Topic 4: Adaptation and Mitigation Measures

4.1 Implementing responses consistent with long-term and strategic goals

Although responses to climate change must be viewed within a strategic long-term context consistent with achieving long-term goals such as limiting global average temperature increase to 2 degrees above pre-industrial levels (Topic 3), the options available today are only those that can be implemented in the near-term. Hence, the near-term responses and operational decisions will have a significant bearing on the outcome of the long-term climate goals. This calls for pursuing climate resilient development pathways, supported by policies and strategies with long-term perspectives and enduring effects, such as investments in capital infrastructure and the sustainable development of human settlements that often have long lifetimes.

Topic 4 highlights the range of mitigation and adaptation options available, along with the enabling factors and constraints in their deployment. This Topic also considers policies and measures across a range of scales and sectors, their trade-offs and synergies, as well as the potential for integrating adaptation and mitigation policies.

4.2 Enabling factors, constraints and limits to adaptation and mitigation

Progress in research, policy, and practice since the AR4 has enhanced understanding of the enabling factors and constraints associated with the implementation of mitigation and adaptation options

Enhancing the mitigative and adaptive capacities of actors is necessary to successfully manage the risks posed by climate change to human and natural systems (*very high confidence*). Such capacities vary significantly among global regions, institutions, sectors, communities, and ecological systems and are closely linked to socioeconomic development pathways. For example, low-income countries have the lowest financial, technological, and institutional capacities to pursue low-carbon, climate-resilient development pathways. Although developed nations generally have greater capacity to manage the risks of climate change, that capacity does not necessarily translate into the implementation of mitigation and adaptation options. *{WGII 1.1, 15.1, 16.3, 16.4, 20.2, 20.6, Box 20-1, SPM, TS; WGIII 4.5, 4.6, SPM, TS}*

Path dependence in global and regional economic development, greenhouse gas emissions, resource consumption, infrastructure and settlement patterns, institutional behaviour, and technology constrains mitigation and adaptation options (*high agreement, medium evidence*). Such constraints may limit the capacity of human and natural systems to remain below particular GHG emissions or climate thresholds or avoid adverse impacts to vulnerable regions, sectors, or ecological systems (Table 4.1). Some constraints may be overcome given the introduction of new technologies and financial resources, increased institutional effectiveness and governance, or through changes in social and cultural attitudes and behaviours. *{WGII 16.3, 16.4, 19.5, SPM, TS; WGIII 1.3, 1.4, 4.5, 5.2, 5.3, SPM, TS}*

Adaptive institutions and systems of governance are essential for creating enabling conditions for the planning and implementation of mitigation and adaptation options (*very high confidence*). Despite the presence of a wide array of multilateral, national, and sub-national institutions focused on mitigation and adaptation, global GHG emissions continue to increase and identified adaptation needs have not been adequately addressed. Constraints associated with mitigation, adaptation, and disaster risk reduction are particularly high in regions with weak institutions and/or that exhibit poor coordination and cooperation in governance. The implementation of effective mitigation and adaptation options may necessitate new institutions and institutional arrangements that span multiple scales (Table 4.1). *{WGII 2.2, 5.5, 8.4, 11.7, 12.5, 14.2, 15.5, 16.3, 25.4, 28.2, Table 14-1, Table 16-1, SPM, TS; WGIII 4.1, 12.6, 13, 14, 15.2, 16}*

Technological innovation and investments in green and sustainable infrastructure can reduce greenhouse gas emissions and enhance societal resilience to climate change (*very high confidence*). Technological innovation and change can expand the availability of mitigation and adaptation options and/or their effectiveness. The enhanced uptake of low carbon and carbon neutral energy technologies can reduce the energy intensity of development, the carbon intensity of energy, and therefore the costs of mitigation. Similarly, new technologies and infrastructure can increase the resilience of human systems while reducing adverse externalities on natural systems. However, investments in technology and infrastructure can be contingent upon access to finance and technology, as well as broader economic development that builds capacity (Table 4.1). *{WGII 14.2, 14.3, 15.4, 16.3, 20.2, 20.6, Table 14-1, Table 16-1, Box 16-2, SPM, TS; WGIII 4.3, 4.5, 5.6, 6, 15.12, 16.2, 16.5, SPM, TS}*

Behaviour, lifestyle and culture have considerable influence on energy use and associated GHG emissions and the vulnerability of human and natural systems to climate change (*high agreement, medium evidence*), with high mitigation potential in some sectors, in particular when complementing technological and structural change (*medium evidence, medium agreement*). Shifts toward more emission-intensive lifestyles might contribute to higher energy and resource consumption and therefore higher mitigation costs, but emissions can be substantially lowered through changes in consumption patterns, dietary change and reduction in food wastes. The social acceptability and/or effectiveness of climate policies may be dependent upon the extent to which they incentivise, or are contingent upon, changes in lifestyles or behaviours (Table 4.1). Similarly, livelihoods that are dependent upon climate-sensitive sectors or resources may be particularly vulnerable to climate change and climate change policies. Individual preferences for lifestyles with a high perceived amenity value may increase exposure of human settlements to climate hazards and affect the resilience of natural systems. *{WGII 2.2, 9.3, 11.3, 12.3, 13.2, 13.3, 16.3, 16.7, 22.4, 23.4, 24.4, 24.5, 25.7, 26.8, 27.3, 28.3, 29.3, 29.4, SPM, TS; WGIII 2.2, 3.9, 4.3, 5.5, SPM, TS}*

Table 4.1: Common constraints influencing mitigative and adaptive capacity.

Constraining Factor	Implications for Mitigation	Implications for Adaptation
Demographic change	Population growth contributes to economic growth, energy demand and consumption, and greenhouse gas emissions. *{WGIII 4.3, 5.3, SPM, TS}*	Population growth associated with hazardous landscapes can increase exposure to climate variability and change as well as demands for, and pressures on, natural resources and ecosystem services. {WGII, Box 16-3}
Knowledge, education, and human capital	Influences national, institutional, and individual risk perception, willingness to change behavioral patterns and practices, and adopt social and technological innovations to reduce emissions. *{WGIII 2.2, 4.3, 11.8, SPM, TS}*	Constrains awareness among actors with respect to climate risk, the relative utility of different types of knowledge, and the costs and benefits of different adaptation options. *{WGII 14.2, 16.3, 16.5, Box 16-2}*
Social attitudes and behaviors	Influences societal perceptions of the utility of mitigation policies and technologies and willingness to pursue sustainable behaviors and technologies. *{WGIII 2.2, 3.7, 3.9, 4.3, 5.5, 11.8, SPM, TS}*	Influences framing of adaptation, perceptions of acceptable vs. intolerable risks, as well as preferences for specific adaptation policies and measures. *{WGII 16.3, 16.5, 17.3, 17.5, SPM, TS}*
Governance, institutions and policy	Influences policies, incentives, and cooperation to develop or impede climate policy and deployment of efficient, carbon neutral, and renewable energy technologies. *{WGIII 4.1, 4.3, 6.4, 14.1, 14.2, 14.3, SPM, TS}*	Influences ability to coordinate adaptation policies and measures and to deliver capacity to actors to plan and implement adaptation. *{WGII 14.2, 15.5, 16.3, 16.5, SPM, TS}*
Finance	Influences the capacity of developed and, particularly, developing nations to pursue policies and technologies that reduce emissions. *{WGIII 12.6, 13.12, 15.12, 16.2, 16.5, SPM, TS}*	Influences the scale of investment in adaptation policies and measures and therefore their effectiveness. *{WGII 14.2, 16.3, 16.5, 17.3, 17.5, SPM, TS}*
Technology	Influences the rate and scale at which society can reduce the carbon intensity of energy production and use and transition toward renewable technologies. *{WGIII 2.4, 4.3, 6.3, 6.5, 6.6, 11.8, TS}*	Influences the range of adaptation options available to actors as well as their effectiveness in reducing or avoiding risk from increasing rates or magnitudes of climate change. *{WGII 16.3, 16.5}*

Natural resources	Influences the relative long-term sustainability of different energy technologies. *{WGIII 4.3, 4.4., 4.5, 11.6, 11.8, TS}*	Influences the coping range of actors, vulnerability to non-climatic factors, and potential competition for resources that enhances vulnerability. *{WGII 16.3, 16.5}*
Adaptation and development deficits	Constrains mitigative capacity and undermines international cooperative efforts on climate owing to a contentious legacy of cooperation on development. *{WGIII 4.3, 4.6}*	Increases vulnerability to current climate variability as well as future climate change. *{WGII 2.4, 14.3, 17.2, TS}*
Inequality	Constrains the ability for poor nations, or different communities or sectors within nations, to contribute to GHG mitigation. *{WGIII 4.7}*	Places the impacts of climate change and the burden of adaptation disproportionately on the most vulnerable and/or displaces them onto future generations. *{WGII 13.2, 16.7}*

4.3 Response options for mitigation

A comprehensive approach to mitigation will include actions across all sectors, with the nature of opportunities and options for mitigation varying substantially across sectors.

In baseline scenarios, GHG emissions are projected to grow (Figure 4.1) in all sectors, except for net CO_2 emissions in the AFOLU sector *(robust evidence, medium agreement)*. In 2010, 35% of direct GHG emissions were released in the energy supply sector, 24% in AFOLU, 21% in industry, 14% in transport and 6% in buildings. Energy supply sector emissions are expected to continue to be the major source of direct GHG emissions in baseline scenarios, while the industry and building sectors dominate if indirect emissions are allocated to the sectors where the energy (mainly electricity) is used. Deforestation decreases in most of the baseline scenarios, leading to a decline in CO_2 emissions in that sector. *{WGIII SPM. 4.2.2}*

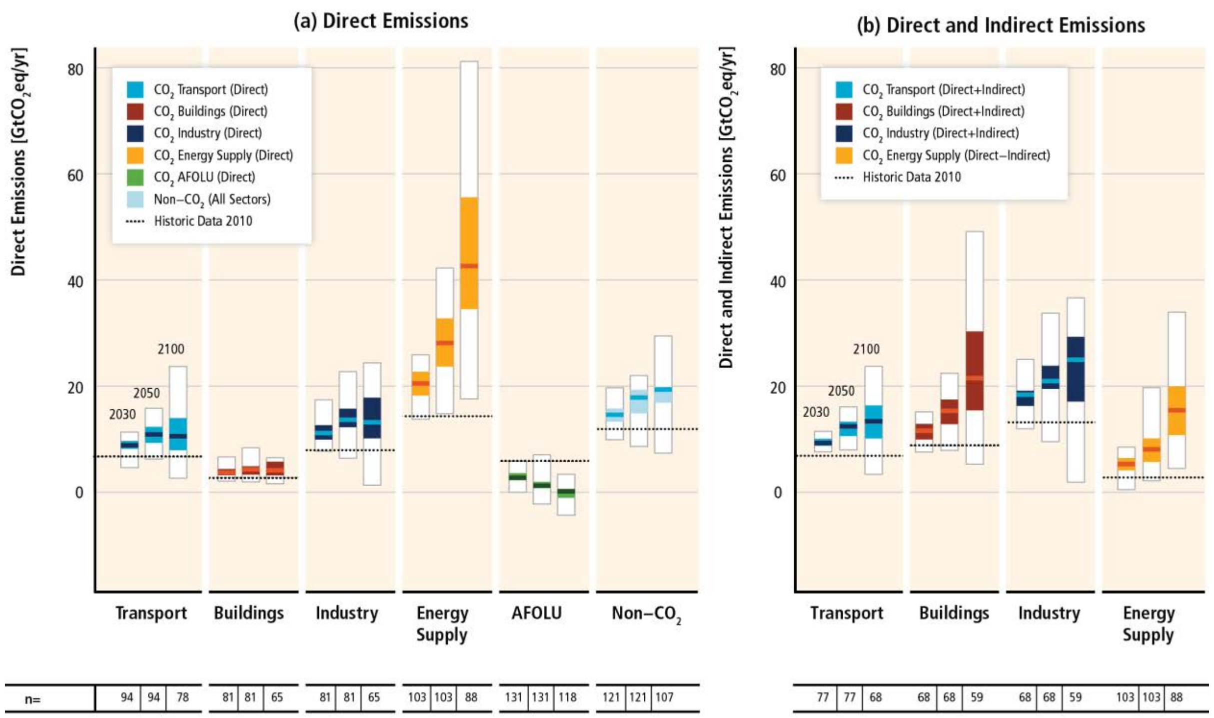

Figure 4.1: Evolution of direct and indirect (CO_2 from electricity generation only) GHG emissions over time by sector in the baseline scenarios of the AR5 scenario database. Non CO_2 GHGs are converted to CO_2 equivalents using 100-year global warming potentials from the IPCC SAR. The emissions shown under "Energy Supply" are the residual emissions, i.e. direct emissions minus those emissions from electricity generation that have been reallocated to the end-use sectors. The thick black lines corresponds to the median, the coloured boxes to the inter-quartile range (25th to 75th percentile) and the whiskers to the total range across scenarios. The numbers below the graphs refer to the number of

scenarios included in the ranges which differs across sectors and time due to different sectoral resolution and time horizon of models; includes only baseline scenarios.

Stabilizing GHG concentrations in the atmosphere at low level; requires mitigation throughout the economy. Efforts in one sector determine the need for mitigation in others (*medium confidence*). Mitigation measures interact through various economic linkages. Low stabilization scenarios are dependent upon a full decarbonization of energy supply in the long term. This entails more flexibility for the end-use sectors. Conversely, demand reductions in the energy end-use sectors decrease emissions directly and reduce the scale of the mitigation challenge for the energy supply side. *{WGIII SPM. 4.2.1}*

Urbanization is expected to continue to be a major driver of energy use and therefore human settlements in rapidly urbanizing areas where urban form and infrastructure are not locked in offer a large mitigation opportunity; but there are often limited governance, technical, financial, and institutional capacities (*robust evidence, high agreement*)**.** Infrastructure developments and long-lived products that lock societies into GHG intensive emissions pathways may be difficult or very costly to change (*robust evidence, high agreement*). However, material, products and infrastructure with long lifetimes and low lifecycle emissions can facilitate a transition to low-emission pathways while also reducing emissions through lower levels of material use. *{WGIII SPM, 4.2.1, 5.6.3, 9.4, 12.3, 12.4}*

Decarbonizing (i.e. reducing the carbon intensity of) electricity generation is a key component of cost-effective mitigation strategies in achieving low-stabilization levels *(medium evidence, high agreement).* In most ambitious long-term mitigation scenarios, the economy is fully decarbonized at the end of the 21st century with many scenarios relying on a net removal of CO_2 from the atmosphere. Accelerated electrification of energy end use, coupled with decarbonization of the majority of electricity generation by 2050 and an associated phase out of freely emitting coal generation, is a common feature of scenarios reaching roughly 550 ppm $C0_2$eq or less by 2100. *{WGIII SPM, 6.8, 7.11, Figures 7.14, TS.18}*

Demand reductions in the energy end-use sectors are a key mitigation strategy and affect the scale of the mitigation challenge for the energy supply side (*high confidence*). Limiting energy demand: 1) increases policy choices by maintaining flexibility in the technology portfolio; 2) reduces the required pace for up-scaling low-carbon energy supply technologies and hedges against related supply side risks (Figure 4.2); 3) avoids lock-in to new, or potentially premature retirement of, carbon-intensive infrastructures; 4) maximizes co-benefits for other policy objectives, since the number of co-benefits for energy end-use measures outweighs the adverse side-effects which is not the case for all supply-side measures *{WGIII Table 4.6, WGIII Tables TS.3–7}*; and 5) increases the cost effectiveness of the transformation (as compared to mitigation strategies with higher levels of energy demand) (*medium confidence*). However, energy service demand reductions are unlikely in developing countries or for poorer population segments whose energy service levels are low or partially unmet. *{WGIII 6.3.4, 6.6, 7.11, 10.4}*

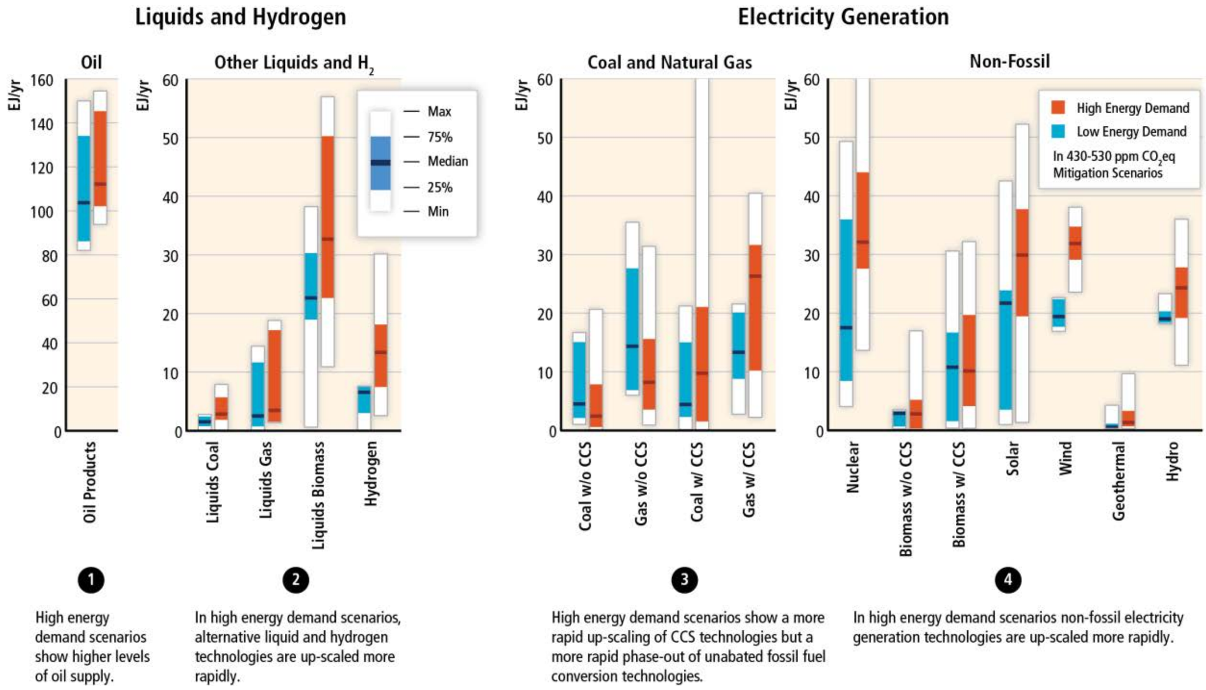

Figure 4.2: Influence of energy demand on the deployment of energy supply technologies in 2050 in mitigation scenarios reaching 430–530 ppm CO_2eq concentrations by 2100. Blue bars for 'low energy demand' show the deployment range of scenarios with limited growth of final energy of <20% in 2050 compared to 2010. Red bars show the deployment range of technologies in case of 'high energy demand' (>20% growth in 2050 compared to 2010). For each technology, the median, interquartile, and full deployment range is displayed. Notes: Scenarios assuming technology restrictions are excluded. Ranges include results from many different integrated models. Multiple scenario results from the same model were averaged to avoid sampling biases; see Chapter 6 for further details. *{WGIII Figure 7.11}*

The broad range of sectoral mitigation options available mainly relate to achieving reductions in GHG emission intensity, energy intensity reduction through improvements in technical efficiency, production and resource efficiency improvements, structural and system efficiency improvement, and changes in activity (Table 4.2). Direct options in AFOLU involve storing carbon in terrestrial systems (for example, through afforestation) and providing bioenergy feedstocks. Options to reduce non-CO_2 emissions exist across all these sectors, but most notably in agriculture, energy supply, and industry.

Table 4.2: Main sectoral mitigation measures categorized by key mitigation strategies and associated sectoral indicators (highlighted in grey). *{WG III Table TS.2}*

	GHG emission intensity reduction	Energy intensity reduction by improving technical efficiency	Production and resource efficiency improvement	Structural and systems efficiency improvement	Activity indicator change
Energy	*Emissions / secondary energy output*	*Energy input / energy output*	*Embodied energy / energy output*		*Final energy use*
	Greater deployment of RES, nuclear energy, and (BE)CCS; fuel switching within the group of fossil fuels; reduction of fugitive (methane) emissions in the fossil fuel chain	Extraction, transport, conversion of fossil fuels; electricity, heat, fuel transmission, distribution, and storage; CHP (cogeneration, *see Buildings*);	Energy embodied in manufacturing of energy extraction, conversion, transmission and distribution technologies.	Addressing integration needs	Demand from end-use sectors for different energy carriers (*see Transport, Buildings and Industry*)
Transport	*Emissions / final energy*	*Final energy/transport service*		*Shares for each mode*	*Total distance per year*
	Fuel carbon intensity (CO_2eq/MJ): Fuel switching to low-carbon fuels (e.g. electricity/hydrogen from low-carbon sources (*see Energy*); specific biofuels in various modes(*see AFOLU*)	Energy intensity (MJ/p-km, t-km): Fuel-efficient engines and vehicle designs; more advanced propulsion systems and designs; use of lighter materials in vehicles	Embodied emissions during vehicle manufacture, material efficiency; and recycling of materials (*see Industry*); infrastructure life-cycle emissions (*see Human Settlements*)	Modal shifts from LDVs to public transit, cycling/walking, and from aviation and HDVs to rail; eco-driving; improved freight logistics; transport (infrastructure) planning	Journey avoidance; higher occupancy/loading rates; reduced transport demand; urban planning (*see Human Settlements*)
Buildings	*Emissions / final energy*	*Final energy / useful energy*	*Embodied energy / operating energy*	*Useful energy / energy service*	*Energy service demand*
	Fuel carbon intensity (CO_2eq/MJ): Building integrated RES; Fuel switching to low-carbon fuels, e.g. electricity (*see Energy*)	Device efficiency: heating/ cooling (high-performance boilers, ventilation, air-conditioning, heat pumps), water heating, cooking (advanced biomass stoves), lighting, appliances	Building lifetime; component, equipment and appliance durability; low(er) energy & emission material choice for construction (*see Industry*)	Systemic efficiency: integrated design process; low/zero energy buildings; building automation and controls; urban planning; district heating/cooling and CHP; smart meters/grids; commissioning	Behavioural change (e.g. thermostat setting, appliance use); lifestyle change (e.g. per capita dwelling size, adaptive comfort)
Industry	*Emissions / Final energy*	*Final energy / material production*	*Material input / product output*	*Product demand / service demand*	*Service demand*
	Emissions intensity: Process emissions reductions; use of waste (e.g., MSP/ sewage sludge in cement kilns) and CCS in industry; HFC replacement and leak repair; Fuel switching among fossil fuels, to low-carbon electricity (*see Energy*) or biomass (*see AFOLU*)	Energy efficiency/BAT: Efficient steam systems; furnace and boiler systems; electric motor (pumps, fans, air compressor, refrigerators and material handling) and electronic control systems; (waste) heat exchanges; recycling	Material efficiency: Reducing yield losses; Manufacturing/construction: process innovations, new design approaches, re-using old material (e.g. structural steel); Product design (e.g. light weight car design); Fly ash substituting clinker	Product-service efficiency: More intensive use of products (e.g. car sharing, using of clothing for longer, new more durable products)	Reduced demand for, e.g., clothing; alternative forms of travel leading to reduced demand for car manufacturing
Human Settlements	*Emissions / Final energy*	*Final energy / useful energy*	*Material input in infrastructure*	*Useful energy / energy service*	*Service demand per capita*
	Integration of urban renewables; urban scale fuel switching programs	Cogeneration, heat cascading, waste to energy	Managed infrastructure supply; reduce primary materials input for infrastructure	Compact urban form; increased accessibility; mixed land use	Increasing accessibility: shorter travel time, more transport mode options
Agriculture, Forestry and other Land use	**Supply-side improvements**				**Demand-side measures**
	Emissions / area or unit product (conserved, restored)				*Animal/crop product consumption per capita*
	Emission reduction: of methane (e.g. livestock management) and nitrous oxide (fertilizer and manure management) and prevention of emissions to the atmosphere by conserving existing carbon pools in soils or vegetation (reducing deforestation and forest degradation, fire prevention/control, agroforestry), Reduced emissions intensity (GHG/unit product).	Sequestration: Increasing the size of existing carbon pools, and thereby extracting carbon dioxide from the atmosphere (e.g. afforestation, reforestation, integrated systems, carbon sequestration in soils)	Substitution: of biological products for fossil fuels or energy-intensive products, thereby reducing CO_2 emissions, e.g. biomass co-firing/CHP (*see Energy*), biofuels (*see Transport*), biomass-based stoves, insulation products (*see Buildings*)		Demand-side measures: Reducing losses and wastes of food, changes in human diets towards less emission-intensive products, use of long-lived wood products)

Energy system related mitigation measures include the decarbonization of the energy supply sector, final energy demand reductions, and switching to low-carbon fuels, including decarbonized electricity. Their relative importance varies with the availability of advanced technologies, cost and the level of behavioural, lifestyle and cultural change.

The energy supply sector is the largest contributor to global GHG emissions and offers opportunity for decarbonisation through renewable energy (RE), nuclear power, and carbon dioxide capture and storage (CCS). Near-term GHG emissions can be reduced by replacing current world average coal-fired plants with highly efficient natural gas combined cycle (NGCC) plants or combined heat and power (CHP) plants, provided that natural gas is available and the fugitive emissions associated with extraction and supply are low or mitigated (*robust evidence, high agreement*). *{WGIII TS 3.2.2}*

- **Renewable energy (RE) technologies have demonstrated substantial performance improvements and cost reductions, and a growing number of RE technologies have achieved maturity to enable deployment at significant scale** (*robust evidence, high agreement*) (SPM. 4.2.2)**.** Some technologies are already economically competitive in various settings. Decentralized RE utilization to meet rural energy needs has also increased, including various modern and advanced traditional biomass options as well as small hydropower, PV, and wind. *{WGIII TS 3.2.2}*
- **Nuclear energy is a mature low GHG emission source of baseload power but its share of global electricity generation has been declining since 1993 (***robust evidence, high agreement***).** Barriers and risks to an increasing use of nuclear energy include concerns about operational risks and the associated concerns, uranium mining risks, financial and regulatory risks, unresolved waste management issues, nuclear weapon proliferation concerns, and adverse public opinion (*robust evidence, high agreement*).New fuel cell cycles and reactor technologies addressing some of these issues are being investigated and progress in research and development has been made concerning safety and waste disposal. *{WGIII 7.5.4, 7.8, 7.9, 7.12, Figure TS.19}*
- **Carbon dioxide capture and storage (CCS) technologies could reduce the life-cycle GHG emissions of fossil fuel power plants and industries** *(medium evidence, medium agreement)***. Among CCS options, BECCS offers prospects of large-scale net negative GHG emissions, which plays an important role in many low stabilization scenarios (e.g., 430-480 ppm), while it entails challenges and risks** *(limited evidence, medium agreement).* Barriers to large-scale deployment of CCS technologies include concerns about the operational safety and long-term integrity of CO_2 storage, as well as risks related to transport and provision of biomass feedstock. *{WGIII SPM 4.2.2, TS 3.2.2}*

An overview of the projections of final demand reduction and low-carbon energy carrier share in end use sectors Transport, Buildings and Industry is given in Figure 4.3.

Transport: Technical and behavioural mitigation measures for all transport modes, plus in new infrastructure and urban redevelopment investments, could reduce final energy demand in 2050 by up to 40% below the baseline. The cost-effectiveness of different carbon reduction measures in the transport sector, including reducing the energy intensity of aircraft, trains, watercraft and road vehicles, varies significantly with vehicle type, transport mode and region. Strategies to reduce the carbon intensities of transport fuels are constrained by energy storage and low energy densities. Mitigation strategies, when associated with non-climate policies, can help decouple transport GHG emissions from economic growth in all regions but will require strong and mutually-reinforcing policies. *{WGIII SPM 4.2.3, TS 3.2.3}*

Buildings: Recent advances in technologies, know-how and policies in the building sector provide opportunities to stabilize or reduce global building sector energy use by mid-century. In addition to technologies and architecture, lifestyle, culture and other behavioural changes may lead to further large reductions in building and appliance energy requirements. A three- to five fold difference in energy use has been shown for provision of similar building-related energy service levels. For developed countries, scenarios indicate that lifestyle and behavioural changes could reduce energy demand by up to 20% in the short term and by up to 50% of present levels by mid-century. In developing countries, integrating elements of traditional lifestyles into building practices and architecture could facilitate the provision of high levels of energy services with much lower energy inputs than baseline. *{WGIII SPM, TS 3.2.4, 4.2.3, 9.3}*

Industry: An absolute reduction in emissions from the industry sector will require deployment of a broad set of mitigation options beyond energy efficiency measures, such as material use efficiency, product use efficiency, or demand reduction, recycling, re-use and deployment of CCS.. Besides sector-specific technologies, cross-cutting technologies (e.g., electronic control systems) and measures applicable in both large energy intensive industries and Small and Medium Enterprises (SMEs) and industrial clustering of SMEs are other options to reduce GHG emissions. *{WGIII SPM, TS 3.2.5}*

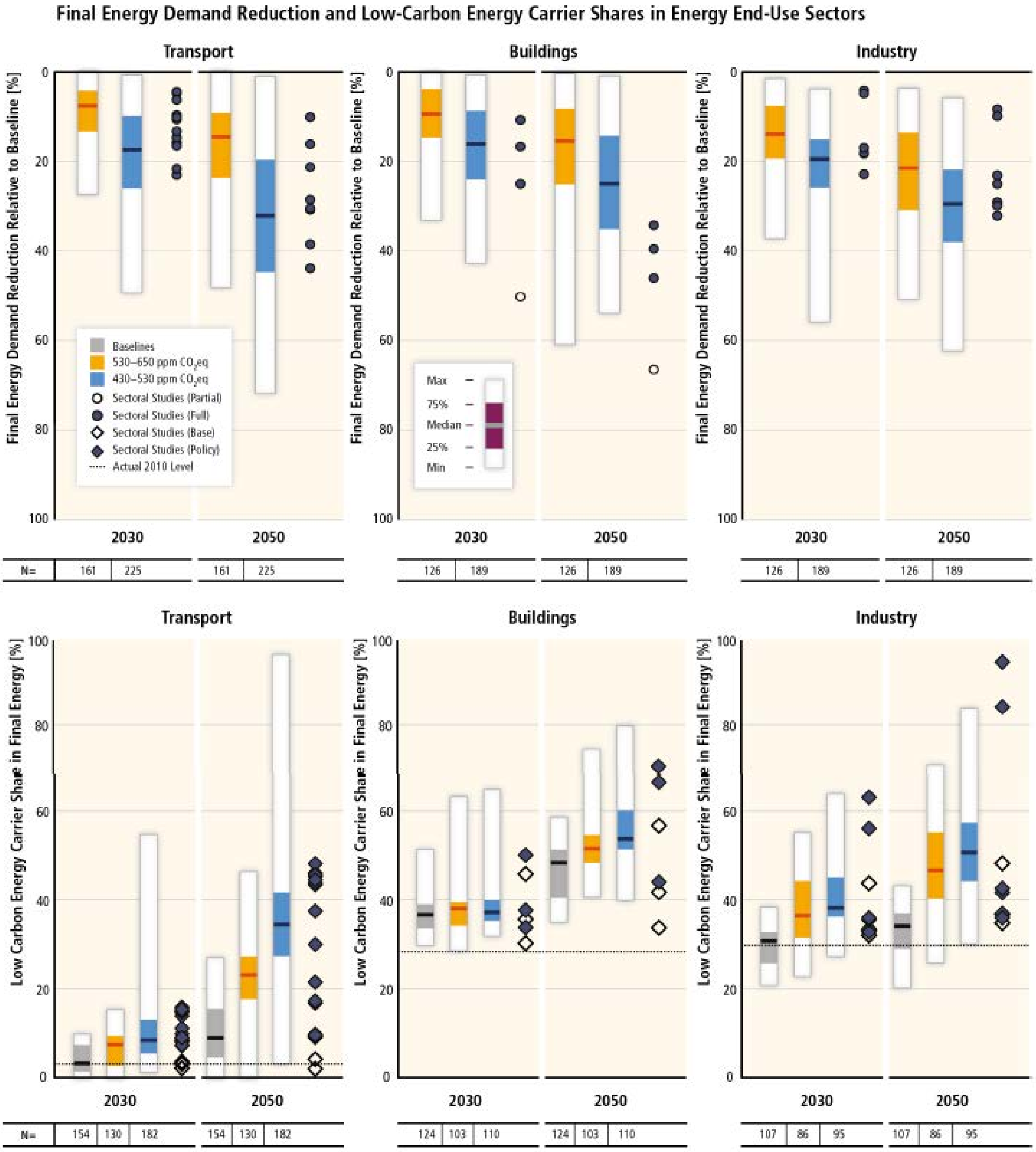

Figure 4.3: Final energy demand reduction relative to baseline (upper row) and low-carbon energy carrier shares in final energy (lower row) in the , transport, buildings, and industry sectors by 2030 and 2050 in mitigation scenarios from two different CO_2-eq concentration categories (see Section 6.3.2) compared to sectoral studies assessed in Chapters 8-10. Low-carbon fuels include electricity, hydrogen and liquid biofuels in transport, electricity in buildings and electricity, heat, hydrogen and bioenergy in industry. The numbers at the bottom of the graphs refer to the number of scenarios included in the ranges which differs across sectors and time due to different sectoral resolution and time horizon of models. *{WG III figure SPM.11}*

REDD+ and sustainable bioenergy have a critical role to play in mitigating climate change, especially in the near term, if food security, socioeconomic and biodiversity concerns are addressed.

The AFOLU sector accounts for about a quarter (~10–12GtCO_2eq/yr) of net anthropogenic GHG emissions (*medium evidence, high agreement*)**.** Most recent estimates indicate a decline in AFOLU CO_2 fluxes, largely due to decreasing deforestation rates and increased afforestation.

The most cost-effective mitigation options in forestry are reducing deforestation, afforestation, and sustainable forest management. In agriculture, the most cost-effective mitigation options are cropland management, grazing land management, and restoration of organic soils (*medium evidence, high agreement*)**..** The economic mitigation potential of supply-side measures is estimated to be 7.2 to 11 GtCO_2eq/year in 2030 (at <100 USD/tCO_2eq), about a third of which can be achieved at a <20 USD/tCO_2eq (*medium evidence, medium agreement*). Demand-side measures, such as changes in diet and reductions of losses in the food supply chain, have a significant, potential to reduce GHG emissions (0.76–8.6 GtCO_2eq/yr by 2050) (*medium evidence, medium agreement*). *{WGIII SPM. 4.2.3}*

Bioenergy can play a critical role for mitigation. However, barriers to large-scale deployment of bioenergy include concerns about GHG emissions from land, food security, water resources, biodiversity conservation and livelihoods. Evidence suggests that options with low lifecycle emissions (e.g., sugar cane, Miscanthus, and sustainable use of biomass residues), can reduce GHG emissions; outcomes are site-specific and rely on sustainable land-use management and governance. In some regions, bioenergy options, such as improved cookstoves, and small-scale biogas and biopower production, could reduce GHG emissions and improve livelihoods and health (*medium evidence, medium agreement*). *{WGIII 11.13}*

4.4 Response Options for Adaptation

A first step for adaptation is often to reduce current climate-related risks. Adaptation options can have multiple and overlapping entry points, and combine to form a portfolio of responses. However, trade-offs exist between some adaptation options.

A first step toward adaptation to future climate change is reducing vulnerability and exposure to present climate variability (*high confidence*). Strategies include actions with co-benefits for other objectives. Integration of appropriate adaptation strategies and actions into development planning and decision-making can proactively prepare for a range of future climates while helping to improve human health and livelihoods, social and economic well-being, and environmental quality now. Such strategies include improved social protection, improved water and land governance, enhanced water storage and services, reduce pollution, greater involvement of affected people in planning, and elevated attention to urban and peri-urban areas heavily affected by migration of poor people. *{WGII Table TS.7, 3.6, 9.4, 11.2, 14.2, 15.2-3, 15.5, 17.2, 20.4, 20.6, 22.4, 24.4, 25.10, 27.3-5, Boxes 25-2, 25-6, 25-8, and 25-9}*

An increased range of adaptation options has been assessed since the AR4 and clarity of the benefits and costs of these options and their links to sustainable development has improved. Adaptations employ a diverse portfolio of planning and practices, including:

- Infrastructure and asset development
- Technological process optimization
- Institutional and behavioural change or reinforcement
- Integrated natural resources management (such as for watersheds and coastal zones)
- Financial services, including risk transfer
- Information systems to support early warning and proactive planning

These approaches (Table 4.3 for examples and details) have a diversity of entry points in vulnerability reduction, disaster risk management and proactive adaptation planning. Appropriate entry points depend on co-benefits and opportunities within wider development plans and strategic goals, and existing other climate and non-climate pressures. *{WGII 15.3, 15.4, 15.6, FAQ 15-2}*

Individual adaptation measures can complement each other, but some approaches entail significant trade-offs with and reduce the effectiveness of other actions (*very high confidence*). Local governments and actors may face difficulties in identifying the most suitable and efficient approaches because of the diversity of possible approaches, from infrastructure development to "softer" approaches such as integrated watershed and coastal zone management. The effectiveness of specific adaptation options is influenced by cultural characteristics, institutional context and capacity, perception of risks, sense of place and role and entitlements to resources, which differ between individuals and institutions. Trade-offs (Table 4.4) often arise from differential values of societal actors and the degree to which individual adaptation options address those values and constrain or enable the simultaneous pursuit of other adaptation objectives. Some near-term responses to increasing risks related to climate change may also limit future choices. For example, enhanced protection of exposed assets can lock in dependence on further protection measures. *{WGII 15.2.1, 15.5.1, 16.2, 16.3.2, Table 16-2}*

The potential for individual adaptation measures to reduce risk differs between sectors and regions, and changes over time. For many natural ecosystems, the adaptation options are limited and focus mostly on reducing other pressures. For many human systems, a wider portfolio of options exists, including transformational responses, but their implementation faces a range of constraints.

Examples of key adaptation approaches for particular sectors are summarized below.

Freshwater resources: **Adaptive water management techniques, including scenario planning, learning-based approaches, and flexible and low-regret solutions, can help create resilience to uncertain hydrological changes and impacts due to climate change (*limited evidence, high agreement*).** Strategies include integrated water management; augmenting supply; reduced mismatch between water supply and demand and reducing non-climate stressors; strengthening institutional capacities; adoption of more water-efficient technologies and water-saving strategies through a range of incentives. *{WGII 3.6, 3.7, Table 16-2, 22.3-4, 23.4, 23.7, 24.4, Box 25-2, 27.2-3}*

Terrestrial and freshwater ecosystems: **Management actions, such as maintenance of genetic diversity, assisted species migration and dispersal, manipulation of disturbance regimes (e.g., fires, floods), and reduction of other stressors, can reduce, but not eliminate, risks of impacts to terrestrial and freshwater ecosystems due to climate change, as well as increase the inherent capacity of ecosystems and their species to adapt to a changing climate (*high confidence*).** Main management adaptation options are to reduce other pressures (e.g., pollution, runoff, fishing, tourism, introduced predators and pests); improve early warning systems and the associated response systems; and incorporate fire protection measures (e.g., prescribed burning, introduction of resilient vegetation). Enhancement of migration corridors can also assist autonomous adaptation. Translocation of species is controversial and becomes less feasible where whole ecosystems are at risk. *{WGII Figure SPM.5, 4.3-4, 25.6, 25.10, 26.4, Box CC-RF}*

Coastal systems and low-lying areas: **Adaptation can reduce some of the projected damages from flooding in river basins and coasts, driven by increasing urbanization and by increasing sea levels and peak river discharges (*high confidence*), but the relative costs of coastal adaptation vary strongly among and within regions and countries for the 21st century.** Significant experience exists in hard flood-protection technologies, but there are high costs for increasing flood protections. *{WGII 23.2-3, 23.7}* Successive building and protection cycles can increase exposure by constraining flexible responses to increasing risks to coastal infrastructure and low-lying ecosystems from sea-level rise; and coastal outfalls can impede drainage with increased water levels (section 3.3). Effective adaptation includes land-use controls and ultimately relocation as well as protection and accommodation *{WGII 25.6, 25.10, Box 25-1}*; appropriate building codes and settlement patterns; maintenance and restoration of coastal landforms and ecosystems including through community based actions; and improved management of soils and freshwater resources.

Marine systems and oceans: **Marine forecasting and early warning systems as well as reducing non-climatic stressors can help reduce risks for some fisheries and aquaculture industries, but options for unique ecosystems such as coral reefs are limited (*high confidence*).** Fisheries and some aquaculture industries with high-technology and/or large investments have high capacities for adaptation due to greater development of environmental monitoring, modelling, and resource assessments. Options include large-scale translocation of industrial fishing activities and flexible management that can react to variability and change. For smaller-scale fisheries and nations with limited adaptive capacities, building social, institutional and mangrove buffers that take advantage of beneficial changes, alternative livelihoods, and occupational flexibility are important strategies for reducing the vulnerability of ocean-dependent human communities.

Expansion of aquaculture can also increase flexibility and resilience. Human adaptation options for coral reef systems are limited to reducing other stressors, mainly by enhancing water quality and limiting pressures from tourism and fishing, but their efficacy will be severely reduced as thermal stress increases. *{WGII 6.3, 6.4, 7.3-4, 29.4, 30.6-7, Box CC-MB, 5.4, 25.6.2; 30.3, 30.5, Box CC-CR}*

Food production system/Rural areas: **Adaptation options for agriculture include technological responses (e.g., stress-tolerant crop varieties, irrigation), enhancing smallholder access to credit and other critical production resources, and strengthening institutions at local to regional levels to support gender-oriented measures (*high confidence*).** Responses to decreased food production and quality include development of new crop varieties including more effective adaptation to changes in CO_2, temperature, and drought; offsetting human and animal health impacts of reduced food quality, and offsetting of economic impacts of land use change. Options exist for adaptation via international agricultural trade (*medium confidence*). Deepening agricultural markets and improving the predictability and the reliability of the world trading system through trade reform could result in reduced market volatility and manage food supply shortages caused by climate change. Investing in the production of small-scale farms in developing countries also provides benefits.*{WGII 9.3, 22.3-4, 22.6, 25.9, 27.3}*

Urban areas, key economic sectors and services: **Urban adaptation benefits from effective multi-level urban risk governance, alignment of policies and incentives, strengthened local government and community adaptation capacity, synergies with the private sector, and appropriate financing and institutional development (*medium confidence*)** (section 3.3). Enhancing the capacity of low-income groups and vulnerable communities and their partnerships with local governments can also be an effective urban climate adaptation strategy.Examples of adaptation mechanisms include large-scale public-private risk reduction initiatives and economic diversification, and government insurance of the non-diversifiable portion of risk. In some locations, especially at the upper end of projected changes, responses could also require transformational changes such as managed retreat. *{WGII 8.3-4, 24.4, 24.5, 26.8, Table 11-3, Box 25-1, 25-9}*

Human health, security and livelihoods: **Adaptation options that focus on strengthening existing delivery systems and institutions as well as insurance and social protection strategies offer the best examples for securing health, security and livelihoods in the near term (*high confidence*).** The most effective adaptation measures for health in the near-term may be programs that implement and improve basic public health measures. Examples include provision of clean water and sanitation, secure essential health care including vaccination and child health services, increased capacity for disaster preparedness and response, and poverty alleviation (*very high confidence*). Health warning systems linked to response strategies, urban planning to reduce heat systems and improvements to the built environment are options to address heat related mortality. Robust institutions can manage many transboundary impacts of climate change to reduce conflict risks. Insurance programs, social protection measures, and disaster risk management may enhance long-term livelihood resilience among poor and marginalized people if policies address multidimensional poverty. *{WGII Figure TS 10, 8.2, 10.8, 11.3-8, 19.3, 22.3, 25.8, 26.6, Box CC-HS}*

Table 4.3: Approaches for managing the risks of climate change through adaptation. These approaches should be considered overlapping rather than discrete, and they are often pursued simultaneously. Examples are presented in no specific order and can be relevant to more than one category. Mitigation is considered essential for managing the risks of climate change; it is not addressed in this table as it is considered in other sections of this report. *{WGII Table SPM.2}*

Overlapping Approaches	Category	Examples
Vulnerability and exposure reduction through development, planning, & practices including many low-regrets measures	Human development	Improved access to education, nutrition, health facilities, energy, safe housing & settlement structures, & social support structures; Reduced gender inequality & marginalization in other forms.
	Poverty alleviation	Improved access to & control of local resources; Land tenure; Disaster risk reduction; Social safety nets & social protection; Insurance schemes.
	Livelihood security	Income, asset, & livelihood diversification; Improved infrastructure; Access to technology & decision-making fora; Increased decision-making power; Changed cropping, livestock, & aquaculture practices; Reliance on social networks.
	Disaster risk management	Early warning systems; Hazard & vulnerability mapping; Diversifying water resources; Improved drainage; Flood & cyclone shelters; Building codes & practices; Storm & wastewater management; Transport & road infrastructure improvements.
	Ecosystem management	Maintaining wetlands & urban green spaces; Coastal afforestation; Watershed & reservoir management; Reduction of other stressors on ecosystems & of habitat fragmentation; Maintenance of genetic diversity; Manipulation of disturbance regimes; Community-based natural resource management.
	Spatial or land-use planning	Provisioning of adequate housing, infrastructure, & services; Managing development in flood prone & other high risk areas; Urban planning & upgrading programs; Land zoning laws; Easements; Protected areas.
Adaptation including incremental and transformational adjustments	Structural/ physical	***Engineered & built-environment options:*** Sea walls & coastal protection structures; Flood levees; Water storage; Improved drainage; Flood & cyclone shelters; Building codes & practices; Storm & wastewater management; Transport & road infrastructure improvements; Floating houses; Power plant & electricity grid adjustments.
		Technological options: New crop & animal varieties; Indigenous, traditional, & local knowledge, technologies, & methods; Efficient irrigation; Water-saving technologies; Desalinization; Conservation agriculture; Food storage & preservation facilities; Hazard & vulnerability mapping & monitoring; Early warning systems; Building insulation; Mechanical & passive cooling; Technology development, transfer, & diffusion.
		Ecosystem-based options: Ecological restoration; Soil conservation; Afforestation & reforestation; Mangrove conservation & replanting; Green infrastructure (e.g., shade trees, green roofs); Controlling overfishing; Fisheries co-management; Assisted species migration & dispersal; Ecological corridors; Seed banks, gene banks, & other ex situ conservation; Community-based natural resource management.
		Services: Social safety nets & social protection; Food banks & distribution of food surplus; Municipal services including water & sanitation; Vaccination programs; Essential public health services; Enhanced emergency medical services.
	Institutional	***Economic options:*** Financial incentives; Insurance; Catastrophe bonds; Payments for ecosystem services; Pricing water to encourage universal provision and careful use; Microfinance; Disaster contingency funds; Cash transfers; Public–private partnerships.
		Laws & regulations: Land zoning laws; Building standards & practices; Easements; Water regulations & agreements; Laws to support disaster risk reduction; Laws to encourage insurance purchasing; Defined property rights & land tenure security; Protected areas; Fishing quotas; Patent pools & technology transfer.
		National & government policies & programs: National & regional adaptation plans including mainstreaming; Sub-national & local adaptation plans; Economic diversification; Urban upgrading programs; Municipal water management programs; Disaster planning & preparedness; Integrated water resource management; Integrated coastal zone management; Ecosystem-based management; Community-based adaptation.
	Social	***Educational options:*** Awareness raising & integrating into education; Gender equity in education; Extension services; Sharing indigenous, traditional, & local knowledge; Participatory action research & social learning; Knowledge-sharing & learning platforms.
		Informational options: Hazard & vulnerability mapping; Early warning & response systems; Systematic monitoring & remote sensing; Climate services; Use of indigenous climate observations; Participatory scenario development; Integrated assessments.
		Behavioral options: Household preparation & evacuation planning; Migration; Soil & water conservation; Storm drain clearance; Livelihood diversification; Changed cropping, livestock, & aquaculture practices; Reliance on social networks.
Transformation	Spheres of change	***Practical:*** Social & technical innovations, behavioral shifts, or institutional & managerial changes that produce substantial shifts in outcomes.
		Political: Political, social, cultural, & ecological decisions and actions consistent with reducing vulnerability & risk and supporting adaptation, mitigation, & sustainable development.
		Personal: Individual & collective assumptions, beliefs, values, & worldviews influencing climate-change responses.

Table 4.4: Examples of potential trade-offs associated with an illustrative set of adaptation options that could be implemented by actors to achieve specific management objectives. *{WGII Table 16-2}*

Sector	Actor's Adaptation Objective	Adaptation Option	Real or Perceived Trade-Off
Agriculture	Enhance drought and pest resistance; enhance yields	Biotechnology and genetically modified crops	Perceived risk to public health and safety; ecological risks associated with introduction of new genetic variants to natural environments
	Provide financial safety net for farmers to ensure continuation of farming enterprises	Subsidized drought assistance; crop insurance	Creates moral hazard and distributional inequalities if not appropriately administered
	Maintain or enhance crop yields; suppress opportunistic agricultural pests and invasive species	Increased use of chemical fertilizer and pesticides	Increased discharge of nutrients and chemical pollution to the environment; adverse impacts of pesticide use on non-target species; increased emissions of greenhouse gases; increased human exposure to pollutants
Biodiversity	Enhance capacity for natural adaptation and migration to changing climatic conditions	Migration corridors; expansion of conservation areas	Unknown efficacy; concerns over property rights regarding land acquisition; governance challenges
	Enhance regulatory protections for species potentially at-risk due to climate and non-climatic changes	Protection of critical habitat for vulnerable species	Addresses secondary rather than primary pressures on species; concerns over property rights; regulatory barriers to regional economic development
	Facilitate conservation of valued species by shifting populations to alternative areas as the climate changes	Assisted migration	Ultimate success of assisted migration is difficult to predict; introduction of species into new ecological regions could have adverse impacts on indigenous flora and fauna
Coasts	Provide near-term protection to financial assets from inundation and/or erosion	Sea walls	High direct and opportunity costs; equity concerns; ecological impacts to coastal wetlands
	Allow natural coastal and ecological processes to proceed; reduce long-term risk to property and assets	Managed retreat	Undermines private property rights; significant governance challenges associated with implementation
	Preserve public health and safety; minimize property damage and risk of stranded assets	Migration out of low-lying areas	Loss of sense of place and cultural identify; erosion of kinship and familial ties; impacts to receiving communities
Water resources management	Increase water resource reliability and drought resilience	Desalination	Ecological risk of saline discharge; high energy demand and associated carbon emissions; creates disincentives for conservation
	Maximize efficiency of water management and use; increases flexibility	Water trading	Undermines public good/social aspects of water
	Enhance efficiency of available water resources	Water recycling/reuse	Perceived risk to public health and safety

4.5 Policy approaches at different scales, including technology development/transfer and finance

Adaptation and mitigation can be promoted by and depend on policies and measures across a range of scales (*very high confidence*).

Climate change has the characteristics of a collective action problem at the global scale, because most GHGs accumulate over time and mix globally, and emissions by any agent (e.g. individual, community, company, country) affect other agents.[18] Therefore, effective mitigation will not be achieved if individual agents advance their own interests independently. While climate change mitigation can also have local co-benefits, climate change adaptation focuses primarily on local to national scale outcomes. However, the effectiveness of adaptation can still depend on links with other sectors and vertical coordination across governance scales, including international cooperation. *{SREX.SPM; WGII.2.2, 15.2; WGIII.13.ES, 14.3, 15.8}*

[18] In the social sciences this is referred to as a 'global commons problem.' As this expression is used in the social sciences, it has no specific implications for legal arrangements or for particular criteria regarding effort-sharing.

4.5.1 Mitigation Policies

A variety of climate policy instruments have been employed and an even wider variety of instruments could be employed at the international, regional, national, and sub-national levels.

4.5.1.1 International and Regional Cooperation

As a global commons problem, effective climate change mitigation requires international cooperation. The UNFCCC has provided a platform for coordinating efforts across nations; and other, increasingly diverse forms of international cooperation have developed over the past decade. These include linkages among regional, national and sub-national policies, and the inclusion of climate change issues in other policy arenas. *{WGIII 13}*

Existing and proposed international climate change cooperation arrangements vary in their focus and degree of centralization and coordination. They span: multilateral agreements, harmonized national policies and decentralized but coordinated national policies, as well as regional and regionally-coordinated policies (Figure 4.4). *{WGIII 13.4}*

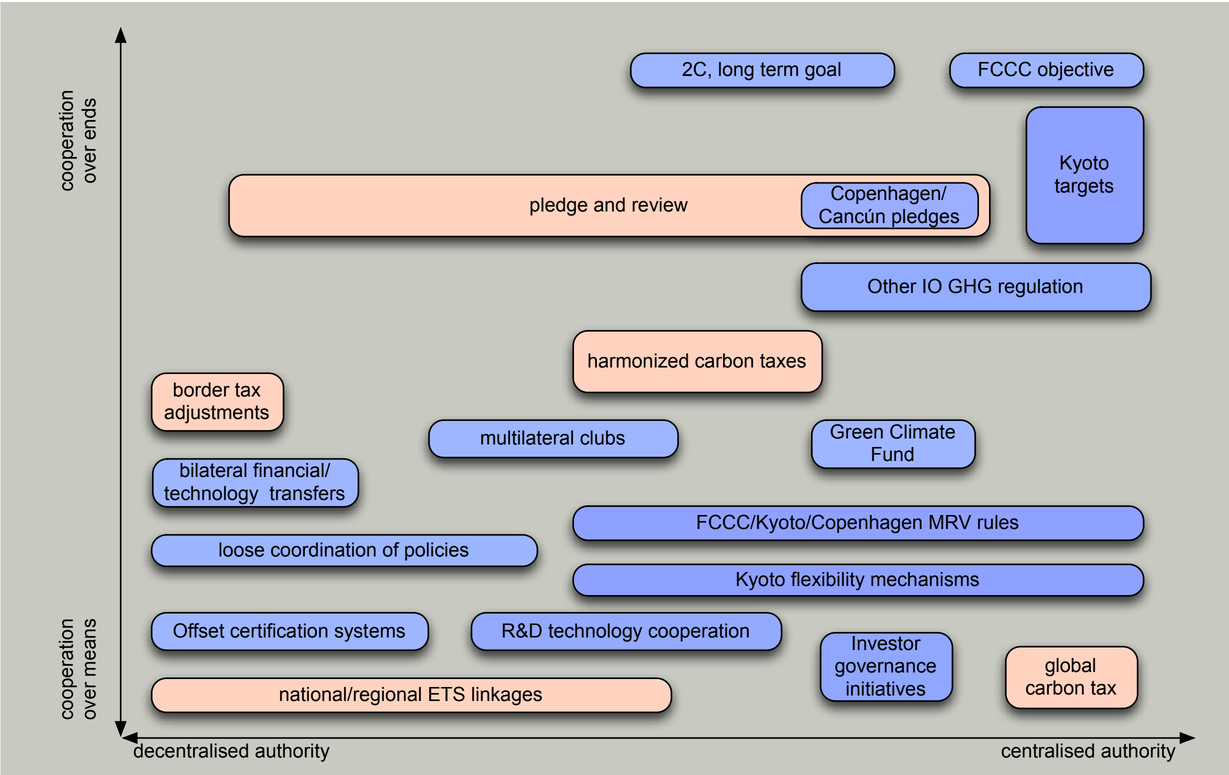

Figure 4.4: International cooperation over ends and means and degrees of centralized authority. Examples in blue are existing agreements. Examples in pale pink are proposed structures for agreements. The width of individual boxes indicates the range of possible degrees of centralization for a particular agreement. The degree of centralization indicates the degree conferred by the agreement, not the process by which is was agreed. *{WGIII Figure 13.2}*

The United Nations Framework Convention on Climate Change (UNFCCC) is the main multilateral forum focused on addressing climate change, with nearly universal participation, but activities since 2007 have led to an increasing number of institutions and other arrangements for international climate change cooperation. Other institutions organized at different levels of governance have resulted in diversifying international climate change cooperation. *{WGIII SPM, 13.3, 13.4, 13.5, 13.8, 16.2}*

The Kyoto Protocol offers lessons towards achieving the ultimate objective of the UNFCCC, particularly with respect to participation, implementation, flexibility mechanism, and environmental effectiveness (*medium evidence, low agreement*). The Parties collectively surpassed their collective emission reduction target in the first commitment period, but the Protocol credited emissions reductions that would have occurred even in its absence. The Kyoto Protocol does not directly influence the emissions of non-Annex I countries, which have grown rapidly over the past decade. The Kyoto Protocol's Clean Development Mechanism (CDM), which created a market for emissions offsets from developing countries, had generated credits equivalent to over 1.3 $GtCO_2eq$ by July 2013. Its environmental effectiveness has been mixed due to concerns about the additionality of projects, the validity of baselines, the possibility of emissions leakage, and recent credit price decreases *(medium evidence; medium agreement)*. CDM projects were concentrated in a limited number of countries. *{WGIII SPM, 5.2, 13.13.1.1, 13.7, 13.13, 14.3, Table TS.9}*

UNFCCC negotiations since 2007 have led to an increasing number of institutions and other arrangements for international climate change cooperation. Under the 2010 Cancún Agreement, developed countries formalized voluntary pledges of quantified, economy-wide emission reduction targets and some developing countries formalized voluntary pledges to mitigation actions. The distributional impact of the agreement will depend in part on the magnitude and sources of financing, although the scientific literature on this point is limited, because financing mechanisms are evolving more rapidly than respective scientific assessments (*low evidence; low agreement)*. Under the 2011 Durban Platform for Enhanced Action, delegates agreed to craft a future legal regime that would be 'applicable to all Parties … under the Convention' and would include substantial new financial support and technology arrangements to benefit developing countries, but the delegates did not specify means for achieving those ends. *{WG III 13.5.1.1, 13.13.1.3, 16.2.1.1}*

Several models for equitable burden sharing—among both developed and developing countries—have been identified in research. Distributional impacts from international cooperative agreements depend on the approach taken, criteria applied to operationalise equity, and the manner in which developing countries' emissions plans are financed. *{WG III 4.6, 13.4}*

The Montreal Protocol, aimed at protecting the stratospheric ozone layer, has achieved significant reductions in global greenhouse gas emissions *(robust evidence, high agreement)*. The Montreal Protocol set limits on emissions of ozone-depleting gases that are also potent GHGs, such as CFCs and HCFCs, but substitutes for those ozone-depleting gases (such as HFCs, which are not ozone-depleting) may also be potent GHGs. *{WGI 8; WG III 13.3.3, 13.3.4, 13.13.1.4}*

Policy linkages among regional, national, and sub-national climate policies offer potential climate change mitigation and adaptation benefits *(medium evidence, medium agreement).* Linkages can be established between carbon markets and through regional cooperation, such as embodying mitigation objectives in trade agreements or the joint construction of infrastructures that facilitate reduction in carbon emissions. These include lower mitigation costs, decreased emission leakage, and increased market liquidity. *{WGIII SPM, 13.3.1, 13.5 13.6, 13.7, 14.5}*

Various regional initiatives between national and global scales are either being developed or implemented, but their impact on global mitigation has been limited to date *(medium confidence).* Many climate policies can be more effective if implemented across geographical regions. *{WGIII Table TS.9, 13.13, 14.4, 14.5}*

4.5.1.2 National and Sub-National Policies

There are increased numbers of national and sub-national plans and strategies to address climate change since AR4 *(high agreement, medium evidence)*, but there is inadequate evidence to assess their impacts on emissions. *{WGIII 15.1, 15.2}*

Sector-specific policies have been more widely used than economy-wide policy instruments *(high agreement, medium evidence)* See Table 4.5. Although most economic theory suggests that economy-wide policies for the singular objective of mitigation would be more cost-effective than sector-specific policies, since AR4 a growing number of studies has demonstrated that administrative and political barriers may make economy-wide policies harder to design and implement than sector-specific policies. *{WG III 8.10, 9.10, 10.10, 15.2, 15.5, 15.8, 15.9}*

Carbon pricing regimes have been implemented in a diverse set of countries. Since AR4 the number of cap and trade systems has increased, but their short-run environmental effects have been limited as a result of loose caps or caps that have not proved to be constraining *(limited evidence, medium agreement)*. **Where implemented, tax-based policies specifically aimed at reducing GHG emissions – alongside technology and other policies - have helped to weaken the link between GHG emissions and GDP, although differentiation across sectors results in heterogenous marginal abatement costs and thus reduces cost-effectiveness. In a large group of countries, fuel taxes have effects that are akin to sectoral carbon taxes**. *(Robust evidence, medium agreement)* Revenues from carbon taxes or auctioned emission allowances can be used to cut distortionary taxes on labor and investment, and thereby to lower net social costs, *{WG III 3.6.3}*. Targeted distribution of revenues and allowances can also be used to render policies more politically acceptable, although potentially at the cost of environmental effectiveness. *{WG III 14.4.2; 15.5.2}*.

Regulatory approaches and information measures are widely used and are often environmentally effective *(medium evidence, medium agreement)*. Examples of regulatory approaches include energy efficiency standards; examples of information programmes include labeling programs that can help consumers make better-informed decisions. *{WG III 3.9.5, 15.5.5, 15.5.6}*

Sub-national climate policies play important roles, both in countries with national policies and in those without. For example, state and provincial climate policies exist in many European countries, in the United States, in China and elsewhere. Some of these are regional cap-and-trade systems, most prominently the Regional Greenhouse Gas Initiative in nine northeastern U.S. states and California's ambitious and multi-faceted Global Warming Solutions Act (AB 32). Likewise, in China, six local, pilot CO_2 cap-and-trade scheme have been launched. In addition, transnational cooperation has arisen among sub-national actors, commonly referred to as "transnational climate governance initiatives", notably by institutional investors, NGOs seeking to govern carbon offset markets, and among networks of cities seeking to collaborate in generating low-carbon urban development. *{WGIII 13.5.2, 15.2.4, 15.3, 15.8}*

Without coordination, policy instruments may not work as expected. Carbon prices to address the emissions externality can interact positively with an R&D subsidy to address innovation market failures. By contrast, while the emission abatement effects of policies nested under a carbon tax are additive, policies nested under a quantity-averaging instrument, such as cap-and-trade, are not (*medium evidence, high agreement*). *{WGIII 15.7.}*

Table 4.5: Sectoral Policy Instruments. *{WGIII Table 15.2}*

Policy Instruments	Energy	Transport	Buildings	Industry	AFOLU	Human Settlements and Infrastructure
Economic Instruments – Taxes (Carbon taxes may be economy-wide)	- Carbon taxes	- Fuel taxes - Congestion charges, vehicle registration fees, road tolls - Vehicle taxes	- Carbon and/or energy taxes (either sectoral or economy wide)	- Carbon tax or energy tax - Waste disposal taxes or charges	- Fertilizer or Nitrogen taxes to reduce nitrous oxide	- Sprawl taxes, Impact fees, exactions, split-rate property taxes, tax increment finance, betterment taxes, congestion charges
Economic Instruments – Tradable Allowances (May be economy-wide)	- Emission trading (EU ETS) - CDM credits - Tradable Green Certificates	-Fuel and vehicle standards	- Tradable certificates for energy efficiency (white certificates)	- Emission trading - Emission credit under CDM - Tradable Green Certificates	- CDM credits - Compliance schemes outside Kyoto protocol Voluntary carbon markets	- Urban-scale Cap-and-Trade
Economic Instruments – Subsidies	- Fossil fuel subsidy removal - Feed in tariffs - Capital subsidies and insurance for CCS	- Biofuel subsidies - Vehicle purchase subsidies - Feebates	- Subsidies or Tax exemptions for, retrofits and products - Subsidized loans	- Subsidies (e.g. for energy audits) - Fiscal incentives (e.g. for fuel switching)	- Credit lines for low carbon agriculture, sustainable forestry.	- Special Improvement or Redevelopment Districts
Regulatory Approaches	- Efficiency or environmental	- Fuel economy standards	- Building codes and	- Energy efficiency standards for	- National policies to	- Mixed use zoning - Development

	performance standards - Renewable Portfolio standards for renewable energy - Equitable access to electricity grid - Legal status of long term CO_2 storage	- Fuel quality standards - GHG emission standards - Regulations to encourage modal shifts (road to rail) - Restriction on use of vehicles - Airport capacity constraints	standards - Equipment and appliance standards - Mandates for energy retailers to assist customers invest in energy efficiency	equipment - Energy management systems (also voluntary) - Voluntary agreements (where bound by regulation) - Labelling and public procurement regulations	support REDD+ including monitoring, reporting and verification - Forest law to reduce deforestation - Air and water pollution control GHG precursors - Land-use planning and governance	restrictions - Affordable housing mandates - Site access controls - Transfer development rights - Design codes - Building codes - Street codes - Design standards
Information Programmes		- Fuel labelling - Vehicle efficiency labelling	- Energy audits - Labelling programmes - Energy advice programmes	- Energy audits - Benchmarking - Brokerage for industrial cooperation	- Certification schemes - Information policies to support REDD+	
Government Provision of Public Goods or Services	- Research and development - Infrastructure expansion	- Investment in transit - Investment in infrastructure - Vehicle procurement	- Public procurement of efficient buildings and appliances	- Training and education - Brokerage for industrial cooperation	- Protection of forests. - Diffusion of innovative technologies	-Provision of utility infrastructure - Park improvements - Trail improvements -Urban rail,
Voluntary Actions			- Labelling programmes for efficient buildings - Product eco-labeling	- Voluntary agreements on energy targets or adoption of energy management systems , or resource efficiency	- Promotion of sustainability by developing standards and educational campaigns	

4.5.2 Adaptation Policies

Adaptation to climate change is transitioning from a phase of awareness to the construction of strategies and embedding in planning processes. Integration across scales of governance and the public and private sector through robust institutions and frameworks are considered important to overcome common constraints to adaptation (*medium evidence, high agreement*), but evaluation of implementation and monitoring of outcomes remains limited.

International mechanisms for supporting adaptation planning have assisted in the creation of adaptation strategies, plans, and actions at the national, sub-national, and local level *(high confidence)*. Examples include the Global Environmental Facility adaptation funds, the Pilot Program for Climate Resilience, the Adaptation Fund set up under the Kyoto Protocol, and special purpose adaptation funds by UN agencies. The directives and initiatives of the European Commission (EC) have fostered the creation of a large number of national adaptation strategies and plans in EU member countries since the last IPCC report. Closer integration at the international level of disaster risk reduction and climate change adaptation, and the mainstreaming of both into international development assistance, could foster greater efficiency in the use of available and committed resources and capacity. *{WGII 15.2.1, SREX 7.4, 8.2, 8.3, 8.5, 8.7}*

Current approaches to adaptation are dominated by top-down consideration of future impacts and often focus on the construction of defensive infrastructure, but this does not necessarily lead to the most cost-effective and efficient adaptation policy decisions. Climate change adaptation takes place as a response to multiple stressors, and the importance of adaptation is influenced by how the issue is framed in particular contexts, and the extent that it is viewed as a public safety issue and disaster risk management issue or a development issue. Coupling adaptive improvements in infrastructure with efforts to improve ecosystem resilience, governance, community welfare, and development can improve community resilience and strengthen both adaptation planning and implementation. *{WGII 15.2.1, 15.3.1, 15.3.3, 15.5.1.2, Box 15-1}*

Local government and the private sector are increasingly recognized as critical to progress in adaptation. National governments can coordinate adaptation efforts of local and subnational governments through finance, legal and policy frameworks, information, and protection of vulnerable groups (*medium to high evidence, high agreement)*. Common constraints on implementation arise from limited financial and human resources; limited integration or coordination of governance; uncertainty about projected impacts; different perceptions of risks; competing values; absence of key adaptation leaders and advocates; and limited tools to monitor adaptation effectiveness. Institutional dimensions in adaptation governance play a key role in promoting the transition from planning to implementation of adaptation. Public action can address some of these constraints, and can in turn influence the degree to which private parties undertake adaptation actions. However, most assessments of adaptation have been restricted to impacts, vulnerability, and adaptation planning, with very few assessing the process of implementation or the effectis of adaptation actions (*medium evidence, high agreement*). *{WGII SPM, 2.1-4, 3.6, 8.3-4, 9.3-4, 14.2, 15.2-3, 15.5, 16.2-5, 17.2-3, 22.4, 24.4, 25.4, 26.8-9, 30.7, Tables 21-1, 21-5, and 21-6, Boxes 16-1, 16-2, and 25-7; SREX 6.2, 6.4}*

Existing and emerging economic instruments can foster adaptation by providing incentives for anticipating and reducing impacts *(medium confidence)*. Instruments include public-private finance partnerships, loans, payments for ecosystem services, improved resource pricing, charges and subsidies, norms and regulations, and risk sharing and transfer mechanisms. Risk financing mechanisms in the public and private sector, such as insurance and risk pools, can contribute to increasing resilience, but without attention to major design challenges, they can also provide disincentives, cause market failure, and decrease equity. Governments often play key roles as regulators, providers, or insurers of last resort. *{WGII SPM, 10.7, 10.9, 13.3, 17.4-5, 22.4, Box 25-7; SREX 6.5}*

4.5.3 Technology development and transfer

Technology development, deployment and diffusion can be important components of mitigation and adaptation efforts, but face varying challenges in terms of scale, integration with existing systems, and integration in local context (*high confidence*).

Technology policy complements other mitigation policies, but worldwide investment in research in support of GHG mitigation is small relative to overall public research spending *(high confidence)***.** Technology policy includes technology-push (e.g. publicly-funded R&D) and demand-pull (e.g. governmental procurement programs). Such policies address a pervasive market failure because the invention of new technologies and practices (the information that flows from R&D efforts) is often a public good, and thus R&D tends to be under-provided by market forces alone. Technology support policies have promoted substantial innovation and diffusion of new technologies, but the cost-effectiveness of such policies is often difficult to assess. *{WGIII 2.6.5, 3.11; 15.6.5}*

Many adaptation efforts critically rely on development and diffusion of technologies and management practices, but their effective use depends on an appropriate institutional, regulatory, social and cultural context *(high confidence)***.** Unlike mitigation, where low-carbon technologies are often new and protected by patents, adaptation technologies are often familiar and already applied. However, successful technology transfer requires not only the provision of finance and information about technological solutions, but also strengthening policy and regulatory environments, and capacities to absorb, employ and improve technologies appropriate to local circumstances. *{WGII 15.4}*

4.5.4 Investment and Finance

Effective mitigation and adaptation efforts can require both changes in patterns of investment in developed and developing countries, and increases in financial support for developing countries (*high confidence*). Appropriate governance arrangements and institutions are essential conditions for efficient, effective, and sustainable financing of mitigation and adaptation measures (*high agreement, robust evidence*).

Substantial reductions in emissions would require large changes in investment patterns (*high agreement, robust evidence*). Over the next two decades (2010-2029) annual investments in conventional fossil fuel technologies associated with the electricity supply sector is projected to decline while annual investment in low carbon electricity supply and energy efficiency in key sectors is projected to rise by several hundred billion dollars per year. Global total annual investment in the energy system is presently about $1200 billion (Figure 4.5). *{WGIII SPM}*

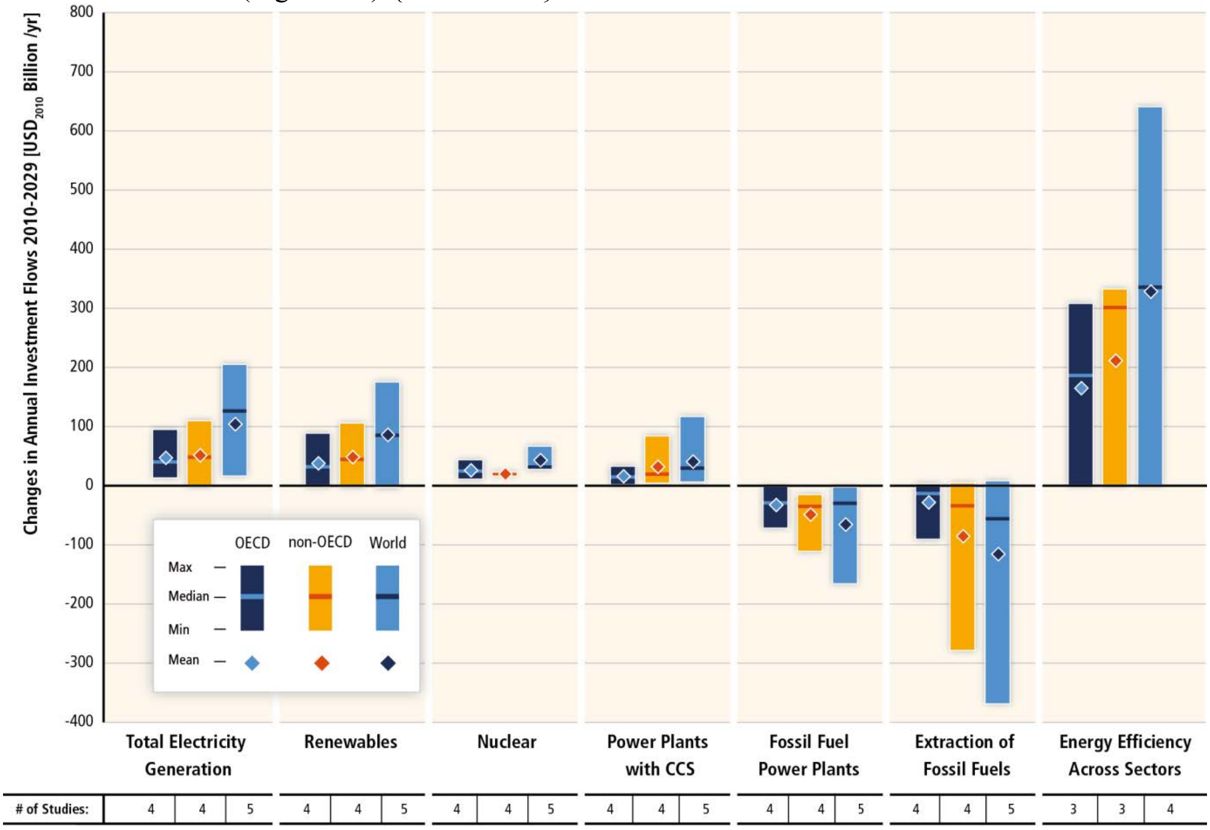

Figure 4.5: Change in annual investment flows from the average baseline level over the next two decades (2010 to 2029) for mitigation scenarios that stabilize concentrations within the range of approximately 430-530 ppm CO_2eq by 2100. The vertical bars indicate the range between minimum and maximum estimate; the horizontal bar indicates the median. The numbers in the bottom row show the total number of studies in the literature used for the assessment. *{WGIII Figure 16.3}*

Increased financial support from developed to developing countries will be needed to stimulate investment in low-carbon energy sources and energy efficiency in developing countries *(high agreement, medium evidence)*. Developed countries have committed to a goal of jointly mobilizing US$ 100 billion per year from various sources by 2020 for adaptation and mitigation in developing countries (see Figure 4.6 for an overview of climate finance). There is lack of agreement on what share of this can be mobilized through the public versus private sectors. Bilateral and multilateral institutions typically provide public climate finance to developing countries as concessional loans and grants. Robust information on private sector flows from developed to developing countries is very limited. *(medium agreement, medium evidence) {WGIII 16.2.1.1, 16.2.1, 16.4}*

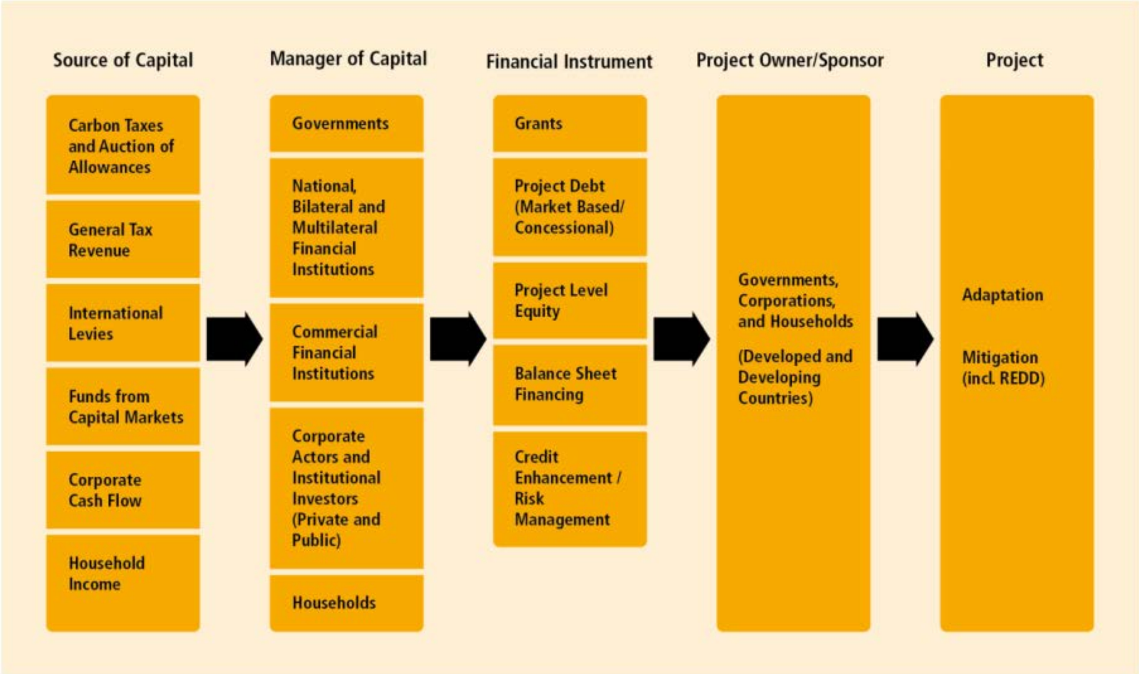

Figure 4.6: Overview of climate finance flows. Note: Capital should be understood to include all relevant financial flows. The size of the boxes is not related to the magnitude of the financial flow. *{WGIII Figure TS.4.5}*

In many countries, the private sector plays central roles in the processes that lead to emissions as well as to mitigation and adaptation. Within appropriate enabling environments, the private sector, along with the public sector, can play an important role in financing mitigation and adaptation. The share of total mitigation finance from the private sector, acknowledging data limitations, is estimated to be on average between two-thirds and three-fourths on the global level (2010-2012) (*limited evidence, medium agreement*). In many countries, public finance interventions by governments and international development banks encourage climate investments by the private sector and provide finance where private sector investment is limited. . The quality of a country's enabling environment includes the effectiveness of its institutions, regulations and guidelines regarding the private sector, security of property rights, credibility of policies and other factors that have a substantial impact on whether private firms invest in new technologies and infrastructures. Dedicated policy instruments, for example, credit insurance, power purchase agreements and feed-in tariffs, concessional finance or rebates provide an incentive for mitigation investment by lowering risks for private actors. Large-scale public-private risk reduction initiatives and economic diversification are examples of adaptation actions relying on private sector participation. *{WGII SPM 10.7, 10.10, 15.2-3, 17.2; WGIII SPM, 16.2.1, 16.3, 16.4}*.

Limited evidence indicates a gap between global adaptation needs and the funds available for adaptation (medium confidence). This gap suggests a growing adaptation deficit, particularly in developing countries. Financial resources for adaptation have been slower to become available for adaptation than for mitigation in both developed and developing countries. Adaptation finance made up probably only a fifth of initial allocations of fast-start funding. *{WGII 14.2, 17.X}*

4.6 Trade-offs, synergies, and integrated responses

Climate policy is increasingly driven by an understanding of the close links between climate and development policies and between different aspects of adaptation and mitigation. Recognizing these linkages and developing tools with which to address them is critical to the success of integrated responses to climate change

4.6.1 Trade-offs and Synergies

There is a growing evidence base indicating significant synergies and tradeoffs between mitigation and adaptation, as well as between these and development outcomes, but tools to understand and manage these interactions remain limited. ***{WGII 8.5, 11.5}*** As an example of synergies across ecosystems and human systems, mangrove, sea grass, and salt marsh ecosystems offer important carbon storage and sequestration opportunities, while also providing ecosystem services such as protection against coastal erosion and storm damage and maintenance of habitats for fisheries. In some cases both synergies and tradeoffs can exist: or facilitating payments under REDD+ can affect rural areas by increasing income and employment opportunities, but may also lead to the expropriation of land, the loss of livelihoods, or food insecurity. *{WGII 23.8, Table 25-7}*

Since AR4, there has been an increased focus on policies designed to integrate multiple objectives, increase co-benefits and reduce adverse side-effects *(high confidence) (Table 4.6).* Governments explicitly reference co-benefits in climate and sectoral plans and strategies *{WGII 15.2}*. Despite the growing attention in policymaking and the scientific literature, since AR4 the analytical and empirical underpinnings for understanding many of these interactive effects are under-developed *{WGII 1.2, 3.6.3, 4.2, 4.8, 6.6} {Box X}*. The scope for co-benefits may be greater in low-income countries, where complementary policies for other objectives, such as air pollution, are often weak. *{WGIII 5.7, 6.6, 15.2}*

Managing trade-offs, synergies and other interactions (Figure 4.X) is challenging due to their complexity and to the limited availability of tools to support decision-making at local and regional scales. *{WGII Box CC-WE}* However, the benefits of addressing climate change using integrated approaches and multiple metrics have been shown to be consistent with the achievement of multiple goals associated with climate resilient pathways for sustainability *{WGII.20.5}*.

Adaptations that do not consider the full range of consequences arising from actions may be maladaptive *{WGII 14.6.1}*. This may result from poor planning, an overemphasis on short-term outcomes, or discounting future consequences. For example, increased use of air conditioning increases energy demand, whereas adaptations focused on energy efficiency and building design can reduce heat exposure as well as energy demand. *{WGII.25.7.4, Box 25-9}* Maladaptation can increase the vulnerability or exposure of the target group in the future, or the vulnerability of other locations or sectors. *{WGII 14.6, 15.5, 17.2-3, 22.4, 25.9}*

Integration of adaptation into planning and decision-making can create synergies with development. *{II 20.3}* Adaptation strategies that strengthen livelihoods, enhance well-being and human security, and reduce poverty include increased access to information and resources, improved health services and social protection, and more effective water and land management and governance. *{WGII 3.6, 9.4, 11.2,14.2, 15.2-3, 15.5, 17.2, 20.4, 20.6, 22.4, 24.4, 25.10, 27.3-5, Boxes 25-2, 25-6, 25-8, and 25-9}* Adaptation can generate larger benefits when linked to development activities and disaster risk reduction. *{WGII 8.3, 9.3, 14.2, 14.6, 15.3, 15.4, 20.2, 20.3, 22.4, 24.5 29.6, Box CC-UR}*

Table 4.6: This is an abridged version of Table III.6.7. Potential co-benefits (blue text) and adverse side-effects (red text) of the main sectoral mitigation measures. Co-benefits and adverse side-effects depend on local circumstances as well as on the implementation practice, pace and scale. For an assessment of macroeconomic, cross-sectoral effects associated with mitigation policies, see Sections XXX *{WGIII.3.9, 6.3.6, 14.4.2}*. The uncertainty qualifiers in brackets denote the level of evidence and agreement on the respective effect. Abbreviations for evidence: l=limited, m=medium, r=robust; for agreement: l=low, m=medium, h=high.

Sectoral mitigation measures	**Effect on additional objectives/concerns**		
	Economic	**Social**	**Environmental**
Energy Supply	*For possible upstream effects of biomass supply for bioenergy, see AFOLU.*		
Nuclear replacing coal power	Energy security (reduced exposure to fuel price volatility) **(m/m)**; local employment impact (but uncertain net effect) **(l/m)**; legacy of waste and abandoned reactors **(m/h)**	Mixed health impact via reduced air pollution and coal mining accidents **(m/h)**, nuclear accidents and waste treatment, uranium mining and milling **(m/l)**; safety and waste concerns **(r/h)**; proliferation risk **(m/m)**	Mixed ecosystem impact via reduced air pollution **(m/h)** and coal mining **(l/h)**, nuclear accidents **(m/m)**
RE (Wind, PV, CSP, hydro, geothermal, bioenergy) replacing coal	Energy security **(r/m)**; local employment (but uncertain net effect) **(m/m)**; water management (for some hydro) **(m/h)**; extra measures to match demand (for PV, wind, some CSP) **(r/h)**; higher use of critical metals for PV and direct drive wind turbines **(r/m)**	Reduced health impact via reduced air pollution (except bioenergy) **(r/h)** and coal mining accidents **(m/h)**; contribution to (off-grid) energy access **(m/l)**; threat of displacement (for large hydro) **(m/h)**	Mixed ecosystem impact via reduced air pollution (except bioenergy) **(m/h)** and coal mining **(l/h)**, habitat impact (for some hydro) **(m/m)**, landscape and wildlife impact (for wind) **(m/m)**; lower/higher water use (for wind, PV **(m/m)**; bioenergy CSP, geothermal and reservoir hydro **(m/h)**)
Fossil CCS replacing coal	Preservation vs lock-in of human and physical capital in the fossil industry **(m/m)**; long-term monitoring of CO_2 storage **(m/h)**	Health impact via risk of CO_2 leakage **(m/m)**, upstream supply-chain activities **(m/h)**; safety concerns (CO_2 storage and transport) **(m/h)**	Ecosystem impact via upstream supply-chain activities **(m/m)**, higher water use **(m/h)**
CH_4 leakage prevention, capture or treatment	Energy security (potential to use gas in some cases) **(l/h)**	Reduced health impact via reduced air pollution **(m/m)**; occupational safety at coal mines **(m/m)**	Reduced ecosystem impact via reduced air pollution **(l/m)**
Transport	*For possible upstream effects of low-carbon electricity, see Energy Supply. For biomass supply, see AFOLU.*		
Reduction of fuel carbon intensity	Energy security (diversification, reduced oil dependence and exposure to oil price volatility) **(m/m)**; technological spillovers **(l/l)**	Mixed health impact via increased/reduced urban air pollution by electricity and hydrogen **(r/h)**, diesel **(l/m)**, noise **(l/m)**; road safety (silent electric LDVs) **(l/l)**	Ecosystem impact of electricity and hydrogen via urban air pollution**(m/m)**, material use (unsustainable mining) **(l/l)**
Reduction of energy intensity	Energy security (reduced oil dependence and exposure to oil price volatility) **(m/m)**	Reduced health impact via reduced urban air pollution **(r/h)**; road safety (via higher crash-worthiness) **(m/m)**	Reduced ecosystem and biodiversity impact via reduced urban air pollution **(m/h)**
Compact urban form + improved transport infrastructure Modal shift	Energy security (reduced oil dependence and exposure to oil price volatility) **(m/m)**; productivity (reduced urban congestion and travel times, affordable and accessible transport) **(m/h)**	Mixed health impact for non-motorized modes via increased activity **(r/h)**, potentially higher exposure to air pollution **(r/h)**, reduced noise (via modal shift and travel reduction) **(r/h)**; mobility access to employment opportunities **(r/h)**; road safety (via modal shift **(r/h)**)	Reduced ecosystem impact via reduced urban air pollution **(r/h)**; land-use competition **(m/m)**
Journey reduction and avoidance	Energy security (reduced oil dependence and exposure to oil price volatility) **(r/h)**; productivity (reduced urban congestion/travel times, walking) **(r/h)**	Reduced health impact (for non-motorized transport modes) **(r/h)**	Mixed ecosystem impact via reduced urban air pollution **(r/h)**, new/shorter shipping routes **(r/h)**; reduced land-use competition (transport infrastructure) **(r/h)**
Buildings	*For possible upstream effects of fuel switching and RES, see Energy Supply.*		
Reduction of emissions intensity (e.g., fuel switching, RES incorporation, green roofs)	Energy security **(m/h)**; employment impact **(m/m)**; lower need for energy subsidies**(l/l)**; asset values of buildings **(l/m)**	Fuel poverty alleviation via reduced energy demand **(m/h)**; energy access (for higher energy cost) **(l/m)**; productive time for women/children (for replaced traditional cookstoves) **(m/h)**	Reduced health impact in residential buildings and ecosystem impact (via reduced fuel poverty **(r/h)**, indoor/ outdoor air pollution **(r/h)**, and UHI effect **(l/m)**); urban biodiversity (for green roofs) **(m/m)**

Retrofits of existing buildings Exemplary new buildings Efficient equipment	Energy security **(m/h)**; employment impact **(m/m)**; productivity (for commercial buildings) **(m/h)**; lower need for energy subsidies **(l/l)**; asset values of buildings **(l/m)**; disaster resilience **(l/m)**	Fuel poverty alleviation via reduced energy demand (for retrofits, efficient equipment) **(m/h)**; energy access (higher cost for housing) **(l/m)**; thermal comfort **(m/h)**; productive time for women and children (for replaced traditional cookstoves) **(m/h)**	Reduced health and ecosystem impact (e.g. via reduced fuel poverty **(r/h)**, indoor/outdoor air pollution **(r/h)** and UHI effect **(l/m)**, improved indoor environmental conditions **(m/h)**); health risk via insufficient ventilation **(m/m)**; reduced water consumption and sewage production **(l/l)**
Behavioral changes reducing energy demand	Energy security **(m/h)**; lower need for energy subsidies **(l/l)**		Reduced health and ecosystem impact (e.g. via improved indoor environmental conditions **(m/h)** and less outdoor air pollution **(r/h)**)
Industry	*For possible upstream effects of low-carbon energy supply (incl CCS), see Energy Supply and of biomass supply, see AFOLU.*		
Reduction of CO_2/non-CO_2 emission intensity	Competitiveness and productivity **(m/h)**	Reduced health impact via reduced local air pollution and better work conditions (PFC from aluminium) **(m/m)**	Reduced ecosystem impact (via reduced local air and water pollution) **(m/m)**; water conservation **(l/m)**
Energy efficiency improvements via new processes/technologies	Energy security (via lower energy intensity) **(m/m)**; employment impact**(l/l)**; competitiveness and productivity **(m/h)**; technological spillovers in DCs **(l/l)**	Reduced health impact via reduced local pollution **(l/m)**; new business opportunities **(m/m)**; water availability and quality **(l/l)**; safety, working conditions and job satisfaction **(m/m)**	Reduced ecosystem impact via fossil fuel extraction **(l/l)**, reduced local pollution and waste **(m/m)**
Material efficiency of goods, recycling	National sales tax revenue (medium term) **(l/l)**; employment impact (waste recycling) **(l/l)**; competitiveness in manufacturing **(l/l)**; new infrastructure for industrial clusters **(l/l)**	Reduced health impacts and safety concerns **(l/m)**; new business opportunities **(m/m)**; local conflicts (reduced resource extraction) **(l/m)**	Reduced ecosystem impact via reduced local air and water pollution and waste material disposal **(m/m)**; reduced use of raw/virgin materials and natural resources implying reduced unsustainable resource mining **(l/l)**
Product demand reductions	National sales tax revenue (medium term) **(l/l)**	Local conflicts (reduced inequity in consumption) **(l/l)**; new diverse lifestyle concept **(l/l)**	Post-consumption waste **(l/l)**
AFOLU	*Note: co-benefits and adverse side-effects depend on the development context and the scale of the intervention (size).*		
<u>Supply side</u>: forestry, land-based agriculture, livestock, integrated systems and **bioenergy** <u>Demand side:</u> reduced losses in the food supply chain, changes in human diets and in demand for wood and forestry products	Mixed employment impact via **entrepreneurship development** **(m/h)**, **use of less labor-intensive technologies in agriculture** **(m/m)**; **diversification of income sources and access to markets** **(r/h)**; **additional income to (sustainable) landscape management** **(m/h)**; **income concentration** **(m/m)**; **energy security (resource sufficiency)** **(m/h)**; Innovative financing mechanisms for sustainable resource management **(m/h)**; technology innovation and transfer **(m/m)**	**Food-crops production through integrated systems and sustainable agriculture intensification** **(r/m)**; **food production (locally) due to large-scale monocultures of non-food crops** **(r/l)**; cultural habitats and recreational areas via (sustainable) forest management and conservation **(m/m)**; **human health and animal welfare e.g. through less pesticides, reduced burning practices and practices like agroforestry & silvo-pastoral systems** **(m/h)**; **human health when using burning practices (in agriculture or bioenergy)** **(m/m)**; mixed impacts on gender, intra- and inter-generational equity via **participation and fair benefit sharing** **(r/h)** and **concentration of benefits** **(m/m)**	Mixed impact on ecosystem services via **large scale monocultures** **(r/h)**, ecosystem conservation, sustainable management as well as sustainable agriculture **(r/h)**; **land use competition** **(r/m)**; soil quality **(r/h)**; erosion **(r/h)**; ecosystem resilience **(m/h)**; albedo and evaporation **(r/h)** Mixed impact on **tenure and use rights at the local level (for indigenous people and local communities)** **(r/h)** and on access to participative mechanisms for land management decisions **(r/h)**; enforcement of existing policies for sustainable resource management **(r/h)**
Human Settlements and Infrastructure	*For compact urban form and improved transport infrastructure, see also Transport.*		
Compact development and infrastructure	Innovation and efficient resource use **(r/h)**; higher rents and property values **(m/m)**	Health from physical activity: *see Transport*	Preservation of open space **(m/m)**
Increased accessibility	Commute savings **(r/h)**	Health from increased physical activity: *see Transport*; social interaction & mental health **(m/m)**	Air quality and reduced ecosystem and health impacts **(m/h)**
Mixed land use	Commute savings **(r/h)**; higher rents and property values **(m/m)**	Health from increased physical activity **(r/h)**; social interaction and mental health **(l/m)**	Air quality and reduced ecosystem and health impacts **(m/h)**

4.6.2 Interactions between energy and mitigation through prices

Changes in energy production and supply through mitigation policies often directly or indirectly lead to changes in relative energy prices, with significant implications for economic, social and environmental outcomes. These synergies or trade-offs can be managed by deliberate attention to the feedbacks and consequences.

The reduction of subsidies for GHG-related activities in various sectors can achieve emission reductions, depending on the social and economic context (high agreement). While subsidies can affect emissions in many sectors, most of the recent literature has focused on subsidies in fossil fuels. Since AR4 a small but growing literature based on economy-wide models has projected that complete removal of subsidies to fossil fuels in all countries could result in reductions in global aggregate emissions by mid-century (*medium evidence, medium agreement)*. Studies vary in methodology, the type and definition of subsidies and the time frame for phase out considered. In particular, the studies assess the impacts of complete removal of all fossil fuel subsides without seeking to assess which subsidies are wasteful and inefficient, keeping in mind national circumstances. Although political barriers are substantial, some countries have reformed their tax and budget systems to reduce fuel subsidies. To help reduce possible adverse effects on lower income groups, who often spend a large fraction of their income on energy services, many governments have utilized lump-sum cash transfers or other mechanisms targeted on the poor. *{WGIII 7.12, 13.13, 14.32, 15.5.2}*

Mitigation policy could devalue fossil fuel assets and reduce revenues for fossil fuel exporters, but differences between regions and fuels exist. Most mitigation scenarios are associated with reduced revenues from coal and oil trade for major exporters. . The effect of mitigation on natural gas export revenues is more uncertain, with some studies showing possible benefits for export revenues in the medium term until about 2050. The availability of CCS would reduce the adverse effect of mitigation on the value of fossil fuel assets. The overall impact on oil exports is more complex. Mitigation policies could reduce export revenues from oil, but those same policies could increase the relative competitiveness of conventional oil vis-à-vis more carbon-intensive unconventional oil and coal-to-liquids. *{WGIII.14.4 6.3.6, 6.6}*

Some mitigation policies raise the prices for some energy services and could hamper the ability of societies to expand access to modern energy services to underserved populations (low confidence). These potential adverse side-effects can be avoided with the adoption of complementary policies *(medium confidence)***.** Whether transformation pathways will have adverse distributional effects and thus impede achieving energy access objectives will depend on the climate policy design and the extent to which complementary policies are in place to support the poor, through either income tax rebates or other benefit transfer mechanisms. *{WGIII.chapter}*

The contribution of renewable energy to energy access can be substantial. About 1.3 billion people worldwide do not have access to electricity and about 3 billion are dependent on traditional solid fuels for cooking and heating, with severe health effects and adverse implications for development. Scenario studies show that the costs for achieving nearly universal access are between US$ 65-86 billion per year until 2030. *{WGIII 4.3, 6.6, 7.9, 9.7, 11.13.6, 16.8}*

4.6.3 Integrated Responses

Integrated responses focused on discrete policy arenas are a productive approach to successful climate policy in the context of sustainable development. Policymaking relevant to climate change is increasingly occurring in the context of sectoral decision-making, particularly with reference to managing synergies and trade-offs across multiple objectives (see also 4.5.1.2, 3.5).

An integrated response to urbanization, which is transforming human settlements, societies and energy use, provides substantial opportunities for enhanced resilience, reduced emissions and more sustainable development. Urban areas account for more than half of global primary energy use and energy-related CO_2 emissions (high agreement, medium evidence), and contain a high proportion of the population and economic activities at risk from climate change. In rapidly growing and urbanizing regions, mitigation strategies based on spatial planning and efficient infrastructure supply can avoid lock-in of high emission patterns. *{WGIII.5.6.3, 9.4, 12.3,12.4}* Mixed use zoning, transport oriented development, increasing density, and co-locating jobs and homes can reduce direct and indirect energy use across sectors. Compact and in-fill development of urban spaces and intelligent densification can save land for agriculture and bioenergy and preserve land carbon stocks. *{WGIII.7.X, 8.4, 9.X, 10.X, 11.X, 12.2, 12.3}*

- Urban adaptation provides opportunities for incremental and transformational adjustments towards resilience and sustainable development. Reduced energy and water consumption in urban areas through greening cities and recycling water are examples of mitigation action with adaptation benefits. Building resilient infrastructure systems can reduce vulnerability of urban settlements and cities from coastal flooding, sea level rise and other climate induced stresses. *{WGII.TS; WGIII.TS}*

Explicit consideration of interactions between water use, food and fibre production, energy generation, and carbon sequestration, is increasingly recognised as critical to making effective decisions for climate resilient pathways (*medium evidence, high agreement*). Both biofuel based power generation and large-scale afforestation designed to mitigate climate change can reduce catchment run-off, which may conflict with alternative water uses for food production, human consumption, or the maintenance of ecosystem function and services. Conversely, irrigation can increase the climate resilience of food and fibre production but reduces water availability for other uses. *{WGII Box CC-WE}*