima, M. G. B., Kissinger, G., Visseren-Hamakers, I. J., Brana-Varela, J., & Gupta, A. (2017)), Andrew, D. (2017), Miles, L. & Kapos, V. (2008), Bustamante, M et al. (2014)
	Afforestation and reforestation			**Responsible decision making (16.7)** ↑ [+1] Land-related mitigation, such as biofuel production, as well as conservation and reforestation action can increase competition for land and natural resources so these measures should be accompanied by complementary policies (Quoted from Epstein, A. H., & Theuer, S. L. H. (2017)) Epstein, A. H., & Theuer, S. L. H. (2017)	**Resource mobilization and Strengthen Partnership (17.1/17.14)** ↑ [+2] Financing at the national and international level is required to grow more Seedlings/sapling, restore land, create awareness education factsheets, providing training of local communities regarding the benefits of afforestation and reforestation. Article 12 of the Kyoto Protocol further sets a Clean Development Mechanism through which countries in Annex I earn 'certified emissions reductions' through projects implemented in developing countries [illegible] Afforestation and reforestation in India are being carried out under various programmes [illegible] (Quoted from Ravindranath, N. H., Chaturvedi, R. K., & Murthy, I. K. (2008)) [illegible] (2015), [illegible] (2017), Ravindranath, N. H., Chaturvedi, R. K., & Murthy, I. K. (2008)
	Behavioural response (responsible sourcing)			**Responsible decision making (16.7)** ↑ [+1] Indonesian factories may seek advantages through complete competition—perhaps by highlighting decent working conditions or the existence of a union—or to see trade associations or government agencies promoting the country as a responsible sourcing location (Quoted from Bartley, T. (2010)) In the absence of domestic legal instruments providing incentives to improve sustainability of sourcing, it appears that initiatives to engage the major importing enterprises in developing responsible sourcing practices and policies is a practical approach. Unless initiatives involve all the major importers, they are unlikely to be successful since the high costs associated with accreditation would increase production costs for these firms relative to their competitors (Quoted from Huang, W., Wilkes, A., Sun, X., & Terheggen, A. (2013)). Bartley, T. (2010), Huang, W., Wilkes, A., Sun, X., & Terheggen, A. (2013)	**Finance and trade (17.1/17.13)** ↑ [+1] Private certification initiatives for wood product and biomass sourcing may extend their schemes with criteria for "leakage" (external GHG effects). Also Recycling of waste wood in pellets is not yet practiced, due to unclear rules in the EU Waste Directive about overseas shipping (Quoted from Sikkema, R., et al. (2014)) Engagement of Chinese government and private sector stakeholders in supply country sustainability initiatives may be the best way to support this gradual process of improvement. (quoted from Huang, W., Wilkes, A., Sun, X., & Terheggen, A. (2013)). Although carrying out due diligence in timber sourcing can require considerable internal resources, it may be substantially less of a financial burden than the potential fines and reputational damage resulting from sourcing unknown or controversial timber. (quoted from Huang, W., Wilkes, A., Sun, X., & Terheggen, A. (2013)) Sikkema, R., et al. (2014), Huang, W., Wilkes, A., Sun, X., & Terheggen, A. (2013).
Oceans	Ocean iron fertilization				
	Blue carbon				
	Enhanced Weathering				

Panel B Part 3


Panel C Part 1
INTERACTION
EVIDENCE
AGREEMENT
CONFIDENCE
No literature
No literature

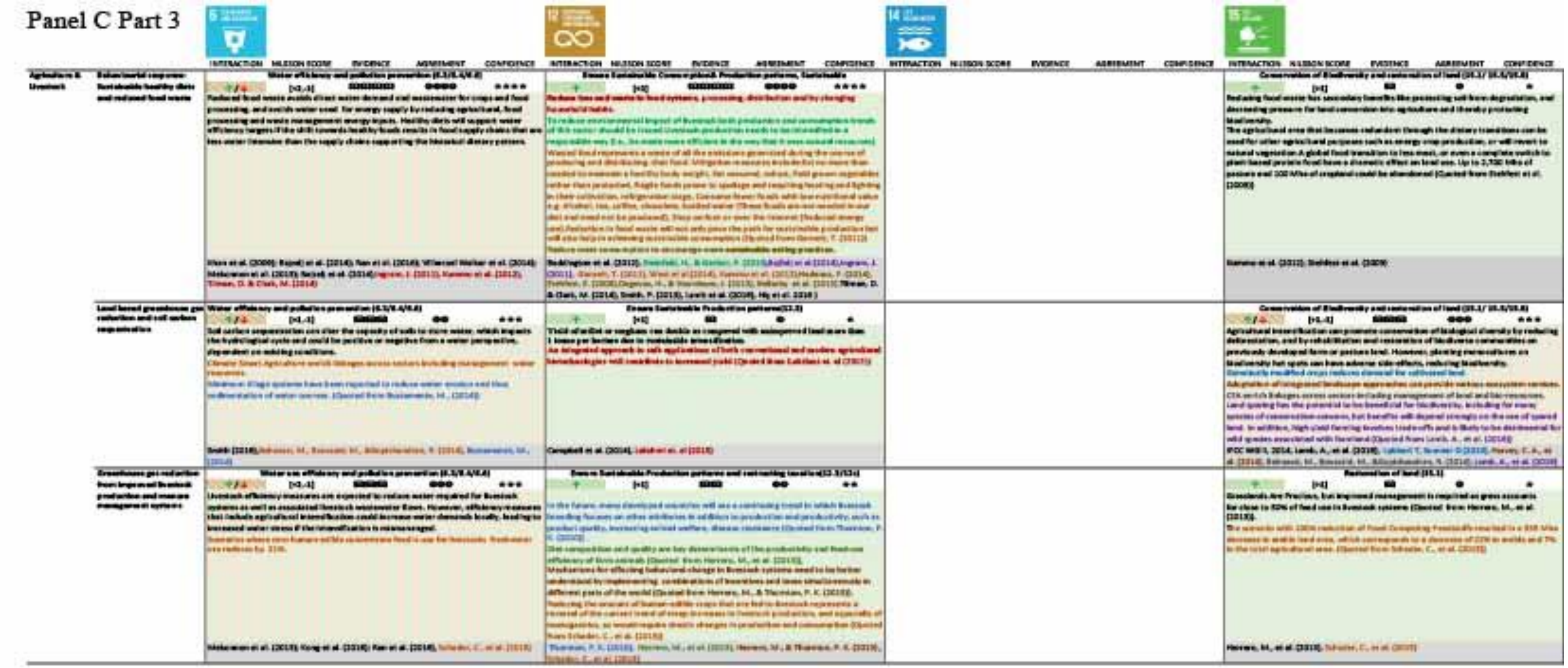
Transport	Behavioural response	**Water efficiency and pollution prevention (6.3/6.4/6.6)** ↑ [+2] ●● ★★ Behavioral changes in the transport sector that lead to reduced transport demand can lead to reduced transport energy supply. As water is used to produce a number of important transport fuels, the reduction in transport demand is anticipated to reduce water consumption and wastewater, resulting in more clean water for other sectors and the environment. Villa et al. (2013); Tiedemann et al. (2016); Fricko et al. (2016); Holland et al. (2016)	**Ensure Sustainable Consumption& Production patterns (12.3)** ↑ [+2] ●● ★★ Urban carbon mitigation must consider the supply chain management of imported goods, the production efficiency within the city, the consumption patterns of urban consumers, and the responsibility of the ultimate consumers outside the city. Important for climate policy of monitoring the CO2 clusters that dominate CO2 emissions in global supply chains because they offer insights on where climate policy can be effectively directed. (Lin, Hu, Cui, Kang, & Ramaswami, 2015) (Dagnet et al., 2015); Fella et al (2016)		
	Accelerating energy efficiency improvement	**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. Villa et al. (2013); Tiedemann et al. (2016); Fricko et al. (2016); Holland et al. (2016)	**Sustainable Consumption (12.1/12.8)** ↑ [+2] ●●● ★★★ Relational complex transport behavior resulting in significant growth in energy-inefficient car choices, as well as differences in mobility patterns (distances driven, driving styles) and actual fuel consumption between different car segments all affect the slow progress on transport decarbonisation. Consumption choices, and individual lifestyles are situated tied to the form of the surrounding urbanization. Major behavioral changes and emissions reductions requires understanding of this relational complexity, consideration of potential interactions with other policies and the local context and implementation of both command and control as well as market-based measures. *(Stanley, Hensher, & Loader, 2011)(Heinonen, Jalas, Juntunen, Ala-Mantila, & Junnila, 2013) (Gallego, Montero, & Salas, 2013); (Azevedo & Peters, 2017); (Ekholm & Salonen, 2017); Azevedo & Leal, 2017*		
	Improved access & fuel switch to modern low-carbon energy	**Water efficiency and pollution prevention (6.3/6.4/6.6)** ↑/↓ [+2,-1] ●● ★★★ 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. Transport electrification could lead to tradeoffs with water use if the electricity is provided with water intensive power generation. Hejazi et al. (2015); Song et al. (2016); Fricko et al. (2016)	**Ensure Sustainable Consumption& Production patterns (12.3)** ↑ [+2] ●●● ★★★ Due to persistent reliance on fossil fuels, it is posited that transport is more difficult to decarbonise than other sectors. This study partially confirms that transport is less reactive to a given carbon tax than the non-transport sectors. In the first half of the century, transport mitigation is delayed by 10–30 years compared to non-transport mitigation. The extent to which earlier mitigation is possible strongly depends on implemented technologies and model structure. *(Pietzcker et al., 2013) (Figueroa, Lah, Fulton, McKinnon, & Tiwari, 2014); IPCC AR5 WG3 (2014); (Creutzig et al., 2015)*		

Panel C Part 1

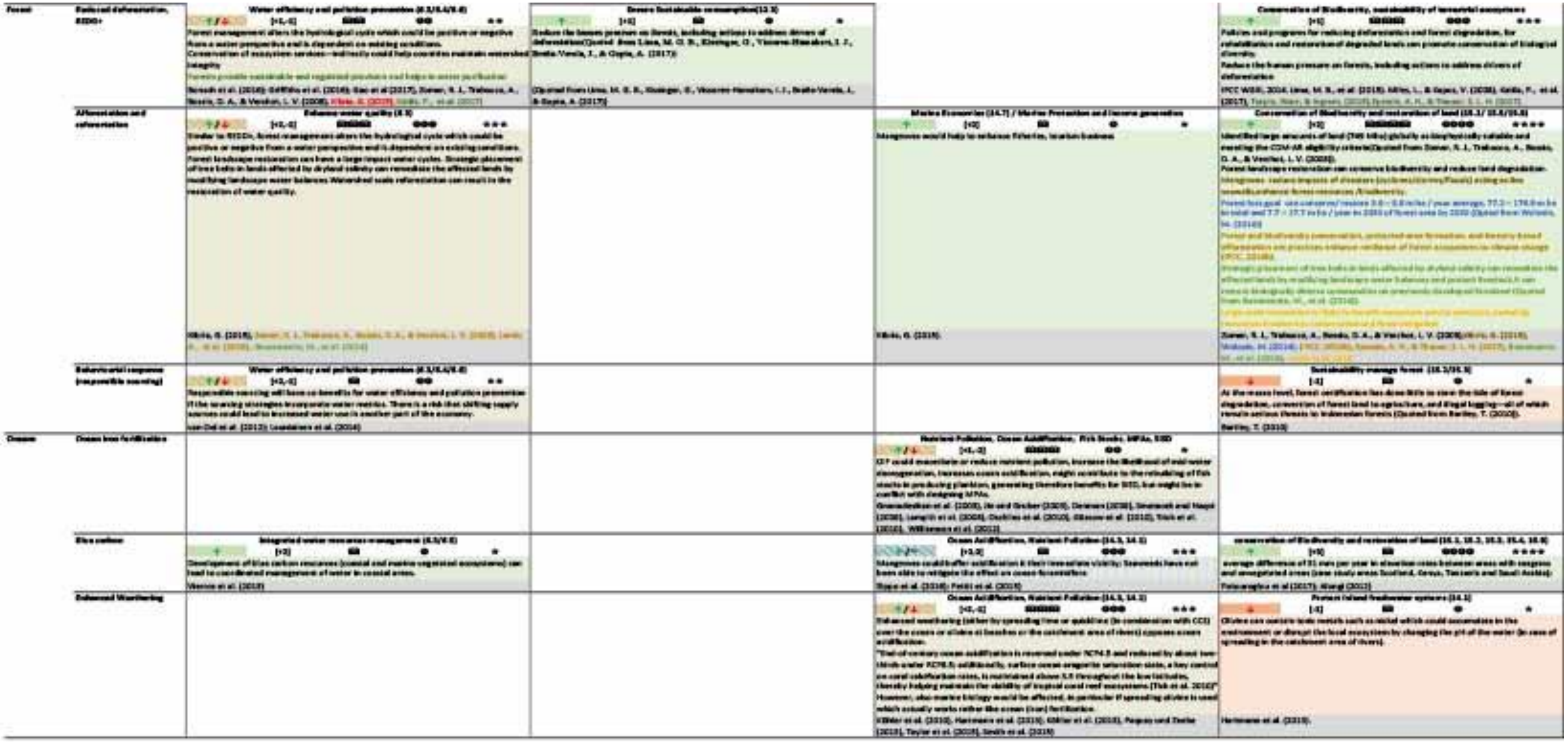


Do N

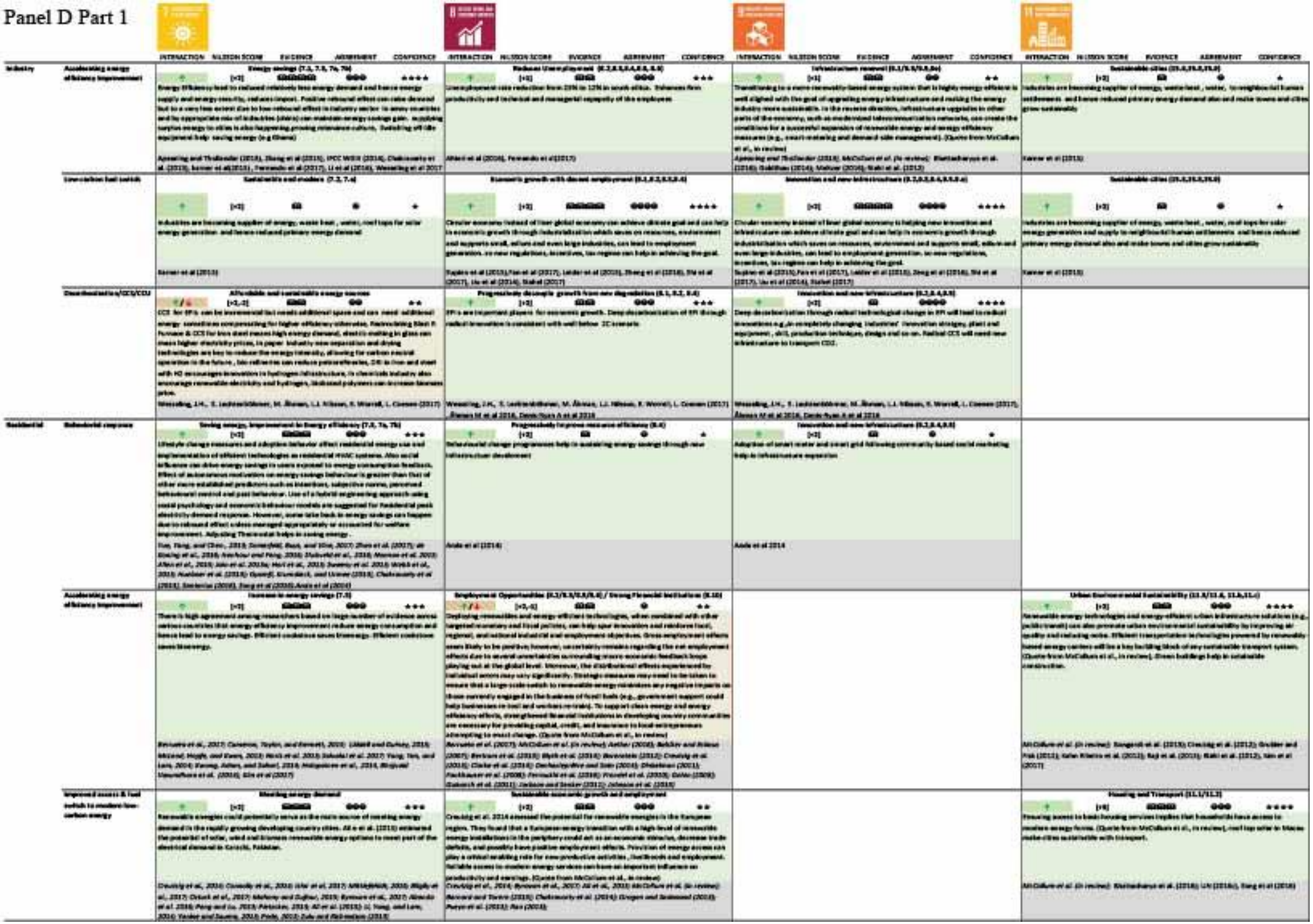
Panel C Part 2



Do N



Panel C Part 3


Panel D Part 1

Transport	Behavioural response	Energy savings (7.3, 7a, 7b) [+2] Behavioural response will reduce the volume of transport needs and, by extension, energy demand. [illegible]	Promote Sustained, Inclusive economic growth (8.3) [-2] [illegible]		Make cities & Human settlements inclusive, safe, resilient (11.2) [+2] [illegible]
	Accelerating energy efficiency improvement	Energy savings (7.3, 7a, 7b) [+2] [illegible]	Promote Sustained, Inclusive economic growth (8.3) [+2,-2] [illegible]	Build Resilient Infrastructure (9.1) [+2,-2] [illegible]	Make cities sustainable (11.2, 11.3) [+2] [illegible]
	Improved access & fuel switch to modern low-carbon energy	Increase share of renewables (7.2) [+2] [illegible]	Promote Sustained, Inclusive economic growth (8.3) [+2,-2] [illegible]	Help building inclusive infrastructure (9.1, 9.a) [+2] [illegible]	Make cities & Human settlements inclusive, safe, resilient (11.2) [+2] [illegible]

Do N

Panel D Part 1

Panel D Part 2

SDG 7

		INTERACTION	NILSSON SCORE	EVIDENCE	AGREEMENT	CONFIDENCE	Description	References
Replacing coal	Non-biomass renewables solar, wind, hydro	↑	[+2]	■■■■	●●●	★★★★	Decarbonisation of the energy system through an up-scaling of renewables will greatly facilitate access to clean, affordable and reliable energy. Hydropower plays an increasingly important role for the global electricity supply. This mitigation option is in line with the targets of SDG7 under the caveat of a transition to modern biomass.	Cherian A. (2015); Rogelj (2013); Cherian A. (2015); Jingura R.M., Kamusoko R.(2016)
	Increased use of biomass	↑	[+2]	■■■■	●●●	★★★	Increased use of modern biomass will facilitate access to clean, affordable and reliable energy. This mitigation option is in line with the targets of SDG7.	Cherian A. (2015); Jingura R.M., Kamusoko R.(2016), Rogelj (2013)
	Nuclear/Advanced Nuclear	↑	[1]	■■■	●	★★	Increased use of nuclear power can provide stable baseload power supply and reduce price volatility.	IPCC AR5 WGIII (2014)
	CCS: Bio energy	↑	[+2]	■■■■	●●●	★★★	Increased use of modern biomass will facilitate access to clean, affordable and reliable energy.	IPCC AR5 WGIII (2014)
Advanced coal	CCS: Fossil	↑	[+2]	■■■■	●●●	★★★	Advanced and cleaner fossil fuel technology is in line with the targets of SDG7.	IPCC AR5 WGIII (2014)

SDG 8

		INTERACTION	NILSSON SCORE	EVIDENCE	AGREEMENT	CONFIDENCE	Description	References
Replacing coal	Non-biomass renewables solar, wind, hydro	-	[0]	■■■	●●	★★	Innovation and Growth (8.1/8.2/9.4): Decarbonisation of the energy system through an up-scaling of renewables and energy efficiency is consistent with sustained economic growth and resource decoupling. Long-term scenarios point towards slight consumption losses caused by a rapid and pervasive expansion of such energy solutions. Whether sustainable growth, as an overarching concept, is attainable or not is more disputed in the literature. Existing literature is also undecided as to whether or not access to modern energy services causes economic growth. (Quote from McCollum et al., in review)	McCollum et al. (in review); Bosan et al. (2016); Clarke et al. (2016); Jackson and Senker (2011); New Climate Economy (2014); OECD (2017); York and McGee (2017)
	Increased use of biomass	↑	[+1]	■	●	★	Decarbonisation of the energy system through an up-scaling of renewables will greatly facilitate access to clean, affordable and reliable energy.	Jingura R.M., Kamusoko R. (2016)
	Nuclear/Advanced Nuclear	↑	[1]	■■■	●	★★	Local employment impact and reduced price volatility.	IPCC AR5 WGIII (2014)
	CCS: Bio energy	↑	[+1]	■	●	★	See positive impacts of bio-energy use.	
Advanced coal	CCS: Fossil	↓	[-1]	■■■■	●●●	★★★	Innovation and Growth (8.1/8.2/9.4): Lock-in of human and physical capital in the fossil resources industry	IPCC AR5 WGIII (2014); Vergragt et al. (2011); Markusson et al. (2012); IPCC (2005); Benson et al. (2005); Fankhauser et al. (2008); Shackley and Thompson (2012); Johnson et al. (2015); Bertram et al. (2015).

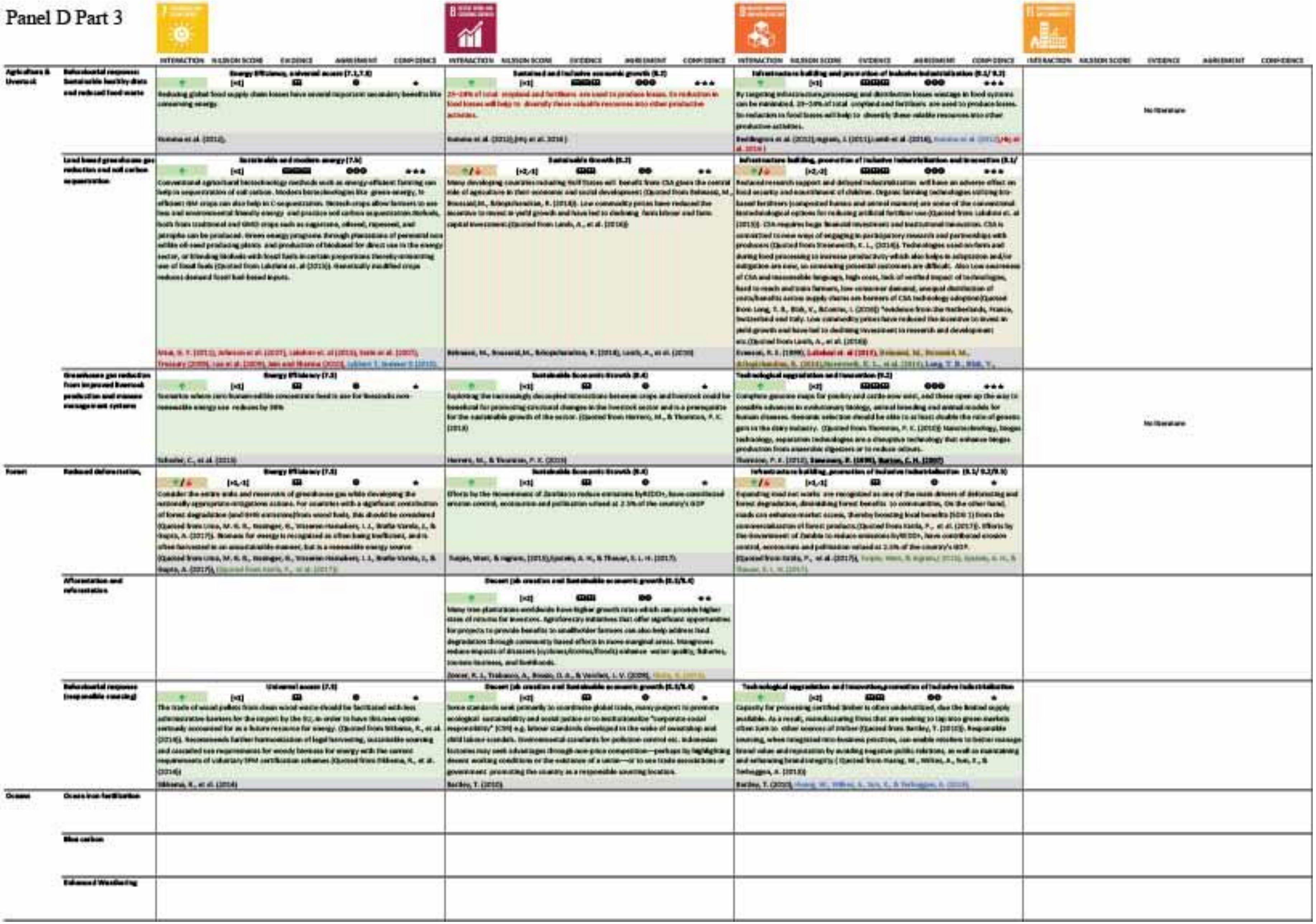
SDG 9

		INTERACTION	NILSSON SCORE	EVIDENCE	AGREEMENT	CONFIDENCE	Description	References
Replacing coal	Non-biomass renewables solar, wind, hydro	- / ↓	[0,-1]	■■■	●●●	★★	Inclusive and Sustainable Industrialization (9.2/9.4): A rapid up-scaling of renewable energies could necessitate the early retirement of fossil energy infrastructure (e.g., power plants, refineries, pipelines) on a large scale. The implications of this could in some cases be negative, unless targeted policies can help alleviate the burden on industry. (Quote from McCollum et al., in review)	McCollum et al. (in review); Bertram et al. (2015); Fankhauser et al. (2008); Guivarch et al. (2011); Johnson et al. (2015)
	Increased use of biomass	↑	[+1]	■■■	●●●	★★	Access to modern and sustainable energy will be critical to sustain economic growth.	Jingura R.M., Kamusoko R. (2016), Shahbaz M., Rasool G., Ahmed K., Mahalik M.K. (2016)
	Nuclear/Advanced Nuclear	↓	[-1]	■■■	●●●	★★★	Innovation and Growth (8.1/8.2/9.4): Legacy cost of waste and abandoned reactors.	IPCC AR5 WGIII (2014); Marra and Palmer (2011); Greenberg, (2013a); Schwenk-Ferrero (2013a); Skipperud et al. (2013); Tyler et al. (2013a).
	CCS: Bio energy	↑	[+1]	■	●	★	See positive impacts of bio-energy use and CCS/CCU in industrial demand.	
Advanced coal	CCS: Fossil	↑	[+1]	■	●	★	See positive impacts of CCS/CCU in industrial demand.	

SDG 11

		INTERACTION	NILSSON SCORE	EVIDENCE	AGREEMENT	CONFIDENCE	Description	References
Replacing coal	Non-biomass renewables solar, wind, hydro	↑	[+2]	■■■■	●●	★★★	Disaster Preparedness and Prevention (11.5): Deployment of renewable energy and improvements in energy efficiency globally will aid climate change mitigation efforts, and this, in turn, can help to reduce the exposure of people to certain types of disasters and extreme events. (Quote from McCollum et al., in review)	McCollum et al. (in review); Daut et al. (2013); Hallegatte et al. (2016); IPCC (2014); Nakd[illegible] et al. (2012); Tully (2006)
	Increased use of biomass							
	Nuclear/Advanced Nuclear							
	CCS: Bio energy							
Advanced coal	CCS: Fossil							

Panel D Part 2


Panel D Part 3
INTERACTION
NILSSON SCORE
EVIDENCE
AGREEMENT
CONFIDENCE