organizational structure. The CIFs were designed as an interim measure to demonstrate how scaled-up support can be provided and include a sunset clause linked to progress on the financial architecture under UNFCCC. They consist of two trust funds: the Clean Technology Fund (CTF), which promotes scaled-up financing for demonstration, deployment, and transfer of low-carbon technologies with significant potential for long-term GHG emissions savings, and the Strategic Climate Fund (SCF), under which are three separate initiatives for piloting transformational, scaled-up action on climate change (World Bank, 2011b; c). The pledges and contributions to the CIFs are recorded as ODA, and therefore constitute a multi-bilateral arrangement (World Bank, 2010).

The CDM and carbon funds are directly linked to emission. Prior to the decline of certificate prices, they played a central role in attracting climate investments. The CDM is one of three trading mechanisms created by the Kyoto Protocol that a developed country can use to help meet its national commitment. The CDM allows a developed country to use credits issued for emission reductions in developing countries. The other two mechanisms—Joint Implementation (JI) and International Emissions Trading (IET)—involve only developed countries with national commitments. The CDM is the largest of the mechanisms (UNFCCC, 2013c). Some of the carbon funds have been established by multilateral financial institutions. The World Bank established the first fund, the Prototype Carbon Fund, in 1999, and has since created several additional funds (World Bank, 2013).

There are several institutions promoting mitigation finance by private actors, which frequently combine financial power of up to several trillions. However, their scope of work differs considerably. Some of the major private sector institutions include inter alia the World Business Council on Sustainable Development (WBCSD) (WBCSD, 2013), the Climate Markets and Investment Association (CMIA) (CMIA, 2013), and the Global Investor Coalition on Climate Change (Global Investor Coalition on Climate Change, 2013).

Regional arrangements play an important role in fostering regional cooperation and stimulating action and funding. These regional institutions include the regional multilateral development banks and the regional economic commissions of the United Nations on the multilateral side.27 They are increasingly engaging in the promotion of mitigation and adaptation activities in their respective regions and establishing and helping to manage regional financing arrangements (Sharan, 2008). In the Asia and Pacific region, examples of regional financial arrangements to promote funding for mitigation activities include ADB's Clean Energy Financing Partnership Facility, the Asia Pacific Carbon Fund, and the Future Carbon Fund. Other regional development banks have been equally active (Asian Development Bank, 2013a; b; c).

[27] Economic Commission for Latin America, Inter American Development Bank (IDB), Economic Commission for Africa (ECA), African Development Bank (AfDB), Economic Commission for Asia and the Pacific (ESCAP), Asian Development Bank (ADB), Economic Commission for Europe (ECE), European Bank for Reconstruction, and Development (EBRD).

Regional groupings such as the Economic Community for West African States (ECOWAS), the Association of Southeast Asian Nations (ASEAN), the Secretariat for Central American Economic Integration, Mercosur, Corporación Andina de Fomento, and the Andean Pact, to name just a few, have been actively promoting sub-regional integration of energy systems and cooperation in climate change activities in developing countries for some years. In the developed world, one of the best examples of these regional political groupings is the European Union, which has been very active in the area of climate change and in supporting activities in developing countries.

Bilateral cooperation arrangements are widely used by donor countries to provide funding to partner country governments and their implementing organizations. They frequently involve development banks and agencies with a proven track record in international cooperation. The three principal means to channel climate change funding bilaterally are (1) bilateral programmes for funding international cooperation in the energy, water, transport, or forestry, (2) dedicated funding windows established to target climate change funding open to a wider range of implementing institutions, and (3) new funds implemented by bilateral development institutions with their own governance structure. The OECD has established a framework for the implementation and reporting modalities that can be applied to all climate-relevant ODA and partially for other official flows (see OECD, (2013b) for agreed principles on statistics, effectiveness, evaluation, and the like). Officially supported export credits provided by export credit agencies on behalf of national governments are also covered by a respective OECD arrangement (OECD, 2013c).

Triangular cooperation arrangements are defined by the OECD as those involving a traditional donor, most likely a member of DAC, an emerging donor in the south (providers of South-South Cooperation), and the beneficiary countries or recipients of development aid (Fordelone, 2011). Although they have grown in number in recent years, triangular arrangements, and particularly those for climate change financing, are a relatively recent mode of development cooperation (ECOSOC, 2008). These arrangements have attracted a number of countries particularly for technology cooperation across sectors or specified industries. The rise of triangular arrangements has been driven by the growing role of middle-income countries and their increasing presence in providing development co-operation in addition to receiving it, and by the desire to experiment with other types of cooperation where the experience of developing countries can be brought to bear.

16.5.2 National and sub-national arrangements

The landscape of institutional arrangements for action on climate change is diverse. In many countries, actions on climate change are not clearly defined as such. Consequently, many of the national arrangements that exist to promote programmes and activities that contribute to mitigation do not appear in the literature as institutions dedicated to support climate finance.

In many countries, particularly in developed countries and in a few larger developing countries, finance for mitigation comes mainly from the private sector, often with public support through regulatory and policy frameworks and/or specialized finance mechanisms. Institutional arrangements and mechanisms that are successful in mobilizing and leveraging private capital tend to be more cost-effective in climate change mitigation, but some projects with low private investments (e.g., projects reducing industrial GHGs or projects owned by state-owned enterprises) are also among the most cost-effective (Stadelmann, 2013). The institutions and public finance mechanisms are diverse, but all aim to help commercial financial institutions to do this job effectively and efficiently. Many of the institutions support specialized public finance mechanisms such as dedicated credit lines, guarantees to share the risks of investments and debt financing of projects, microfinance or incentive funds, and schemes to mobilize R&D and technical assistance funds to build capacities across the sectors, including the private and commercial sectors (Maclean et al., 2008). National development banks play an important role in financing domestic climate projects in many countries especially by providing concessional funding (Smallridge et al., 2012; Höhne et al., 2012; IDFC, 2013).

Many developing countries, other than the larger ones, are trying to cope with the multiplicity of sources, agents and channels offering climate finance (Glemarec, 2011). These efforts take two forms.

One form is coordination of national efforts to address climate change by relevant government institutions. Very few developing countries have an institution fully dedicated to climate finance (Gomez-Echeverri, 2010). Rather, climate finance decisions involve multiple ministries and agencies often coordinated by the ministry of the environment. Involvement of ministries of foreign affairs and ministries of finance is becoming more common due to their engagement in international negotiations and the promise of increased resources under UNFCCC.

The second form is the establishment of specialized national funding entities designed specifically to mainstream climate change activities in overall development strategies. These institutions blend international climate funding with domestic public funds and private sector resources (Flynn, 2011). Table 16.2 lists examples of national funding entities. A common feature is the desire to allocate resources for activities that are fully mainstreamed to the national needs and priorities. To do this, the national funding entities seek to tap the numerous international sources of climate finance and supplement them with domestic resources. They are also expected to develop the governance and capacity requirements for 'direct access' to funds from the Adaptation Fund and the GCF.[28]

[28] Direct access means that an accredited institution in the recipient country may receive funds directly to implement a project. Currently, most international funding institutions insist that projects be implemented by a multilateral development bank or UN agency.

In many countries, sub-national arrangements are increasingly becoming an effective vehicle for advancing energy and climate change goals. These arrangements and the institutions that support them are being established to advance regional collaboration in areas of common interest and to benefit from greater efficiency and effectiveness through actions with greater geographical coverage (Setzer, 2009). For example, because of their population densities and economic activities, cities are major contributors to global GHG emissions, and as such they are major potential contributors to worldwide mitigation efforts (Corfee-Morlot et al., 2009). In recent years, there has been an increase in the number of networks and initiatives specifically dedicated to enhance the role of cities in the fight against climate change. As a result, these initiatives are potentially big contributors to mitigation efforts, but because of the lack of clear processes linking these initiatives to national and international climate change policy, their impact in broader policy frameworks is less certain (UN-Habitat, 2011). One possible opportunity for enhancing this linkage is through the new National Appropriate Mitigation Actions (NAMAs) being submitted by developing countries within the context of UNFCCC. The NAMA process agreed to at Bali provides an opportunity to incorporate sectoral policies with relevance to their cities (Li, 2011).

16.5.3 Performance in a complex institutional landscape

The institutional landscape for climate finance is becoming increasingly complex as interest of actors to enter the field of climate change finance and mitigation activities in developing countries increases. As in other international cooperation, there are discussions about effectiveness of climate finance (see OECD (2008) for politically agreed principles on aid effectiveness). Concerns have been raised about diverting attention and resources from development aid, i.e., ODA, such as health and education, the additionality of expanded funding for mitigation and adaptation (Michaelowa and Michaelowa, 2011), the difficulty of defining and measuring comparable results and achieving coherence with national priorities and development strategies, the lack of transparency, the fragmentation and duplication of efforts, and that the number of established funds may undermine the authority of the operating entities of the financial mechanism of the UNFCCC (Poerter et al., 2008). The proliferation of climate funds (HBF and ODI, 2013) and funding channels with their own governance procedures can create a substantial bureaucratic burden for recipients (Greene, 2004). Compounding these problems is the fragmentation of governance architectures that prevail in most developing countries (Biermann et al., 2009). Climate finance may be more effective if the operation of related institutions is streamlined and the capacity in developing countries to cope with the increasing number of these institutions is developed further. Evidence on the effectiveness of institutions to mainstream climate change mitigation and adaptation activities is currently lacking.

Table 16.2 | A sample of national funding entities in developing countries. Sources: Adapted from Gomez-Echeverri (2010), updated based on UNDP and World Bank (2012), Amazon Fund (2012), BCCRF (2012), CDMF (2012), ICCTF (2012), World Bank (2012b), UNDP (2013b).

Name, country, establishment	Description	Source of fund and operations	Governance
Amazon Fund, Brazil (2010)	Established to combat deforestation and promote sustainable development in the Amazon. Focus: adaptation and mitigation	Designed to attract national and private investment for Amazon rainforest projects as well as donations and earnings from non-reimbursable investments made	Managed by the Brazilian Development Bank (BNDES), a Guidance Committee composed of federal and state governments and civil society, and a Technical Committee
Bangladesh Climate Change Resilience Fund (BCCRF) (2010)	Established to provide support for the implementation of Bangladesh's Climate Change Strategy and Action Plan 2009–2018 and particularly vulnerable communities. Focus: adaptation and mitigation	Designed to attract funds from UNFCCC finance mechanisms, and direct donor support	Managed by a board composed of Ministers of Environment, Finance, Agriculture, Foreign Affairs, and Women and Children Affairs and disaster management, as well as donors and civil society organizations
China CDM Fund (CDMF) (2007)	Established jointly by Ministries of Finance, Foreign Affairs, Science and Technology, and National Development and Reform Commission (NDRC). Focus: mitigation	Funded by revenues generated from CDM projects in China, as well as grants from domestic and international institutions	Governed by the Board of the China CDM Fund that comprises representatives of seven line ministries, and managed and operated by a management centre affiliated with the Ministry of Finance
Indonesia Climate Change Trust Fund (ICCTF) (2010)	Established jointly by the National Development Planning Agency and Ministry of Finance to pool and coordinate funds from various sources to finance Indonesia's climate change policies and programmes	Currently funded by grants from development partners but designed for direct access to international climate funding and to attract private funding	The UNDP is an interim Trustee operating under a Steering Committee headed by the National Development Planning Agency that also includes donors and other line ministries
Guyana REDD Investment Fund (GRIF) (2010)	Established to finance activities under the Low Carbon Development Strategy of Guyana and to create an innovative climate finance mechanism. Focus: mitigation and adaptation	Designed to attract donor support. Operates under a performance-based funding modality, based on an independent verification of Guyana's deforestation and forest degradation rates and progress on REDD+ enabling activities	A Steering Committee with members of government and financial contributors chaired by the Government of Guyana, is the decision making and oversight body. The International Development Association (IDA) of the World Bank Group acts as Trustee and the partner entities provide operational services
Ethiopia Climate Resilient Green Economy Facility (2012)	Established to support country's vision of attaining a middle-income economy with low-carbon growth by 2020. Focus: mitigation and adaptation	Designed to mobilize, access, and blend both local and international public and private resources to support Ethiopia's Climate Resilience Green Economy Strategy	Governed by a Ministerial Steering Committee chaired by Ministry of Finance and Economic Development with an advisory body composed of development partners, multilateral organizations, national non-governmental organizations (NGOs), civil society, private sector, and academia

16.6 Synergies and tradeoffs between financing mitigation and adaptation

This section introduces a conceptual framework linking adaptation and mitigation in terms of financing and investment. Estimates of investments needed for mitigation are provided in Section 16.2.2, and for adaptation investments in the sectoral chapters of the Working Group II report. First, this section addresses the interactions of financing adaptation and mitigation in terms of their specific effectiveness and tradeoffs, as well as their competition for funding over time. Second, it discusses examples of integrated financing approaches.

16.6.1 Optimal balance between mitigation and adaptation and time dimension

Both mitigation and adaptation measures are necessary to effectively avoid harmful climate impacts. However, an assessment on whether, where, and which types of adaptation and mitigation measures and policies are substitutes or complements requires theoretical analysis and empirical evidence (Section 13.3.3). Investing in mitigation may reduce the need to invest in adaptation, and vice versa. Several authors have recognized that optimal mitigation and adaptation strategies should be jointly determined (Schelling, 1992; Kane and Shogren, 2000; Dellink et al., 2009; Bosello et al., 2010), including from the perspective of a global decision maker. The optimal balance of mitigation and adaptation depends on their relative costs, for any given profile of climate change impacts. To avoid inefficiencies, the socially discounted rate of return on resources invested in mitigation and adaptation should be equal. Therefore, mitigation and adaptation compete to attract investments. From the perspective of simple economic models, a reduction in the costs of mitigation should lead to more mitigation and less adaptation, and, according to this view, they are substitutes (Ingham et al., 2005).

From the perspective of development and climate studies (Tol, 2007; Ayers and Huq, 2009), climate change in most cases will impact the economy by reducing its production potential (part of the residual damage), and the level of impacts will depend on its efficiency, diversity, and vulnerability, as well as on how institutions are able to adapt.

On the other hand, policies to address mitigation and/or adaptation could promote the transfer of technologies and financial resources, and strengthen institutions and markets, which could lead to the enhancement of a country's productive capacity (Halsnæs and Verhagen, 2007).

Combined mitigation and adaptation strategies taking into account cost-effectiveness may involve economic tradeoffs. The optimal balance, including allocation of resources, should be determined taking into account possible co-benefits, which may be difficult to assess. Many actions that integrate mitigation and adaptation have enough co-benefits to make obvious sense of their immediate implementation (see Working Group II report), in spite of the fact that in many cases, assessment of their effective combination, cost-effectiveness, and tradeoffs requires improved information, improved capacities for analysis and action, and further policymaking (Wilbanks and Sathaye, 2007). Modelling of any direct interaction between adaptation and mitigation in terms of their specific effectiveness and tradeoffs would also be desirable (Wang and McCarl, 2011).

An analysis on the time composition (timing of mitigation and adaptation) of the optimal climate change strategy is also important to assess how to best allocate climate change funds. Emerging frameworks for assessing the tradeoffs between adaptation and mitigation include those from the point of view of risks and costs. People invest resources to reduce the risk they confront or create (Ehrlich and Becker, 1972; Lewis and Nickerson, 1989). Recent studies have used integrated assessment models to numerically calculate the optimal allocation of investments between mitigation and adaptation. They confirm the analytical insights of Kane and Shogren (2000) and suggest that investments in mitigation should anticipate investments in adaptation (Lecocq and Shalizi, 2007; de Bruin et al., 2009; Bosello et al., 2010). The reason for this is because climate and economic systems have inertia and delaying action increases the costs of achieving a given temperature target. These studies suggest that the competition between mitigation and adaptation funds extends over time.

By arguing "uncertainty on the location of damages reduces the benefits of 'targeted' proactive adaptation with regard to mitigation and reactive adaptation", some authors reinforce the idea that it is optimal to wait to invest in adaptation (Lecocq and Shalizi, 2007). For the above reasons, Carraro and Massetti (2011) suggest that the greatest share of the GCF should finance emissions reductions rather than adaptation in developing countries. Other authors propose a framework that could integrate into an optimization model not only mitigation and adaptation, but also climate change residual damages. In the light of the uncertain impacts of climate change, prioritizing mitigation measures is justified, on the basis of a precautionary approach. Adaptation actions "should be optimally designed, consistently with mitigation, as a residual strategy addressing the damage not accommodated by mitigation" (Bosello et al., 2010).

Wang and McCarl (2011) recognizes that, in terms of an overall investment shared between mitigation and adaptation, mitigation tackles the long-run cause of climate change while adaptation tackles the short-run reduction of damages and is preferred when damage stocks are small. Contrary to Bosello et al. (2010), they advocate that, instead of taking adaptation as a 'residual' strategy, well-planned adaptation is an economically effective complement to mitigation since the beginning and should occur in parallel. Thus, adaptation investment should be considered as an important current policy option due to the near-term nature of given benefits.

Moreover, the optimal balance of adaptation and mitigation measures and investments should be determined in function of the magnitude of climate change; "if mitigation can keep climate change to a moderate level, then adaptation can handle a larger share of the resulting impact vulnerabilities" (Wilbanks et al., 2007). While the uncertainties about specific pathways remain, and although there are different considerations on their optimal balance, there is a general agreement that funding for both mitigation and adaptation is needed.

16.6.2 Integrated financing approaches

Despite the lack of modelling of any direct interaction between adaptation and mitigation in terms of financing, there is an increasing interest in promoting integrated financing approaches, addressing both adaptation and mitigation activities in different sectors and at different levels. Although the GCF will have thematic funding windows for adaptation and mitigation, an integrated approach will be used to allow for cross-cutting projects and programmes (UNFCCC, 2011c, para 37).

The theoretical literature reviewed in Section 16.1.1 provides only general guidance on financing mitigation and adaptation measures. Analysis of specific adaptation and mitigation options in different sectors reveals that adaptation and mitigation can positively and negatively influence the effectiveness of each other (see also Working Group II report). Particular opportunities for synergies exist in some sectors (Klein et al., 2007), including agriculture (Niggli et al., 2009), forestry (Ravindranath, 2007; Isenberg and Potvin, 2010), and buildings and urban infrastructure (Satterthwaite, 2007).

Mitigation activities have global benefits while most adaptation activities benefit a smaller geographical area or population. Funding sources with a regional, national or sub-national perspective, therefore, will increasingly favour adaptation over mitigation measures (Dowlatabadi, 2007; Wilbanks and Sathaye, 2007). Thus the sources of climate finance available may yield a mix of mitigation and adaptation measures quite different from the global optimal mix. Additional studies "to understand the complex way in which local adaptation aggregates to the global level" are needed (Patt et al., 2009). Although the optimal mix cannot be determined precisely, the availability of international climate finance for both mitigation and adaptation is necessary to counteract such tendencies.

Taking into account the strong regional nature of climate change impacts, a regional financing arrangement will be more responsive and relevant than a global one, and may play an important role in adaptation (Sharan, 2008). Regional funding tools have made arrangements for financing adaptation activities in complement to mitigation measures: e.g., the Poverty and Environment Fund (PEF) of the Asian Development Bank promotes the mainstreaming of environmental and climate change considerations into development strategies, plans, programmes, and projects of the bank (ADB, 2003).

The AfDB acts as manager and coordinator of new funding for the Congo Basin forest ecosystem conservation and sustainable management (UNEP, 2008). According to the operational procedures by AfDB, to be eligible for financing under the Congo Basin Forest Fund (CBFF), project proposals and initiatives considered for funding should, among other things, aim at slowing the rate of deforestation, contribute to poverty alleviation, provide some contribution to climate stabilization and GHG emissions reduction, and may show environment, economic, and social risk assessment in addition to appropriate mitigation measures, as well as be supported by national strategies to combat deforestation while preserving biodiversity and promoting sustainable development (AfDB, 2009). See Section 14.3.2 for additional information on regional examples of cooperation schemes identifying synergies between mitigation and adaptation financing.

Many ongoing bilateral and multilateral development activities address mitigation and adaptation at the same time. A recent survey by Illmann et al. (2013) discusses examples from agriculture (conversion of fallow systems into continuously cultivated area; the reuse of wastewater for irrigation), forestry (reforestation with drought-resistant varieties; mangrove plantations), and from the energy sector (rural electrification with renewable energy, production of charcoal briquettes from agricultural waste). The study identifies significant potential to further mobilize these synergies within existing development cooperation programmes.

Another point of debate regarding synergies and tradeoffs between financing mitigation and adaptation relates to the conceptual framework that suggests allocating responsibility for international financing of adaptation based on the historical contribution of countries to climate change in terms of GHG emissions and their capacity to pay for the costs of adaptation at international level (Dellink et al., 2009). The provision of international climate finance, of course, raises other issues of equity and burden sharing, which are beyond the scope of this chapter.

16.7 Financing developed countries' mitigation activities

This and the next section consider the manner in which developed and developing countries may choose to finance the incremental investments and operating costs associated with GHG mitigation activities. It is fully recognized that a country's individual circumstances will in large part determine how financing is accomplished, and further, that individual national circumstances vary widely among members of the developed and developing country groups.

The manner in which developed countries finance their mitigation activities depends largely on the policies chosen to limit GHG emissions and the ownership of the sources of emissions. Policies and ownership also determine the distribution of the burdens posed by the financing needs, i.e., if it will be financed by households and firms through higher prices, taxes, or both.

In 2011 and 2012, on average, 177 billion USD of global climate finances were invested in developed countries (49% of the global total climate finance) of which the vast majority (81%) originated in the same country as the investment was undertaken (2011/2012 USD) (Buchner et al., 2013b). Due to the financial crisis investment in renewable energy in developed countries dropped 14% in 2009 (Frankfurt School-UNEP Centre and BNEF, 2012), but saw a rapid recovery due to the green stimulus packages (IEA, 2009; REN21, 2010). The eight development banks of OECD countries that are members of the International Development Finance Club (IDFC) allocated 28 billion USD (2011 USD) and 33 billion USD (2012 USD) 'green'[29] finance to domestic projects in 2011 and 2012, respectively (Höhne et al., 2012; IDFC, 2013). Public climate finance was also directed to developing countries at a range of 35–49 billion USD per year for 2011 and 2012 (2011/2012 USD) (Buchner et al., 2013b).

Without climate policy, an estimated 96 (70–126) billion USD per year of investment in fossil power generation will occur in developed countries from 2010–2029; from 2030 to 2049, this figure increases to 131 (86–215) billion USD per year. In a climate policy scenario compatible with a 2°C warming limit in 2100, OECD countries are expected to reduce investments in fossil power generation by 57% (–2 to –89%) during 2010–2029, but investments will drop by 90% (–80 to –98%) during 2030–2049. Investment in renewable power generation instead will increase by 86% (58 to 116%) during 2010–2029 and by 200% (77 to 270%) during 2030–2049 (based on IEA (2011), Carraro et al. (2012), Calvin et al. (2012) and McCollum et al. (2013), used in Section 16.2.2).

To date, public sourcing for climate finance originates primarily from general tax revenues. However, under ambitious stabilization targets, financial sources that yield mitigation benefits have the potential to generate high revenues that could be used for climate finance. Carbon taxes and the auctioning of emissions allowances carry the highest potential, a phaseout of fossil fuel subsidies, and a levy or emission trading scheme for international aviation and shipping emissions are

29 'Green' finance as reported by IDFC includes projects with other environmental benefits. Approximately 93% (80%) of the 'green' finance by IDFC in 2011 (2012) was climate finance (Höhne et al., 2012; IDFC, 2013).

estimated to generate considerable revenues as well (UNFCCC, 2007; AGF, 2010; World Bank Group et al., 2011).

Most developed countries offer a reasonably attractive core and broader enabling environment for climate investments. Developed countries, as do many emerging economies, combine substantial energy-related GHG emission reduction potential with low country risks. At the end of 2012, 29 out of 36 assessed developed countries fell into the group of lower risk country grade, producing 39 % of global fuel-related CO_2 emissions (Harnisch and Enting, 2013). Private finance can thus be the main source of low-carbon investment in these countries, however private actors are often dependent on public support through regulatory and policy frameworks and/or specialized finance mechanisms.

While macroeconomic and policy risk have been reasonably low in the past, low-carbon policy risks have affected investments in developed countries. In principle, risk-mitigation instruments and access to long-term finance can be provided at reasonably low cost. Suitable institutions exist to implement specialized public finance mechanisms to provide dedicated credit lines, guarantees to share the risks of investments, debt financing of projects, microfinance or incentive funds, and schemes to mobilize R&D and technical assistance funds for building capacities across the sectors. The institutions and types of public finance mechanisms in existence across countries are diverse but share the common aim of helping commercial financial institutions to effectively and efficiently perform this job (Maclean et al., 2008).

In 2012, the most widespread fiscal incentives were capital subsidies, grants, and rebates. They were in place in almost 90 % of high-income countries. In 70 % of the countries public funds were used to support renewable energy, e.g., public investment loans and grants. Feed-in tariffs were in place in 27 high-income countries at national or state level (75 % of all countries analyzed) (REN21, 2012).

16.8 Financing mitigation activities in and for developing countries including for technology development, transfer, and diffusion

Analogous to the previous section, this section outlines key assessment results for mitigation finance in and for developing countries, i.e., embracing domestic flows as well as financing provided by developed countries.

An estimated 51 % of the total global climate finance in 2011 and 2012, namely on average 182 billion USD per year, was invested in developing countries (2011/2012 USD). Thereof, 72 % was originating in the same country as it was invested) (Buchner et al., 2013b). The total climate finance flowing from developed to developing countries is estimated to be between 39 and 120 billion USD per year in 2011 and 2012 (2011/2012 USD). This range covers public and the more uncertain flows of private funding for mitigation and adaptation. Clapp et al. (2012) estimate the total at 70–120 billion USD per year based on 2009–2010 data. Data from Buchner et al. (2013a) suggest a net flow to developing countries for 2010 and 2011 of the order of 40 to 60 billion USD. North-South flows are estimated at 39 to 62 billion USD per year for 2011 and 2012 (2011/2012 USD) (Buchner et al., 2013b).

Public climate finance provided by developed countries to developing countries was estimated at 35 to 49 billion USD per year in 2011 and 2012 (2011/2012USD) (Buchner et al., 2013b). Multilateral and bilateral institutions played an important role in delivering climate finance to developing countries. Seven MDBs[30] reported climate finance commitments of about 24.1 and 26.8 billion USD in 2011 and 2012, respectively[31] (2011 and 2012 USD) (AfDB et al., 2012a; b, 2013). These institutions manage a range of multi-donor trust climate funds, such as the Climate Investment Funds, and the funds of the financial mechanism of the Convention (GEF, SCCF, LDCF). The GCF is expected to become an additional international mechanism to support climate activities in developing countries. Bilateral climate-related ODA commitments were at an average of 20 billion USD per year in 2010 and 2011 (2010/2011 USD) (OECD, 2013a)[32] and were implemented by bilateral development banks or bilateral agencies, provided to national government directly or to dedicated multilateral climate funds (Buchner et al., 2012). However, bilateral and multilateral commitments are not fully comparable due to differences between methodologies.

Climate projects in developing countries showed a higher share of balance-sheet financing and concessional funding provided by national and international development finance institutions than developed countries (Buchner et al., 2012). Domestic public development banks played an important role in this regard. The 11 non-OECD development

30 African Development Bank (AfDB), the Asian Development Bank (ADB), the European Bank for Reconstruction and Development (EBRD), the European Investment Bank (EIB), the Inter-American Development Bank (IDB), the World Bank (WB), and the International Finance Corporation (IFC).

31 The reporting is activity-based allowing counting entire projects but also project components. Recipient countries include developing countries and 13 EU member states. It covers grant, loan, guarantee, equity, and performance-based instruments, not requiring a specific grant element. The volume covers MDBs' own resources as well as external resources managed by the MDBs that might also be reported to OECD DAC (such as contributions to the GEF, CIFs, and Carbon Funds).

32 It covers total funding committed to projects that have climate change mitigation or adaptation as a 'principal' or 'significant' objective. The ODA is defined as those flows to countries on the DAC List of ODA Recipients and to multilateral institutions provided by official agencies or by their executive agencies. Resources must be used to promote the economic development and welfare of developing countries as a main objective and they must be concessional in character (OECD, 2013a).

Box 16.3 | Least Developed Countries' investment and finance for low-carbon activities

This box highlights key issues related to investment and finance for Least Developed Countries (LDCs), however some of these issues are certainly also relevant for other developing countries.

Climate change increased the challenges LDCs are facing regarding food, water, and energy that exacerbate sustainable development. Most LDCs are highly exposed to climate change effects as they are heavily reliant on climate-vulnerable sectors such as agriculture (Harmeling and Eckstein, 2012). Most of the LDCs, already overwhelmed by poverty, natural disasters, conflicts, and geophysical constraints, are now at risk of further devastating impacts of climate change. In turn, they contribute very little to carbon emissions (Baumert et al., 2005; Fisher, 2013).

At the same time, LDCs are faced with a lack of access to energy services and with an expected increase in energy demand due to the population and GDP growth. Of the 1.2 billion people without electricity in 2010, around 85 % live in rural areas and 87 % in Sub-Saharan Africa and Southern Asia. For cooking, the access deficit amounts to 2.8 billion people who primarily rely on solid fuels. About 78 % of that population lives in rural areas, and 96 % are geographically concentrated in Sub-Saharan Africa, Eastern Asia, Southern Asia, and South-Eastern Asia (Sustainable Energy for All, 2013) (see Section 14.3.2.1 for other estimates provided by the literature). By investing in mitigation activities in the early and interim stages, access to clean and sustainable energy can be provided and environmentally harmful technologies can potentially be leapfrogged. Consequently, needs for finance and investment are pressing both for adaptation and mitigation.

Regarding specific mitigation finance needs, there are no robust data for LDCs. It is estimated that shifting the large populations that rely on traditional solid fuels (such as unprocessed biomass, charcoal, and coal) to modern energy systems and expanding electricity supply for basic human needs could yield substantial improvements in human welfare for a relatively low cost (72–95 billion USD per year until 2030 to achieve nearly universal access) (Pachauri et al., 2013). For instance, in Bangladesh, the costs to provide a minimum power from solar home system's energy source to off-grid areas was around 285 USD per household (World Bank, 2012c). However, the very few country studies on mitigation needs and costs are not representative of the whole group of LDCs and are not comparable. Data on international and domestic private sector activities in LDCs are also lacking, as are data on domestic public flows. With respect to North-South flows, the OECD DAC reported that developed countries provided 730 million USD in mitigation related ODA to LDCs in the year 2011. Bangladesh received the highest share with 117 million USD, followed by Uganda and Haiti with more than 70 million USD (OECD, 2012).

Most LDCs have very few CDM projects that are also an important vehicle for mitigation (UNFCCC, 2012d; UNEP Risø, 2013). To improve the regional distribution of CDM projects, the CDM Executive Board has promoted the regulatory reform of CDM standards, procedures, and guidelines. Furthermore, stakeholder interaction has been enhanced and a CDM loan scheme has been established by UNFCCC to provide interest-free loans for CDM project preparation in LDCs (UNFCCC, 2012e).

Some LDCs are starting to allocate public funds to mitigation and adaptation activities, e.g., NAPAs or national climate funds (Khan et al., 2012). However, pressing financial needs to combat poverty favour other expenditures over climate-related activities.

Most LDCs struggle to provide an enabling environment for private business activities, a very common general development issue (Stadelmann and Michaelowa, 2011). It is noteworthy that among the 30 lowest-ranking countries in the World Bank's Doing Business Index, 23 countries are LDCs (World Bank, 2011a). Obstacles to general private business activities in turn hinder long-term private climate investments (Hamilton and Justice, 2009). Due to very high perceived risk in LDCs, risk premiums are very high. This is particularly problematic as low-carbon investments are very responsive to the cost of capital (Eyraud et al., 2011). In a challenging environment, it is difficult to implement targeted public policies and financial instruments to mobilize private mitigation finance. Moreover, the weakness of technological capabilities in LDCs presents a challenge for successful development and transfer of climate-relevant technologies (ICTSD, 2012).

To develop along a low-carbon growth path, LDCs rely on international grant and concessional finance. It is especially important to ensure the predictability and sustainability of climate finance for LDCs, as these countries are inherently more vulnerable to economic shocks due to their structural weaknesses (UNCTAD, 2010).

While all donors and development institutions provide mitigation finance to LDCs, there are some dedicated institutional arrangements, such as the LDCF and the SCCF under the Convention. Some LDCs have also implemented national funding institutions, e.g., Benin, Senegal, and Rwanda in the framework of the Adaptation Fund, or the Bangladesh Climate Change Resilience Fund.

While knowledge and data gaps regarding mitigation finance are generally higher in developing than in developed countries, they are even more severe in LDCs.

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bank members of IDFC provided 44 billion USD of domestic 'green'[33] finance in 2011 and 2012 (2011 and 2012 USD) (Höhne et al., 2012; IDFC, 2013).

According to UNFCCC (2011a), Annex II countries provided an average of almost 10 billion USD per year of climate finance to developing countries. In 2009, developed countries committed to provide new and additional resources approaching 30 billion USD of 'FSF' to support mitigation and adaptation action in developing countries during 2010–2012. The sum of the announced commitments exceeds 33 billion USD (UNFCCC, 2011b, 2012b; c, 2013a). Data on the amount actually disbursed is not available. Some analyses question whether these funds were 'new and additional' (Brown et al., 2010; Stadelmann et al., 2010, 2011b).

There is limited robust information on the current magnitude of private flows from developed to developing countries. Clapp et al. (2012) estimate the private investment at 37–72 billion USD per year based on 2009–2010 data (2008/2009 USD) and Stadelmann et al. (2013) estimate foreign direct investment as equity and loans in the range of 10 to 37 billion USD (2010 and 2008 USD) per year based on 2008–2011 data.

In reference scenarios as well as in policy scenarios compatible with a 2 °C warming target in 2100, non-OECD countries absorb the greatest share of incremental investments in power generation technologies. Without climate policy, investments in the power sector are mainly directed towards fossil fuels. About 73 % (65 % to 80 %) of global investment in fossil power plants between 2010–2029, and 78 % (76 to 80 %) between 2030–2049, would flow into in the non-OECD because many developing countries rely on low-cost coal power plants to supply an ever-growing demand of electricity in the scenarios examined (based on IEA (2011), Carraro et al. (2012), Calvin et al. (2012), and McCollum et al. (2013) used in Section 16.2.2). In a climate policy scenario compatible with a 2 °C warming limit in 2100, non-OECD countries are expected to absorb 51 % (34 % to 66 %) of incremental average annual investment in renewables over 2010–2029, and 67 % (61 % to 73 %) over 2030–2049.

In tackling climate change, developing countries face different types and magnitudes of constraints. Out of the 149 assessed developing countries, only 37 were assigned lower risk country grades. These countries, being attractive for international private sector investment in low-carbon technologies, represent 38 % of global CO_2 emissions. However, the majority of developing countries currently exhibits higher country risk grades—reflecting less attractive international investment conditions—and finds it more difficult to attract foreign private investment (Harnisch and Enting, 2013). Moreover, the lack of technical capacity and training systems is a significant barrier for low-carbon investment in many developing economies (Ölz and Beerepoot, 2010). Between 2005 and 2009, developed countries provided 2.5 billion USD of ODA to support creation of general enabling environments in developing countries (2005–2009 USD) (Stadelmann and Michaelowa, 2011).

Since investment risks for low-carbon projects in developing countries are typically perceived to be higher than in developed countries, the cost of capital and the return requirements of investors are respectively higher. The IRR for general infrastructure in developing countries, for instance, is a median of 20 % compared to about 12 % in developed countries (Ward et al., 2009). Access to affordable long-term capital is limited in many developing countries (Maclean et al., 2008), where local banks are not able to lend for 15–25 years due to balance sheet constraints (Hamilton, 2010), such as the mismatch in the maturity of assets and liabilities. In addition, appropriate financing mechanism for end-users' up-take are also often missing (Derrick, 1998). Moreover, equity finance is scarce in many developed countries, increasing the dependence on project finance. Especially in low-income countries, project sponsors frequently rely on external assistance to cover project development costs for many investments because of their high risks and non-commercial nature (World Bank, 2011d).

Many developing countries use a range of incentives for investments in renewable energies (REs), especially fiscal incentives (OECD, 2013d). Public financing instruments to stimulate RE, such as public investment, loans, or grants, were in place in 57 % of the countries analyzed and FITs were established in 39 developing countries in 2012 (REN21, 2012). Carbon pricing has not yet widely been adopted by developing countries, apart from the non-perfect carbon price incentive via the CDM. However, currently new ETS are set up, planned, or under consideration in some developing countries such as China (provinces and cities), Kazakhstan, Ukraine, Chile, Brazil, and South Korea, but it will take time until such ETS will be fully operational and provide enough investment certainty (Kossoy et al., 2013).

Regional groupings such as the ECOWAS, the ASEAN, and the Mercosur, have been actively promoting sub-regional integration of energy systems and cooperation in climate change activities.

On the national level, there is an on-going attempt to cope with the multiplicity of sources, agents, and channels offering financial resources for climate action (Glemarec, 2011). Most developing countries rely on relevant ministries and agencies chaired by the ministry of the environment or finance to coordinate climate change finance (Gomez-Echeverri, 2010). Some developing countries are establishing national implementing entities and funds that mainstream climate change activities into overall development strategies. Often these institutions are designed to blend international funding with domestic and private sector resources (Flynn, 2011).

[33] 'Green' finance as reported by IDFC includes projects with other environmental benefits. Approximately 93 % (80 %) of the 'green' finance by IDFC in 2011 (2012) was climate finance (Höhne et al., 2012; IDFC, 2013).

16.9 Gaps in knowledge and data

Scientific literature on investment and finance for low-carbon activities is still very limited and knowledge gaps are substantive.

- **Common definitions and data availability.** To date there are no common definitions for central concepts related to climate finance or financial accounting rules. Neither are there complete or reasonably accurate data on current climate finance and its components, namely developed country sources or commitments, developing country sources or commitments, international flows, and private vs. public sources. The role of domestic and South-South flows and domestic investments in developing countries is also not adequately understood and documented. Frequently it is not possible to distinguish exactly between adaptation and development finance, since they are closely interconnected. Another difficult assessment is on the differences between funding under the ODA and 'new and additional' funds available. Important metrics like the high-carbon investment by sub-sector and region, the carbon intensity of new investments, downward deviations from reference emission pathways, or the cost-effectiveness of global mitigation investments are not tracked systematically.

- **Model outputs and approaches.** Only very limited model results exist for additional investments and incremental costs to abate CO_2 emissions in sectors other than energy supply, e.g., via energy efficiency in industry, buildings, and transport, as well as in other sectors like forestry, agriculture, and waste, or to mitigate process and non-CO_2 emissions in the petroleum and gas, cement, and chemical industry, or from refrigeration and air conditioning. Very limited analysis has been published that takes a globally consistent perspective of incremental investments and costs at the level of nation states and regions. This perspective could enrich the scientific discussion because global and regional netting approaches among sectors and sub-sectors may fall short of the complexity of real political decision making processes.

- A comprehensive and transparent treatment of investment and technology risks in energy models is not available. The impact of fuel price volatility on low-carbon investments is generally not considered. Reasonably robust quantitative results of the need for additional R&D for low-carbon technologies and practices and on the timing of these needs (infrastructure and technology deployment roadmaps) are not available. While there is literature on mitigation technology diffusion and transfer in general, it is not clear whether specific financial requirements to this end are different from finance for other mitigation activities.

- For the energy sector, there is no convergence on the order of magnitude of net incremental investment costs across its sub-sectors. Interactions of stringent climate policies with overall growth and investment of individual economies and the world economy as a whole are also not yet well understood.

- **Effectiveness and efficiency of climate finance.** Knowledge about enabling environments for effective deployment of climate finance in any country is insufficient. There is very limited empirical evidence to relate the concept of low-carbon activities to macro determinants from a cross-country perspective. More research is especially needed regarding determinants for mitigation investment in LDCs.

- There is only case-specific knowledge by practitioners on the selection and combination of instruments that are most effective at shifting (leveraging) private investment to mitigation and adaptation. There is no general understanding of what are the efficient levers to mobilize private investment and its potential in any country (since they will differ by investment and country).

- The effectiveness of different public climate finance channels in driving low-carbon development is insufficiently analyzed. Estimates of the incremental cost value of public guarantees, export insurances, and non-concessional loans of development banks would provide valuable insights. Little is known on determinants for an economically efficient and effective allocation of public climate finance. A comprehensive assessment of the interrelation between private and public sector actors in sharing incremental costs and risks of mitigation investments, for example, via concessional loans or guarantee instruments has not been undertaken yet.

- There is no agreement yet which institutional arrangements are more effective at which level (international—national—local) and for what investment in which sector. However, an understanding of the key determinants of this efficiency and of the nature of a future international climate policy agreement is needed first.

- **Balance between mitigation and adaptation finance and investment.** The optimal balance, including its time dimension, is a difficult exercise given the lack of modelling of any direct interaction between adaptation and mitigation in terms of their specific effectiveness and tradeoffs. A better-informed assessment of the effective integration of mitigation and adaptation, including tradeoffs and cost avoidance estimates, is needed. Moreover, there is limited research and literature to assess synergies and tradeoffs between and across sector-specific mitigation and adaptation measures from the specific financing and investment point of view.

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16.10 Frequently Asked Questions

FAQ 16.1 What is climate finance?

There is no agreed definition of climate finance. The term 'climate finance' is applied both to the financial resources devoted to addressing climate change globally and to financial flows to developing countries to assist them in addressing climate change. The literature includes multiple concepts within each of these broad categories.

There are basically three types of metrics for **financial resources devoted to addressing climate change globally.** *Total climate finance* includes all financial flows whose expected effect is to reduce net greenhouse gas emissions and/or to enhance resilience to the impacts of climate variability and the projected climate change. This covers private and public funds, domestic and international flows, expenditures for mitigation and adaptation, and adaptation to current climate variability as well as future climate change. It covers the full value of the financial flow rather than the share associated with the climate change benefit; e.g., the entire investment in a wind turbine rather than the portion attributed to the emission reductions. The *incremental investment* is the extra capital required for the initial investment to implement a mitigation or adaptation measure, for example, the investment in wind turbines less the investment that would have been required for a natural gas generating unit displaced. Since the value depends on a hypothetical alternative, the incremental investment is uncertain. The *incremental costs* reflect the cost of capital of the incremental investment and the change of operating and maintenance costs for a mitigation or adaptation project in comparison to a reference project. It can be calculated as the difference of the net present values of the two projects. Values depend on the incremental investment as well as projected operating costs, including fossil fuel prices, and the discount rate.

Financial flows to assist developing countries in addressing climate change typically cover the following three concepts. The *total climate finance* flowing to developing countries is the amount of the total climate finance invested in developing countries that comes from developed countries. This covers private and public funds for mitigation and adaptation. *Public climate finance* provided to developing countries is the finance provided by developed countries' governments and bilateral institutions as well as multilateral institutions for mitigation and adaptation activities in developing countries. *Private climate finance flowing to developing countries* is finance and investment by private actors in/from developed countries for activities in developing countries. Under the UNFCCC, *climate finance* is not well-defined. Annex II Parties provide and mobilize funding for climate related activities in developing countries. Most of the funds provided are concessional loans and grants.

FAQ 16.2 How much investment and finance is currently directed to projects that contribute to mitigate climate change and how much extra flows will be required in the future to stay below the 2 °C limit?

Current climate finance was estimated at around 359 billion USD per year of which 337 billion USD per year was invested in mitigation using a mix of 2011 and 2012 data (2011/2012 USD). This covers the full investment in mitigation measures, such as renewable energy generation technologies that also produce other goods or services. Climate finance invested in developed countries amounted to 177 billion USD and in developing countries 182 billion USD (2011/2012 USD).

Climate policy is expected to induce a significant change in investment pattern in all scenarios compatible with a 2 °C limit. Based on data from a limited number of scenarios, there would need to happen a remarkable reallocation of investments in the power sector from fossil fuels to low-emissions generation technologies (renewable power generation, nuclear, and electricity generation with CCS). While annual investment in conventional *fossil-fired power plants without CCS* is estimated to decline by about 30 billion USD per year in 2010–2029 (i.e., by 20 % compared to 2010), annual investment in *low-emission generation technologies* is expected to increase by about 147 billion USD per year (i.e., by 100 % compared to 2010), over the same period.

Investment in *energy efficiency in the building, transport, and industry sector* would need to increase by several hundred billion USD per year from 2010–2029. Information on investment needs in other sectors, e.g., CO_2 to abatement processes or non-CO_2 emissions, is sparse.

Model results suggest that *deforestation* could be reduced against current deforestation trends by 50 % with an investment of 21 to 35 billion USD annually.

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Annexes

ANNEX

I

Glossary, Acronyms and Chemical Symbols

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Glossary

This glossary defines some specific terms as the Lead Authors intend them to be interpreted in the context of this report. Glossary **entries** (highlighted in bold) are by preference subjects; a main entry can contain ***subentries***, in bold and italic, for example, ***Primary Energy*** is defined under the entry **Energy**. Blue, italicized *words* indicate that the term is defined in the Glossary. The glossary is followed by a list of acronyms and chemical symbols. Please refer to Annex II for standard units, prefixes, and unit conversion (Section A.II.1) and for regions and country groupings (Section A.II.2).

Abrupt climate change: A large-scale change in the *climate system* that takes place over a few decades or less, persists (or is anticipated to persist) for at least a few decades, and causes substantial disruptions in human and natural systems. See also *Climate threshold*.

Adaptability: See *Adaptive capacity*.

Adaptation: The process of adjustment to actual or expected *climate* and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected *climate* and its effects.[1]

Adaptation Fund: A Fund established under the *Kyoto Protocol* in 2001 and officially launched in 2007. The Fund finances *adaptation* projects and programmes in *developing countries* that are Parties to the *Kyoto Protocol*. Financing comes mainly from sales of *Certified Emissions Reductions (CERs)* and a share of proceeds amounting to 2% of the value of CERs issued each year for *Clean Development Mechanism (CDM)* projects. The Adaptation Fund can also receive funds from government, private sector, and individuals.

Adaptive capacity: The ability of systems, *institutions*, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.[2]

Additionality: *Mitigation* projects (e.g., under the *Kyoto Mechanisms*), *mitigation policies*, or *climate finance* are additional if they go beyond a *business-as-usual* level, or *baseline*. Additionality is required to guarantee the environmental integrity of project-based offset mechanisms, but difficult to establish in practice due to the counterfactual nature of the *baseline*.

Adverse side-effects: The negative effects that a *policy* or *measure* aimed at one objective might have on other objectives, without yet evaluating the net effect on overall social welfare. Adverse side-effects are often subject to *uncertainty* and depend on, among others, local circumstances and implementation practices. See also *Co-benefits*, *Risk*, and *Risk tradeoff*.

Aerosol: A suspension of airborne solid or liquid particles, with a typical size between a few nanometres and 10 μm that reside in the *atmosphere* for at least several hours. For convenience the term aerosol, which includes both the particles and the suspending gas, is often used in this report in its plural form to mean aerosol *particles*. Aerosols may be of either natural or anthropogenic origin. Aerosols may influence *climate* in several ways: directly through scattering and absorbing radiation, and indirectly by acting as cloud condensation nuclei or ice nuclei, modifying the optical properties and lifetime of clouds. Atmospheric aerosols, whether natural or anthropogenic, originate from two different pathways: emissions of primary *particulate matter (PM)*, and formation of secondary *PM* from gaseous *precursors*. The bulk of aerosols are of natural origin. Some scientists use group labels that refer to the chemical composition, namely: sea salt, organic carbon, *black carbon (BC)*, mineral species (mainly desert dust), sulphate, nitrate, and ammonium. These labels are, however, imperfect as aerosols combine particles to create complex mixtures. See also *Short-lived climate pollutants (SLCPs)*.

Afforestation: Planting of new *forests* on lands that historically have not contained *forests*. Afforestation projects are eligible under a number of schemes including, among others, *Joint Implementation (JI)* and the *Clean Development Mechanism (CDM)* under the *Kyoto Protocol* for which particular criteria apply (e.g., proof must be given that the land was not forested for at least 50 years or converted to alternative uses before 31 December 1989).

For a discussion of the term *forest* and related terms such as afforestation, *reforestation* and *deforestation*, see the IPCC Special Report on Land Use, Land-Use Change and Forestry (IPCC, 2000). See also the report on Definitions and Methodological Options to Inventory Emissions from Direct Human-induced Degradation of Forests and Devegetation of Other Vegetation Types (IPCC, 2003).

Agreement: In this report, the degree of agreement is the level of concurrence in the literature on a particular finding as assessed by the authors. See also *Evidence*, *Confidence*, *Likelihood*, and *Uncertainty*.

Agricultural emissions: See *Emissions*.

Agriculture, Forestry and Other Land Use (AFOLU): Agriculture, Forestry and Other Land Use plays a central role for *food security* and *sustainable development (SD)*. The main *mitigation* options within AFOLU involve one or more of three strategies: *prevention* of emissions to the *atmosphere* by conserving existing *carbon pools* in soils or vegetation or by reducing emissions of *methane* (CH_4) and *nitrous*

[1] Reflecting progress in science, this glossary entry differs in breadth and focus from the entry used in the Fourth Assessment Report and other IPCC reports.

[2] This glossary entry builds from definitions used in previous IPCC reports and the Millennium Ecosystem Assessment (MEA, 2005).

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oxide (N_2O); *sequestration*—increasing the size of existing *carbon pools*, and thereby extracting *carbon dioxide (CO_2)* from the *atmosphere*; and *substitution*—substituting biological products for *fossil fuels* or energy-intensive products, thereby reducing CO_2 emissions. Demand-side measures (e.g., by reducing losses and wastes of food, changes in human diet, or changes in wood consumption) may also play a role. FOLU (Forestry and Other Land Use)—also referred to as *LULUCF (Land use, land-use change, and forestry)*—is the subset of AFOLU emissions and removals of *greenhouse gases (GHGs)* resulting from direct human-induced land use, land-use change and forestry activities excluding *agricultural emissions*.

Albedo: The fraction of solar radiation reflected by a surface or object, often expressed as a percentage. Snow-covered surfaces have a high albedo, the albedo of soils ranges from high to low, and vegetation-covered surfaces and oceans have a low albedo. The earth's planetary albedo varies mainly through varying cloudiness, snow, ice, leaf area and land cover changes.

Alliance of Small Island States (AOSIS): The Alliance of Small Island States (AOSIS) is a coalition of small islands and low-lying coastal countries with a membership of 44 states and observers that share and are active in global debates and negotiations on the environment, especially those related to their vulnerability to the adverse effects of *climate change*. Established in 1990, AOSIS acts as an ad-hoc lobby and negotiating voice for small island development states (SIDS) within the United Nations including the *United Nations Framework Convention on Climate Change (UNFCCC)* climate change negotiations.

Ancillary benefits: See *Co-benefits*.

Annex I Parties/countries: The group of countries listed in Annex I to the *United Nations Framework Convention on Climate Change (UNFCCC)*. Under Articles 4.2 (a) and 4.2 (b) of the UNFCCC, Annex I Parties were committed to adopting national *policies* and *measures* with the non-legally binding aim to return their *greenhouse gas (GHG)* emissions to 1990 levels by 2000. The group is largely similar to the *Annex B Parties* to the *Kyoto Protocol* that also adopted emissions reduction targets for 2008–2012. By default, the other countries are referred to as *Non-Annex I Parties*.

Annex II Parties/countries: The group of countries listed in Annex II to the *United Nations Framework Convention on Climate Change (UNFCCC)*. Under Article 4 of the UNFCCC, these countries have a special obligation to provide financial resources to meet the agreed full incremental costs of implementing *measures* mentioned under Article 12, paragraph 1. They are also obliged to provide financial resources, including for the transfer of technology, to meet the agreed incremental costs of implementing *measures* covered by Article 12, paragraph 1 and agreed between *developing country* Parties and international entities referred to in Article 11 of the UNFCCC. This group of countries shall also assist countries that are particularly vulnerable to the adverse effects of *climate change*.

Annex B Parties/countries: The subset of *Annex I Parties* that have accepted *greenhouse gas (GHG)* emission reduction targets for the period 2008–2012 under Article 3 of the *Kyoto Protocol*. By default, the other countries are referred to as *Non-Annex I Parties*.

Anthropogenic emissions: See *Emissions*.

Assigned Amount (AA): Under the *Kyoto Protocol*, the AA is the quantity of *greenhouse gas (GHG)* emissions that an *Annex B country* has agreed to as its *cap* on its emissions in the first five-year commitment period (2008–2012). The AA is the country's total GHG emissions in 1990 multiplied by five (for the five-year commitment period) and by the percentage it agreed to as listed in Annex B of the *Kyoto Protocol* (e.g., 92 % for the EU). See also *Assigned Amount Unit (AAU)*.

Assigned Amount Unit (AAU): An AAU equals 1 tonne (metric ton) of *CO_2-equivalent emissions* calculated using the *Global Warming Potential (GWP)*. See also *Assigned Amount (AA)*.

Atmosphere: The gaseous envelope surrounding the earth, divided into five layers—the *troposphere* which contains half of the earth's atmosphere, the *stratosphere*, the mesosphere, the thermosphere, and the exosphere, which is the outer limit of the atmosphere. The dry atmosphere consists almost entirely of nitrogen (78.1 % volume mixing ratio) and oxygen (20.9 % volume mixing ratio), together with a number of *trace gases*, such as argon (0.93 % volume mixing ratio), helium and radiatively active *greenhouse gases (GHGs)* such as *carbon dioxide (CO_2)* (0.035 % volume mixing ratio) and *ozone (O_3)*. In addition, the atmosphere contains the GHG water vapour (H_2O), whose amounts are highly variable but typically around 1 % volume mixing ratio. The atmosphere also contains clouds and *aerosols*.

Backstop technology: *Models* estimating *mitigation* often use an arbitrary carbon-free technology (often for power generation) that might become available in the future in unlimited supply over the horizon of the *model*. This allows modellers to explore the consequences and importance of a generic solution technology without becoming enmeshed in picking the actual technology. This 'backstop' technology might be a nuclear technology, fossil technology with *Carbon Dioxide Capture and Storage (CCS)*, *solar energy*, or something as yet unimagined. The backstop technology is typically assumed either not to currently exist, or to exist only at higher costs relative to conventional alternatives.

Banking (of Assigned Amount Units): Any transfer of *Assigned Amount Units (AAUs)* from an existing period into a future commitment period. According to the *Kyoto Protocol* [Article 3 (13)], Parties included in Annex I to the *United Nations Framework Convention on Climate Change (UNFCCC)* may save excess AAUs from the first commitment period for compliance with their respective *cap* in subsequent commitment periods (post-2012).

Baseline/reference: The state against which change is measured. In the context of *transformation pathways*, the term 'baseline scenarios' refers to *scenarios* that are based on the assumption that no *mitigation policies* or *measures* will be implemented beyond those that are already in force and/or are legislated or planned to be adopted. Baseline scenarios are not intended to be predictions of the future, but rather counterfactual constructions that can serve to highlight the level of emissions that would occur without further *policy* effort. Typically, baseline scenarios are then compared to *mitigation scenarios* that are constructed to meet different goals for *greenhouse gas (GHG)* emissions, atmospheric concentrations, or temperature change. The term 'baseline scenario' is used interchangeably with 'reference scenario' and 'no policy scenario'. In much of the literature the term is also synonymous with the term 'business-as-usual (BAU) scenario,' although the term 'BAU' has fallen out of favour because the idea of 'business-as-usual' in century-long socioeconomic projections is hard to fathom. See also *Climate scenario*, *Emission scenario*, *Representative concentration pathways (RCPs)*, *Shared socio-economic pathways*, *Socio-economic scenarios*, *SRES scenarios*, and *Stabilization*.

Behaviour: In this report, behaviour refers to human decisions and actions (and the perceptions and judgments on which they are based) that directly or indirectly influence *mitigation* or the effects of potential *climate change* impacts (*adaptation*). Human decisions and actions are relevant at different levels, from international, national, and subnational actors, to NGO, tribe, or firm-level decision makers, to communities, households, and individual citizens and consumers. See also *Behavioural change* and *Drivers of behaviour*.

Behavioural change: In this report, behavioural change refers to alteration of human decisions and actions in ways that mitigate *climate change* and/or reduce negative consequences of *climate change* impacts. See also *Drivers of behaviour*.

Biochar: *Biomass* stabilization can be an alternative or enhancement to *bioenergy* in a land-based *mitigation* strategy. Heating *biomass* with exclusion of air produces a stable carbon-rich co-product (char). When added to soil a system, char creates a system that has greater abatement potential than typical *bioenergy*. The relative benefit of biochar systems is increased if changes in crop yield and soil emissions of *methane* (CH_4) and *nitrous oxide* (N_2O) are taken into account.

Biochemical oxygen demand (BOD): The amount of dissolved oxygen consumed by micro-organisms (bacteria) in the bio-chemical oxidation of organic and inorganic matter in wastewater. See also *Chemical oxygen demand (COD)*.

Biodiversity: The variability among living organisms from terrestrial, marine, and other *ecosystems*. Biodiversity includes variability at the genetic, species, and *ecosystem* levels.[3]

[3] This glossary entry builds from definitions used in the Global Biodiversity Assessment (Heywood, 1995) and the Millennium Ecosystem Assessment (MEA, 2005).

Bioenergy: *Energy* derived from any form of *biomass* such as recently living organisms or their metabolic by-products.

Bioenergy and Carbon Dioxide Capture and Storage (BECCS): The application of *Carbon Dioxide Capture and Storage (CCS)* technology to *bioenergy* conversion processes. Depending on the total life-cycle emissions, including total marginal consequential effects (from *indirect land use change (iLUC)* and other processes), BECCS has the potential for net *carbon dioxide* (CO_2) removal from the *atmosphere*. See also *Sequestration*.

Bioethanol: Ethanol produced from *biomass* (e.g., sugar cane or corn). See also *Biofuel*.

Biofuel: A fuel, generally in liquid form, produced from organic matter or combustible oils produced by living or recently living plants. Examples of biofuel include alcohol (*bioethanol*), black liquor from the paper-manufacturing process, and soybean oil.

First-generation manufactured biofuel: First-generation manufactured biofuel is derived from grains, oilseeds, animal fats, and waste vegetable oils with mature conversion technologies.

Second-generation biofuel: Second-generation biofuel uses non-traditional biochemical and thermochemical conversion processes and feedstock mostly derived from the lignocellulosic fractions of, for example, agricultural and forestry residues, municipal solid waste, etc.

Third-generation biofuel: Third-generation biofuel would be derived from feedstocks such as algae and energy crops by advanced processes still under development.

These second- and third-generation biofuels produced through new processes are also referred to as next-generation or advanced biofuels, or advanced biofuel technologies.

Biomass: The total mass of living organisms in a given area or volume; dead plant material can be included as dead biomass. In the context of this report, biomass includes products, by-products, and waste of biological origin (plants or animal matter), excluding material embedded in geological formations and transformed to *fossil fuels* or peat.

Traditional biomass: Traditional biomass refers to the biomass—fuelwood, charcoal, agricultural residues, and animal dung—used with the so-called traditional technologies such as open fires for cooking, rustic kilns and ovens for small industries. Widely used in *developing countries*, where about 2.6 billion people cook with open wood fires, and hundreds of thousands small-industries. The use of these rustic technologies leads to high pollution levels and, in specific circumstances, to *forest* degradation and *deforestation*. There are many successful initiatives around the world to make traditional biomass burned more efficiently and cleanly using efficient cookstoves and kilns. This last use of traditional biomass is sustainable and provides large health and economic benefits to local populations in *developing countries*, particularly in rural and peri-urban areas.

Modern biomass: All biomass used in high efficiency conversion systems.

Biomass burning: Biomass burning is the burning of living and dead vegetation.

Biosphere (terrestrial and marine): The part of the earth system comprising all *ecosystems* and living organisms, in the *atmosphere*, on land (terrestrial biosphere) or in the oceans (marine biosphere), including derived dead organic matter, such as litter, soil organic matter and oceanic detritus.

Black carbon (BC): Operationally defined *aerosol* species based on measurement of light absorption and chemical reactivity and/or thermal stability. It is sometimes referred to as soot. BC is mostly formed by the incomplete combustion of *fossil fuels*, *biofuels*, and *biomass* but it also occurs naturally. It stays in the *atmosphere* only for days or weeks. It is the most strongly light-absorbing component of *particulate matter (PM)* and has a warming effect by absorbing heat into the *atmosphere* and reducing the *albedo* when deposited on ice or snow.

Burden sharing (also referred to as Effort sharing): In the context of *mitigation*, burden sharing refers to sharing the effort of reducing the *sources* or enhancing the *sinks* of *greenhouse gases (GHGs)* from historical or projected levels, usually allocated by some criteria, as well as sharing the cost burden across countries.

Business-as-usual (BAU): See *Baseline/reference*.

Cancún Agreements: A set of decisions adopted at the 16th Session of the *Conference of the Parties (COP)* to the *United Nations Framework Convention on Climate Change (UNFCCC)*, including the following, among others: the newly established *Green Climate Fund (GCF)*, a newly established technology mechanism, a process for advancing discussions on *adaptation*, a formal process for reporting *mitigation* commitments, a goal of limiting *global mean surface temperature* increase to 2 °C, and an agreement on MRV—Measuring, Reporting and Verifying for those countries that receive international support for their *mitigation* efforts.

Cancún Pledges: During 2010, many countries submitted their existing plans for controlling *greenhouse gas (GHG)* emissions to the Climate Change Secretariat and these proposals have now been formally acknowledged under the *United Nations Framework Convention on Climate Change (UNFCCC)*. *Developed countries* presented their plans in the shape of economy-wide targets to reduce emissions, mainly up to 2020, while *developing countries* proposed ways to limit their growth of emissions in the shape of plans of action.

Cap, on emissions: Mandated restraint as an upper limit on emissions within a given period. For example, the *Kyoto Protocol* mandates emissions caps in a scheduled timeframe on the anthropogenic *greenhouse gas (GHG)* emissions released by *Annex B countries*.

Carbon budget: The area under a *greenhouse gas (GHG)* emissions trajectory that satisfies assumptions about limits on cumulative emissions estimated to avoid a certain level of *global mean surface temperature* rise. Carbon budgets may be defined at the global level, national, or sub-national levels.

Carbon credit: See *Emission allowance*.

Carbon cycle: The term used to describe the flow of carbon (in various forms, e.g., as *carbon dioxide*) through the *atmosphere*, ocean, terrestrial and marine *biosphere* and lithosphere. In this report, the reference unit for the global carbon cycle is GtC or $GtCO_2$ (1 GtC corresponds to 3.667 $GtCO_2$). Carbon is the major chemical constituent of most organic matter and is stored in the following major *reservoirs*: organic molecules in the *biosphere*, *carbon dioxide* (CO_2) in the *atmosphere*, organic matter in the soils, in the lithosphere, and in the oceans.

Carbon dioxide (CO_2): A naturally occurring gas, also a by-product of burning *fossil fuels* from fossil carbon deposits, such as oil, gas and coal, of burning *biomass*, of *land use changes (LUC)* and of industrial processes (e.g., cement production). It is the principal anthropogenic *greenhouse gas (GHG)* that affects the earth's radiative balance. It is the reference gas against which other GHGs are measured and therefore has a *Global Warming Potential (GWP)* of 1. See Annex II.9.1 for GWP values for other GHGs.

Carbon Dioxide Capture and Storage (CCS): A process in which a relatively pure stream of *carbon dioxide* (CO_2) from industrial and energy-related *sources* is separated (captured), conditioned, compressed, and transported to a storage location for long-term isolation from the *atmosphere*. See also *Bioenergy and carbon capture and storage (BECCS)*, *CCS-ready*, and *Sequestration*.

Carbon dioxide fertilization: The enhancement of the growth of plants as a result of increased atmospheric *carbon dioxide* (CO_2) concentration.

Carbon Dioxide Removal (CDR): Carbon Dioxide Removal methods refer to a set of techniques that aim to remove *carbon dioxide* (CO_2) directly from the *atmosphere* by either (1) increasing natural *sinks* for carbon or (2) using chemical engineering to remove the CO_2, with the intent of reducing the atmospheric CO_2 concentration. CDR methods involve the ocean, land, and technical systems, including such methods as *iron fertilization*, large-scale *afforestation*, and *direct capture* of CO_2 from the *atmosphere* using engineered chemical means. Some CDR methods fall under the category of *geoengineering*, though this may not be the case for others, with the distinction being based on the magnitude, scale, and impact of the particular CDR activities. The boundary between CDR and *mitigation* is not clear and there could be some overlap between the two given current definitions (IPCC, 2012, p. 2). See also *Solar Radiation Management (SRM)*.

Carbon footprint: Measure of the exclusive total amount of emissions of *carbon dioxide* (CO_2) that is directly and indirectly caused by an activity or is accumulated over the life stages of a product (Wiedmann and Minx, 2008).

Carbon intensity: The amount of emissions of *carbon dioxide* (CO_2) released per unit of another variable such as *gross domestic product (GDP)*, output energy use, or transport.

Carbon leakage: See *Leakage*.

Carbon pool: See *Reservoir*.

Carbon price: The price for avoided or released *carbon dioxide* (CO_2) or CO_2*-equivalent* emissions. This may refer to the rate of a *carbon tax*, or the price of *emission permits*. In many *models* that are used to assess the economic costs of *mitigation*, carbon prices are used as a proxy to represent the level of effort in *mitigation policies*.

Carbon sequestration: See *Sequestration*.

Carbon tax: A levy on the carbon content of *fossil fuels*. Because virtually all of the carbon in *fossil fuels* is ultimately emitted as *carbon dioxide* (CO_2), a carbon tax is equivalent to an emission tax on CO_2 emissions.

CCS-ready: New large-scale, stationary *carbon dioxide* (CO_2) point *sources* intended to be retrofitted with *Carbon Dioxide Capture and Storage (CCS)* could be designed and located to be 'CCS-ready' by reserving space for the capture installation, designing the unit for optimal performance when capture is added, and siting the plant to enable access to storage locations. See also *Bioenergy and Carbon Dioxide Capture and Storage (BECCS)*.

Certified Emission Reduction Unit (CER): Equal to one metric tonne of CO_2*-equivalent emissions* reduced or of *carbon dioxide* (CO_2) removed from the *atmosphere* through the *Clean Development Mechanism (CDM)* (defined in Article 12 of the *Kyoto Protocol*) project, calculated using *Global Warming Potentials (GWP)*. See also *Emissions Reduction Units (ERU)* and *Emissions trading*.

Chemical oxygen demand (COD): The quantity of oxygen required for the complete oxidation of organic chemical compounds in water; used as a measure of the level of organic pollutants in natural and waste waters. See also *Biochemical oxygen demand (BOD)*.

Chlorofluorocarbons (CFCs): A chlorofluorocarbon is an organic compound that contains chlorine, carbon, hydrogen, and fluorine and is used for refrigeration, air conditioning, packaging, plastic foam, insulation, solvents, or *aerosol* propellants. Because they are not destroyed in the lower *atmosphere*, CFCs drift into the upper *atmosphere* where, given suitable conditions, they break down *ozone* (O_3). It is one of the *greenhouse gases (GHGs)* covered under the 1987 *Montreal Protocol* as a result of which manufacturing of these gases has been phased out and they are being replaced by other compounds, including *hydrofluorocarbons (HFCs)* which are GHGs covered under the *Kyoto Protocol*.

Clean Development Mechanism (CDM): A mechanism defined under Article 12 of the *Kyoto Protocol* through which investors (governments or companies) from developed (*Annex B*) *countries* may finance *greenhouse gas (GHG)* emission reduction or removal projects in developing (*Non-Annex B*) *countries*, and receive *Certified Emission Reduction Units (CERs)* for doing so. The *CERs* can be credited towards the commitments of the respective *developed countries*. The *CDM* is intended to facilitate the two objectives of promoting *sustainable development (SD)* in *developing countries* and of helping *industrialized countries* to reach their emissions commitments in a *cost-effective* way. See also *Kyoto Mechanisms*.

Climate: Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the *climate system*.

Climate change: Climate change refers to a change in the state of the *climate* that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the *atmosphere* or in *land use*. Note that the *United Nations Framework Convention on Climate Change (UNFCCC)*, in its Article 1, defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes. See also *Climate change commitment*.

Climate change commitment: Due to the thermal inertia of the ocean and slow processes in the cryosphere and land surfaces, the *climate* would continue to change even if the atmospheric composition were held fixed at today's values. Past change in atmospheric composition leads to a committed *climate change*, which continues for as long as a radiative imbalance persists and until all components of the *climate system* have adjusted to a new state. The further change in temperature after the composition of the *atmosphere* is held constant is referred to as the constant composition temperature commitment or simply committed warming or warming commitment. Climate change commitment includes other future changes, for example in the hydrological cycle, in extreme weather events, in extreme climate events, and in sea level change. The constant emission commitment is the committed climate change that would result from keeping *anthropogenic emissions* constant and the zero emission commitment is the climate change commitment when emissions are set to zero. See also *Climate change*.

Climate (change) feedback: An interaction in which a perturbation in one *climate* quantity causes a change in a second, and the change in the second quantity ultimately leads to an additional change in the first. A negative feedback is one in which the initial perturbation is weakened by the changes it causes; a positive feedback is one in which the initial perturbation is enhanced. In this Assessment Report, a somewhat narrower definition is often used in which the climate quantity that is perturbed is the *global mean surface temperature*, which in turn causes changes in the global radiation budget. In either case, the initial perturbation can either be externally forced or arise as part of internal variability.

Climate engineering: See *Geoengineering*.

Climate finance: There is no agreed definition of climate finance. The term 'climate finance' is applied both to the financial resources devoted to addressing *climate change* globally and to financial flows to *developing countries* to assist them in addressing *climate change*. The literature includes several concepts in these categories, among which the most commonly used include:

Incremental costs: The cost of capital of the *incremental investment* and the change of operating and maintenance costs for a *mitigation* or *adaptation* project in comparison to a reference project. It can be calculated as the difference of the net present values of the two projects. See also *Additionality*.

Incremental investment: The extra capital required for the initial investment for a *mitigation* or *adaptation* project in comparison to a reference project. See also *Additionality*.

Total climate finance: All financial flows whose expected effect is to reduce net *greenhouse gas (GHG)* emissions and/or to enhance *resilience* to the impacts of *climate variability* and the projected *climate change*. This covers private and public funds, domestic and international flows, expenditures for *mitigation* and *adaptation* to current *climate variability* as well as future *climate change*.

Total climate finance flowing to developing countries: The amount of the *total climate finance* invested in *developing countries* that comes from *developed countries*. This covers private and public funds.

Private climate finance flowing to developing countries: Finance and investment by private actors in/from *developed countries* for *mitigation* and *adaptation* activities in *developing countries*.

Public climate finance flowing to developing countries: Finance provided by *developed countries'* governments and bilateral institutions as well as by multilateral institutions for *mitigation* and *adaptation* activities in *developing countries*. Most of the funds provided are concessional loans and grants.

Climate model (spectrum or hierarchy): A numerical representation of the *climate system* based on the physical, chemical and biological properties of its components, their interactions and feedback processes, and accounting for some of its known properties. The climate system can be represented by models of varying complexity, that is, for any one component or combination of components a spectrum or hierarchy of models can be identified, differing in such aspects as the number of spatial dimensions, the extent to which physical, chemical or biological processes are explicitly represented, or the level at which empirical parametrizations are involved. Coupled Atmosphere-Ocean *General Circulation Models* (AOGCMs) provide a representation of the *climate system* that is near or at the most comprehensive end of the spectrum currently available. There is an evolution towards more complex models with interactive chemistry and biology. Climate models are applied as a research tool to study and simulate the *climate*, and for operational purposes, including monthly, seasonal and interannual *climate predictions*.

Climate prediction: A climate prediction or climate forecast is the result of an attempt to produce (starting from a particular state of the *climate system*) an estimate of the actual evolution of the climate in the future, for example, at seasonal, interannual, or decadal time scales. Because the future evolution of the *climate system* may be highly sensitive to initial conditions, such predictions are usually probabilistic in nature. See also *Climate projection*, and *Climate scenario*.

Climate projection: A climate projection is the simulated response of the *climate system* to a scenario of future *emission* or concentration of *greenhouse gases (GHGs)* and *aerosols*, generally derived using *climate models*. Climate projections are distinguished from *climate predictions* by their dependence on the emission/concentration/*radiative forcing* scenario used, which is in turn based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized. See also *Climate scenario*.

Climate scenario: A plausible and often simplified representation of the future *climate*, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic *climate* *change*, often serving as input to impact models. *Climate projections* often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as the observed current *climate*. See also *Baseline/reference*, *Emission scenario*, *Mitigation scenario*, *Representative concentration pathways (RCPs)*, *Scenario*, *Shared socio-economic pathways*, *Socio-economic scenario*, *SRES scenarios*, *Stabilization*, and *Transformation pathway*.

Climate sensitivity: In IPCC reports, equilibrium climate sensitivity (units: °C) refers to the equilibrium (steady state) change in the annual *global mean surface temperature* following a doubling of the atmospheric *CO_2-equivalent concentration*. Owing to computational constraints, the equilibrium climate sensitivity in a *climate model* is sometimes estimated by running an atmospheric *general circulation model (GCM)* coupled to a mixed-layer ocean model, because equilibrium climate sensitivity is largely determined by atmospheric processes. Efficient models can be run to equilibrium with a dynamic ocean. The climate sensitivity parameter (units: °C $(W\ m^{-2})^{-1}$) refers to the equilibrium change in the annual *global mean surface temperature* following a unit change in *radiative forcing*.

The effective climate sensitivity (units: °C) is an estimate of the *global mean surface temperature* response to doubled *carbon dioxide (CO_2)* concentration that is evaluated from model output or observations for evolving non-equilibrium conditions. It is a measure of the strengths of the *climate feedbacks* at a particular time and may vary with forcing history and *climate* state, and therefore may differ from equilibrium climate sensitivity.

The transient climate response (units: °C) is the change in the *global mean surface temperature*, averaged over a 20-year period, centred at the time of atmospheric CO_2 doubling, in a *climate model* simulation in which CO_2 increases at 1 % yr^{-1}. It is a measure of the strength and rapidity of the surface temperature response to *greenhouse gas (GHG)* forcing.

Climate system: The climate system is the highly complex system consisting of five major components: the *atmosphere*, the hydrosphere, the cryosphere, the lithosphere and the *biosphere*, and the interactions between them. The climate system evolves in time under the influence of its own internal dynamics and because of external forcings such as volcanic eruptions, solar variations and anthropogenic forcings such as the changing composition of the *atmosphere* and *land use change (LUC)*.

Climate threshold: A limit within the *climate system* that, when crossed, induces a non-linear response to a given forcing. See also *Abrupt climate change*.

Climate variability: Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the *climate* on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the *climate system* (internal variability), or to variations in natural or anthropogenic external forcing (external variability). See also *Climate change*.

CO_2-equivalent concentration: The concentration of *carbon dioxide (CO_2)* that would cause the same *radiative forcing* as a given mixture of CO_2 and other forcing components. Those values may consider only *greenhouse gases (GHGs)*, or a combination of GHGs, *aerosols*, and surface *albedo* changes. CO_2-equivalent concentration is a metric for comparing *radiative forcing* of a mix of different forcing components at a particular time but does not imply equivalence of the corresponding *climate change* responses nor future forcing. There is generally no connection between *CO_2-equivalent emissions* and resulting CO_2-equivalent concentrations.

CO_2-equivalent emission: The amount of *carbon dioxide (CO_2)* emission that would cause the same integrated *radiative forcing*, over a given time horizon, as an emitted amount of a *greenhouse gas (GHG)* or a mixture of GHGs. The CO_2-equivalent emission is obtained by multiplying the emission of a GHG by its *Global Warming Potential (GWP)* for the given time horizon (see Annex II.9.1 and WGI AR5 Table 8.A.1 for GWP values of the different GHGs). For a mix of GHGs it is obtained by summing the CO_2-equivalent emissions of each gas. CO_2-equivalent emission is a common scale for comparing emissions of different GHGs but does not imply equivalence of the corresponding *climate change* responses. See also *CO_2-equivalent concentration*.

Co-benefits: The positive effects that a *policy* or *measure* aimed at one objective might have on other objectives, without yet evaluating the net effect on overall social welfare. Co-benefits are often subject to *uncertainty* and depend on, among others, local circumstances and implementation practices. Co-benefits are often referred to as ancillary benefits. See also *Adverse side-effect*, *Risk*, and *Risk tradeoff*.

Cogeneration: Cogeneration (also referred to as combined heat and power, or CHP) is the simultaneous generation and useful application of electricity and useful heat.

Combined-cycle gas turbine: A power plant that combines two processes for generating electricity. First, fuel combustion drives a gas turbine. Second, exhaust gases from the turbine are used to heat water to drive a steam turbine.

Combined heat and power (CHP): See *Cogeneration*.

Computable General Equilibrium (CGE) Model: See *Models*.

Conference of the Parties (COP): The supreme body of the *United Nations Framework Convention on Climate Change (UNFCCC)*, comprising countries with a right to vote that have ratified or acceded to the convention. See also *Meeting of the Parties (CMP)*.

Confidence: The validity of a finding based on the type, amount, quality, and consistency of *evidence* (e.g., mechanistic understanding, theory, data, *models*, expert judgment) and on the degree of *agreement*. In this report, confidence is expressed qualitatively (Mastrandrea et al., 2010). See WGI AR5 Figure 1.11 for the levels of confidence and WGI AR5 Table 1.2 for the list of *likelihood* qualifiers. See also *Uncertainty*.

Consumption-based accounting: Consumption-based accounting provides a measure of emissions released to the *atmosphere* in order to generate the goods and services consumed by a certain entity (e.g., person, firm, country, or region). See also *Production-based accounting*.

Contingent valuation method: An approach to quantitatively assess values assigned by people in monetary (willingness to pay) and non-monetary (willingness to contribute with time, resources etc.) terms. It is a direct method to estimate economic values for *ecosystem* and environmental services. In a survey, people are asked their willingness to pay/contribute for access to, or their willingness to accept compensation for removal of, a specific environmental service, based on a hypothetical *scenario* and description of the environmental service.

Conventional fuels: See *Fossil fuels*.

Copenhagen Accord: The political (as opposed to legal) agreement that emerged at the 15th Session of the *Conference of the Parties (COP)* at which delegates 'agreed to take note' due to a lack of consensus that an agreement would require. Some of the key elements include: recognition of the importance of the scientific view on the need to limit the increase in *global mean surface temperature* to 2° C; commitment by *Annex I Parties* to implement economy-wide emissions targets by 2020 and *non-Annex I Parties* to implement *mitigation* actions; agreement to have emission targets of *Annex I Parties* and their delivery of finance for *developing countries* subject to Measurement, Reporting and Verification (MRV) and actions by *developing countries* to be subject to domestic MRV; calls for scaled up financing including a fast track financing of USD 30 billion and USD 100 billion by 2020; the establishment of a new *Green Climate Fund (GCF)*; and the establishment of a new technology mechanism. Some of these elements were later adopted in the *Cancún Agreements*.

Cost-benefit analysis (CBA): Monetary measurement of all negative and positive impacts associated with a given action. Costs and benefits are compared in terms of their difference and/or ratio as an indicator of how a given investment or other *policy* effort pays off seen from the society's point of view.

Cost of conserved energy (CCE): See *Levelized cost of conserved energy (LCCE)*.

Cost-effectiveness: A *policy* is more cost-effective if it achieves a goal, such as a given pollution abatement level, at lower cost. A critical condition for cost-effectiveness is that marginal abatement costs be equal among obliged parties. *Integrated models* approximate cost-effective solutions, unless they are specifically constrained to behave otherwise. Cost-effective *mitigation scenarios* are those based on a stylized implementation approach in which a single price on *carbon dioxide (CO_2)* and other *greenhouse gases (GHGs)* is applied across the globe in every sector of every country and that rises over time in a way that achieves lowest global discounted costs.

Cost-effectiveness analysis (CEA): A tool based on constrained optimization for comparing *policies* designed to meet a prespecified target.

Crediting period, Clean Development Mechanism (CDM): The time during which a project activity is able to generate *Certified Emission Reduction Units (CERs)*. Under certain conditions, the crediting period can be renewed up to two times.

Cropland management: The system of practices on land on which agricultural crops are grown and on land that is set aside or temporarily not being used for crop production (UNFCCC, 2002).

Decarbonization: The process by which countries or other entities aim to achieve a low-carbon economy, or by which individuals aim to reduce their carbon consumption.

Decomposition approach: Decomposition methods disaggregate the total amount of historical changes of a policy variable into contributions made by its various determinants.

Deforestation: Conversion of *forest* to non-forest is one of the major *sources* of *greenhouse gas (GHG)* emissions. Under Article 3.3 of the *Kyoto Protocol*, "the net changes in greenhouse gas emissions by sources and removals by sinks resulting from direct human-induced land-use change and forestry activities, limited to afforestation, reforestation and deforestation since 1990, measured as verifiable changes in carbon stocks in each commitment period, shall be sued to meet the commitments under this Article of each Party included in Annex I". Reducing emissions from deforestation is not eligible for *Joint Implementation (JI)* or *Clean Development Mechanism (CDM)* projects but has been introduced in the program of work under *REDD (Reducing Emissions from Deforestation and Forest Degradation)* under the *United Nations Framework Convention on Climate Change (UNFCCC)*.

For a discussion of the term *forest* and related terms such as *afforestation*, *reforestation*, and deforestation see the IPCC Special Report on Land Use, Land-Use Change and Forestry (IPCC, 2000). See also the report on Definitions and Methodological Options to Inventory Emissions from Direct Human-induced Degradation of Forests and Devegetation of Other Vegetation Types (IPCC, 2003).

Dematerialization: The ambition to reduce the total material inputs required to deliver a final service.

Descriptive analysis: Descriptive (also termed positive) approaches to analysis focus on how the world works or actors behave, not how they should behave in some idealized world. See also *Normative analysis*.

Desertification: Land degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors, including climatic variations and human activities. Land degradation in arid, semi-arid, and dry sub-humid areas is a reduction or loss of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, *forest*, and woodlands resulting from *land uses* or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as (1) soil erosion caused by wind and/or water; (2) deterioration of the physical, chemical, biological, or economic properties of soil; and (3) long-term loss of natural vegetation (UNCCD, 1994).

Designated national authority (DNA): A designated national authority is a national *institution* that authorizes and approves *Clean Development Mechansim (CDM)* projects in that country. In CDM host countries, the DNA assesses whether proposed projects assist the host country in achieving its *sustainable development (SD)* goals, certification of which is a prerequisite for registration of the project by the CDM Executive Board.

Developed/developing countries: See *Industrialized/developing countries*.

Development pathway: An evolution based on an array of technological, economic, social, institutional, cultural, and biophysical characteristics that determine the interactions between human and natural systems, including consumption and production patterns in all countries, over time at a particular scale.

Direct Air Capture (DAC): Chemical process by which a pure *carbon dioxide* (CO_2) stream is produced by capturing CO_2 from the ambient air.

Direct emissions: See *Emissions*.

Discounting: A mathematical operation making monetary (or other) amounts received or expended at different times (years) comparable across time. The discounter uses a fixed or possibly time-varying discount rate (> 0) from year to year that makes future value worth less today. See also *Present value*.

Double dividend: The extent to which revenue-generating instruments, such as *carbon taxes* or auctioned (tradable) *emission permits* can (1) contribute to *mitigation* and (2) offset at least part of the potential welfare losses of climate *policies* through recycling the revenue in the economy to reduce other taxes likely to cause distortions.

Drivers of behaviour: Determinants of human decisions and actions, including peoples' values and goals and the factors that constrain action, including economic factors and incentives, information access, regulatory and technological constraints, cognitive and emotional processing capacity, and social norms. See also *Behaviour* and *Behavioural change*.

Drivers of emissions: Drivers of emissions refer to the processes, mechanisms and properties that influence emissions through factors. Factors comprise the terms in a decomposition of emissions. Factors and drivers may in return affect *policies*, *measures* and other drivers.

Economic efficiency: Economic efficiency refers to an economy's allocation of resources (goods, services, inputs, productive activities). An allocation is efficient if it is not possible to reallocate resources so as to make at least one person better off without making someone else worse off. An allocation is inefficient if such a reallocation is possible. This is also known as the Pareto Criterion for efficiency. See also *Pareto optimum*.

Economies in Transition (EITs): Countries with their economies changing from a planned economic system to a market economy. See Annex II.2.1.

Ecosystem: A functional unit consisting of living organisms, their non-living environment, and the interactions within and between them. The components included in a given ecosystem and its spatial boundaries depend on the purpose for which the ecosystem is defined: in some cases they are relatively sharp, while in others they are diffuse. Ecosystem boundaries can change over time. Ecosystems are nested within other ecosystems, and their scale can range from very small to the entire *biosphere*. In the current era, most ecosystems either contain people as key organisms, or are influenced by the effects of human activities in their environment.

Ecosystem services: Ecological processes or functions having monetary or non-monetary value to individuals or society at large. These are frequently classified as (1) supporting services such as productivity or *biodiversity* maintenance, (2) provisioning services such as food, fiber, or fish, (3) regulating services such as *climate* regulation or carbon *sequestration*, and (4) cultural services such as tourism or spiritual and aesthetic appreciation.

Embodied emissions: See *Emissions*.

Embodied energy: See *Energy*.

Emission allowance: See *Emission permit*.

Emission factor/Emissions intensity: The emissions released per unit of activity. See also *Carbon intensity*.

Emission permit: An entitlement allocated by a government to a legal entity (company or other emitter) to emit a specified amount of a substance. Emission permits are often used as part of *emissions trading* schemes.

Emission quota: The portion of total allowable emissions assigned to a country or group of countries within a framework of maximum total emissions.

Emission scenario: A plausible representation of the future development of emissions of substances that are potentially radiatively active (e.g., *greenhouse gases*, *aerosols*) based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socioeconomic development, *technological change*, *energy* and *land use*) and their key relationships. Concentration scenarios, derived from emission scenarios, are used as input to a *climate model* to compute *climate projections*. In IPCC (1992) a set of emission scenarios was presented which were used as a basis for the *climate projections* in IPCC (1996). These emission scenarios are referred to as the IS92 scenarios. In the IPCC Special Report on Emission Scenarios (Nakićenović and Swart, 2000) emission scenarios, the so-called *SRES scenarios*, were published, some of which were used, among others, as a basis for the *climate projections* presented in Chapters 9 to 11 of IPCC (2001) and Chapters 10 and 11 of IPCC (2007). New emission scenarios for *climate change*, the four *Representative Concentration Pathways (RCPs)*, were developed for, but independently of, the present IPCC assessment. See also *Baseline/reference*, *Climate scenario*, *Mitigation scenario*, *Shared socio-economic pathways*, *Scenario*, *Socio-economic scenario*, *Stabilization*, and *Transformation pathway*.

Emission trajectories: A projected development in time of the emission of a *greenhouse gas (GHG)* or group of GHGs, *aerosols*, and GHG *precursors*.

Emissions:

Agricultural emissions: Emissions associated with agricultural systems—predominantly *methane* (CH_4) or *nitrous oxide* (N_2O). These include emissions from enteric fermentation in domestic livestock, manure management, rice cultivation, prescribed burning of savannas and grassland, and from soils (IPCC, 2006).

Anthropogenic emissions: Emissions of *greenhouse gases (GHGs)*, *aerosols*, and *precursors* of a GHG or *aerosol* caused by human activities. These activities include the burning of *fossil fuels*, *deforestation*, *land use changes (LUC)*, livestock production, fertilization, waste management, and industrial processes.

Direct emissions: Emissions that physically arise from activities within well-defined boundaries of, for instance, a region, an economic sector, a company, or a process.

Embodied emissions: Emissions that arise from the production and delivery of a good or service or the build-up of infrastructure. Depending on the chosen system boundaries, upstream emissions are often included (e.g., emissions resulting from the extraction of raw materials). See also *Lifecycle assessment (LCA)*.

Indirect emissions: Emissions that are a consequence of the activities within well-defined boundaries of, for instance, a region, an economic sector, a company or process, but which occur outside the specified boundaries. For example, emissions are described as indirect if they relate to the use of heat but physically arise outside the boundaries of the heat user, or to electricity production but physically arise outside of the boundaries of the power supply sector.

Scope 1, Scope 2, and Scope 3 emissions: Emissions responsibility as defined by the GHG Protocol, a private sector initiative. 'Scope 1' indicates direct *greenhouse gas (GHG)* emissions that are from *sources* owned or controlled by the reporting entity. 'Scope 2' indicates indirect GHG emissions associated with the production of electricity, heat, or steam purchased by the reporting entity. 'Scope 3' indicates all other *indirect emissions*, i.e., emissions associated with the extraction and production of purchased materials, fuels, and services, including transport in vehicles not owned or controlled by the reporting entity, outsourced activities, waste disposal, etc. (WBCSD and WRI, 2004).

Territorial emissions: Emissions that take place within the territories of a particular jurisdiction.

Emissions Reduction Unit (ERU): Equal to one metric tonne of *CO_2-equivalent emissions* reduced or of *carbon dioxide* (CO_2) removed from the *atmosphere* through a *Joint Implementation (JI)* (defined in Article 6 of the *Kyoto Protocol*) project, calculated using *Global Warming Potentials (GWPs)*. See also *Certified Emission Reduction Unit (CER)* and *Emissions trading*.

Emission standard: An emission level that, by law or by *voluntary agreement*, may not be exceeded. Many *standards* use *emission factors* in their prescription and therefore do not impose absolute limits on the emissions.

Emissions trading: A market-based instrument used to limit emissions. The environmental objective or sum of total allowed emissions is expressed as an emissions *cap*. The *cap* is divided in tradable *emission permits* that are allocated—either by auctioning or handing out for free (grandfathering)—to entities within the jurisdiction of the trading scheme. Entities need to surrender *emission permits* equal to the amount of their emissions (e.g., tonnes of *carbon dioxide*). An entity may sell excess permits. Trading schemes may occur at the intra-company, domestic, or international level and may apply to *carbon dioxide* (CO_2), other *greenhouse gases (GHGs)*, or other substances. Emissions trading is also one of the mechanisms under the *Kyoto Protocol*. See also *Kyoto Mechanisms*.

Energy: The power of 'doing work' possessed at any instant by a body or system of bodies. Energy is classified in a variety of types and becomes available to human ends when it flows from one place to another or is converted from one type into another.

Embodied energy: The *energy* used to produce a material substance or product (such as processed metals or building materials), taking into account *energy* used at the manufacturing facility, *energy* used in producing the materials that are used in the manufacturing facility, and so on.

Final energy: See *Primary energy*.

Primary energy: Primary energy (also referred to as energy *sources*) is the *energy* stored in natural resources (e.g., coal, crude oil, natural gas, uranium, and renewable sources). It is defined in several alternative ways. The International Energy Agency (IEA) utilizes the physical energy content method, which defines primary energy as *energy* that has not undergone any anthropogenic conversion. The method used in this report is the direct equivalent method (see Annex II.4), which counts one unit of secondary energy provided from non-combustible sources as one unit of primary energy, but treats combustion energy as the energy potential contained in fuels prior to treatment or combustion. Primary energy is transformed into secondary energy by cleaning (natural gas), refining (crude oil to oil products) or by conversion into electricity or heat. When the secondary energy is delivered at the end-use facilities it is called final energy (e.g., electricity at the wall outlet), where it becomes usable energy in supplying *energy services* (e.g., light).

Renewable energy (RE): Any form of energy from solar, geophysical, or biological sources that is replenished by natural processes at a rate that equals or exceeds its rate of use. For a more detailed description see *Bioenergy*, *Solar energy*, *Hydropower*, *Ocean*, *Geothermal*, and *Wind energy*.

Secondary energy: See *Primary energy*.

Energy access: Access to clean, reliable and affordable *energy services* for cooking and heating, lighting, communications, and productive uses (AGECC, 2010).

Energy carrier: A substance for delivering mechanical work or transfer of heat. Examples of energy carriers include: solid, liquid, or gaseous fuels (e.g., *biomass*, coal, oil, natural gas, hydrogen); pressurized/heated/cooled fluids (air, water, steam); and electric current.

Energy density: The ratio of stored *energy* to the volume or mass of a fuel or battery.

Energy efficiency (EE): The ratio of useful *energy* output of a system, conversion process, or activity to its *energy* input. In economics, the term may describe the ratio of economic output to *energy* input. See also *Energy intensity*.

Energy intensity: The ratio of *energy* use to economic or physical output.

Energy poverty: A lack of access to modern *energy services*. See also *Energy access*.

Energy security: The goal of a given country, or the global community as a whole, to maintain an adequate, stable, and predictable *energy* supply. Measures encompass safeguarding the sufficiency of *energy* resources to meet national *energy* demand at competitive and stable prices and the resilience of the *energy* supply; enabling development and deployment of technologies; building sufficient infrastructure to generate, store and transmit *energy* supplies; and ensuring enforceable contracts of delivery.

Energy services: An energy service is the benefit received as a result of *energy* use.

Energy system: The energy system comprises all components related to the production, conversion, delivery, and use of *energy*.

Environmental effectiveness: A *policy* is environmentally effective to the extent by which it achieves its expected environmental target (e.g., *greenhouse gas (GHG)* emission reduction).

Environmental input-output analysis: An analytical method used to allocate environmental impacts arising in production to categories of final consumption, by means of the Leontief inverse of a country's economic input-output tables. See also Annex II.6.2.

Environmental Kuznets Curve: The hypothesis that various environmental impacts first increase and then eventually decrease as income per capita increases.

Evidence: Information indicating the degree to which a belief or proposition is true or valid. In this report, the degree of evidence reflects the amount, quality, and consistency of scientific/technical information on which the Lead Authors are basing their findings. See also *Agreement*, *Confidence*, *Likelihood* and *Uncertainty*.

Externality/external cost/external benefit: Externalities arise from a human activity when agents responsible for the activity do not take full account of the activity's impacts on others' production and consumption possibilities, and no compensation exists for such impacts. When the impacts are negative, they are external costs. When the impacts are positive, they are external benefits. See also *Social costs*.

Feed-in tariff (FIT): The price per unit of electricity (heat) that a utility or power (heat) supplier has to pay for distributed or renewable electricity (heat) fed into the power grid (heat supply system) by non-utility generators. A public authority regulates the tariff.

Final energy: See *Primary energy*.

Flaring: Open air burning of waste gases and volatile liquids, through a chimney, at oil wells or rigs, in refineries or chemical plants, and at landfills.

Flexibility Mechanisms: See *Kyoto Mechanisms*.

Food security: A state that prevails when people have secure access to sufficient amounts of safe and nutritious food for normal growth, development, and an active and healthy life.[4]

Forest: A vegetation type dominated by trees. Many definitions of the term forest are in use throughout the world, reflecting wide differences in biogeophysical conditions, social structure and economics. According to the 2005 *United Nations Framework Convention on Climate Change (UNFCCC)* definition a forest is an area of land of at least 0.05–1 hectare, of which more than 10–30 % is covered by tree canopy. Trees must have a potential to reach a minimum of 25 meters at maturity in situ. Parties to the Convention can choose to define a forest from within those ranges. Currently, the definition does not recognize different biomes, nor do they distinguish natural forests from plantations, an anomaly being pointed out by many as in need of rectification.

For a discussion of the term forest and related terms such as *afforestation*, *reforestation* and *deforestation* see the IPCC Report on Land Use, Land-Use Change and Forestry (IPCC, 2000). See also the Report on Definitions and Methodological Options to Inventory Emissions from Direct Human-induced Degradation of Forests and Devegetation of Other Vegetation Types (IPCC, 2003).

Forest management: A system of practices for stewardship and use of *forest* land aimed at fulfilling relevant ecological (including *biological diversity*), economic and social functions of the *forest* in a sustainable manner (UNFCCC, 2002).

Forestry and Other Land Use (FOLU): See *Agriculture, Forestry and Other Land Use (AFOLU)*.

Fossil fuels: Carbon-based fuels from fossil hydrocarbon deposits, including coal, peat, oil, and natural gas.

Free Rider: One who benefits from a common good without contributing to its creation or preservation.

[4] This glossary entry builds on definitions used in FAO (2000) and previous IPCC reports.

Fuel cell: A fuel cell generates electricity in a direct and continuous way from the controlled electrochemical reaction of hydrogen or another fuel and oxygen. With hydrogen as fuel the cell emits only water and heat (no *carbon dioxide*) and the heat can be utilized (see also *Cogeneration*).

Fuel poverty: A condition in which a household is unable to guarantee a certain level of consumption of domestic *energy services* (especially heating) or suffers disproportionate expenditure burdens to meet these needs.

Fuel switching: In general, fuel switching refers to substituting fuel A for fuel B. In the context of *mitigation* it is implicit that fuel A has lower carbon content than fuel B, e.g., switching from natural gas to coal.

General circulation (climate) model (GCM): See *Climate model*.

General equilibrium analysis: General equilibrium analysis considers simultaneously all the markets and feedback effects among these markets in an economy leading to market clearance. *(Computable) general equilibrium (CGE) models* are the operational tools used to perform this type of analysis.

Geoengineering: Geoengineering refers to a broad set of methods and technologies that aim to deliberately alter the *climate system* in order to alleviate the impacts of *climate change*. Most, but not all, methods seek to either (1) reduce the amount of absorbed *solar energy* in the *climate system* (*Solar Radiation Management*) or (2) increase net carbon *sinks* from the *atmosphere* at a scale sufficiently large to alter *climate* (*Carbon Dioxide Removal*). Scale and intent are of central importance. Two key characteristics of geoengineering methods of particular concern are that they use or affect the *climate system* (e.g., *atmosphere*, land or ocean) globally or regionally and/or could have substantive unintended effects that cross national boundaries. Geoengineering is different from weather modification and ecological engineering, but the boundary can be fuzzy (IPCC, 2012, p. 2).

Geothermal energy: Accessible thermal *energy* stored in the earth's interior.

Global Environment Facility (GEF): The Global Environment Facility, established in 1991, helps *developing countries* fund projects and programmes that protect the global environment. GEF grants support projects related to *biodiversity*, *climate change*, international waters, land degradation, the *ozone (O_3)* layer, and persistent organic pollutants.

Global mean surface temperature: An estimate of the global mean surface air temperature. However, for changes over time, only anomalies, as departures from a climatology, are used, most commonly based on the area-weighted global average of the sea surface temperature anomaly and land surface air temperature anomaly.

Global warming: Global warming refers to the gradual increase, observed or projected, in global surface temperature, as one of the consequences of *radiative forcing* caused by *anthropogenic emissions*.

Global Warming Potential (GWP): An index, based on radiative properties of *greenhouse gases (GHGs)*, measuring the *radiative forcing* following a pulse emission of a unit mass of a given GHG in the present-day *atmosphere* integrated over a chosen time horizon, relative to that of *carbon dioxide* (CO_2). The GWP represents the combined effect of the differing times these gases remain in the *atmosphere* and their relative effectiveness in causing *radiative forcing*. The *Kyoto Protocol* is based on GWPs from pulse emissions over a 100-year time frame. Unless stated otherwise, this report uses GWP values calculated with a 100-year time horizon which are often derived from the IPCC Second Assessment Report (see Annex II.9.1 for the GWP values of the different GHGs).

Governance: A comprehensive and inclusive concept of the full range of means for deciding, managing, and implementing *policies* and *measures*. Whereas government is defined strictly in terms of the nation-state, the more inclusive concept of governance recognizes the contributions of various levels of government (global, international, regional, local) and the contributing roles of the private sector, of nongovernmental actors, and of civil society to addressing the many types of issues facing the global community.

Grazing land management: The system of practices on land used for livestock production aimed at manipulating the amount and type of vegetation and livestock produced (UNFCCC, 2002).

Green Climate Fund (GCF): The Green Climate Fund was established by the 16th Session of the *Conference of the Parties (COP)* in 2010 as an operating entity of the financial mechanism of the *United Nations Framework Convention on Climate Change (UNFCCC)*, in accordance with Article 11 of the Convention, to support projects, programmes and *policies* and other activities in *developing country* Parties. The Fund is governed by a Board and will receive guidance of the COP. The Fund is headquartered in Songdo, Republic of Korea.

Greenhouse effect: The infrared radiative effect of all infrared-absorbing constituents in the *atmosphere*. *Greenhouse gases (GHGs)*, clouds, and (to a small extent) *aerosols* absorb terrestrial radiation emitted by the earth's surface and elsewhere in the *atmosphere*. These substances emit infrared radiation in all directions, but, everything else being equal, the net amount emitted to space is normally less than would have been emitted in the absence of these absorbers because of the decline of temperature with altitude in the *troposphere* and the consequent weakening of emission. An increase in the concentration of GHGs increases the magnitude of this effect; the difference is sometimes called the enhanced greenhouse effect. The change in a GHG concentration because of *anthropogenic emissions* contributes to an instantaneous *radiative forcing*. Surface temperature and *troposphere* warm in response to this forcing, gradually restoring the radiative balance at the top of the *atmosphere*.

Greenhouse gas (GHG): Greenhouse gases are those gaseous constituents of the *atmosphere*, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the earth's surface, the *atmosphere* itself, and by clouds. This property causes the *greenhouse effect*. Water vapour (H_2O), *carbon dioxide* (CO_2), *nitrous oxide* (N_2O), *methane* (CH_4) and *ozone* (O_3) are the primary GHGs in the earth's *atmosphere*. Moreover, there are a number of entirely human-made GHGs in the *atmosphere*, such as the halocarbons and other chlorine- and bromine-containing substances, dealt with under the *Montreal Protocol*. Beside CO_2, N_2O and CH_4, the *Kyoto Protocol* deals with the GHGs *sulphur hexafluoride* (SF_6), *hydrofluorocarbons (HFCs)* and *perfluorocarbons (PFCs)*. For a list of well-mixed GHGs, see WGI AR5 Table 2.A.1.

Gross domestic product (GDP): The sum of gross value added, at purchasers' prices, by all resident and non-resident producers in the economy, plus any taxes and minus any subsidies not included in the value of the products in a country or a geographic region for a given period, normally one year. GDP is calculated without deducting for depreciation of fabricated assets or depletion and degradation of natural resources.

Gross national expenditure (GNE): The total amount of public and private consumption and capital expenditures of a nation. In general, national account is balanced such that *gross domestic product (GDP)* + import = GNE + export.

Gross national product: The value added from domestic and foreign sources claimed by residents. GNP comprises *gross domestic product (GDP)* plus net receipts of primary income from non-resident income.

Gross world product: An aggregation of the individual country's *gross domestic products (GDP)* to obtain the world or global *GDP*.

Heat island: The relative warmth of a city compared with surrounding rural areas, associated with changes in runoff, effects on heat retention, and changes in surface *albedo*.

Human Development Index (HDI): The Human Development Index allows the assessment of countries' progress regarding social and economic development as a composite index of three indicators: (1) health measured by life expectancy at birth; (2) knowledge as measured by a combination of the adult literacy rate and the combined primary, secondary and tertiary school enrolment ratio; and (3) standard of living as *gross domestic product (GDP)* per capita (in purchasing power parity). The HDI sets a minimum and a maximum for each dimension, called goalposts, and then shows where each country stands in relation to these goalposts, expressed as a value between 0 and 1. The HDI only acts as a broad proxy for some of the key issues of human development; for instance, it does not reflect issues such as political participation or gender inequalities.

Hybrid vehicle: Any vehicle that employs two sources of propulsion, particularly a vehicle that combines an internal combustion engine with an electric motor.

Hydrofluorocarbons (HFCs): One of the six types of *greenhouse gases (GHGs)* or groups of GHGs to be mitigated under the *Kyoto Protocol*. They are produced commercially as a substitute for *chlorofluorocarbons (CFCs)*. HFCs largely are used in refrigeration and semiconductor manufacturing. See also *Global Warming Potential (GWP)* and Annex II.9.1 for GWP values.

Hydropower: Power harnessed from the flow of water.

Incremental costs: See *Climate finance*.

Incremental investment: See *Climate finance*.

AI

Indigenous peoples: Indigenous peoples and nations are those that, having a historical continuity with pre-invasion and pre-colonial societies that developed on their territories, consider themselves distinct from other sectors of the societies now prevailing on those territories, or parts of them. They form at present principally non-dominant sectors of society and are often determined to preserve, develop, and transmit to future generations their ancestral territories, and their ethnic identity, as the basis of their continued existence as peoples, in accordance with their own cultural patterns, social *institutions*, and common law system.[5]

Indirect emissions: See *Emissions*.

Indirect land use change (iLUC): See *Land use*.

Industrial Revolution: A period of rapid industrial growth with far-reaching social and economic consequences, beginning in Britain during the second half of the 18th century and spreading to Europe and later to other countries including the United States. The invention of the steam engine was an important trigger of this development. The industrial revolution marks the beginning of a strong increase in the use of *fossil fuels* and emission of, in particular, fossil *carbon dioxide*. In this report the terms pre-industrial and industrial refer, somewhat arbitrarily, to the periods before and after 1750, respectively.

Industrialized countries/developing countries: There are a diversity of approaches for categorizing countries on the basis of their level of development, and for defining terms such as industrialized, developed, or developing. Several categorizations are used in this report. (1) In the United Nations system, there is no established convention for designating of developed and developing countries or areas. (2) The United Nations Statistics Division specifies developed and developing regions based on common practice. In addition, specific countries are designated as *Least Developed Countries (LCD)*, landlocked developing countries, small island developing states, and transition economies. Many countries appear in more than one of these categories. (3) The World Bank uses income as the main criterion for classifying countries as low, lower middle, upper middle, and high income. (4) The UNDP aggregates indicators for life expectancy, educational attainment, and income into a single composite *Human Development Index (HDI)* to classify countries as low, medium, high, or very high human development. See WGII AR5 Box 1–2.

Input-output analysis: See *Environmental input-output analysis*.

Institution: Institutions are rules and norms held in common by social actors that guide, constrain and shape human interaction. Institutions can be formal, such as laws and policies, or informal, such as norms and conventions. Organizations—such as parliaments, regulatory agencies, private firms, and community bodies—develop and act in response to institutional frameworks and the incentives they frame. Institutions can guide, constrain and shape human interaction through direct control, through incentives, and through processes of socialization.

Institutional feasibility: Institutional feasibility has two key parts: (1) the extent of administrative workload, both for public authorities and for regulated entities, and (2) the extent to which the *policy* is viewed as legitimate, gains acceptance, is adopted, and is implemented.

Integrated assessment: A method of analysis that combines results and models from the physical, biological, economic, and social sciences, and the interactions among these components in a consistent framework to evaluate the status and the consequences of environmental change and the *policy* responses to it. See also *Integrated Models*.

Integrated models: See *Models*.

IPAT identity: IPAT is the lettering of a formula put forward to describe the impact of human activity on the environment. Impact (I) is viewed as the product of population size (P), affluence (A=GDP/person) and technology (T= impact per GDP unit). In this conceptualization, population growth by definition leads to greater environmental impact if A and T are constant, and likewise higher income leads to more impact (Ehrlich and Holdren, 1971).

Iron fertilization: Deliberate introduction of iron to the upper ocean intended to enhance biological productivity which can sequester additional atmospheric *carbon dioxide* (CO_2) into the oceans. See also *Geoengineering* and *Carbon Dioxide Removal (CDR)*.

Jevon's paradox: See *Rebound effect*.

5 This glossary entry builds on the definitions used in Cobo (1987) and previous IPCC reports.

Joint Implementation (JI): A mechanism defined in Article 6 of the *Kyoto Protocol*, through which investors (governments or companies) from developed *(Annex B) countries* may implement projects jointly that limit or reduce emissions or enhance *sinks*, and to share the *Emissions Reduction Units (ERU)*. See also *Kyoto Mechanisms*.

Kaya identity: In this identity global emissions are equal to the population size, multiplied by per capita output (*gross world product*), multiplied by the *energy intensity* of production, multiplied by the *carbon intensity* of *energy*.

Kyoto Mechanisms (also referred to as Flexibility Mechanisms): Market-based mechanisms that Parties to the *Kyoto Protocol* can use in an attempt to lessen the potential economic impacts of their commitment to limit or reduce *greenhouse gas (GHG)* emissions. They include *Joint Implementation (JI)* (Article 6), *Clean Development Mechanism (CDM)* (Article 12), and *Emissions trading* (Article 17).

Kyoto Protocol: The Kyoto Protocol to the *United Nations Framework Convention on Climate Change (UNFCCC)* was adopted in 1997 in Kyoto, Japan, at the Third Session of the *Conference of the Parties (COP)* to the UNFCCC. It contains legally binding commitments, in addition to those included in the UNFCCC. Countries included in *Annex B* of the Protocol (most Organisation for Economic Cooperation and Development countries and countries with economies in transition) agreed to reduce their anthropogenic *greenhouse gas (GHG)* emissions (*carbon dioxide* *(CO_2)*, *methane (CH_4)*, *nitrous oxide (N_2O)*, *hydrofluorocarbons (HFCs)*, *perfluorocarbons (PFCs)*, and *sulphur hexafluoride (SF_6)*) by at least 5 % below 1990 levels in the commitment period 2008–2012. The Kyoto Protocol entered into force on 16 February 2005.

Land use (change, direct and indirect): Land use refers to the total of arrangements, activities and inputs undertaken in a certain land cover type (a set of human actions). The term land use is also used in the sense of the social and economic purposes for which land is managed (e.g., grazing, timber extraction and conservation). In urban settlements it is related to land uses within cities and their hinterlands. Urban land use has implications on city management, structure, and form and thus on energy demand, *greenhouse gas (GHG)* emissions, and mobility, among other aspects.

Land use change (LUC): Land use change refers to a change in the use or management of land by humans, which may lead to a change in land cover. Land cover and LUC may have an impact on the surface *albedo*, evapotranspiration, *sources* and *sinks* of GHGs, or other properties of the *climate system* and may thus give rise to *radiative forcing* and/or other impacts on *climate*, locally or globally. See also the IPCC Report on Land Use, Land-Use Change, and Forestry (IPCC, 2000).

Indirect land use change (iLUC): Indirect land use change refers to shifts in land use induced by a change in the production level of an agricultural product elsewhere, often mediated by markets or driven by *policies*. For example, if agricultural land is diverted to fuel production, *forest* clearance may occur elsewhere to replace the former agricultural production. See also *Afforestation*, *Deforestation* and *Reforestation*.

Land use, land use change and forestry (LULUCF): A *greenhouse gas (GHG)* inventory sector that covers *emissions* and removals of GHGs resulting from direct human-induced *land use*, *land use change* and forestry activities excluding *agricultural emissions*. See also *Agriculture, Forestry and Other Land Use (AFOLU)*.

Land value capture: A financing mechanism usually based around transit systems, or other infrastructure and services, that captures the increased value of land due to improved accessibility.

Leakage: Phenomena whereby the reduction in emissions (relative to a *baseline*) in a jurisdiction/sector associated with the implementation of *mitigation policy* is offset to some degree by an increase outside the jurisdiction/sector through induced changes in consumption, production, prices, land use and/or trade across the jurisdictions/sectors. Leakage can occur at a number of levels, be it a project, state, province, nation, or world region. See also *Rebound effect*.

In the context of *Carbon Dioxide Capture and Storage (CCS)*, 'CO_2 leakage' refers to the escape of injected *carbon dioxide (CO_2)* from the storage location and eventual release to the atmosphere. In the context of other substances, the term is used more generically, such as for '*methane (CH_4)* leakage' (e.g., from *fossil fuel* extraction activities), and '*hydrofluorocarbon (HFC)* leakage' (e.g., from refrigeration and air-conditioning systems).

Learning curve/rate: Decreasing cost-prices of technologies shown as a function of increasing (total or yearly) supplies. The learning rate is the percent decrease of the cost-price for every doubling of the cumulative supplies (also called progress ratio).

Least Developed Countries (LDCs): A list of countries designated by the Economic and Social Council of the United Nations (ECOSOC) as meeting three criteria: (1) a low income criterion below a certain threshold of gross national income per capita of between USD 750 and USD 900, (2) a human resource weakness based on indicators of health, education, adult literacy, and (3) an economic vulnerability weakness based on indicators on instability of agricultural production, instability of export of goods and services, economic importance of non-traditional activities, merchandise export concentration, and the handicap of economic smallness. Countries in this category are eligible for a number of programmes focused on assisting countries most in need. These privileges include certain benefits under the articles of the *United Nations Framework Convention on Climate Change (UNFCCC)*. See also *Industrialized/developing countries*.

Levelized cost of conserved carbon (LCCC): See Annex II.3.1.3 for concepts and definition.

Levelized cost of conserved energy (LCCE): See Annex II.3.1.2 for concepts and definition.

Levelized cost of energy (LCOE): See Annex II.3.1.1 for concepts and definition.

Lifecycle assessment (LCA): A widely used technique defined by ISO 14040 as a "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle". The results of LCA studies are strongly dependent on the system boundaries within which they are conducted. The technique is intended for relative comparison of two similar means to complete a product. See also Annex II.6.3.

Likelihood: The chance of a specific outcome occurring, where this might be estimated probabilistically. This is expressed in this report using a standard terminology (Mastrandrea et al., 2010): virtually certain 99–100 % probability, very likely 90–100 %, likely 66–100 %, about as likely as not 33–66 %, unlikely 0–33 %, very unlikely 0–10 %, exceptionally unlikely 0–1 %. Additional terms (more likely than not > 50–100 %, and more unlikely than likely 0–< 50 %) may also be used when appropriate. Assessed likelihood is typeset in italics, e. g., *very likely*. See also *Agreement*, *Confidence*, *Evidence* and *Uncertainty*.

AI

Lock-in: Lock-in occurs when a market is stuck with a *standard* even though participants would be better off with an alternative.

Marginal abatement cost (MAC): The cost of one unit of additional *mitigation*.

Market barriers: In the context of climate change *mitigation*, market barriers are conditions that prevent or impede the diffusion of *cost-effective* technologies or practices that would mitigate *greenhouse gas (GHG)* emissions.

Market-based mechanisms, GHG emissions: Regulatory approaches using price mechanisms (e.g., taxes and auctioned *emission permits*), among other instruments, to reduce the *sources* or enhance the *sinks* of *greenhouse gases (GHGs)*.

Market exchange rate (MER): The rate at which foreign currencies are exchanged. Most economies post such rates daily and they vary little across all the exchanges. For some developing economies, official rates and black-market rates may differ significantly and the MER is difficult to pin down. See also *Purchasing power parity (PPP)* and Annex II.1.3 for the monetary conversion process applied throughout this report.

Market failure: When private decisions are based on market prices that do not reflect the real scarcity of goods and services but rather reflect market distortions, they do not generate an efficient allocation of resources but cause welfare losses. A market distortion is any event in which a market reaches a market clearing price that is substantially different from the price that a market would achieve while operating under conditions of perfect competition and state enforcement of legal contracts and the ownership of private property. Examples of factors causing market prices to deviate from real economic scarcity are environmental *externalities*, *public goods*, monopoly power, information asymmetry, *transaction costs*, and non-rational *behaviour*. See also *Economic efficiency*.

Material flow analysis (MFA): A systematic assessment of the flows and stocks of materials within a system defined in space and time (Brunner and Rechberger, 2004). See also Annex II.6.1.

Measures: In climate *policy*, measures are technologies, processes or practices that contribute to *mitigation*, for example *renewable energy (RE)* technologies, waste minimization processes, public transport commuting practices.

Meeting of the Parties (CMP): The *Conference of the Parties (COP)* to the *United Nations Framework Convention on Climate Change (UNFCCC)* serves as the CMP, the supreme body of the *Kyoto Protocol*, since the latter entered into force on 16 February 2005. Only Parties to the *Kyoto Protocol* may participate in deliberations and make decisions.

Methane (CH_4): One of the six *greenhouse gases (GHGs)* to be mitigated under the *Kyoto Protocol* and is the major component of natural gas and associated with all hydrocarbon fuels. Significant emissions occur as a result of animal husbandry and agriculture and their management represents a major *mitigation* option. See also *Global Warming Potential (GWP)* and Annex II.9.1 for GWP values.

Methane recovery: Any process by which *methane (CH_4)* emissions (e.g., from oil or gas wells, coal beds, peat bogs, gas transmission pipelines, landfills, or anaerobic digesters) are captured and used as a fuel or for some other economic purpose (e.g., chemical feedstock).

Millennium Development Goals (MDGs): A set of eight time-bound and measurable goals for combating poverty, hunger, disease, illiteracy, discrimination against women and environmental degradation. These goals were agreed to at the UN Millennium Summit in 2000 together with an action plan to reach the goals.

Mitigation (of climate change): A human intervention to reduce the *sources* or enhance the *sinks* of *greenhouse gases (GHGs)*. This report also assesses human interventions to reduce the *sources* of other substances which may contribute directly or indirectly to limiting *climate change*, including, for example, the reduction of *particulate matter (PM)* emissions that can directly alter the radiation balance (e.g., *black carbon*) or *measures* that control emissions of carbon monoxide, *nitrogen oxides (NO_x)*, *Volatile Organic Compounds (VOCs)* and other pollutants that can alter the concentration of tropospheric *ozone (O_3)* which has an indirect effect on the *climate*.

Mitigation capacity: A country's ability to reduce anthropogenic *greenhouse gas (GHG)* emissions or to enhance natural *sinks*, where ability refers to skills, competencies, fitness, and proficiencies that a country has attained and depends on technology, *institutions*, wealth, equity, infrastructure, and information. Mitigative capacity is rooted in a country's *sustainable development (SD)* path.

Mitigation scenario: A plausible description of the future that describes how the (studied) system responds to the implementation of *mitigation policies* and *measures*. See also *Baseline/reference*, *Climate scenario*, *Emission scenario*, *Representative Concentration Pathways (RCPs)*, *Scenario*, *Shared socio-economic pathways*, *Socio-economic scenarios*, *SRES scenarios*, *Stabilization*, and *Transformation pathways*.

Models: Structured imitations of a system's attributes and mechanisms to mimic appearance or functioning of systems, for example, the *climate*, the economy of a country, or a crop. Mathematical models assemble (many) variables and relations (often in a computer code) to simulate system functioning and performance for variations in parameters and inputs.

Computable General Equilibrium (CGE) Model: A class of economic models that use actual economic data (i.e., input/output data), simplify the characterization of economic *behaviour*, and solve the whole system numerically. CGE models specify all economic relationships in mathematical terms and predict the changes in variables such as prices, output and economic welfare resulting from a change in economic policies, given information about technologies and consumer preferences (Hertel, 1997). See also *General equilibrium analysis*.

Integrated Model: Integrated models explore the interactions between multiple sectors of the economy or components of particular systems, such as the *energy system*. In the context of *transformation pathways*, they refer to models that, at a minimum, include full and disaggregated representations of the *energy system* and its linkage to the overall economy that will allow for consideration of interactions among different elements of that system. Integrated models may also include representations of the full economy, *land use* and *land use change (LUC)*, and the *climate system*. See also *Integrated assessment*.

Sectoral Model: In the context of this report, sectoral models address only one of the core sectors that are discussed in this report, such as buildings, industry, transport, energy supply, and *Agriculture, Forestry and Other Land Use (AFOLU)*.

Montreal Protocol: The Montreal Protocol on Substances that Deplete the Ozone Layer was adopted in Montreal in 1987, and subsequently adjusted and amended in London (1990), Copenhagen (1992), Vienna (1995), Montreal (1997) and Beijing (1999). It controls the consumption and production of chlorine- and bromine- containing chemicals that destroy stratospheric *ozone (O_3)*, such as *chlorofluorocarbons (CFCs)*, methyl chloroform, carbon tetrachloride and many others.

Multi-criteria analysis (MCA): Integrates different decision parameters and values without assigning monetary values to all parameters. Multi-criteria analysis can combine quantitative and qualitative information. Also referred to as multi-attribute analysis.

Multi-attribute analysis: See *Multi-criteria analysis (MCA)*.

Multi-gas: Next to *carbon dioxide (CO_2)*, there are other forcing components taken into account in, e.g., achieving reduction for a basket of *greenhouse gas (GHG)* emissions (CO_2, *methane (CH_4)*, *nitrous oxide (N_2O)*, and fluorinated gases) or *stabilization* of *CO_2-equivalent concentrations* (multi-gas *stabilization*, including GHGs and *aerosols*).

Nationally Appropriate Mitigation Action (NAMA): Nationally Appropriate Mitigation Actions are a concept for recognizing and financing emission reductions by *developing countries* in a post-2012 climate regime achieved through action considered appropriate in a given national context. The concept was first introduced in the Bali Action Plan in 2007 and is contained in the *Cancún Agreements*.

Nitrogen oxides (NO_X): Any of several oxides of nitrogen.

Nitrous oxide (N_2O): One of the six *greenhouse gases (GHGs)* to be mitigated under the *Kyoto Protocol*. The main anthropogenic source of N_2O is agriculture (soil and animal manure management), but important contributions also come from sewage treatment, *fossil fuel* combustion, and chemical industrial processes. N_2O is also produced naturally from a wide variety of biological sources in soil and water, particularly microbial action in wet tropical forests. See also *Global Warming Potential (GWP)* and Annex II.9.1 for GWP values.

Non-Annex I Parties/countries: Non-Annex I Parties are mostly *developing countries*. Certain groups of *developing countries* are recognized by the Convention as being especially vulnerable to the adverse impacts of *climate change*, including countries with low-lying coastal areas and those prone to *desertification* and drought. Others, such as countries that rely heavily on income from *fossil fuel* production and commerce, feel more vulnerable to the potential economic impacts of *climate change* response measures. The Convention emphasizes activities that promise to answer the special needs and concerns of these vulnerable countries, such as investment, insurance, and technology transfer. See also *Annex I Parties/countries*.

Normative analysis: Analysis in which judgments about the desirability of various *policies* are made. The conclusions rest on value judgments as well as on facts and theories. See also *Descriptive analysis*.

Ocean energy: *Energy* obtained from the ocean via waves, tidal ranges, tidal and ocean currents, and thermal and saline gradients.

Offset (in climate policy): A unit of *CO_2-equivalent emissions* that is reduced, avoided, or sequestered to compensate for emissions occurring elsewhere.

Oil sands and oil shale: Unconsolidated porous sands, sandstone rock, and shales containing bituminous material that can be mined and converted to a liquid fuel. See also *Unconventional fuels*.

Overshoot pathways: Emissions, concentration, or temperature pathways in which the metric of interest temporarily exceeds, or 'overshoots', the long-term goal.

Ozone (O_3): Ozone, the triatomic form of oxygen (O_3), is a gaseous atmospheric constituent. In the *troposphere*, it is created both naturally and by photochemical reactions involving gases resulting from human activities (smog). Tropospheric O_3 acts as a *greenhouse gas (GHG)*. In the *stratosphere*, it is created by the interaction between solar ultraviolet radiation and molecular oxygen (O_2). Stratospheric O_3 plays a dominant role in the stratospheric radiative balance. Its concentration is highest in the O_3 layer.

Paratransit: Denotes flexible passenger transportation, often but not only in areas with low population density, that does not follow fixed routes or schedules. Options include minibuses (matatus, marshrutka), shared taxis and jitneys. Sometimes paratransit is also called community transit.

Pareto optimum: A state in which no one's welfare can be increased without reducing someone else's welfare. See also *Economic efficiency*.

Particulate matter (PM): Very small solid particles emitted during the combustion of *biomass* and *fossil fuels*. PM may consist of a wide variety of substances. Of greatest concern for health are particulates of diameter less than or equal to 10 nanometers, usually designated as PM_{10}. See also *Aerosol*.

Passive design: The word 'passive' in this context implies the ideal target that the only *energy* required to use the designed product or service comes from renewable sources.

Path dependence: The generic situation where decisions, events, or outcomes at one point in time constrain *adaptation*, *mitigation*, or other actions or options at a later point in time.

Payback period: Mostly used in investment appraisal as financial payback, which is the time needed to repay the initial investment by the returns of a project. A payback gap exists when, for example, private investors and micro-financing schemes require higher profitability rates from *renewable energy (RE)* projects than from fossil-fired projects. Energy payback is the time an *energy* project needs to deliver as much *energy* as had been used for setting the project online. Carbon payback is the time a *renewable energy (RE)* project needs to deliver as much net *greenhouse gas (GHG)* savings (with respect to the fossil reference *energy system*) as its realization has caused GHG emissions from a perspective of *lifecycle assessment (LCA)* (including *land use changes (LUC)* and loss of terrestrial carbon stocks).

Perfluorocarbons (PFCs): One of the six types of *greenhouse gases (GHGs)* or groups of GHGs to be mitigated under the *Kyoto Protocol*. PFCs are by-products of aluminium smelting and uranium enrichment. They also replace *chlorofluorocarbons (CFCs)* in manufacturing semiconductors. See also *Global Warming Potential (GWP)* and Annex II.9.1 for GWP values.

Photovoltaic cells (PV): Electronic devices that generate electricity from light *energy*. See also *Solar energy*.

Policies (for mitigation of or adaptation to climate change): Policies are a course of action taken and/or mandated by a government, e.g., to enhance *mitigation* and *adaptation*. Examples of *policies* aimed at *mitigation* are support mechanisms for *renewable energy (RE)* supplies, carbon or energy taxes, fuel efficiency *standards* for automobiles. See also *Measures*.

Polluter pays principle (PPP): The party causing the pollution is responsible for paying for remediation or for compensating the damage.

Positive analysis: See *Descriptive analysis*.

Potential: The possibility of something happening, or of someone doing something in the future. Different metrics are used throughout this report for the quantification of different types of potentials, including the following:

> ***Technical potential:*** Technical potential is the amount by which it is possible to pursue a specific objective through an increase in deployment of technologies or implementation of processes and practices that were not previously used or implemented. Quantification of technical potentials may take into account other than technical considerations, including social, economic and/or environmental considerations.

Precautionary principle: A provision under Article 3 of the *United Nations Framework Convention on Climate Change (UNFCCC)*, stipulating that the Parties should take precautionary *measures* to anticipate, prevent, or minimize the causes of *climate change* and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason to postpone such *measures*, taking into account that *policies* and *measures* to deal with *climate change* should be *cost-effective* in order to ensure global benefits at the lowest possible cost.

Precursors: Atmospheric compounds that are not *greenhouse gases (GHGs)* or *aerosols*, but that have an effect on GHG or *aerosol* concentrations by taking part in physical or chemical processes regulating their production or destruction rates.

Pre-industrial: See *Industrial Revolution*.

Present value: Amounts of money available at different dates in the future are discounted back to a present value, and summed to get the present value of a series of future cash flows. See also *Discounting*.

Primary production: All forms of production accomplished by plants, also called primary producers.

Primary energy: See *Energy*.

Private costs: Private costs are carried by individuals, companies or other private entities that undertake an action, whereas social costs include additionally the *external costs* on the environment and on society as a whole. Quantitative estimates of both private and social costs may be incomplete, because of difficulties in measuring all relevant effects.

Production-based accounting: Production-based accounting provides a measure of emissions released to the *atmosphere* for the production of goods and services by a certain entity (e.g., person, firm, country, or region). See also *Consumption-based accounting*.

Public good: Public goods are non-rivalrous (goods whose consumption by one consumer does not prevent simultaneous consumption by other consumers) and non-excludable (goods for which it is not possible to prevent people who have not paid for it from having access to it).

Purchasing power parity (PPP): The purchasing power of a currency is expressed using a basket of goods and services that can be bought with a given amount in the home country. International comparison of, for example, *gross domestic products (GDP)* of countries can be based on the purchasing power of currencies rather than on current exchange rates. PPP estimates tend to lower per capita *GDP* in *industrialized countries* and raise per capita *GDP* in *developing countries*. (PPP is also an acronym for *polluter pays principle*). See also *Market exchange rate (MER)* and Annex II.1.3 for the monetary conversion process applied throughout this report.

Radiation management: See *Solar Radiation Management*.

Radiative forcing: Radiative forcing is the change in the net, downward minus upward, radiative flux (expressed in W m^{-2}) at the tropopause or top of *atmosphere* due to a change in an external driver of *climate change*, such as, for example, a change in the concentration of *carbon dioxide* (CO_2) or the output of the sun. For the purposes of this report, radiative forcing is further defined as the change relative to the year 1750 and refers to a global and annual average value.

Rebound effect: Phenomena whereby the reduction in *energy* consumption or emissions (relative to a *baseline*) associated with the implementation of *mitigation measures* in a jurisdiction is offset to some degree through induced changes in consumption, production, and prices within the same jurisdiction. The rebound effect is most typically ascribed to technological *energy efficiency (EE)* improvements. See also *Leakage*.

Reducing Emissions from Deforestation and Forest Degradation (REDD): An effort to create financial value for the carbon stored in *forests*, offering incentives for *developing countries* to reduce emissions from forested lands and invest in low-carbon paths to *sustainable development (SD)*. It is therefore a mechanism for *mitigation* that results from avoiding *deforestation*. REDD+ goes beyond *reforestation* and *forest* degradation, and includes the role of conservation, sustainable management of forests and enhancement of forest carbon stocks. The concept was first introduced in 2005 in the 11th Session of the *Conference of the Parties (COP)* in Montreal and later given greater recognition in the 13th Session of the COP in 2007 at Bali and inclusion in the Bali Action Plan which called for "policy approaches and positive incentives on issues relating to reducing emissions to deforestation and forest degradation in developing countries (REDD) and the role of conservation, sustainable management of forests and enhancement of forest carbon stock in developing countries". Since then, support for REDD has increased and has slowly become a framework for action supported by a number of countries.

Reference scenario: See *Baseline/reference*.

Reforestation: Planting of *forests* on lands that have previously sustained *forests* but that have been converted to some other use. Under the *United Nations Framework Convention on Climate Change (UNFCCC)* and the *Kyoto Protocol*, reforestation is the direct human-induced conversion of non-forested land to forested land through planting, seeding, and/or human-induced promotion of natural seed sources, on land that was previously forested but converted to non-forested land. For the first commitment period of the *Kyoto Protocol*, reforestation activities will be limited to reforestation occurring on those lands that did not contain forest on 31 December 1989.

For a discussion of the term *forest* and related terms such as *afforestation*, reforestation and *deforestation*, see the IPCC Report on Land Use, Land-Use Change and Forestry (IPCC, 2000). See also the Report on Definitions and Methodological Options to Inventory Emissions from Direct Human-induced Degradation of Forests and Devegetation of Other Vegetation Types (IPCC, 2003).

Renewable energy (RE): See *Energy*.

Representative Concentration Pathways (RCPs): *Scenarios* that include time series of emissions and concentrations of the full suite of *greenhouse gases (GHGs)* and *aerosols* and chemically active gases, as well as *land use*/land cover (Moss et al., 2008). The word *representative* signifies that each RCP provides only one of many possible *scenarios* that would lead to the specific *radiative forcing* characteristics. The term *pathway* emphasizes that not only the long-term concentration levels are of interest, but also the trajectory taken over time to reach that outcome (Moss et al., 2010).

RCPs usually refer to the portion of the concentration pathway extending up to 2100, for which Integrated Assessment Models produced corresponding *emission scenarios*. Extended Concentration Pathways (ECPs) describe extensions of the RCPs from 2100 to 2500 that were calculated using simple rules generated by stakeholder consultations, and do not represent fully consistent *scenarios*.

Four RCPs produced from Integrated Assessment Models were selected from the published literature and are used in the present IPCC Assessment as a basis for the *climate predictions* and *projections* presented in WGI AR5 Chapters 11 to 14:

RCP2.6 One pathway where *radiative forcing* peaks at approximately 3 W m^{-2} before 2100 and then declines (the corresponding ECP assuming constant emissions after 2100);

RCP4.5 and RCP6.0 Two intermediate *stabilization* pathways in which *radiative forcing* is stabilized at approximately 4.5 W m^{-2} and 6.0 W m^{-2} after 2100 (the corresponding ECPs assuming constant concentrations after 2150);

RCP8.5 One high pathway for which *radiative forcing* reaches greater than 8.5 W m^{-2} by 2100 and continues to rise for some amount of time (the corresponding ECP assuming constant emissions after 2100 and constant concentrations after 2250).

For further description of future *scenarios*, see WGI AR5 Box 1.1. See also *Baseline/reference*, *Climate prediction*, *Climate projection*, *Climate scenario*, *Shared socio-economic pathways*, *Socio-economic scenario*, *SRES scenarios*, and *Transformation pathway*.

Reservoir: A component of the *climate system*, other than the *atmosphere*, which has the capacity to store, accumulate or release a substance of concern, for example, carbon, a *greenhouse gas (GHG)* or a *precursor*. Oceans, soils and *forests* are examples of reservoirs of carbon. Pool is an equivalent term (note that the definition of pool often includes the *atmosphere*). The absolute quantity of the substance of concern held within a reservoir at a specified time is called the stock. In the context of *Carbon Dioxide Capture and Storage (CCS)*, this term is sometimes used to refer to a geological *carbon dioxide (CO_2)* storage location. See also *Sequestration*.

Resilience: The capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for *adaptation*, learning, and transformation (Arctic Council, 2013).

Revegetation: A direct human-induced activity to increase carbon stocks on sites through the establishment of vegetation that covers a minimum area of 0.05 hectares and does not meet the definitions of *afforestation* and *reforestation* contained here (UNFCCC, 2002).

Risk: In this report, the term risk is often used to refer to the potential, when the outcome is uncertain, for adverse consequences on lives, livelihoods, health, *ecosystems* and species, economic, social and cultural assets, services (including environmental services), and infrastructure.

Risk assessment: The qualitative and/or quantitative scientific estimation of *risks*.

Risk management: The plans, actions, or policies to reduce the likelihood and/or consequences of a given *risk*.

Risk perception: The subjective judgment that people make about the characteristics and severity of a *risk*.

Risk tradeoff: The change in the portfolio of *risks* that occurs when a countervailing *risk* is generated (knowingly or inadvertently) by an intervention to reduce the target *risk* (Wiener and Graham, 2009). See also *Adverse side-effect*, and *Co-benefit*.

Risk transfer: The practice of formally or informally shifting the *risk* of financial consequences for particular negative events from one party to another.

Scenario: A plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g., rate of *technological change (TC)*, prices) and relationships. Note that scenarios are neither predictions nor forecasts, but are useful to provide a view of the implications of developments and actions. See also *Baseline/reference*, *Climate scenario*, *Emission scenario*, *Mitigation scenario*, *Representative Concentration Pathways (RCPs)*, *Shared socio-economic pathways*, *Socioeconomic scenarios*, *SRES scenarios*, *Stabilization*, and *Transformation pathway*.

Scope 1, Scope 2, and Scope 3 emissions: See *Emissions*.

Secondary energy: See *Primary energy*.

Sectoral Models: See *Models*.

Sensitivity analysis: Sensitivity analysis with respect to quantitative analysis assesses how changing assumptions alters the outcomes. For example, one chooses different values for specific parameters and re-runs a given *model* to assess the impact of these changes on model output.

Sequestration: The uptake (i.e., the addition of a substance of concern to a *reservoir*) of carbon containing substances, in particular *carbon dioxide (CO_2)*, in terrestrial or marine *reservoirs*. Biological sequestration includes direct removal of CO_2 from the *atmosphere* through *land-use change (LUC)*, *afforestation*, *reforestation*, *revegetation*, carbon storage in landfills, and practices that enhance soil carbon in agriculture (*cropland management*, *grazing land management*). In parts of the literature, but not in this report, (carbon) sequestration is used to refer to *Carbon Dioxide Capture and Storage (CCS)*.

Shadow pricing: Setting prices of goods and services that are not, or are incompletely, priced by market forces or by administrative regulation, at the height of their social marginal value. This technique is used in *cost-benefit analysis (CBA)*.

Shared socio-economic pathways (SSPs): Currently, the idea of SSPs is developed as a basis for new emissions and *socio-economic scenarios*. An SSP is one of a collection of pathways that describe alternative futures of socio-economic development in the absence of climate *policy* intervention. The combination of SSP-based *socio-economic scenarios* and *Representative Concentration Pathway (RCP)*-based *climate projections* should provide a useful integrative frame for climate impact and *policy* analysis. See also *Baseline/reference*, *Climate scenario*, *Emission scenario*, *Mitigation scenario*, *Scenario*, *SRES scenarios*, *Stabilization*, and *Transformation pathway*.

Short-lived climate pollutant (SLCP): Pollutant emissions that have a warming influence on *climate* and have a relatively short lifetime in the *atmosphere* (a few days to a few decades). The main SLCPs are *black carbon (BC)* ('soot'), *methane (CH_4)* and some *hydroflurorcarbons (HFCs)* some of which are regulated under the *Kyoto Protocol*. Some pollutants of this type, including CH_4, are also *precursors* to the formation of tropospheric *ozone (O_3)*, a strong warming agent. These pollutants are of interest for at least two reasons. First, because they are short-lived, efforts to control them will have prompt effects on *global warming*—unlike long-lived pollutants that build up in the *atmosphere* and respond to changes in emissions at a more sluggish pace. Second, many of these pollutants also have adverse local impacts such as on human health.

Sink: Any process, activity or mechanism that removes a *greenhouse gas (GHG)*, an *aerosol*, or a *precursor* of a GHG or *aerosol* from the *atmosphere*.

Smart grids: A smart grid uses information and communications technology to gather data on the *behaviours* of suppliers and consumers in the production, distribution, and use of electricity. Through automated responses or the provision of price signals, this information can then be used to improve the efficiency, reliability, economics, and *sustainability* of the electricity network.

Smart meter: A meter that communicates consumption of electricity or gas back to the utility provider.

Social cost of carbon (SCC): The net present value of climate damages (with harmful damages expressed as a positive number) from one more tonne of carbon in the form of *carbon dioxide (CO_2)*, conditional on a global emissions trajectory over time.

Social costs: See *Private costs*.

Socio-economic scenario: A *scenario* that describes a possible future in terms of population, *gross domestic product (GDP)*, and other socio-economic factors relevant to understanding the implications of *climate change*. See also *Baseline/reference*, *Climate scenario*, *Emission scenario*, *Mitigation scenario*, *Representative Concentration Pathways (RCPs)*, *Scenario*, *Shared socio-economic pathways*, *SRES scenarios*, *Stabilization*, and *Transformation pathway*.

Solar energy: *Energy* from the sun. Often the phrase is used to mean *energy* that is captured from solar radiation either as heat, as light that is converted into chemical energy by natural or artificial photosynthesis, or by photovoltaic panels and converted directly into electricity.

Solar Radiation Management (SRM): Solar Radiation Management refers to the intentional modification of the earth's shortwave radiative budget with the aim to reduce *climate change* according to a given metric (e.g., surface temperature, precipitation, regional impacts, etc.). Artificial injection of stratospheric *aerosols* and cloud brightening are two examples of SRM techniques. Methods to modify some fast-responding elements of the longwave radiative budget (such as cirrus clouds), although not strictly speaking SRM, can be related to SRM. SRM techniques do not fall within the usual definitions of *mitigation* and *adaptation* (IPCC, 2012, p. 2). See also *Carbon Dioxide Removal (CDR)* and *Geoengineering*.

Source: Any process, activity or mechanism that releases a *greenhouse gas (GHG)*, an *aerosol* or a *precursor* of a GHG or *aerosol* into the *atmosphere*. Source can also refer to, e.g., an *energy* source.

Spill-over effect: The effects of domestic or sector *mitigation measures* on other countries or sectors. Spill-over effects can be positive or negative and include effects on trade, (carbon) *leakage*, transfer of innovations, and diffusion of environmentally sound technology and other issues.

SRES scenarios: SRES scenarios are *emission scenarios* developed by Nakićenović and Swart (2000) and used, among others, as a basis for some of the *climate projections* shown in Chapters 9 to 11 of IPCC (2001) and Chapters 10 and 11 of IPCC (2007) as well as WGI AR5. The following terms are relevant for a better understanding of the structure and use of the set of SRES scenarios:

Scenario family: *Scenarios* that have a similar demographic, societal, economic and technical change storyline. Four scenario families comprise the SRES scenario set: A1, A2, B1, and B2.

Illustrative Scenario: A *scenario* that is illustrative for each of the six scenario groups reflected in the Summary for Policymakers of Nakićenović and Swart (2000). They include four revised marker scenarios for the scenario groups A1B, A2, B1, B2, and two additional *scenarios* for the A1FI and A1T groups. All scenario groups are equally sound.

Marker Scenario: A *scenario* that was originally posted in draft form on the SRES website to represent a given scenario family. The choice of markers was based on which of the initial quantifications best reflected the storyline, and the features of specific models. Markers are no more likely than other scenarios, but are considered by the SRES writing team as illustrative of a particular storyline. They are included in revised form in Nakićenović and Swart (2000). These scenarios received the closest scrutiny of the entire writing team and via the SRES open process. *Scenarios* were also selected to illustrate the other two scenario groups.

Storyline: A narrative description of a *scenario* (or family of *scenarios*), highlighting the main *scenario* characteristics, relationships between key driving forces and the dynamics of their evolution.

See also *Baseline/reference*, *Climate scenario*, *Emission scenario*, *Mitigation scenario*, *Representative Concentration Pathways (RCPs)*, *Shared socio-economic pathways*, *Socio-economic scenario*, *Stabilization*, and *Transformation pathway*.

Stabilization (of GHG or CO_2-equivalent concentration): A state in which the atmospheric concentrations of one *greenhouse gas (GHG)* (e.g., *carbon dioxide*) or of a *CO_2-equivalent* basket of GHGs (or a combination of GHGs and *aerosols*) remains constant over time.

Standards: Set of rules or codes mandating or defining product performance (e.g., grades, dimensions, characteristics, test methods, and rules for use). Product, technology or performance standards establish minimum requirements for affected products or technologies. Standards impose reductions in *greenhouse gas (GHG)* emissions associated with the manufacture or use of the products and/or application of the technology.

Stratosphere: The highly stratified region of the *atmosphere* above the *troposphere* extending from about 10 km (ranging from 9 km at high latitudes to 16 km in the tropics on average) to about 50 km altitude.

Structural change: Changes, for example, in the relative share of *gross domestic product (GDP)* produced by the industrial, agricultural, or services sectors of an economy, or more generally, systems transformations whereby some components are either replaced or potentially substituted by other components.

Subsidiarity: The principle that decisions of government (other things being equal) are best made and implemented, if possible, at the lowest most decentralized level, that is, closest to the citizen. Subsidiarity is designed to strengthen accountability and reduce the dangers of making decisions in places remote from their point of application. The principle does not necessarily limit or constrain the action of higher orders of government, but merely counsels against the unnecessary assumption of responsibilities at a higher level.

Sulphur hexafluoride (SF_6): One of the six types of *greenhouse gases (GHGs)* to be mitigated under the *Kyoto Protocol*. SF_6 is largely used in heavy industry to insulate high-voltage equipment and to assist in the manufacturing of cable-cooling systems and semi-conductors. See *Global Warming Potential (GWP)* and Annex II.9.1 for GWP values.

Sustainability: A dynamic process that guarantees the persistence of natural and human systems in an equitable manner.

Sustainable development (SD): Development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987).

Technical potential: See *Potential*.

Technological change (TC): Economic models distinguish autonomous (exogenous), endogenous, and induced TC.

Autonomous (exogenous) technological change: Autonomous (exogenous) technological change is imposed from outside the model (i.e., as a parameter), usually in the form of a time trend affecting factor and/or energy productivity and therefore *energy* demand and/or economic growth.

Endogenous technological change: Endogenous technological change is the outcome of economic activity within the model (i.e., as a variable) so that factor productivity or the choice of technologies is included within the model and affects *energy* demand and/or economic growth.

Induced technological change: Induced technological change implies endogenous technological change but adds further changes induced by *policies* and *measures*, such as *carbon taxes* triggering research and development efforts.

Technological learning: See *Learning curve/rate*.

Technological/knowledge spillovers: Any positive *externality* that results from purposeful investment in technological innovation or development (Weyant and Olavson, 1999).

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Territorial emissions: See *Emissions*.

Trace gas: A minor constituent of the *atmosphere*, next to nitrogen and oxygen that together make up 99% of all volume. The most important trace gases contributing to the *greenhouse effect* are *carbon dioxide (CO_2)*, *ozone (O_3)*, *methane (CH_4)*, *nitrous oxide (N_2O)*, *perfluorocarbons (PFCs)*, *chlorofluorocarbons (CFCs)*, *hydrofluorocarbons (HFCs)*, *sulphur hexafluoride (SF_6)* and water vapour (H_2O).

Tradable (green) certificates scheme: A *market-based mechanism* to achieve an environmentally desirable outcome (*renewable energy (RE)* generation, *energy efficiency (EE)* requirements) in a *cost-effective* way by allowing purchase and sale of certificates representing under and over-compliance respectively with a quota.

Tradable (emission) permit: See *Emission permit*.

Tradable quota system: See *Emissions trading*.

Transaction costs: The costs that arise from initiating and completing transactions, such as finding partners, holding negotiations, consulting with lawyers or other experts, monitoring agreements, or opportunity costs, such as lost time or resources (Michaelowa et al., 2003).

Transformation pathway: The trajectory taken over time to meet different goals for *greenhouse gas (GHG)* emissions, atmospheric concentrations, or *global mean surface temperature* change that implies a set of economic, *technological*, and *behavioural changes*. This can encompass changes in the way *energy* and infrastructure is used and produced, natural resources are managed, *institutions* are set up, and in the pace and direction of *technological change (TC)*. See also *Baseline/reference*, *Climate scenario*, *Emission scenario*, *Mitigation scenario*, *Representative Concentration Pathways (RCPs)*, *Scenario*, *Shared socio-economic pathways*, *Socio-economic scenarios*, *SRES scenarios*, and *Stabilization*.

Transient climate response: See *Climate sensitivity*.

Transit oriented development (TOD): Urban development within walking distance of a transit station, usually dense and mixed with the character of a walkable environment.

Troposphere: The lowest part of the *atmosphere*, from the surface to about 10 km in altitude at mid-latitudes (ranging from 9 km at high latitudes to 16 km in the tropics on average), where clouds and weather phenomena occur. In the troposphere, temperatures generally decrease with height. See also *Stratosphere*.

Uncertainty: A cognitive state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, or uncertain projections of human *behaviour*. Uncertainty can therefore be represented by quantitative measures (e.g., a probability density function) or by qualitative statements (e.g., reflecting the judgment of a team of experts) (see Moss and Schneider, 2000; Manning et al., 2004; Mastrandrea et al., 2010). See also *Agreement*, *Evidence*, *Confidence* and *Likelihood*.

Unconventional resources: A loose term to describe *fossil fuel* reserves that cannot be extracted by the well-established drilling and mining processes that dominated extraction of coal, gas, and oil throughout the 20th century. The boundary between conventional and unconventional resources is not clearly defined. Unconventional oils include *oil shales*, tar sands/bitumen, heavy and extra heavy crude oils, and deep-sea oil occurrences. Unconventional natural gas includes gas in Devonian shales, tight sandstone formations, geopressured aquifers, coal-bed gas, and *methane (CH_4)* in clathrate structures (gas hydrates) (Rogner, 1997).

United Nations Framework Convention on Climate Change (UNFCCC): The Convention was adopted on 9 May 1992 in New York and signed at the 1992 Earth Summit in Rio de Janeiro by more than 150 countries and the European Community. Its ultimate objective is the 'stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'. It contains commitments for all Parties under the principle of 'common but differentiated responsibilities'. Under the Convention, Parties included in *Annex I* aimed to return *greenhouse gas (GHG)* emissions not controlled by the *Montreal Protocol* to 1990 levels by the year 2000. The convention entered in force in March 1994. In 1997, the UNFCCC adopted the *Kyoto Protocol*.

Urban heat island: See *Heat island*.

Verified Emissions Reductions: Emission reductions that are verified by an independent third party outside the framework of the *United Nations Framework Convention on Climate Change (UNFCCC)* and its *Kyoto Protocol*. Also called 'Voluntary Emission Reductions'.

Volatile Organic Compounds (VOCs): Important class of organic chemical air pollutants that are volatile at ambient air conditions. Other terms used to represent VOCs are *hydrocarbons* (HCs), *reactive organic gases* (ROGs) and *non-methane volatile organic compounds* (NMVOCs). NMVOCs are major contributors—together with *nitrogen oxides (NO_x)*, and carbon monoxide (CO)—to the formation of photochemical oxidants such as *ozone (O_3)*.

Voluntary action: Informal programmes, self-commitments, and declarations, where the parties (individual companies or groups of companies) entering into the action set their own targets and often do their own monitoring and reporting.

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Voluntary agreement (VA): An agreement between a government authority and one or more private parties to achieve environmental objectives or to improve environmental performance beyond compliance with regulated obligations. Not all voluntary agreements are truly voluntary; some include rewards and/or penalties associated with joining or achieving commitments.

Voluntary Emission Reductions: See *Verified Emissions Reductions*.

Watts per square meter ($W\ m^{-2}$): See *Radiative forcing*.

Wind energy: Kinetic *energy* from air currents arising from uneven heating of the earth's surface. A wind turbine is a rotating machine for converting the kinetic energy of the wind to mechanical shaft energy to generate electricity. A windmill has oblique vanes or sails and the mechanical power obtained is mostly used directly, for example, for water pumping. A wind farm, wind project, or wind power plant is a group of wind turbines interconnected to a common utility system through a system of transformers, distribution lines, and (usually) one substation.

AI

Acronyms and chemical symbols

AAU	Assigned Amount Unit
ADB	Asian Development Bank
AfDB	African Development Bank
AFOLU	Agriculture, Forestry and Other Land Use
AME	Asian Modeling Exercise
AMPERE	Assessment of Climate Change Mitigation Pathways and Evaluation of the Robustness of Mitigation Cost Estimates
AOSIS	Alliance of Small Island States
APEC	Asia-Pacific Economic Cooperation
AR4	IPCC Fourth Assessment Report
ASEAN	Association of Southeast Asian Nations
ASIA	Non-OECD Asia
BAMs	Border adjustment measures
BAT	Best available technology
BAU	Business-as-usual
BC	Black carbon
BECCS	Bioenergy with carbon dioxide capture and storage
BEVs	Battery electric vehicles
BNDES	Brazilian Development Bank
BOD	Biochemical Oxygen Demand
BRT	Bus rapid transit
C	Carbon
C40	C40 Cities Climate Leadership Group
CBA	Cost-benefit analysis
CBD	Convention on Biological Diversity
CBD	Central business district
CCA	Climate Change Agreement
CCE	Cost of conserved energy
CCL	Climate Change Levy
CCS	Carbon dioxide capture and storage
CDM	Clean Development Mechanism
CDR	Carbon dioxide removal
CEA	Cost-effectiveness analysis
CERs	Certified Emissions Reductions
CFCs	Chlorofluorocarbons
CGE	Computable general equilibrium
CH_4	Methane
CHP	Combined heat and power
CIFs	Climate Investment Funds
CMIP	Coupled Model Intercomparison Project
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide-equivalent, CO_2-equivalent
COD	Chemical oxygen demand
COP	Conference of the Parties
CRF	Capital recovery factor
CSP	Concentrated solar power
CTCN	Climate Technology Centre and Network
DAC	Direct air capture
DAC	Development Assistance Committee
DALYs	Disability-adjusted life years
DANN	Designated National Authority
DCs	Developing countries
DRI	Direct reduced iron
DSM	Demand-side management
EAF	Electric arc furnace
EAS	East Asia
ECA	Economic Commission for Africa
ECN	Energy Research Center of the Netherlands
ECOWAS	Economic Community of West African States
EDGAR	Emissions Database for Global Atmospheric Research
EE	Energy efficiency
EIA	U.S. Energy Information Administration
EITs	Economies in Transition
EMF	Energy Modeling Forum
EPA	U.S. Environmental Protection Agency
EPC	Energy performance contracting
ERU	Emissions reduction unit
ESCOs	Energy service companies
ETS	Emissions Trading System
EU	European Union
EU ETS	European Union Emissions Trading Scheme
EVs	Electric vehicles
F-gases	Fluorinated gases
FAO	Food and Agriculture Organization of the United Nations
FAQ	Frequently asked questions
FAR	IPCC First Assessment Report
FCVs	Fuel cell vehicles
FDI	Foreign Direct Investment
FE	Final energy
FEEM	Fondazione Eni Enrico Mattei
FF&I	Fossil fuel and industrial
FIT	Feed-in tariff
FOLU	Forestry and Other Land Use
FSF	Fast-start Finance
G20	Group of Twenty Finance Ministers
G8	Group of Eight Finance Ministers
GATT	General Agreement on Tariffs and Trade
GCAM	Global Change Assessment Model
GCF	Green Climate Fund
GCM	General Circulation Model
GDP	Gross domestic product
GEA	Global Energy Assessment
GEF	Global Environment Facility
GHG	Greenhouse gas
GNE	Gross national expenditure
GSEP	Global Superior Energy Performance Partnership
GTM	Global Timber Model
GTP	Global Temperature Change Potential
GWP	Global Warming Potential

AI

H_2	Hydrogen
HCFCs	Hydrochlorofluorocarbons
HDI	Human Development Index
HDVs	Heavy-duty vehicles
HFCs	Hydrofluorocarbon
HFC-23	Trifluoromethane
Hg	Mercury
HHV	Higher heating value
HIC	High-income countries
HVAC	Heating, ventilation and air conditioning
IAEA	International Atomic Energy Agency
IAMC	Integrated Assessment Modelling Consortium
ICAO	International Civil Aviation Organization
ICE	Internal combustion engine
ICLEI	International Council for Local Environmental Initiatives
ICT	Information and communication technology
IDB	Inter-American Development Bank
IDP	Integrated Design Process
IEA	International Energy Agency
IET	International Emissions Trading
IGCC	Integrated gasification combined cycle
IIASA	International Institute for Applied Systems Analysis
iLUC	Indirect land-use change
IMF	International Monetary Fund
IMO	International Maritime Organization
INT TRA	International transport
IO	International organization
IP	Intellectual property
IPAT	Income-Population-Affluence-Technology
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
IRR	Internal rate of return
ISO	International Organization for Standardization
JI	Joint Implementation
JICA	Japan International Cooperation Agency
KfW	Kreditanstalt für Wiederaufbau
LAM	Latin America
LCA	Lifecycle Assessment
LCCC	Levelized costs of conserved carbon
LCD	Liquid crystal display
LCCE	Levelized cost of conserved energy
LCOE	Levelized costs of energy
LDCs	Least Developed Countries
LDCF	Least Developed Countries Fund
LDVs	Light-duty vehicles
LED	Light-emitting diode
LHV	Lower heating value
LIC	Low-income countries
LIMITS	Low Climate Impact Scenarios and Implications of Required Tight Emission Control Strategies
LMC	Lower-middle income countries
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
LUC	Land-use change
LULUCF	Land Use, Land-Use Change and Forestry
MAC	Marginal abatement cost
MAF	Middle East and Africa
MAGICC	Model for the Assessment of Greenhouse Gas Induced Climate Change
MCA	Multi-criteria analysis
MDB	Multilateral Development Bank
MDGs	Millennium Development Goals
MEF	Major Economies Forum on Energy and Climate
MER	Market exchange rate
MFA	Material flow analysis
MNA	Middle East and North Africa
MRIO	Multi-Regional Input-Output Analysis
MRV	Measurement, reporting, and verification
MSW	Municipal solid waste
N	Nitrogen
N_2O	Nitrous oxide
NAM	North America
NAMA	Nationally Appropriate Mitigation Action
NAPA	National Adaptation Programmes of Action
NAS	U.S. National Academy of Science
NF_3	Nitrogen trifluoride
NGCC	Natural gas combined cycle
NGO	Non-governmental organization
NH_3	Ammonia
NO_x	Nitrogen oxides
NPV	Net present value
NRC	U.S. National Research Council
NREL	U.S. National Renewable Energy Laboratory
NZEB	Net zero energy buildings
O_3	Ozone
O&M	Operation and maintenance
OC	Organic carbon
ODA	Official development assistance
ODS	Ozone-depleting substances
OECD	Organisation for Economic Co-operation and Development
OPEC	Organization of Petroleum Exporting Countries
PACE	Property Assessed Clean Energy
PAS	South-East Asia and Pacific
PBL	Netherlands Environmental Assessment Agency
PC	Pulverized Coal
PDF	Probability density function
PEVs	Plug-in electric vehicles
PFC	Perfluorocarbons
PHEVs	Plug-in hybrid electric vehicles
PIK	Potsdam Institute for Climate Impact Research
PM	Particulate Matter
PNNL	Pacific Northwest National Laboratories
POEDC	Pacific OECD 1990 members (Japan, Aus, NZ)
PPP	Polluter pays principle

PPP	Purchasing power parity
PV	Photovoltaic
R&D	Research and development
RCPs	Representative Concentration Pathways
RD&D	Research, Development and Demonstration
RE	Renewable energy
RECIPE	Report on Energy and Climate Policy in Europe
REDD	Reducing Emissions From Deforestation and Forest Degradation
REEEP	Renewable Energy and Energy Efficiency Partnership
RES	Renewable energy sources
RGGI	Regional Greenhouse Gas Initiative
RoSE	Roadmaps towards Sustainable Energy futures
ROW	Rest of the World
RPS	Renewable portfolio standards
SAR	IPCC Second Assessment Report
SAS	South Asia
SCC	Social cost of carbon
SCCF	Special Climate Change Fund
SCP	Sustainable consumption and production
SD	Sustainable development
SF_6	Sulphur hexafluoride
SLCP	Short-lived climate pollutant
SMEs	Small and Medium Enterprises
SO_2	Sulphur dioxide
SPM	Summary for Policymakers
SRES	IPCC Special Report on Emission Scenarios
SREX	IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation
SRM	Solar radiation management
SRREN	IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation
SRCSS	IPCC Special Report on Carbon dioxide Capture and Storage
SSA	Sub-Saharan Africa
SUVs	Sport Utility Vehicles
SWF	Social welfare function
TAR	IPCC Third Assessment Report
TC	Technological change
TCR	Transient climate response
Th	Thorium
TNAs	Technology Needs Assessments
TOD	Transit-oriented development
TPES	Total primary energy supply
TRIPs	Trade Related Intellectual Property Rights
TT	Technology transfer
U	Uranium
UHI	Urban heat island
UMC	Upper-middle income countries
UN	United Nations
UN DESA	United Nations Department for Economic and Social Affairs
UNCCD	United Nations Convention to Combat Desertification
UNCSD	United Nations Conference on Sustainable Development
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization
USD	U.S. Dollars
VAs	Voluntary agreements
VOCs	Volatile Organic Compounds
VKT	Vehicle kilometers travelled
WACC	Weighted costs of capital
WBCSD	World Business Council on Sustainable Development
WCED	World Commission on Environment and Development
WCI	Western Climate Initiative
WEU	Western Europe
WGI	IPCC Working Group I
WGII	IPCC Working Group II
WGIII	IPCC Working Group III
WHO	World Health Organization
WTP	Willingness to pay
WWTP	Wastewater plant
WTO	World Trade Organization

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ANNEX

II

Metrics & Methodology

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Contents

AII

This annex on methods and metrics provides background information on material used in the Working Group III Contribution to the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (WGIII AR5). The material presented in this annex documents metrics, methods, and common data sets that are typically used across multiple chapters of the report. The annex is composed of three parts: Part I introduces standards metrics and common definitions adopted in the report; Part II presents methods to derive or calculate certain quantities used in the report; and Part III provides more detailed background information about common data sources that go beyond what can be included in the chapters. While this structure may help readers to navigate through the annex, it is not possible in all cases to unambiguously assign a certain topic to one of these parts, naturally leading to some overlap between the parts.

Part I: Units and definitions

A.II.1 Standard units and unit conversion

The following section, A.II.1.1, introduces standard units of measurement that are used throughout this report. This includes Système International (SI) units, SI-derived units, and other non-SI units as well the standard prefixes for basic physical units. It builds upon similar material from previous IPCC reports (IPCC, 2001; Moomaw et al., 2011).

In addition to establishing a consistent set of units for reporting throughout the report, harmonized conventions for converting units as reported in the scientific literature have been established and are summarized in Section A.II.1.2 (physical unit conversion) and Section A.II.1.3 (monetary unit conversion).

A.II.1.1 Standard units

Table A.II.1 | Système International (SI) units.

Physical Quantity	Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Thermodynamic temperature	kelvin	K
Amount of Substance	mole	mol

Table A.II.2 | Special names and symbols for certain SI-derived units.

Physical Quantity	Unit	Symbol	Definition
Force	Newton	N	kg m s^2
Pressure	Pascal	Pa	kg m^–1 s^–2 (= N m^–2)
Energy	Joule	J	kg m^2 s^–2
Power	Watt	W	kg m^2 s^–3 (= J s^–1)
Frequency	Hertz	Hz	s^–1 (cycles per second)
Ionizing Radiation Dose	sievert	Sv	J kg^-1

Table A.II.3 | Non-SI standard units.

Monetary units	Unit	Symbol
Currency (Market Exchange Rate, MER)	constant US Dollar 2010	USD_{2010}
Currency (Purchasing Power Parity, PPP)	constant International Dollar 2005	$Int\$_{2005}$
Emission- and Climate-related units	**Unit**	**Symbol**
Emissions	Metric tonnes	t
CO_2 Emissions	Metric tonnes CO_2	tCO_2
CO_2-equivalent Emissions	Metric tonnes CO_2-equivalent*	tCO_2eq
Abatement Costs and Emissions Prices/Taxes	constant US Dollar 2010 per metric tonne	USD_{2010}/t
CO_2 concentration or Mixing Ratio (μmol mol–1)	Parts per million (10^6)	ppm
CH_4 concentration or Mixing Ratio (μmol mol–1)	Parts per billion (10^9)	ppb
N_2O concentration or Mixing Ratio (μmol mol–1)	Parts per billion (10^9)	ppb
Radiative forcing	Watts per square meter	W/m^2
Energy-related units	**Unit**	**Symbol**
Energy	Joule	J
Electricity and Heat generation	Watt Hours	Wh
Power (Peak Capacity)	Watt (Watt thermal, Watt electric)	W (W_{th}, W_e)
Capacity Factor	Percent	%
Technical and Economic Lifetime	Years	yr
Specific Energy Investment Costs	US Dollar 2010 per kW (peak capacity)	USD_{2010}/kW
Energy Costs (e.g., LCOE) and Prices	constant US Dollar 2010 per GJ or US Cents 2010 per kWh	USD_{2010}/GJ and $USct_{2010}/kWh$
Passenger-Distance	passenger-kilometer	p-km
Payload-Distance	tonne-kilometer	t-km
Land-related units	**Unit**	**Symbol**
Area	Hectare	ha

Note:
* CO_2-equivalent emissions in this report are—if not stated otherwise—aggregated using global warming potentials (GWPs) over a 100-year time horizon, often derived from the IPCC Second Assessment Report (IPCC, 1995a). A discussion about different GHG metrics can be found in Sections 1.2.5 and 3.9.6 (see Annex II.9.1 for the GWP values of the different GHGs).

Table A.II.4 | Prefixes for basic physical units.

Multiple	Prefix	Symbol	Fraction	Prefix	Symbol
1E+21	zeta	Z	1E-01	deci	d
1E+18	exa	E	1E-02	centi	c
1E+15	peta	P	1E-03	milli	m
1E+12	tera	T	1E-06	micro	µ
1E+09	giga	G	1E-09	nano	n
1E+06	mega	M	1E-12	pico	p
1E+03	kilo	k	1E-15	femto	f
1E+02	hecto	h	1E-18	atto	a
1E+01	deca	da	1E-21	zepto	z

A.II.1.2 Physical unit conversion

Table A.II.5 | Conversion table for common mass units (IPCC, 2001).

To:		kg	t	lt	St	lb
From:	multiply by:					
kilogram	kg	1	1.00E-03	9.84E-04	1.10E-03	2.20E+00
tonne	t	1.00E+03	1	9.84E-01	1.10E+00	2.20E+03
long ton	lt	1.02E+03	1.02E+00	1	1.12E+00	2.24E+03
short ton	st	9.07E+02	9.07E-01	8.93E-01	1	2.00E+03
Pound	lb	4.54E-01	4.54E-04	4.46E-04	5.00E-04	1

A.II.1.3 Monetary unit conversion

To achieve comparability across cost und price information from different regions, where possible all monetary quantities reported in the WGIII AR5 have been converted to constant US Dollars 2010 (USD_{2010}). This only applies to monetary quantities reported in market exchange rates (MER), and not to those reported in purchasing power parity (PPP, unit: Int$).

To facilitate a consistent monetary unit conversion process, a simple and transparent procedure to convert different monetary units from the literature to USD_{2010} was established which is described below.

It is important to note that there is no single agreed upon method of dealing with monetary unit conversion, and thus data availability, transparency, and—for practical reasons—simplicity, were the most important criteria for choosing a method to be used throughout this report.

To convert from year X local currency unit (LCU_X) to 2010 US Dollars (USD_{2010}) two steps are necessary:

1. in-/deflating from year X to 2010, and
2. converting from LCU to USD.

Table A.II.6 | Conversion table for common volumetric units (IPCC, 2001).

To:		gal US	gal UK	bbl	ft³	l	m³
From:	multiply by:						
US Gallon	gal US	1	8.33E-01	2.38E-02	1.34E-01	3.79E+00	3.80E-03
UK/Imperial Gallon	gal UK	1.20E+00	1	2.86E-02	1.61E-01	4.55E+00	4.50E-03
Barrel	bbl	4.20E+01	3.50E+01	1	5.62E+00	1.59E+02	1.59E-01
Cubic foot	ft³	7.48E+00	6.23E+00	1.78E-01	1	2.83E+01	2.83E-02
Liter	l	2.64E-01	2.20E-01	6.30E-03	3.53E-02	1	1.00E-03
Cubic meter	m³	2.64E+02	2.20E+02	6.29E+00	3.53E+01	1.00E+03	1

Table A.II.7 | Conversion table for common energy units (NAS, 2007; IEA, 2012a).

To:		TJ	Gcal	Mtoe	Mtce	MBtu	GWh
From:	multiply by:						
Tera Joule	TJ	1	2.39E+02	2.39E-05	3.41E-05	9.48E+02	2.78E-01
Giga Calorie	Gcal	4.19E-03	1	1.00E-07	1.43E-07	3.97E+00	1.16E-03
Mega Tonne Oil Equivalent	Mtoe	4.19E+04	1.00E+07	1	1.43E+00	3.97E+07	1.16E+04
Mega Tonne Coal Equivalent	Mtce	2.93E+04	7.00E+06	7.00E-01	1	2.78E+07	8.14E+03
Million British Thermal Units	MBtu	1.06E-03	2.52E-01	2.52E-08	3.60E-08	1	2.93E-04
Giga Watt Hours	GWh	3.60E+00	8.60E+02	8.60E-05	0.000123	3.41E+03	1

In practice, the order of applying these two steps will lead to different results. In this report, the conversion route LCU_X -> LCU_{2010} -> USD_{2010} is adopted, i.e., national/regional deflators are used to measure country- or region-specific inflation between year X and 2010 in local currency and current (2010) exchange rates are then used to convert to USD_{2010}.

To reflect the change in prices of all goods and services that an economy produces, and to keep the procedure simple, the economy's GDP deflator is chosen to convert to a common base year. Finally, when converting from LCU_{2010} to USD_{2010}, official 2010 exchange rates, which are readily available, but on the downside often fluctuate significantly in the short term, are adopted for currency conversion in the report.

Consistent with the choice of the World Bank databases as the primary source for gross domestic product (GDP) (see Section A.II.9) and other financial data throughout the report, deflators and exchange rates from the World Bank's World Development Indicators (WDI) database (World Bank, 2013) is used.

To summarize, the following procedure has been adopted to convert monetary quantities reported in LCU_X to USD_{2010}:

1. Use the country-/region-specific deflator and multiply with the deflator value to convert from LCU_X to LCU_{2010}. In case national/regional data are reported in non-LCU units (e.g., USD_X or $Euro_X$), which is often the case in multi-national or global studies, apply the corresponding currency deflator to convert to 2010 currency (i.e., the US deflator and the Eurozone deflator in the examples above).
2. Use the appropriate 2010 exchange rate to convert from LCU_{2010} to USD_{2010}.

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A.II.2 Region definitions

In this report a number of different sets of regions are used to present results of analysis. These region sets are referred to as RC5, RC10 (Region Categorization 5 and 10, respectively), see Table A.II.8, and ECON4 (income-based economic categorization), see Table A.II.9. RC10 is a breakdown of RC5 and can be aggregated to RC5 as shown in Table A.II.8. Note that for some exceptional cases in this report there are minor deviations from the RC5 and RC10 definitions given here. In addition to these three standard aggregations some chapters feature an 11 region aggregation (GEA R11) used in the Global Energy Assessment (GEA, 2012) and other studies.

A.II.2.1 RC10

NAM (North America): Canada, Guam, Saint Pierre and Miquelon, United States

WEU (Western Europe): Aland Islands, Andorra, Austria, Belgium, Channel Islands, Denmark, Faroe Islands, Finland, France, Germany, Gibraltar, Greece, Greenland, Guernsey, Holy See (Vatican City State), Iceland, Ireland, Isle of Man, Italy, Jersey, Liechtenstein, Luxembourg, Monaco, Netherlands, Norway, Portugal, San Marino, Spain, Svalbard and Jan Mayen, Sweden, Switzerland, United Kingdom, Turkey

POECD (Pacific OECD): Australia, Japan, New Zealand

EIT (Economies in Transition): Croatia, Cyprus, Czech Republic, Estonia, Latvia, Lithuania, Malta, Poland, Russian Federation, Slovakia,

Table A.II.8 | Description of regions in the RC5 and RC10 region sets.

RC5		RC10	
OECD-1990	OECD Countries in 1990	**NAM**	North America
		WEU	Western Europe
		POECD	Pacific OECD (Japan, Australia, New Zealand)
EIT	Economies in Transition (sometimes referred to as Reforming Economies)	**EIT**	Economies in Transition (Eastern Europe and part of former Soviet Union)
LAM	Latin America and Caribbean	**LAM**	Latin America and Caribbean
MAF	Middle East and Africa	**SSA**	Sub-Saharan Africa
		MNA	Middle East and North Africa
ASIA	Non-OECD Asia	**EAS**	East Asia
		SAS	South Asia
		PAS	South-East Asia and Pacific
INT TRA	International transport	**INT TRA**	International transport

Slovenia, Kyrgyzstan, Tajikistan, Armenia, Georgia, Moldova (Republic of), Ukraine, Uzbekistan, Albania, Azerbaijan, Belarus, Bosnia and Herzegovina, Bulgaria, Hungary, Kazakhstan, Macedonia, Montenegro, Romania, Serbia, Serbia and Montenegro, Turkmenistan

Table A.II.9 | ECON4 income-based economic country aggregations.

HIC	High-income countries
UMC	Upper-middle income countries
LMC	Lower-middle income countries
LIC	Low income countries
INT-TRA	International transport

LAM (Latin America and Caribbean): Anguilla, Antarctica, Antigua and Barbuda, Aruba, Bahamas, Barbados, Bermuda, Bouvet Island, British Virgin Islands, Cayman Islands, Chile, Curacao, Falkland Islands (Malvinas), French Guiana, French Southern Territories, Guadeloupe, Martinique, Montserrat, Netherlands Antilles, Puerto Rico, Saint Kitts and Nevis, Sint Maarten, South Georgia and the South Sandwich Islands, Trinidad and Tobago, Turks and Caicos Islands, Uruguay, US Virgin Islands, Haiti, Bolivia, El Salvador, Guatemala, Guyana, Honduras, Nicaragua, Paraguay, Argentina, Belize, Brazil, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, Grenada, Jamaica, Mexico, Panama, Peru, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Venezuela

SSA (Sub Saharan Africa): Equatorial Guinea, Mayotte, Reunion, Saint Helena, Benin, Burkina Faso, Burundi, Central African Republic, Chad, Comoros, Congo (The Democratic Republic of the), Eritrea, Ethiopia, Gambia, Guinea, Guinea-Bissau, Kenya, Liberia, Madagascar, Malawi, Mali, Mozambique, Niger, Rwanda, Sierra Leone, Somalia, Tanzania, Togo, Uganda, Zimbabwe, Cameroon, Cape Verde, Congo, Cote d'Ivoire, Djibouti, Ghana, Lesotho, Mauritania, Nigeria, Sao Tome and Principe, Senegal, Swaziland, Zambia, Angola, Botswana, Gabon, Mauritius, Namibia, Seychelles, South Africa

MNA (Middle East and North Africa): Bahrain, Israel, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates, Egypt, Morocco, Palestine, South Sudan, Sudan, Syrian Arab Republic, Western Sahara, Yemen, Algeria, Iran, Iraq, Jordan, Lebanon, Libya, Tunisia

EAS (East Asia): South Korea, Korea (Democratic People's Republic of), Mongolia, China

SAS (South Asia): British Indian Ocean Territory, Afghanistan, Bangladesh, Nepal, Bhutan, India, Pakistan, Sri Lanka, Maldives

PAS (South-East Asia and Pacific): Brunei Darussalam, Christmas Island, Cocos (Keeling) Islands, French Polynesia, Heard Island and McDonald Islands, New Caledonia, Norfolk Island, Northern Mariana Islands, Pitcairn, Singapore, Tokelau, US Minor Outlying Islands, Wallis and Futuna, Cambodia, Myanmar, Indonesia, Kiribati, Laos (People's Democratic Republic), Micronesia (Federated States of), Nauru, Papua New Guinea, Philippines, Samoa, Solomon Islands, Timor-Leste, Vanuatu, Viet Nam, Niue, American Samoa, Cook Islands, Fiji, Malaysia, Marshall Islands, Palau, Thailand, Tonga, Tuvalu

INT TRA (International transport): International Aviation, International Shipping

A.II.2.2 RC5

For country mapping to each of the RC5 regions see RC10 mappings (Section A.II.2.1) and their aggregation to RC5 regions in Table A.II.8. It should be noted that this region set was also used in the so-called Representative Concentration Pathways (RCPs, see Section 6.3.2) and therefore has been adopted as a standard in integrated modelling scenarios (Section A.II.10).

A.II.2.3 ECON4

High Income (HIC): Aland Islands, Andorra, Anguilla, Antarctica, Antigua and Barbuda, Aruba, Australia, Austria, Bahamas, Bahrain, Barbados, Belgium, Bermuda, Bouvet Island, British Indian Ocean Territory, British Virgin Islands, Brunei Darussalam, Canada, Cayman Islands, Channel Islands, Chile, Christmas Island, Cocos (Keeling) Islands, Croatia, Curacao, Cyprus, Czech Republic, Denmark, Equatorial Guinea, Estonia, Falkland Islands (Malvinas), Faroe Islands, Finland, France, French Guiana, French Polynesia, French Southern Territories, Germany, Gibraltar, Greece, Greenland, Guadeloupe, Guam, Guernsey, Heard Island and McDonald Islands, Holy See (Vatican City State), Iceland, Ireland, Isle of Man, Israel, Italy, Japan, Jersey, Kuwait, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Martinique, Mayotte, Monaco, Montserrat, Netherlands, Netherlands Antilles, New Caledonia, New Zealand, Norfolk Island, Northern Mariana Islands, Norway, Oman, Pitcairn, Poland, Portugal, Puerto Rico, Qatar, Reunion, Russian Federation, Saint Helena, Saint Kitts and Nevis, Saint Pierre and Miquelon, San Marino, Saudi Arabia, Singapore, Sint Maarten, Slovakia, Slovenia, South Georgia and the South Sandwich Islands, South Korea, Spain, Svalbard and Jan Mayen, Sweden, Switzerland, Tokelau, Trinidad and Tobago, Turks and Caicos Islands, United Arab Emirates, United Kingdom, United States, Uruguay, US Minor Outlying Islands, US Virgin Islands, Wallis and Futuna

Upper Middle Income (UMC): Albania, Algeria, American Samoa, Angola, Argentina, Azerbaijan, Belarus, Belize, Bosnia and Herzegovina, Botswana, Brazil, Bulgaria, China, Colombia, Cook Islands, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, Fiji, Gabon, Grenada, Hungary, Iran, Iraq, Jamaica, Jordan, Kazakhstan, Lebanon, Libya, Macedonia, Malaysia, Maldives, Marshall Islands, Mauritius, Mexico, Montenegro, Namibia, Niue, Palau, Panama, Peru, Romania, Saint Lucia, Saint Vincent and the Grenadines, Serbia, Serbia and Montenegro, Seychelles, South Africa, Suriname, Thailand, Tonga, Tunisia, Turkey, Turkmenistan, Tuvalu, Venezuela

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Lower Middle Income (LMC): Armenia, Bhutan, Bolivia, Cameroon, Cape Verde, Congo, Cote d'Ivoire, Djibouti, Egypt, El Salvador, Georgia, Ghana, Guatemala, Guyana, Honduras, India, Indonesia, Kiribati, Laos (People's Democratic Republic), Lesotho, Mauritania, Micronesia (Federated States of), Moldova (Republic of), Mongolia, Morocco, Nauru, Nicaragua, Nigeria, Pakistan, Palestine, Papua New Guinea, Paraguay, Philippines, Samoa, Sao Tome and Principe, Senegal, Solomon Islands, South Sudan, Sri Lanka, Sudan, Swaziland, Syrian Arab Republic, Timor-Leste, Ukraine, Uzbekistan, Vanuatu, Viet Nam, Western Sahara, Yemen, Zambia

Low Income (LIC): Afghanistan, Bangladesh, Benin, Burkina Faso, Burundi, Cambodia, Central African Republic, Chad, Comoros, Congo (The Democratic Republic of the), Eritrea, Ethiopia, Gambia, Guinea, Guinea-Bissau, Haiti, Kenya, Korea (Democratic People's Republic of), Kyrgyzstan, Liberia, Madagascar, Malawi, Mali, Mozambique, Myanmar, Nepal, Niger, Rwanda, Sierra Leone, Somalia, Tajikistan, Tanzania, Togo, Uganda, Zimbabwe

INT TRA (International transport): International Aviation, International Shipping

A.II.2.4 GEA R11

The 11 regions of GEA R11 are similar to the above RC10 and consist of North America (NAM), Western Europe (WEU), Pacific OECD (POECD [PAO]), Central and Eastern Europe (EEU), Former Soviet Union (FSU), Centrally Planned Asia and China (CPA), South Asia (SAS), Other Pacific Asia (PAS), Middle East and North Africa (MNA [MEA]), Latin America and the Caribbean (LAM [LAC]) and Sub-Saharan Africa (SSA [AFR]). The differences to RC10 are the following:

- RC10 EIT is split in GEA R11 FSU and EEU. To FSU belong Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Republic of Moldova, Russian Federation, Tajikistan, Turkmenistan, Ukraine and Uzbekistan and to EEU belong Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Estonia, Macedonia, Hungary, Latvia, Lithuania, Montenegro, Poland, Romania, Serbia, Slovak Republic and Slovenia.
- GEA R11 NAM matches RC10 NAM plus Puerto Rico and the British Virgin Islands.
- GEA R11 LAM matches RC10 LAM without Puerto Rico and the British Virgin Islands.
- GEA R11 CPA matches RC10 EAS plus Cambodia, Laos (People's Democratic Republic), Viet Nam, without South Korea.
- GEA R11 PAS matches RC10 PAS plus South Korea and Taiwan, Province of China, without Cambodia, Laos (People's Democratic Republic), Viet Nam.

Part II: Methods

A.II.3 Costs metrics

Across this report, a number of different metrics to characterize cost of climate change mitigation are employed. These cost metrics reflect the different levels of detail and system boundaries at which mitigation analysis is conducted. For example, in response to mitigation policies, different technologies are deployed across different sectors. To facilitate a meaningful comparison of economics across diverse options at the technology level, the metric of 'levelized costs' is used throughout several chapters (7, 8, 9, 10, and 11) of this report in various forms (Section A.II.3.1). In holistic approaches to mitigation, such as the ones used in Chapter 6 on transformation pathways, different mitigation cost metrics are used, the differences among which are discussed in Section A.II.3.2.

A.II.3.1 Levelized costs

Levelizing costs means to express all lifetime expenditures of a stream of relatively homogeneous outputs that occur over time as cost per unit of output. Most commonly, the concept is applied to electricity as an output. It is also being applied to express costs of other streams of outputs such as energy savings and greenhouse gas (GHG) emission savings. Each of these metrics provides a benchmark for comparing different technologies or practices of providing the respective output. Each also comes with a set of context-specific caveats that need to be taken into account for correct interpretation. Various literature sources caution against drawing too strong conclusions from these metrics. The levelized cost of energy (LCOE), the levelized cost of conserved energy (LCCE), and the levelized cost of conserved carbon (LCCC) are used throughout the WGIII AR5 to provide output-specific benchmarks for comparison. They are explained and discussed below in the mentioned order.[1]

A.II.3.1.1 Levelized cost of energy

Background

In order to compare energy supply technologies from an economic point of view, the concept of 'levelized cost of energy' (LCOE, also called levelized unit cost or levelized generation cost) frequently is applied (IEA and NEA, 2005; IEA, 2010a; Fischedick et al., 2011; Lar-

[1] This section, however, does not take into account the implications for additional objectives beyond energy supply (LCOE), energy savings (LCCE) or mitigation (LCCC)—often referred to as co-benefits and adverse side-effects (see Glossary in Annex I). In particular, external costs are not taken into account if they are not internalized (e.g., via carbon pricing).

son et al., 2012; Turkenburg et al., 2012; UNEP, 2012; IRENA, 2013). Simply put, 'levelized' cost of energy is a measure that can be loosely defined as the long-run 'average' cost of a unit of energy provided by the considered technology (albeit, calculated correctly in an economic sense by taking into account the time value of money). Strictly speaking, the levelized cost of energy is "the cost per unit of energy that, if held constant through the analysis period, would provide the same net present revenue value as the net present value cost of the system." (Short et al., 1995, p. 93). The calculation of the respective 'average' cost (expressed, for instance in US cent/kWh or USD/GJ) palpably facilitates the comparison of projects, which differ in terms of plant size and/or plant lifetime.

General formula and simplifications

According to the definition given above, "the levelized cost is the unique break-even cost price where discounted revenues (price x quantities) are equal to the discounted net expenses" (Moomaw et al., 2011):

$$\sum_{t=0}^{n}\frac{E_t \cdot LCOE}{(1+i)^t} := \sum_{t=0}^{n}\frac{Expenses_t}{(1+i)^t} \qquad \text{(Equation A.II.1)}$$

where $LCOE$ are the levelized cost of energy, E_t is the energy delivered in year t (which might vary from year to year), $Expenses_t$ cover all (net) expenses in the year t, i is the discount rate and n the lifetime of the project.

After solving for LCOE this gives:

$$LCOE := \frac{\sum_{t=0}^{n}\frac{Expenses_t}{(1+i)^t}}{\sum_{t=0}^{n}\frac{E_t}{(1+i)^t}} \qquad \text{(Equation A.II.2)}$$

Note that while it appears as if energy amounts were discounted in Equation A.II.2, this is just an arithmetic result of rearranging Equation A.II.1 (Branker et al., 2011). In fact, originally, revenues are discounted and not energy amounts per se (see Equation A.II.1).

Considering energy conversion technologies, the lifetime expenses comprise investment costs I, operation and maintenance cost $O\&M$ (including waste management costs), fuel costs F, carbon costs C, and decommissioning costs D. In this case, levelized cost can be determined by (IEA, 2010a):

$$LCOE := \frac{\sum_{t=0}^{n}\frac{I_t + O\&M_t + F_t + C_t + D_t}{(1+i)^t}}{\sum_{t=0}^{n}\frac{E_t}{(1+i)^t}} \qquad \text{(Equation A.II.3)}$$

In simple cases, where the energy E provided annually is constant during the lifetime of the project, this translates to:

$$LCOE := \frac{CRF \cdot NPV\,(Lifetime\ Expenses)}{E} = \frac{Annuity\,(Lifetime\ Expenses)}{E} \qquad \text{(Equation A.II.4)}$$

where $CRF := \frac{i}{1-(1+i)^{-n}}$ is the capital recovery factor and NPV the net present value of all lifetime expenditures (Suerkemper et al., 2011). For the simplified case, where the annual costs are also assumed constant over time, this can be further simplified to ($O\&M$ costs and fuel costs F constants):

$$LCOE = \frac{CRF \cdot I + O\&M + F}{E} \qquad \text{(Equation A.II.5)}$$

Where I is the upfront investment, $O\&M$ are the annual operation and maintenance costs, F are the annual fuel costs, and E is the annual energy provision. The investment I should be interpreted (here and also in Equations A.II.7 and A.II.9) as the sum of all capital expenditures needed to make the investment fully operational discounted to $t = 0$. These might include discounted payments for retrofit payments during the lifetime and discounted decommissioning costs at the end of the lifetime. Where applicable, annual O&M costs have to take into account revenues for by-products and existing carbon costs must be added or treated as part of the annual fuel costs.

Discussion of LCOE

The LCOE of a technology is only one indicator for its economic competitiveness, but there are more dimensions to it. Integration costs, time dependent revenue opportunities (especially in the case of intermittent renewables), and relative environmental impacts (e.g., external costs) play an important role as well (Heptonstall, 2007; Fischedick et al., 2011; Joskow, 2011a; Borenstein, 2012; Mills and Wiser, 2012; Edenhofer et al., 2013a; Hirth, 2013). Joskow (2011b) for instance, pointed out that LCOE comparisons of intermittent generating technologies (such as solar energy converters and wind turbines) with dispatchable power plants (e.g., coal or gas power plants) may be misleading as these comparisons fail to take into account the different production schedule and the associated differences in the market value of the electricity that is provided. An extended criticism of the concept of LCOE as applied to renewable energies is provided by (Edenhofer et al., 2013b).

Taking these shortcomings into account, there seems to be a clear understanding that LCOE are not intended to be a definitive guide to actual electricity generation investment decisions (IEA and NEA, 2005; DTI, 2006). Some studies suggest that the role of levelized costs is to give a 'first order assessment' (EERE, 2004) of project viability.

In order to capture the existing uncertainty, sensitivity analyses, which are sometimes based on Monte Carlo methods, are frequently carried out in numerical studies. Darling et al. (2011), for instance, suggest that transparency could be improved by calculating LCOE as a distribution, constructed using input parameter distributions, rather than a single number. Studies based on empirical data, in contrast, may suffer from using samples that do not cover all cases. Summarizing country studies in an effort to provide a global assessment, for instance, might have a bias as data for developing countries often are not available (IEA, 2010a).

As Section 7.8.2 shows, typical LCOE ranges are broad as values vary across the globe depending on the site-specific renewable energy resource base, on local fuel and feedstock prices as well as on country specific projected costs of investment, and operation and maintenance. While noting that system and installation costs vary widely, Branker et al. (2011) document significant variations in the underlying assumptions that go into calculating LCOE for photovoltaic (PV), with many analysts not taking into account recent cost reductions or the associated technological advancements. In summary, a comparison between different technologies should not be based on LCOE data solely; instead, site-, project- and investor specific conditions should be considered (Fischedick et al., 2011).

A.II.3.1.2 Levelized cost of conserved energy

Background

The concept of 'levelized cost of conserved energy' (LCCE), or more frequently referred to as 'cost of conserved energy (CCE)', is very similar to the LCOE concept, primarily intended to be used for comparing the cost of a unit of energy saved to the purchasing cost per unit of energy. In essence the concept, similarly to LCOE, also annualizes the investment and operation and maintenance cost differences between a baseline technology and the energy-efficiency alternative, and divides this quantity by the annual energy savings (Brown et al., 2008). Similarly to LCOE, it also bridges the time lag between the initial additional investment and the future energy savings through the application of the capital recovery factor (Meier, 1983).

General formula and simplifications

The conceptual formula for LCCE is essentially the same as Equation A.II.4 above, with ΔE meaning in this context the amount of energy saved annually (Suerkemper et al., 2011):

$$LCCE := \frac{CRF \cdot NPV(\Delta \text{Lifetime Expenses})}{\Delta E} = \frac{\text{Annuity } (\Delta \text{Lifetime Expenses})}{\Delta E}$$

(Equation A.II.6)

In the case of assumed annually constant O&M costs over the lifetime, this simplifies to (equivalent to Equation A.II.5) (Hansen, 2012):

$$LCCE = \frac{CRF \cdot \Delta I + \Delta O\&M}{\Delta E}$$

(Equation A.II.7)

Where ΔI is the difference in investment costs of an energy saving measure (e.g., in USD) as compared to a baseline investment; $\Delta O\&M$ is the difference in annual operation and maintenance costs of an energy saving measure (e.g., in USD) as compared to the baseline in which the energy saving measure is not implemented; ΔE is the annual energy conserved by the measure (e.g., in kWh) as compared to the usage of the baseline technology; and *CRF* is the capital recovery factor depending on the discount rate i and the lifetime of the measure *n* in years as defined above. It should be stressed once more that this equation is only valid if $\Delta O\&M$ and ΔE are constant over the lifetime. As LCCE are designed to be compared with complementary levelized cost of energy supply, they do not include the annual fuel cost difference. Any additional monetary benefits that are associated with the energy saving measure must be taken into account as part of the O&M difference.

Discussion of LCCE

The main strength of the LCCE concept is that it provides a metric of energy saving investments that are independent of the energy price, and can thus be compared to different energy purchasing cost values for determining the profitability of the investment (Suerkemper et al., 2011).

The key difference in the concept with LCOE is the usage of a reference/baseline technology. LCCE can only be interpreted in context of a reference, and is thus very sensitive to how this reference is chosen (see Section 9.3 and 9.6). For instance, the replacement of a very inefficient refrigerator can be very cost-effective, but if we consider an already relatively efficient product as the reference technology, the LCCE value can be many times higher. This is one of the main challenges in interpreting LCCE.

Another challenge in the calculation of LCCE should be pinpointed. The lifetimes of the efficient and the reference technology may be different. In this case the investment cost difference needs to be used that incurs throughout the lifetime of the longer-living technology. For instance, a compact fluorescent lamp (CFL) lasts as much as 10 times as long as an incandescent lamp. Thus, in the calculation of the LCCE for a CFL replacing an incandescent lamp the saved investments in multiple incandescent lamps should be taken into account (Ürge-Vorsatz, 1996). In such a case, as in some other cases, too, the difference in annualized investment cost can be negative resulting in negative LCCE values. Negative LCCE values mean that the investment is already profitable at the investment level, without the need for the energy savings to recover the extra investment costs.

Taking into account incremental operation and maintenance cost can be important for applications where those are significant, for instance, the lamp replacement on streetlamps, bridges. In such cases a longer-lifetime product, as it typically applies to efficient lighting technologies, is already associated with negative costs at the investment level (less frequent needs for labour to replace the lamps), and thus can result in significantly negative LCCEs or cost savings (Ürge-Vorsatz, 1996). In case of such negative incremental investment cost, some peculiarities may occur. For instance, as can be seen from Equation A.II.7, LCCE decrease (become more negative) with increasing *CRF*, e.g., as a result of an increase in discount rates.

A.II.3.1.3 Levelized cost of conserved carbon

Background

Many find it useful to have a simple metric for identifying the costs of GHG emission mitigation. The metric can be used for comparing mitigation costs per unit of avoided emissions, and comparing these specific emission reduction costs for different options, within a company, within a sector, or even between sectors. This metric is often referred to as levelized cost of conserved carbon (LCCC) or specific GHG mitigation costs. There are several caveats, which will be discussed below, after the general approach is introduced.

General formula and simplification

For calculation of specific mitigation costs, the following, equation holds, where ΔC is the annual reduction in GHG emissions achieved through the implementation of an option. The equation is equivalent to Equations A.II.4 and A.II.6.

$$LCCC := \frac{CRF \cdot NPV(\Delta LifetimeExpenses)}{\Delta C} = \frac{Annuity(\Delta LifetimeExpenses)}{\Delta C}$$

(Equation A.II.8)

Also this equation can be simplified under the assumption of annual GHG emission reduction, annual O&M costs and annual benefits ΔB being constant over the lifetime of the option.

$$LCCC = \frac{CRF \cdot \Delta I + \Delta O\&M - \Delta B}{\Delta C} \qquad \text{(Equation A.II.9)}$$

Where ΔI is the difference in investment costs of a mitigation measure (e.g., in USD) as compared to a baseline investment; $\Delta O\&M$ is the difference in annual operation and maintenance costs (e.g., in USD) and ΔB denotes the annual benefits, all compared to a baseline for which the option is not implemented. Note that annual benefits include reduced expenditures for fuels, if the investment project reduces GHG emissions via a reduction in fuel use. As such LCCC depend on energy prices.

An important characteristic of this equation is that LCCC can become negative if ΔB is bigger than the sum of the other two terms in the numerator.

Discussion of LCCC

Several issues need to be taken into account when using LCCC. First of all, the calculation of LCCC for one specific option does not take into account the fact that each option is implemented in a system, and the value of the LCCC of one option will depend on whether other options will be implemented or not (e.g., because the latter might influence the specific emissions of the background system). To solve this issue, analysts use integrated models, in which ideally these interactions are taken into account (see Chapter 6). Second, energy prices and other benefits are highly variable from region to region, rarely constant over time, and often difficult to predict. This issue is relevant for any analysis on mitigation, but it is always important to be aware of the fact that even if one single LCCC number is reported, there will be substantial uncertainty in that number. Uncertainty tends to increase from LCOE to LCCE, for example, due to additional uncertainty with regard to the choice of the baseline, and even further for LCCC, since not only a baseline needs to be defined, but furthermore the monetary benefit from energy savings needs to be taken into account (if the mitigation measure affects energy consumption). Moving from LCOE to LCCC in the field of energy supply technologies, for instance, results in comparing LCOE differences to the differences of the specific emissions of the mitigation technology compared to the reference plant (Rubin, 2012). As Sections 7.8.1 and 7.8.2 have shown, LCOE and specific emissions exhibit large uncertainties in their own, which result in an even exaggerated uncertainty once combined to yield the LCCC. Third, options with negative costs can occur, for example, in cases where incremental investment cost are taken to be negative. Finally, there is also a debate whether options with negative costs can occur at all, as it apparently suggests a situation of non-optimized behaviour. For further discussion of negative costs, see Box 3.10 in Chapter 3 of this report.

Levelized costs of conserved carbon are used to determine abatement cost curves, which are frequently applied in climate change decision making. The merits and shortcoming of abatement cost curves are discussed in the IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN) (Fischedick et al., 2011) and in Chapter 3 (Section 3.9.3) of the AR5. In order to avoid some of the shortcomings of abatement cost curves, the AR5 opted to use integrated modelling scenarios in order to evaluate the economic potential of specific mitigation options in a consistent way. Integrated models are able to determine the economic potential of single mitigation options within the context of (other) competing supply-side and demand-side options by taking their interaction and potential endogenous learning effects into account. The results obtained in this way are discussed in Chapter 6.

A.II.3.2 Mitigation cost metrics

There is no single metric for reporting the costs of mitigation, and the metrics that are available are not directly comparable (see Section 3.9.3 for a more general discussion; see Section 6.3.6 for an overview of costs used in model analysis). In economic theory the most direct cost measure is a change in welfare due to changes in the amount and composition of consumption of goods and services by individuals. Important measures of welfare change include 'equivalent variation' and 'compensating variation', which attempt to discern how much individual income would need to change to keep consumers just as well off after the imposition of a policy as before. However, these are quite difficult to calculate, so a more common welfare measurement is change in consumption, which captures the total amount of money consumers are able to spend on goods and services. Another common metric is the change in gross domestic product (GDP). However, GDP is a less satisfactory measure of overall mitigation cost than those focused on individual income and consumption, because it is an output-related measure that in addition to consumption also includes investment, imports and exports, and government spending. Aggregate consumption and GDP losses are only available from an analysis of the policy impact on the full economy. Common cost measures used in studies of the policy impact on specific economic sectors, such as the energy sector, are the reduction in consumer and producer surplus and the 'area under the marginal abatement cost function'.

From a practical perspective, different modelling frameworks applied in mitigation analysis are capable of producing different cost estimates (Section 6.2). Therefore, when comparing cost estimates across mitigation scenarios from different models, some degree of incomparability must necessarily result. In representing costs across transformation pathways in this report and more specifically Chapter 6, consumption losses are used preferentially when available from general equilibrium models, and costs represented by the area under the marginal abatement cost function or the reduction of consumer and producer surplus are used for partial equilibrium models. Costs are generally measured relative to a baseline scenario without mitigation policy. Consumption losses can be expressed in terms of, inter alia, the reduction of baseline consumption in a given year or the annual average reduction of consumption growth in the baseline over a given time period.

AII

One popular measure used in different studies to evaluate the economic implications of mitigation actions is the emissions price, often presented in per tonne of CO_2 or per tonne of CO_2-equivalent (CO_2eq). However, it is important to emphasize that emissions prices are not cost measures. There are two important reasons why emissions prices are not a meaningful representation of costs. First, emissions prices measure marginal cost, i.e., the cost of an incremental reduction of emissions by one unit. In contrast, total costs represent the costs of all mitigation that took place at lower cost than the emissions price. Without explicitly accounting for these 'inframarginal' costs, it is impossible to know how the carbon price relates to total mitigation costs. Second, emissions prices can interact with other existing or new policies and measures, such as regulatory policies that aim at reducing GHG emissions (e.g., feed-in tariffs, subsidies to low-carbon technologies, renewable portfolio standards) or other taxes on energy, labour, or capital. If mitigation is achieved partly by these other measures, the emissions price will not take into account the full costs of an additional unit of emissions reductions, and will indicate a lower marginal cost than is actually warranted.

It is important to calculate the total cost of mitigation over the entire lifetime of a policy. The application of discounting is common practice in economics when comparing costs over time. In Chapter 3, Section 3.6.2 provides some theoretical background on the choice of discount rates in the context of cost-benefit analysis (CBA), where discounting is crucial, because potential climate damages, and thus benefits from their avoidance, will occur far in the future, are highly uncertain, and are often in the form of non-market goods. In Chapter 6, mitigation costs are assessed primarily in the context of cost-effectiveness analysis, in which a target for the long-term climate outcome is specified and models are used to estimate the cost of reaching it, under a variety of constraints and assumptions (Section 6.3.2). These scenarios do not involve the valuation of damages and the difficulties arising from their aggregation. Nonetheless, the models surveyed in Chapter 6 consider transformation pathways over long time horizons, so they must specify how decision makers view intertemporal tradeoffs.

The standard approach is to use a discount rate that approximates the interest rate, that is, the marginal productivity of capital. Empirical estimates of the long-run average return to a diversified portfolio are typically in the 4%–6% range. In scenarios where the long-term target is set, the discounting approach will have an effect only on the speed and shape of the mitigation schedule, not on the overall level of stringency (note that this is in sharp contrast to cost-benefit analysis, where the discounting approach is a strong determinant of the level of stringency). Although a systematic comparison of alternative discounting approaches in a cost-effectiveness setting does not exist in the literature, we can make the qualitative inference that when a policy-maker places more (less) weight on the future, mitigation effort will be shifted sooner (later) in time. Because of long-lived capital dynamics in the energy system, and also because of expected technical change, mitigation effort in a cost-effectiveness analysis typically begins gradually and increases over time, leading to a rising cost profile. Thus, an analogous inference can be made that when a policy-maker places more (less) weight on the future, mitigation costs will be higher (lower) earlier and lower (higher) later.

Estimates of the macroeconomic cost of mitigation usually represent direct mitigation costs and do not take into account co-benefits or adverse side-effects of mitigation actions (see red arrows in Figure A.II.1). Further, these costs are only those of mitigation; they do not capture the benefits of reducing CO_2eq concentrations and limiting climate change.

Two further concepts are introduced in Chapter 6 to classify cost estimates (Section 6.3.6). The first is an idealized implementation approach in which a ubiquitous price on carbon and other GHGs is applied across the globe in every sector of every country and which rises over time at a rate that reflects the increase in the cost of the next available unit of emissions reduction. The second is an idealized implementation environment of efficient global markets in which there are no pre-existing distortions or interactions with other, non-climate market failures. An idealized implementation approach minimizes mitigation costs in an idealized implementation environment. This is not necessarily the case in non-idealized environments in which climate policies interact with existing distortions in labour, energy, capital, and land markets. If those market distortions persist or are aggravated by climate policy, mitigation costs tend to be higher. In turn, if climate policy is brought to bear on reducing such distortions, mitigation costs can be lowered by what has been frequently called a double dividend of climate policy (see blue arrows in Figure A.II.1). Whether or not such a double dividend is available will depend on assumptions about the policy environment and available climate policies.

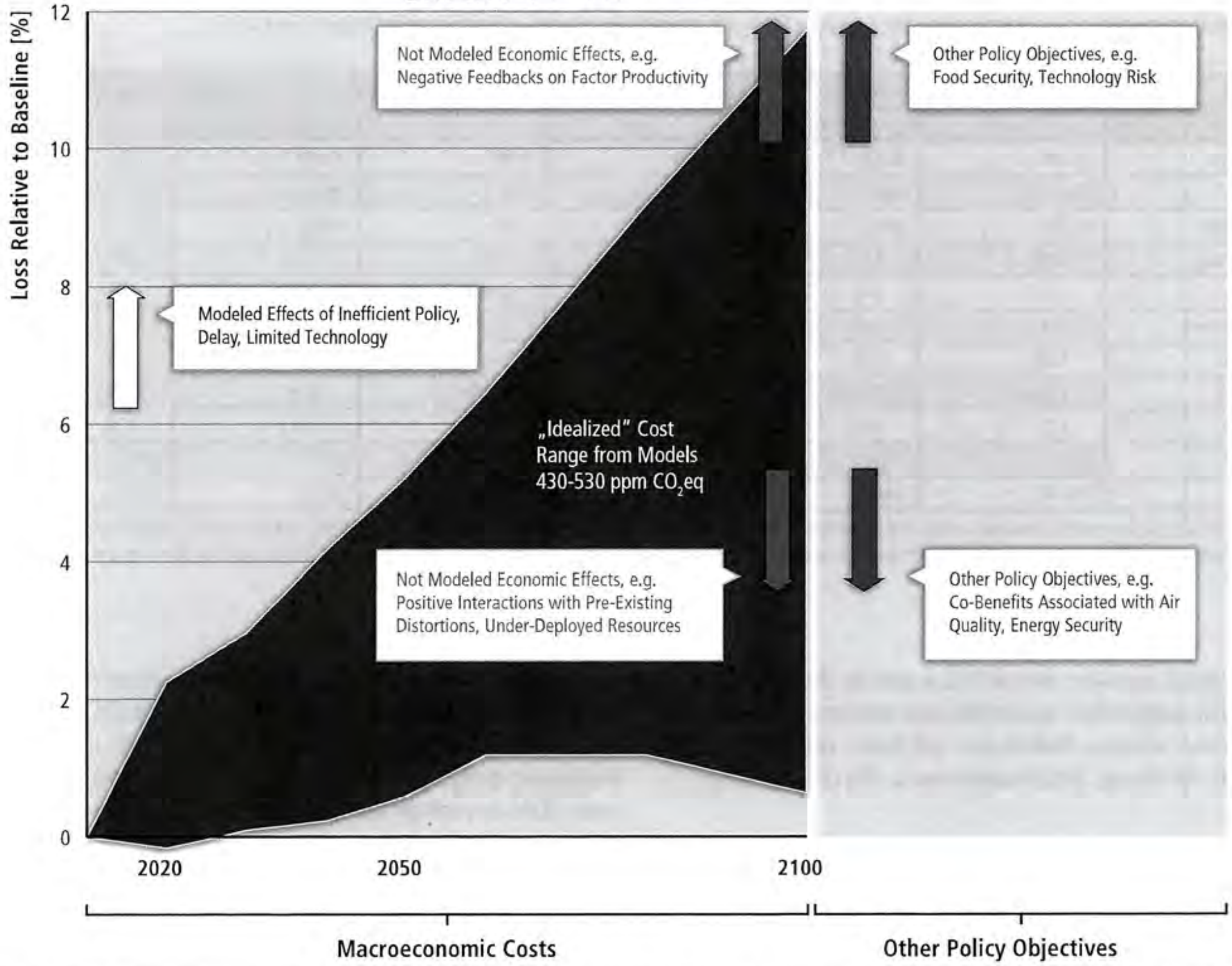

Figure A.II.1 | Modelled policy costs in a broader context. The plotted range summarizes costs expressed as percentage loss relative to baseline across models for cost-effective scenarios reaching 430–530 ppm CO_2eq. Scenarios were sorted by total NPV costs for each available metric (loss in GDP, loss in consumption, area under marginal abatement cost curve as a fraction of GDP). The lower boundary of the plotted range reflects the minimum across metrics of the 25th percentile, while the upper boundary reflects the maximum across metrics of the 75th percentile. A comprehensive treatment of costs and cost metrics, including the effects of non-idealized scenario assumptions, is provided in Section 6.3.6. Other arrows and annotations indicate the potential effects of considerations outside of those included in models. Source: WGIII AR5 Scenario Database.

A.II.4 Primary energy accounting

Following the standard set by the SRREN, this report adopts the direct-equivalent accounting method for the reporting of primary energy from non-combustible energy sources. The following section largely reproduces Annex A.II.4 of the SRREN (Moomaw et al., 2011) with some updates and further clarifications added.

Different energy analyses use a variety of accounting methods that lead to different quantitative outcomes for both reporting of current primary energy use and primary energy use in scenarios that explore future energy transitions. Multiple definitions, methodologies, and metrics are applied. Energy accounting systems are utilized in the literature often without a clear statement as to which system is being used (Lightfoot, 2007; Martinot et al., 2007). An overview of differences in primary energy accounting from different statistics has been described by Macknick (2011) and the implications of applying different accounting systems in long-term scenario analysis were illustrated by Nakicenovic et al., (1998), Moomaw et al. (2011) and Grubler et al. (2012).

Three alternative methods are predominantly used to report primary energy. While the accounting of combustible sources, including all fossil energy forms and biomass, is identical across the different methods, they feature different conventions on how to calculate primary energy supplied by non-combustible energy sources, i.e., nuclear energy and all renewable energy sources except biomass. These methods are:

- *the physical energy content method* adopted, for example, by the OECD, the International Energy Agency (IEA) and Eurostat (IEA/OECD/Eurostat, 2005);
- *the substitution method*, which is used in slightly different variants by BP (2012) and the U.S. Energy Information Administration (EIA, 2012a, b, Table A6), both of which publish international energy statistics; and

Table A.II.10 | Comparison of global total primary energy supply in 2010 using different primary energy accounting methods (data from IEA 2012b).

	Physical content method		Direct equivalent method		Substitution method*	
	EJ	%	EJ	%	EJ	%
Fossil fuels	432.99	81.32	432.99	84.88	432.99	78.83
Nuclear	30.10	5.65	9.95	1.95	26.14	4.76
Renewables	69.28	13.01	67.12	13.16	90.08	16.40
Bioenergy	52.21	9.81	52.21	10.24	52.21	9.51
Solar	0.75	0.14	0.73	0.14	1.03	0.19
Geothermal	2.71	0.51	0.57	0.11	1.02	0.19
Hydro	12.38	2.32	12.38	2.43	32.57	5.93
Ocean	0.002	0.0004	0.002	0.0004	0.005	0.001
Wind	1.23	0.23	1.23	0.24	3.24	0.59
Other	0.07	0.01	0.07	0.01	0.07	0.01
Total	532.44	100.00	510.13	100.00	549.29	100.00

* For the substitution method, conversion efficiencies of 38 % for electricity and 85 % for heat from non-combustible sources were used. The value of 38 % is used by BP for electricity generated from hydro and nuclear. BP does not report solar, wind, and geothermal in its statistics for which, here, also 38 % is used for electricity and 85 % for heat.

- *the direct equivalent method* that is used by UN Statistics (2010) and in multiple IPCC reports that deal with long-term energy and emission scenarios (Nakicenovic and Swart, 2000; Morita et al., 2001; Fisher et al., 2007; Fischedick et al., 2011).

For non-combustible energy sources, the *physical energy content method* adopts the principle that the primary energy form should be the first energy form used down-stream in the production process for which multiple energy uses are practical (IEA/OECD/Eurostat, 2005). This leads to the choice of the following *primary* energy forms:

- heat for nuclear, geothermal, and solar thermal, and
- electricity for hydro, wind, tide/wave/ocean, and solar PV.

Using this method, the primary energy equivalent of hydro energy and solar PV, for example, assumes a 100 % conversion efficiency to 'primary electricity', so that the gross energy input for the source is 3.6 MJ of primary energy = 1 kWh of electricity. Nuclear energy is calculated from the gross generation by assuming a 33 % thermal conversion efficiency[2], i.e., 1 kWh = (3.6 ÷ 0.33) = 10.9 MJ. For geothermal, if no country-specific information is available, the primary energy equivalent is calculated using 10 % conversion efficiency for geothermal electricity (so 1 kWh = (3.6 ÷ 0.1) = 36 MJ), and 50 % for geothermal heat.

The *substitution method* reports primary energy from non-combustible sources in such a way as if they had been substituted for combustible energy. Note, however, that different variants of the substitution method use somewhat different conversion factors. For example, BP applies 38 % conversion efficiency to electricity generated from nuclear and hydro whereas the World Energy Council used 38.6 % for nuclear and non-combustible renewables (WEC, 1993; Grübler et al., 1996; Nakicenovic et al., 1998), and the U.S. Energy Information Administration (EIA) uses still different values. For useful heat generated from non-combustible energy sources, other conversion efficiencies are used. Macknick (2011) provides a more complete overview.

The *direct equivalent method* counts one unit of secondary energy provided from non-combustible sources as one unit of primary energy, i.e., 1 kWh of electricity or heat is accounted for as 1 kWh = 3.6 MJ of primary energy. This method is mostly used in the long-term scenarios literature, including multiple IPCC reports (IPCC, 1995b; Nakicenovic and Swart, 2000; Morita et al., 2001; Fisher et al., 2007; Fischedick et al., 2011), because it deals with fundamental transitions of energy systems that rely to a large extent on low-carbon, non-combustible energy sources.

The accounting of combustible sources, including all fossil energy forms and biomass, includes some ambiguities related to the definition of the heating value of combustible fuels. The higher heating value (HHV), also known as gross calorific value (GCV) or higher calorific value (HCV), includes the latent heat of vaporization of the water produced during combustion of the fuel. In contrast, the lower heating value (LHV) (also: net calorific value (NCV) or lower calorific value (LCV)) excludes this latent heat of vaporization. For coal and oil, the LHV is about 5 % smaller than the HHV, for natural gas and derived gases the difference is roughly 9–10 %, while the concept does not apply to non-combustible energy carriers such as electricity and heat for which LHV and HHV are therefore identical (IEA, 2012a).

In the WGIII AR5, IEA data are utilized, but energy supply is reported using the *direct equivalent method*. In addition, the reporting of com-

[2] As the amount of heat produced in nuclear reactors is not always known, the IEA estimates the primary energy equivalent from the electricity generation by assuming an efficiency of 33 %, which is the average of nuclear power plants in Europe (IEA, 2012b).

bustible energy quantities, including primary energy, should use the LHV which is consistent with the IEA energy balances (IEA, 2012a; b). Table A.II.10 compares the amounts of global primary energy by source and percentages using the *physical energy content, the direct equivalent* and a variant of the *substitution method* for the year 2010 based on IEA data (IEA, 2012b). In current statistical energy data, the main differences in absolute terms appear when comparing nuclear and hydro power. As they both produced comparable amounts of electricity in 2010, under both *direct equivalent* and *substitution methods*, their share of meeting total final consumption is similar, whereas under the *physical energy content method,* nuclear is reported at about three times the primary energy of hydro.

The alternative methods outlined above emphasize different aspects of primary energy supply. Therefore, depending on the application, one method may be more appropriate than another. However, none of them is superior to the others in all facets. In addition, it is important to realize that total primary energy supply does not fully describe an energy system, but is merely one indicator amongst many. Energy balances as published by IEA (2012a; b) offer a much wider set of indicators which allows tracing the flow of energy from the resource to final energy use. For instance, complementing total primary energy consumption by other indicators, such as total final energy consumption and secondary energy production (e.g., of electricity, heat), using different sources helps link the conversion processes with the final use of energy.

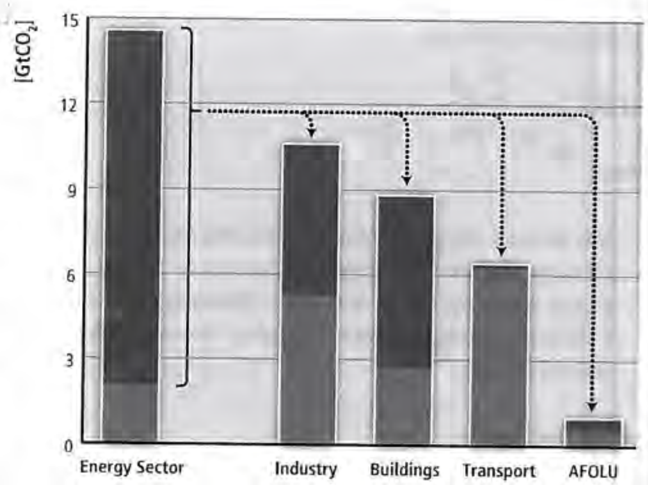

Figure A.II.2 | Energy sector electricity and heat CO_2 emissions calculated for the end-use sectors in 2010. Note that industry sector CO_2 emissions do not include process emissions. Data source: (IEA, 2012b; c).

A.II.5 Indirect primary energy use and CO_2 emissions

Energy statistics in most countries of the world and at the International Energy Agency (IEA) display energy use and carbon dioxide (CO_2) emissions from fuel combustion directly in the energy sectors. As a result, the energy sector is the major source of reported energy use and CO_2 emissions, with the electricity and heat industries representing the largest shares.

However, the main driver for these energy sector emissions is the consumption of electricity and heat in the end use sectors (industry, buildings, transport, and agriculture). Electricity and heat mitigation opportunities in these end use sectors reduce the need for producing these energy carriers upstream and therefore reduce energy and emissions in the energy sector.

In order to account for the impact of mitigation activities in the end use sectors, a methodology has been developed to reallocate the energy consumption and related CO_2 emissions from electricity and heat produced and delivered to the end use sectors (de la Rue du Can and Price, 2008).

Using IEA data, the methodology calculates a series of primary energy factors and CO_2 emissions factors for electricity and heat production at the country level. These factors are then used to re-estimate energy and emissions from electricity and heat produced and delivered to the end use sectors proportionally to their use in each end-use sectors. The calculated results are referred to as primary energy[3] and indirect CO_2 emissions.

The purpose of allocating primary energy consumption and indirect CO_2 emissions to the sectoral level is to relate the energy used and the emissions produced along the entire supply chain to provide energy services in each sector (consumption-based approach). For example, the consumption of one kWh of electricity is not equivalent to the consumption of one kWh of coal or natural gas, because of the energy required and the emissions produced in the generation of one kWh of electricity.

Figure A.II.2 shows the resulting reallocation of CO_2 emissions from electricity and heat production from the energy sector to the industrial, buildings, transport, and agriculture sectors at the global level based on the methodology outlined in de la Rue du Can and Price (2008) and described further below.

A.II.5.1 Primary electricity and heat factors

Primary electricity and heat factors have been derived as the ratio of fuel inputs of power plants relative to the electricity and heat delivered. These factors reflect the efficiency of these transformations.

[3] Note that final energy and primary energy consumption are different concepts (Section A.II.3.4). Final energy consumption (sometimes called site energy consumption) represents the amount of energy consumed in end use applications whereas primary energy consumption (sometimes called source energy consumption) in addition includes the energy required to generate, transmit and distribute electricity and heat.

Primary Electricity Factor:

$$PEF = \frac{\sum_{e,p} EI}{\sum_{p} EO - E\ OU - E\ DL}$$

Where

- *EI* is the total energy (e) inputs for producing Electricity in TJ
- *EO* is the total Electricity Output produced in TJ
- *E OU* is the energy use for own use for Electricity production
- *E DL* is the distribution losses needed to deliver electricity to the end use sectors

Primary Heat Factor:

$$PHF = \frac{\sum_{e,p} HI}{\sum_{p} HO - H\ OU - H\ DL}$$

Where

- *HI* is the total energy (e) inputs for producing Heat in TJ
- *HO* is the total Heat Output produced in TJ
- *H OU* is the energy use for own use for Heat production
- *H DL* is the distribution losses needed to deliver heat to the end use sectors

p represents the 6 plant types in the IEA statistics (Main Activity Electricity Plant, Autoproducer Electricity Plant, Main Activity CHP plant, Autoproducer CHP plant, Main Activity Heat Plant and Autoproducer Heat Plant)

e represents the energy products

It is important to note that two accounting conventions were used to calculate these factors. The first involves estimating the portion of fuel input that produces electricity in combined heat and power plants (CHP) and the second involves accounting for the primary energy value of non-combustible fuel energy used as inputs for the production of electricity and heat. The source of historical data for these calculations is the International Energy Agency (IEA, 2012c; d).

For the CHP calculation, fuel inputs for electricity production were separated from inputs for heat production according to the fixed-heat-efficiency approach used by the IEA (IEA, 2012c). This approach fixes the efficiency for heat production equal to 90 %, which is the typical efficiency of a heat boiler (except when the total CHP efficiency was greater than 90 %, in which case the observed efficiency is used). The estimated input for heat production based on this efficiency was then subtracted from the total CHP fuel inputs, and the remaining fuel inputs to CHP were attributed to the production of electricity. As noted by the IEA, this approach may overstate the actual heat efficiency in certain circumstances (IEA, 2012c; d).

As described in Section A.II.4 in more detail, different accounting methods to report primary energy use of electricity and heat production from non-combustible energy sources, including non-biomass renewable energy and nuclear energy, exist. The direct equivalent accounting method is used here for this calculation.

Global average primary and electricity factors and their historical trends are presented in Figure A.II.3. Average factors for fossil power and heat plants are in the range of 2.5 and 3 and factors for non-biomass renewable energy and nuclear energy are by convention a little above one, depending on heat and electricity own use consumption and distribution losses.

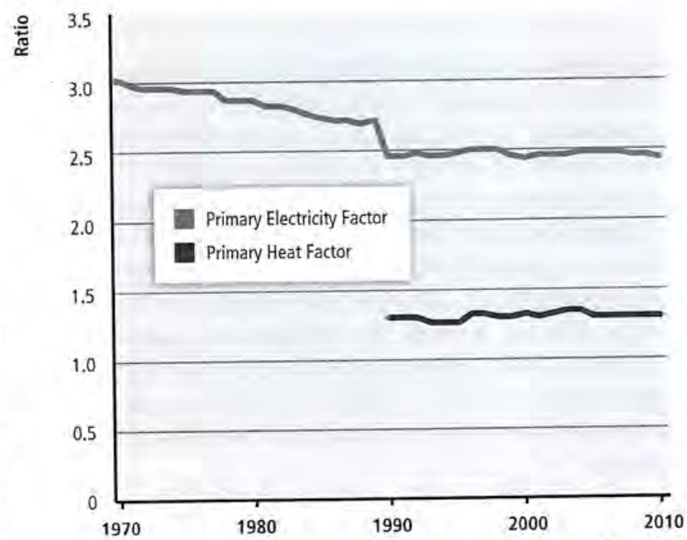

Figure A.II.3 | Historical primary electricity and heat factors. Data source: (IEA, 2012b).

A.II.5.2 Carbon dioxide emission factors

Carbon dioxide emission factors for electricity and heat have been derived as the ratio of CO_2 emissions from fuel inputs of power plants relative to the electricity and heat delivered. The method is equivalent to the one described above for primary factors. The fuel inputs have in addition been multiplied by their CO_2 emission factors of each fuel type as defined in IPCC (2006). The calculation of electricity and heat related CO_2 emission factors are conducted at the country level. Indirect carbon emissions related to electricity and heat consumption are then derived by simply multiplying the amount of electricity and heat consumed with the derived electricity and heat CO_2 emission factors at the sectoral level.

When the results of the methodology described above to estimate end-use CO_2 emissions from electricity and heat production are compared with the reported IEA direct emissions from the heat and electricity sectors there is an average difference of + 1.36 % over the years 1970 to 2010, indicating a slight overestimation of global CO_2 emissions. This difference varies by year, with the largest negative dif-

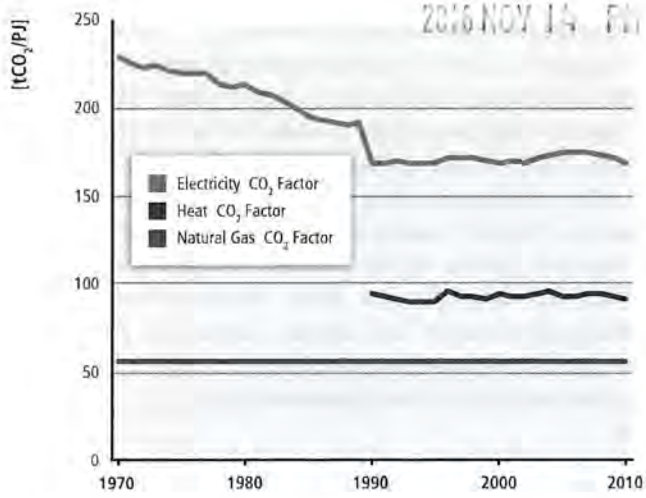

Figure A.II.4 | Historical electricity and heat CO_2 emissions factors. Data source: (IEA, 2012b; c).

ference in 1976 (-2.99 %) and the largest positive difference in 1990 (3.23 %).

The cross-sectoral annual total indirect carbon emissions were then normalized to the direct emission from electricity and heat production on the global level.

Figure A.II.4 shows the historical electricity CO_2 emission factors. The factors reflect both the fuel mix and conversion efficiencies in electricity generation and the distribution losses. Regions with high shares of non-fossil electricity generation have low emissions coefficients. For example, Latin America has a high share of hydro power and therefore a low CO_2 emission factor in electricity generation.

Primary heat and heat carbon factors were also calculated however, due to irregularity in data availability over the years at the global level, only data from 1990 are shown in the figures.

The emission factor for natural gas, 56.1 tCO_2 per PJ combusted, is shown in the graph for comparison.

A.II.6 Material flow analysis, input-output analysis, and lifecycle assessment

In the WGIII AR5, findings from material flow analysis, input-output analysis, and lifecycle assessment are used in Chapters 1, 4, 5, 7, 8, 9, 11, and 12. The following section briefly sketches the intellectual background of these methods and discusses their usefulness for mitigation research, and discusses some relevant assumptions, limitations, and methodological issues.

The anthropogenic contributions to climate change, caused by fossil fuel combustion, land conversion for agriculture, commercial forestry and infrastructure, and numerous agricultural and industrial processes, result from the use of natural resources, i. e., the manipulation of material and energy flows by humans for human purposes. Mitigation research has a long tradition of addressing the energy flows and associated emissions, however, the sectors involved in energy supply and use are coupled with each other through material stocks and flows, which leads to feedbacks and delays. These linkages between energy and material stocks and flows have, despite their considerable relevance for GHG emissions, so far gained little attention in climate change mitigation (and adaptation). The research agendas of industrial ecology and ecological economics with their focus on the socioeconomic metabolism (Wolman, 1965; Baccini and Brunner, 1991; Ayres and Simonis, 1994; Fischer-Kowalski and Haberl, 1997) also known as the biophysical economy (Cleveland et al., 1984), can complement energy assessments in important manners and support the development of a broader framing of mitigation research as part of sustainability science. The socio-economic metabolism consists of the physical stocks and flows with which a society maintains and reproduces itself (Fischer-Kowalski and Haberl, 2007). These research traditions are relevant for sustainability because they comprehensively account for resource flows and hence can be used to address the dynamics, efficiency, and emissions of production systems that convert or utilize resources to provide goods and services to final consumers. Central to the socio-metabolic research methods are material and energy balance principles applied at various scales ranging from individual production processes to companies, regions, value chains, economic sectors, and nations.

An important application of these methods is carbon footprinting, i. e., the determination of lifecycle GHG emissions of products, organizations, households, municipalities, or nations. The carbon footprint of products usually determined using lifecycle assessment, while the carbon footprint of households, regional entities, or nations is commonly modeled using input-output analysis.

A.II.6.1 Material flow analysis

Material flow analysis (MFA)—including substance flow analysis (SFA)—is a method for describing, modelling (using socio-economic and technological drivers), simulating (scenario development), and visualizing the socioeconomic stocks and flows of matter and energy in systems defined in space and time to inform policies on resource and waste management and pollution control. Mass- and energy balance consistency is enforced at the level of goods and/or individual substances. As a result of the application of consistency criteria they are useful to analyze feedbacks within complex systems, e. g., the interrelations between diets, food production in cropland and livestock systems, and availability of area for bioenergy production (e.g., Erb et al. (2012), see Section 11.4).

The concept of socioeconomic metabolism (Ayres and Kneese, 1969; Boulding, 1972; Martinez-Alier, 1987; Baccini and Brunner, 1991; Ayres and Simonis, 1994; Fischer-Kowalski and Haberl, 1997) has been developed as an approach to study the extraction of materials or energy from the environment, their conversion in production and consumption processes, and the resulting outputs to the environment. Accordingly, the unit of analysis is the socioeconomic system (or some of its components), treated as a systemic entity, in analogy to an organism or a sophisticated machine that requires material and energy inputs from the natural environment in order to carry out certain defined functions and that results in outputs such as wastes and emissions.

Some MFAs trace the stocks and flows of aggregated groups of materials (fossil fuels, biomass, ores and industrial minerals, construction materials) through societies and can be performed on the global scale (Krausmann et al., 2009), for national economies and groups of countries (Weisz et al., 2006), urban systems (Wolman, 1965; Kennedy et al., 2007) or other socioeconomic subsystems. Similarly comprehensive methods that apply the same system boundaries have been developed to account for energy flows (Haberl, 2001a; b; Haberl et al., 2006), carbon flows (Erb et al., 2008) and biomass flows (Krausmann et al., 2008) and are often subsumed in the Material and Energy Flow Accounting (MEFA) framework (Haberl et al., 2004). Other MFAs have been conducted for analyzing the cycles of individual substances (e.g., carbon, nitrogen, or phosphorus cycles; Erb et al., 2008) or metals (e.g., copper, iron, or cadmium cycles; Graedel and Cao, 2010) within socioeconomic systems. A third group of MFAs have a focus on individual processes with an aim to balance a wide variety of goods and substances (e.g., waste incineration, a shredder plant, or a city).

The MFA approach has also been extended towards the analysis of socio-ecological systems, i.e., coupled human-environment systems. One example for this research strand is the 'human appropriation of net primary production' or HANPP which assesses human-induced changes in biomass flows in terrestrial ecosystems (Vitousek et al., 1986; Wright, 1990; Imhoff et al., 2004; Haberl et al., 2007). The socio-ecological metabolism approach is particularly useful for assessing feedbacks in the global land system, e.g., interrelations between production and consumption of food, agricultural intensity, livestock feeding efficiency, and bioenergy potentials, both residue potentials and area availability for energy crops (Haberl et al., 2011; Erb et al., 2012).

Anthropogenic stocks (built environment) play a crucial role in socio-metabolic systems: (1) they provide services to the inhabitants, (2) their operation often requires energy and releases emissions, (3) any increase or renewal/maintenance of these stocks requires materials, and (4) the stocks embody materials (often accumulated over the past decades or centuries) that may be recovered at the end of the stocks' service lives ('urban mining') and, when recycled or reused, substitute primary resources and save energy and emissions in materials production (Müller et al., 2006). In contrast to flow variables, which tend to fluctuate much more, stock variables usually behave more robustly and are therefore often suitable as drivers for developing long-term scenarios (Müller, 2006). The exploration of built environment stocks (secondary resources), including their composition, performance, and dynamics, is therefore a crucial pre-requisite for examining long-term transformation pathways (Liu et al., 2012). Anthropogenic stocks have therefore been described as the engines of socio-metabolic systems. Moreover, socioeconomic stocks sequester carbon (Lauk et al., 2012); hence policies to increase the carbon content of long-lived infrastructures may contribute to climate-change mitigation (Gustavsson et al., 2006).

So far, MFAs have been used mainly to inform policies for resource and waste management. Studies with an explicit focus on climate change mitigation are less frequent, but rapidly growing. Examples involve the exploration of long-term mitigation pathways for the iron/steel industry (Milford et al., 2013; Pauliuk et al., 2013a), the aluminium industry (Liu et al., 2011, 2012), the vehicle stock (Pauliuk et al., 2011; Melaina and Webster, 2011), or the building stock (Pauliuk et al., 2013b).

A.II.6.2 Input-output analysis

Input-output (IO) analysis is an approach to trace the production process of products by economic sectors, and their use as intermediate demand by producing sectors (industries) and final demand including that by households and the public sector (Miller and Blair, 1985). Input-output tables describe the structure of the economy, i.e., the interdependence of different producing sectors and their role in final demand. Input-output tables are produced as part of national economic accounts (Leontief, 1936). Through the assumption of fixed input coefficients, input-output models can be formed, determining, e.g., the economic activity in all sectors required to produce a unit of final demand. The mathematics of input-output analysis can be used with flows denoted in physical or monetary units and has been applied also outside economics, e.g., to describe energy and nutrient flows in ecosystems (Hannon et al., 1986).

Environmental applications of input-output analysis include analyzing the economic role of abatement sectors (Leontief, 1971), quantifying embodied energy (Bullard and Herendeen, 1975) and the employment benefits of energy efficiency measures (Hannon et al., 1978), describing the benefits of pre-consumer scrap recycling (Nakamura and Kondo, 2001), tracing the material composition of vehicles (Nakamura et al., 2007), and identifying an environmentally desirable global division of labour (Stromman et al., 2009). Important for mitigation research, input-output analysis has been used to estimate the GHG emissions associated with the production and delivery of goods for final consumption, the 'carbon footprint' (Wiedmann and Minx, 2008). This type of analysis basically redistributes the emissions occurring in producing sectors to final consumption. It can be used to quantify GHG emissions associated with import and export (Wyckoff and Roop, 1994), with national consumption (Hertwich and Peters, 2009), or the consumption by specific groups of society (Lenzen and Schaeffer, 2004), regions (Turner et al., 2007), or institutions (Larsen and Hertwich, 2009; Minx et al., 2009; Peters, 2010; Berners-Lee et al., 2011).[4]

Global, multiregional input-output models are currently seen as the state-of-the-art tool to quantify 'consumer responsibility' (Chapter 5) (Hertwich, 2011; Wiedmann et al., 2011). Multiregional tables are necessary to adequately represent national production patterns and technologies in the increasing number of globally sourced products. Important insights provided to mitigation research are the quantification of the total CO_2 emissions embodied in global trade (Peters and Hertwich, 2008), the growth of net emissions embodied in trade from non-Annex B to Annex B countries (Peters et al., 2011b), to show that the UK (Druckman et al., 2008; Wiedmann et al., 2010) and other Annex B countries have increasing carbon footprints while their territorial emissions are decreasing, to identify the contribution of different commodity exports to the rapid growth in China's GHG emissions (Xu et al., 2009), and to quantify the income elasticity of the carbon footprint of different consumption categories like food, mobility, and clothing (Hertwich and Peters, 2009).

Input-output models have an increasingly important instrumental role in mitigation. They are used as a backbone for consumer carbon calculators, to provide sometimes spatially explicit regional analysis (Lenzen et al., 2004), to help companies and public institutions target climate mitigation efforts , and to provide initial estimates of emissions associated with different alternatives (Minx et al., 2009).

Input-output calculations are usually based on industry-average production patterns and emissions intensities and do not provide an insight into marginal emissions caused by additional purchases. However, efforts to estimate future and marginal production patterns and emissions intensities exist (Lan et al., 2012). At the same time, economic sector classifications in many countries are not very fine, so that IO tables provide carbon footprint averages of broad product groups rather than specific products, but efforts to disaggregate tables to provide more detail in environmentally relevant sectors exist (Tukker et al., 2013). Many models are not good at addressing waste management and recycling opportunities, although hybrid models with a physical representation of end-of-life processes do exist (Nakamura and Kondo, 2001). At the time of publication, national input-output tables describe the economy several years ago. Multiregional input-output tables are produced as part of research efforts and need to reconcile different national conventions for the construction of the tables and conflicting international trade data (Tukker et al., 2013). Efforts to provide a higher level of detail of environmentally relevant sectors and to nowcast tables are currently under development (Lenzen et al., 2012).

[4] GHG emissions related to land-use change have not yet been addressed in MRIO-based carbon footprint analysis due to data limitations.

A.II.6.3 Lifecycle assessment

Product lifecycle assessment (LCA) was developed as a method to determine the embodied energy use (Boustead and Hancock, 1979) and environmental pressures associated with specific product systems (Finnveden et al., 2009). A product system describes the production, distribution, operation, maintenance, and disposal of the product. From the beginning, the assessment of energy technologies has been important, addressing questions such as how many years of use would be required to recover the energy expended in producing a photovoltaic cell (Kato et al., 1998). Applications in the consumer products industry addressing questions of whether cloth or paper nappies (diapers) are more environmentally friendly (Vizcarra et al., 1994), or what type of washing powder, prompted the development of a wider range of impact assessment methods addressing issues such as aquatic toxicity (Gandhi et al., 2010), eutrophication, and acidification (Huijbregts et al., 2000). By now, a wide range of methods has been developed addressing either the contribution to specific environmental problems (midpoint methods) or the damage caused to ecosystem or human health (endpoint methods). At the same time, commonly used databases have collected lifecycle inventory information for materials, energy products, transportation services, chemicals, and other widely used products. Together, these methods form the backbone for the wide application of LCA in industry and for environmental product declarations, as well as in policy.

Lifecycle assessment plays an increasingly important role in climate mitigation research (SRREN Annex II, Moomaw et al., 2011). In WGIII AR5, lifecycle assessment has been used to quantify the GHG emissions associated with mitigation technologies, e.g., wind power, heat recovery ventilation systems, or carbon dioxide capture and storage. Lifecycle assessment is thus used to compare different ways to deliver the same functional unit, such as one kWh of electricity.

Lifecycle assessment has also been used to quantify co-benefits and detrimental side-effects of mitigation technologies and measures, including other environmental problems and the use of resources such as water, land, and metals. Impact assessment methods have been developed to model a wide range of impact pathways.

A range of approaches is used in LCA to address the climate impact of environmental interventions, starting from GHG through other pollutants (such as aerosols) to the inclusion of geophysical effects such as albedo changes or indirect climate effects (Bright et al., 2012), also exploring radiation-based climate metrics (Peters et al., 2011a). The timing of emissions and removals has traditionally not been considered, but issues associated with biomass production and use have given rise to a approaches to quantify the effects of carbon sequestration and temporary carbon storage in long-lived products (Brandão et al., 2013; Guest et al., 2013; Levasseur et al., 2013) and of temporarily increased atmospheric CO_2 concentrations from 'carbon-neutral' bioenergy systems (Cherubini et al., 2011).

AII

Life-cycle inventories are normally derived from empirical information on actual processes or modelled based on engineering calculations. A key aspect of lifecycle inventories for energy technologies is that they contribute to understanding the thermodynamics of the wider product system; combined with appropriate engineering insight, they can provide some upper bound for possible technological improvements. These process LCAs provide detail and specificity, but do usually not cover all input requirements, as this would be too demanding. The cut-off error is the part of the inventory that is not covered by conventional process analysis; it is commonly between 20–50 % of the total impact (Lenzen, 2001). Hybrid lifecycle assessment utilizes input-output models to cover inputs of services or items that are used in small quantities (Treloar, 1996; Suh et al., 2004; Williams et al., 2009). Through their better coverage of the entire product system, hybrid LCAs tend to more accurately represent all inputs to production (Majeau-Bettez et al., 2011). They have also been used to estimate the cut-off error of process LCAs (Norris, 2002; Deng et al., 2011).

It must be emphasized that LCA is a research method that answers specific research questions. To understand how to interpret and use the results of an LCA case study, it is important to understand what the research question is. The research questions "what are the environmental impacts of product x" or "… of technology y" needs to be specified with respect to timing, regional context, operational mode, background system, etc. Modelling choices and assumption thus become part of an LCA. This implies that LCA studies are not always comparable because they do not address the same research question. Further, most LCAs are interpreted strictly on a functional unit basis, expressing the impact of a unit of the product system in a described production system, without either up-scaling the impacts to total impacts in the entire economy or saying something about the scale-dependency of the activity. For example, an LCA may identify the use of recycled material as beneficial, but the supply of recycled material is limited by the availability of suitable waste, so that an up-scaling of recycling is not feasible. Hence, an LCA that shows that recycling is beneficial is not sufficient to document the availability of further opportunities to reduce emissions. Lifecycle assessment, however, coupled with an appropriate system models (using material flow data) is suitable to model the emission gains from the expansion of further recycling activities.

Lifecycle assessment was developed with the intention to quantify resource use and emissions associated with existing or prospective product systems, where the association reflects physical causality within economic systems. Depending on the research question, it can be sensible to investigate average or marginal inputs to production. Departing from this descriptive approach, it has been proposed to model a wider socioeconomic causality describing the consequences of actions (Ekvall and Weidema, 2004). While established methods and a common practice exist for descriptive or 'attributional' LCA, such methods and standard practice are not yet established in 'consequential' LCA (Zamagni et al., 2012). Consequential LCAs are dependent on the decision context. It is increasingly acknowledged in LCA that for investigating larger sustainability questions, the product focus is not sufficient and larger system changes need to be modelled as such (Guinée et al., 2010).

For climate change mitigation analysis, it is useful to put LCA in a wider scenario context (Arvesen and Hertwich, 2011; Viebahn et al., 2011). The purpose is to better understand the contribution a technology can make to climate change mitigation and to quantify the magnitude of its resource requirements, co-benefits and side-effects. For mitigation technologies on both the demand and supply side, important contributors to the total impact are usually energy, materials, and transport. Understanding these contributions is already valuable for mitigation analysis. As all of these sectors will change as part of the scenario, LCA-based scenarios show how much impacts per unit are likely to change as part of the scenario.

Some LCAs take into account behavioural responses to different technologies (Takase et al., 2005; Girod et al., 2011). Here, two issues must be distinguished. One is the use of the technology. For example, it has been found that better insulated houses consistently are heated or cooled to higher/lower average temperature (Haas and Schipper, 1998; Greening et al., 2001). Not all of the theoretically possible technical gain in energy efficiency results in reduced energy use (Sorrell and Dimitropoulos, 2008). Such direct rebound effects can be taken into account through an appropriate definition of the energy services compared, which do not necessarily need to be identical in terms of the temperature or comfort levels. Another issue are larger market-related effects and spillover effects. A better-insulated house leads to energy savings. Both questions of (1) whether the saved energy would then be used elsewhere in the economy rather than not produced, and (2) what the consumer does with the money saved, are not part of the product system and hence of product lifecycle assessment. They are sometimes taken up in LCA studies, quantified, and compared. However, for climate mitigation analysis, these mechanisms need to be addressed by scenario models on a macro level. (See also Section 11.4 for a discussion of such systemic effects).

A.II.7 Fat tailed distributions

If we have observed N independent loss events from a given loss distribution, the probability that the next loss event will be worse than all the others is $1/(N+1)$. How much worse it will be depends on the tail of the loss distribution. Many loss distributions including losses due to hurricanes are very fat tailed. The notion of a 'fat tailed distribution' may be given a precise mathematical meaning in several ways, each capturing different intuitions. Older definitions refer to 'fat tails' as 'leptokurtic' meaning that the tails are fatter than the normal distribution. Nowadays, mathematical definitions are most commonly framed in terms of regular variation or subexponentiality (Embrechts et al., 1997).

A positive random variable X has regular variation with tail index $\alpha > 0$ if the probability $P(X > x)$ of exceeding a value x decreases at a polynomial rate x^{-a} as x gets large. For any $r > \alpha$, the *r-th* moment of X is infinite, the α-th moment may be finite or infinite depending on the distribution. If the first moment is infinite, then running averages of independent realizations of X increase to infinity. If the second moment is infinite, then running averages have an infinite variance and do not converge to a finite value. In either case, historical averages have little predictive value. The gamma, exponential, and Weibull distributions all have finite *r-th* moment for all positive *r*.

A positive random variable X is subexponential if for any n independent copies $X1,\ldots Xn$, the probability that the sum $X1+\ldots+Xn$ exceeds a value x becomes identical to the probability that the maximum of $X1,\ldots Xn$ exceeds x, as x gets large. In other words, 'the sum of $X1,\ldots Xn$ is driven by the largest of the $X1,\ldots Xn$'. Every regularly varying distribution is subexponential, but the converse does not hold. The Weibull distribution with shape parameter less than one is subexponential but not regularly varying. All its moments are finite, but the sum of n independent realizations tends to be dominated by the single largest value.

For X with finite first moment, the mean excess curve is a useful diagnostic. The mean excess curve of X at point x is the expected value of $X - x$ given that X exceeds x. If X is regularly varying with tail index $\alpha > 1$, the mean excess curve of X is asymptotically linear with slope $1/(\alpha\text{-}1)$. If X is subexponential its mean excess curve increases to infinity, but is not necessarily asymptotically linear. Thus, the mean excess curve for a subexponential distribution may be 'worse' than a regularly varying distribution, even though the former has finite moments. The mean excess curve for the exponential distribution is constant, that for the normal distribution is decreasing. The following figures show mean excess curves for flood insurance claims in the United States, per county per year per dollar income (hereby correcting for growth in exposure, Figure A.II.5) and insurance indemnities for crop loss per county per year in the United States (Figure A.II.6). Note that flood claims' mean excess curve lies well above the line with unit slope, whereas that for crop losses lie below (Kousky and Cooke, 2009).

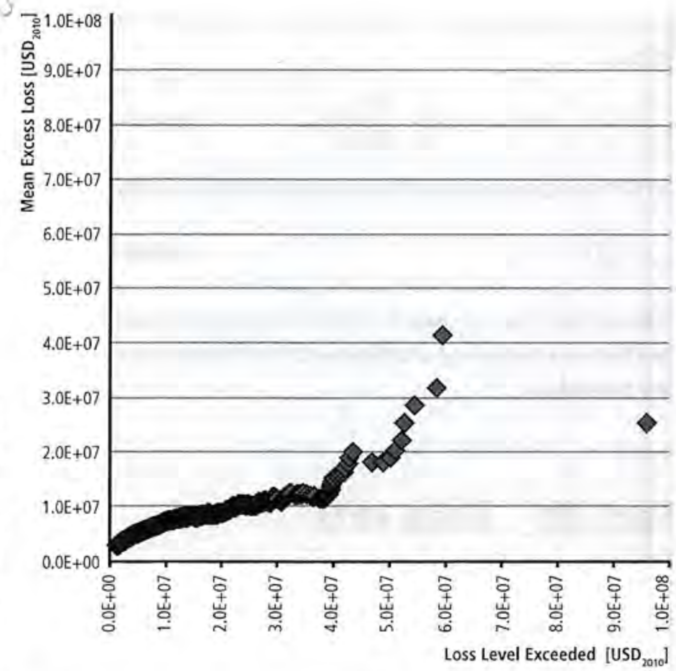

Figure A.II.6 | Mean excess curve of US crop insurance indemnities paid from the US Department of Agriculture's Risk Management Agency, aggregated by county and year for the years 1980 to 2008 in USD_{2010}. Note: The vertical axis gives mean excess loss, given loss at least as large as the horizontal axis. Source: adapted from (Kousky and Cooke, 2009).

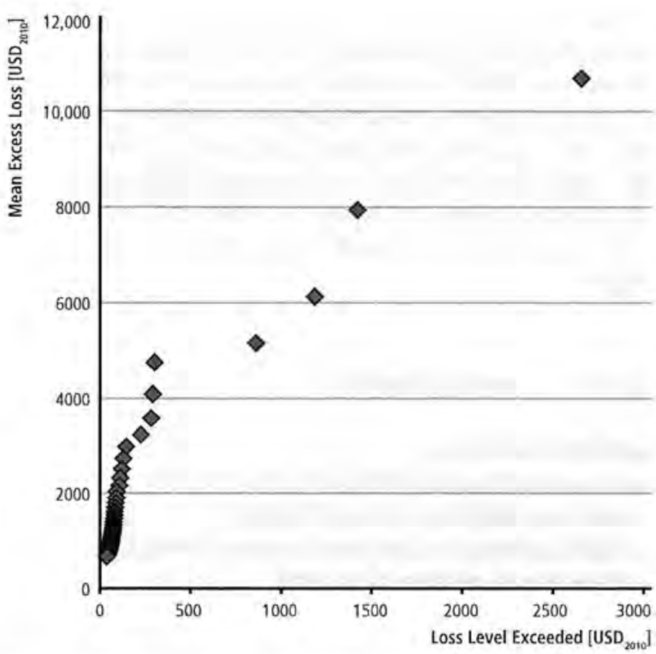

Figure A.II.5 | Mean excess curve for US flood insurance claims from the National Flood Insurance Program per dollar income per county per year for the years 1980 to 2008 in USD_{2010}. Considering dollar claims per dollar income in each county corrects for increasing exposure. Note: The vertical axis gives mean excess loss, given loss at least as large as the horizontal axis. Source: adapted from (Kousky and Cooke, 2009).

A.II.8 Growth rates

For the calculation of annual growth rates as frequently shown in this report, a number of different methods exist, all of which lead to slightly different numerical results. If not stated otherwise, the annual growth rates shown, have been derived using the *Log Difference Regression* technique or *Geometric Average*, techniques which can be shown to be equivalent.

The Log Difference Regression growth rate r_{LD} is calculated the following way:

$$r_{LD} = e^{\beta} - 1 \quad with \quad \beta = \frac{1}{T-1} \sum_{t=2}^{T} \Delta lnX_t \qquad \text{(Equation A.II.10)}$$

The *Geometric Average* growth rate r_{GEO} is calculated as shown below:

$$r_{GEO} = \left(\frac{X_T}{X_1}\right)^{\frac{1}{T-1}} - 1 \qquad \text{(Equation A.II.11)}$$

Other methods that are used to calculate annual growth rates include the *Ordinary Least Square* technique and the *Average Annual Growth Rate* technique.

Part III: Data sets

A.II.9 Historical data

To aid coherency and consistency, core historic data presented throughout the report uses the same sources and applied the same methodologies and standards—these are detailed here:

- The standard country aggregations to regions are detailed in Section A.II.2.
- The central historic GHG emission data set was based on IEA (2012c) and Emissions Database for Global Atmospheric Research (EDGAR) (JRC/PBL, 2013) data. This data set provides annual emissions on a country level for the time span 1970 to 2010. The two sources are mapped as described in Section A.II.9.1.
- As default dataset for GDP in Purchasing Power Parity (PPP) World Bank data was supplemented according to the methodology described in Section A.II.9.2.
- The data sources and methodology for historic indirect emissions from electricity and heat production are defined in Section A.II.5.
- Lifecycle GHG emission data sets of energy supply technologies, predominantly used in Chapter 7, are introduced in Section A.II.9.3. The underlying methodology is explained in Section A.II.6 of this Annex.

A.II.9.1 Mapping of emission sources to sectors

The list below shows how emission sources are mapped to sectors throughout the WGIII AR5. This defines unambiguous system boundaries for the sectors as represented in Chapters 7–11 in the report and enables a discussion and representation of emission sources without double-counting.

Emission sources refer to the definitions by the IPCC Task Force on National Greenhouse Gas Inventories (TFI) (IPCC, 2006). Where further disaggregated data was required, additional source categories were introduced consistent with the underlying datasets (IEA, 2012c; JRC/PBL, 2013). This information appears in the following systematic sequence throughout this section:

Emission source category (chapter emission source category numbering)

Emission Source (Sub-)Category (IPCC Task force definition) [gases emitted by emission source (CO_2 data set used)]

A common dataset ('IEA/EDGAR') is used across WGIII AR5 chapters to ensure consistent representation of emission trends across the report. Uncertainties of this data are discussed in the respective chapters (Chapter 1; Chapter 5; and Chapter 11). CO_2 emissions from fossil fuel combustion are taken from IEA (2012c), the remaining CO_2 and non-CO_2 GHG emissions are taken from EDGAR (JRC/PBL, 2013), see the following sections for categories and sources used. For the FOLU sub-sector EDGAR (JRC/PBL, 2013) represents land-based CO_2 emissions from forest and peat fires and decay to approximate the CO_2 flux from anthropogenic emission sources.

Following general scientific practice, 100-year GWPs from the IPCC Second Assessment Report (SAR) (Schimel et al., 1996) are used as the index for converting GHG emissions to common units of CO_2-equivalent emissions in EDGAR (JRC/PBL, 2013). The following gases and associated GWPs based on the SAR are covered in EDGAR: CO_2 (1), CH_4 (21), N_2O (310), HFC-125 (2800), HFC-134a (1300), HFC-143a (3800), HFC-152a (140), HFC-227ea (2900), HFC-23 (11700), HFC-236fa (6300), HFC-245fa (560), HFC-32 (650), HFC-365mfc (1000), HFC-43–10-mee (1300), C_2F_6 (9200), C_3F_8 (7000), C_4F_{10} (7000), C_5F_{12} (7500), C_6F_{14} (7400), C_7F_{16} (7400), c-C_4F_8 (8700), CF_4 (6500), SF_6 (23900).

A.II.9.1.1 Energy (Chapter 7)

Electricity & heat (7.1)

Power and Heat Generation (1A1a) [CO_2 (IEA), CH_4, N_2O]
Public Electricity Plants (1A1a1) [CO_2 (IEA)]
Public Combined Heat and Power Generation (1A1a2) [CO_2 (IEA)]
Public Heat Plants (1A1a3) [CO_2 (IEA)]
Public Electricity Generation (own use) (1A1a4) [CO_2 (IEA)]
Electricity Generation (autoproducers) (1A1a5) [CO_2 (IEA)]
Combined Heat and Power Generation (autoproducers) (1A1a6) [CO_2 (IEA)]
Heat Plants (autoproducers) (1A1a7) [CO_2 (IEA)]
Public Electricity and Heat Production (biomass) (1A1ax) [CH_4, N_2O]

Petroleum refining (7.2)
Other Energy Industries (1A1bc) [CO_2 (IEA)]

Manufacture of solid fuels (7.3)
Other transformation sector (BKB, etc.) (1A1r) [CH_4, N_2O]
Manufacture of Solid Fuels and Other Energy Industries (biomass) (1A1cx) [CH_4, N_2O]

Fuel production and transport (7.4)
Fugitive emissions from solids fuels except coke ovens (1B1r) [CO_2 (EDGAR), CH_4, N_2O]
Flaring and fugitive emissions from oil and Natural Gas (1B2) [CO_2 (EDGAR), CH_4, N_2O]

Others (7.5)
Electrical Equipment Manufacture (2F8a) [SF_6]
Electrical Equipment Use (includes site installation) (2F8b) [SF_6]
Fossil fuel fires (7A) [CO_2 (EDGAR), CH_4, N_2O]

Indirect N2O emissions from energy (7.6)
Indirect N_2O from NO_x emitted in cat. 1A1 (7B1) [N_2O]
Indirect N_2O from NH_3 emitted in cat. 1A1 (7C1) [N_2O]

A.II.9.1.2 Transport (Chapter 8)

Aviation (8.1)
Domestic air transport (1A3a) [CO_2 (IEA), CH_4, N_2O]

Road transportation (8.2)
Road transport (includes evaporation) (fossil) (1A3b) [CO_2 (IEA), CH_4, N_2O]
Road transport (includes evaporation) (biomass) (1A3bx) [CH_4, N_2O]
Adiabatic prop: tyres (2F9b) [SF_6]

Rail transportation (8.3)
Rail transport (1A3c) [CO_2 (IEA), CH_4, N_2O]
Non-road transport (rail, etc.) (fossil) (biomass) (1A3cx) [CH_4, N_2O]

Navigation (8.4)
Inland shipping (fossil) (1A3d) [CO_2 (IEA), CH_4, N_2O]
Inland shipping (fossil) (biomass) (1A3dx) [CH_4, N_2O]

Others incl. indirect N_2O emissions from transport (8.5)
Non-road transport (fossil) (1A3e) [CO_2 (IEA), CH_4, N_2O]
  Pipeline transport (1A3e1) [CO_2 (IEA)]
  Non-specified transport (1A3er) [CO_2 (IEA)]
Non-road transport (fossil) (biomass) (1A3ex) [CH_4, N_2O]
Refrigeration and Air Conditioning Equipment (HFC) (Transport) (2F1a1) [HFC]
Indirect N_2O from NO_x emitted in cat. 1A3 (7B3) [N_2O]
Indirect N_2O from NH_3 emitted in cat. 1A3 (7C3) [N_2O]

International Aviation (8.6)
Memo: International aviation (1C1) [CO_2 (IEA), CH_4, N_2O]

International Shipping (8.7)
Memo: International navigation (1C2) [CO_2 (IEA), CH_4, N_2O]

A.II.9.1.3 Buildings (Chapter 9)

Commercial (9.1)
Commercial and public services (fossil) (1A4a) [CO_2 (IEA), CH_4, N_2O]
Commercial and public services (biomass) (1A4ax) [CH_4, N_2O]

Residential (9.2)
Residential (fossil) (1A4b) [CO_2 (IEA), CH_4, N_2O]
Residential (biomass) (1A4bx) [CH_4, N_2O]

Others (9.3)
Refrigeration and Air Conditioning Equipment (HFC) (Building) (2F1a2) [HFC]
Fire Extinguishers (2F3) [PFC]
Aerosols/ Metered Dose Inhalers (2F4) [HFC]
Adiabatic prop: shoes and others (2F9a) [SF_6]
Soundproof windows (2F9c) [SF_6]

Indirect N_2O emissions from buildings (9.4)
Indirect N_2O from NO_x emitted in cat. 1A4 (7B4) [N_2O]
Indirect N_2O from NH_3 emitted in cat. 1A4 (7C4) [N_2O]

A.II.9.1.4 Industry (Chapter 10)

Ferrous and non-ferrous metals (10.1)
Fuel combustion coke ovens (1A1c1) [CH_4, N_2O]
Blast furnaces (pig iron prod.) (1A1c2) [CH_4, N_2O]
Iron and steel (1A2a) [CO_2 (IEA), CH_4, N_2O]
Non-ferrous metals (1A2b) [CO_2 (IEA), CH_4, N_2O]
Iron and steel (biomass) (1A2ax) [CH_4, N_2O]
Non-ferrous metals (biomass) (1A2bx) [CH_4, N_2O]
Fuel transformation coke ovens (1B1b1) [CO_2 (EDGAR), CH_4]
Metal Production (2C) [CO_2 (EDGAR), CH_4, PFC, SF_6]
  Iron and Steel Production (2C1) [CO_2 (EDGAR)]
    Crude steel production total (2C1a) [CO_2 (EDGAR)]
  Ferroy Alloy Production (2C2) [CO_2 (EDGAR)]
  Aluminum production (primary) (2C3) [PFC]
  SF6 Used in Aluminium and Magnesium Foundries (2C4) [SF_6]
    Magnesium foundries: SF_6 use (2C4a) [SF_6]
    Aluminium foundries: SF_6 use (2C4b) [SF_6]
  Non-ferrous metals production (2Cr) [CO_2 (EDGAR)]

Chemicals (10.2)
Chemicals (1A2c) [CO_2 (IEA), CH_4, N_2O]
Chemicals (biomass) (1A2cx) [CH_4, N_2O]

Production of chemicals (2B) [CO_2 (EDGAR), CH_4, N_2O]
Production of Halocarbons and SF6 (2E) [HFC, SF6]
Non-energy use of lubricants/waxes (2G) [CO_2 (EDGAR)]
Solvent and other product use: paint (3A) [CO_2 (EDGAR)]
Solvent and other product use: degrease (3B) [CO_2 (EDGAR)]
Solvent and other product use: chemicals (3C) [CO_2 (EDGAR)]
Other product use (3D) [CO_2 (EDGAR), N_2O]

Cement production (10.3)
Cement production (2A1) [CO_2 (EDGAR)]

Landfill & waste incineration (10.4)
Solid waste disposal on land (6A) [CH_4]
Waste incineration (6C) [CO_2 (EDGAR), CH_4, N_2O]
Other waste handling (6D) [CH_4, N_2O]

Wastewater treatment (10.5)
Wastewater handling (6B) [CH_4, N_2O]

Other industries (10.6)
Pulp and paper (1A2d) [CO_2 (IEA), CH_4, N_2O]
Food and tobacco (1A2e) [CO_2 (IEA), CH_4, N_2O]
Other industries (stationary) (fossil) (1A2f) [CO_2 (IEA), CH_4, N_2O]
  Non-metallic minerals (1A2f1) [CO_2 (IEA)]
  Transport equipment (1A2f2) [CO_2 (IEA)]
  Machinery (1A2f3) [CO_2 (IEA)]
  Mining and quarrying (1A2f4) [CO_2 (IEA)]
  Wood and wood products (1A2f5) [CO_2 (IEA)]
  Construction (1A2f6) [CO_2 (IEA)]
  Textile and leather (1A2f7) [CO_2 (IEA)]
  Non-specified industry (1A2f8) [CO_2 (IEA)]
Pulp and paper (biomass) (1A2dx) [CH_4, N_2O]
Food and tobacco (biomass) (1A2ex) [CH_4, N_2O]
Off-road machinery: mining (diesel) (1A5b1) [CH_4, N_2O]
Lime production (2A2) [CO_2 (EDGAR)]
Limestone and Dolomite Use (2A3) [CO_2 (EDGAR)]
Production of other minerals (2A7) [CO_2 (EDGAR)]
Refrigeration and Air Conditioning Equipment (PFC) (2F1b) [PFC]
Foam Blowing (2F2) [HFC]
F-gas as Solvent (2F5) [PFC]
Semiconductor Manufacture (2F7a) [HFC, PFC, SF_6]
Flat Panel Display (FPD) Manufacture (2F7b) [PFC, SF_6]
Photo Voltaic (PV) Cell Manufacture (2F7c) [PFC]
Other use of PFC and HFC (2F9) [HFC, PFC]
Accelerators/HEP (2F9d) [SF_6]
Misc. HFCs/SF_6 consumption (AWACS, other military, misc.) (2F9e) [SF6]
Unknown SF_6 use (2F9f) [SF_6]

Indirect N_2O emissions from industry (10.7)
Indirect N_2O from NO_x emitted in cat. 1A2 (7B2) [N_2O]
Indirect N_2O from NH_3 emitted in cat. 1A2 (7C2) [N_2O]

A.II.9.1.5 AFOLU (Chapter 11)

Fuel combustion (11.1)
Agriculture and forestry (fossil) (1A4c1) [CO_2 (IEA), CH_4, N_2O]
Off-road machinery: agric./for. (diesel) (1A4c2) [CH_4, N_2O]
Fishing (fossil) (1A4c3) [CO_2 (IEA), CH_4, N_2O]
Non-specified Other Sectors (1A4d) [CO_2 (IEA), CH_4, N_2O]
Agriculture and forestry (biomass) (1A4c1x) [CH_4, N_2O]
Fishing (biomass) (1A4c3x) [N_2O]
Non-specified other (biomass) (1A4dx) [CH_4, N_2O]

Livestock (11.2)
Enteric Fermentation (4A) [CH_4]
Manure management (4B) [CH_4, N_2O]

Rice cultivation (11.3)
Rice cultivation (4C) [CH_4]

Direct soil emissions (11.4)
Other direct soil emissions (4D4) [CO_2 (EDGAR)]
Agricultural soils (direct) (4Dr) [N_2O]

Forrest fires and decay (11.5)
Savannah burning (4E) [CH_4, N_2O]
Forest fires (5A) [CO_2 (EDGAR), CH_4, N_2O]
Grassland fires (5C) [CH_4, N_2O]
Forest Fires-Post burn decay (5F2) [CO_2 (EDGAR), N_2O]

Peat fires and decay (11.6)
Agricultural waste burning (4F) [CH_4, N_2O]
Peat fires and decay of drained peatland (5D) [CO_2 (EDGAR), CH_4, N_2O]

Indirect N_2O emissions from AFOLU (11.7)
Indirect Emissions (4D3) [N_2O]
Indirect N_2O from NO_x emitted in cat. 5 (7B5) [N_2O]
Indirect N_2O from NH_3 emitted in cat. 5 (7C5) [N_2O]

A.II.9.1.6 Comparison of IEA and EDGAR CO_2 emission datasets

As described above the merged IEA/EDGAR historic emission dataset uses emission data from IEA (2012c) and EDGAR (JRC/PBL, 2013). Here we compare IEA/EDGAR to the pure EDGAR dataset (JRC/PBL, 2013). The comparison details the differences between the two datasets as the remaining CO_2 and non-CO_2 GHG emissions are identical between the two datasets. Table A.II.11 maps EDGAR categories to the IEA categories used in IEA/EDGAR forming 21 groups. Figure A.II.7 shows the quantitative differences for aggregated global emissions of these 21 groups between the two sources.

Table A.II.11 | Mapping of IEA (2012c) and EDGAR (JRC/PBL, 2013) CO_2 emission categories. Figure A.II.7 shows the quantitative difference for each Comparison Group (using Comparison Group number as reference).

Comparison Groups		EDGAR		IEA	IEA/EDGAR category
number	group name	IPCC category	category name	category name	
1	Power Generation	1A1a	Public electricity and heat production	Main activity electricity plants	1A1a1
				Main activity CHP plants	1A1a2
				Main activity heat plants	1A1a3
				Own use in electricity, CHP and heat plants	1A1a4
				Autoproducer electricity plants	1A1a5
				Autoproducer CHP plants	1A1a6
				Autoproducer heat plants	1A1a7
2	Other Energy Industries	1A1c1	Fuel combustion coke ovens	Other energy industry own use	1A1bc
		1A1c2	Blast furnaces (pig iron prod.)		
		1A1r	Other transformation sector (BKB, etc.)		
3	Iron and steel	1A2a	Iron and steel	Iron and steel	1A2a
4	Non-ferrous metals	1A2b	Non-ferrous metals	Non-ferrous metals	1A2b
5	Chemicals	1A2c	Chemicals	Chemical and petrochemical	1A2c
6	Pulp and paper	1A2d	Pulp and paper	Paper, pulp and printing	1A2d
7	Food and tobacco	1A2e	Food and tobacco	Food and tobacco	1A2e
8	Other Industries w/o NMM	1A2f	Other industries (incl. offroad) (fos.)	Transport equipment	1A2f2
				Machinery	1A2f3
				Mining and quarrying	1A2f4
				Wood and wood products	1A2f5
				Construction	1A2f6
				Textile and leather	1A2f7
				Non-specified industry	1A2f8
9	Non-metallic minerals	1A2f-NMM	Non-metallic minerals (cement proxy)	Non-metallic minerals	1A2f1
10	Domestic air transport	1A3a	Domestic air transport	Domestic aviation	1A3a
11	Road transport (incl. evap.) (foss.)	1A3b	Road transport (incl. evap.) (foss.)	Road	1A3b
12	Rail transport	1A3c	Non-road transport (rail, etc.) (fos.)	Rail	1A3c
13	Inland shipping (fos.)	1A3d	Inland shipping (fos.)	Domestic navigation	1A3d
14	Other transport	1A3e	Non-road transport (fos.)	Pipeline transport	1A3e1
				Non-specified transport	1A3er
				Non-energy use in transport	1A3er
15	Commercial and public services (fos.)	1A4a	Commercial and public services (fos.)	Commercial and public services	1A4a
16	Residential (fos.)	1A4b	Residential (fos.)	Residential	1A4b
17	Agriculture and forestry (fos.)	1A4c1	Agriculture and forestry (fos.)	Agriculture/forestry	1A4c1
		1A4c2	Off-road machinery: agric./for. (diesel)		
		1A5b1	Off-road machinery: mining (diesel)		
18	Fishing (fos.)	1A4c3	Fishing (fos.)	Fishing	1A4c3
19	Non-specified Other Sectors	1A4d	Non-specified other (fos.)	Non-specified other	1A4d
20	Memo: International aviation	1C1	International air transport	Memo: International aviation bunkers	1C1
21	Memo: International navigation	1C2	International marine transport (bunkers)	Memo: International marine bunkers	1C2

AII

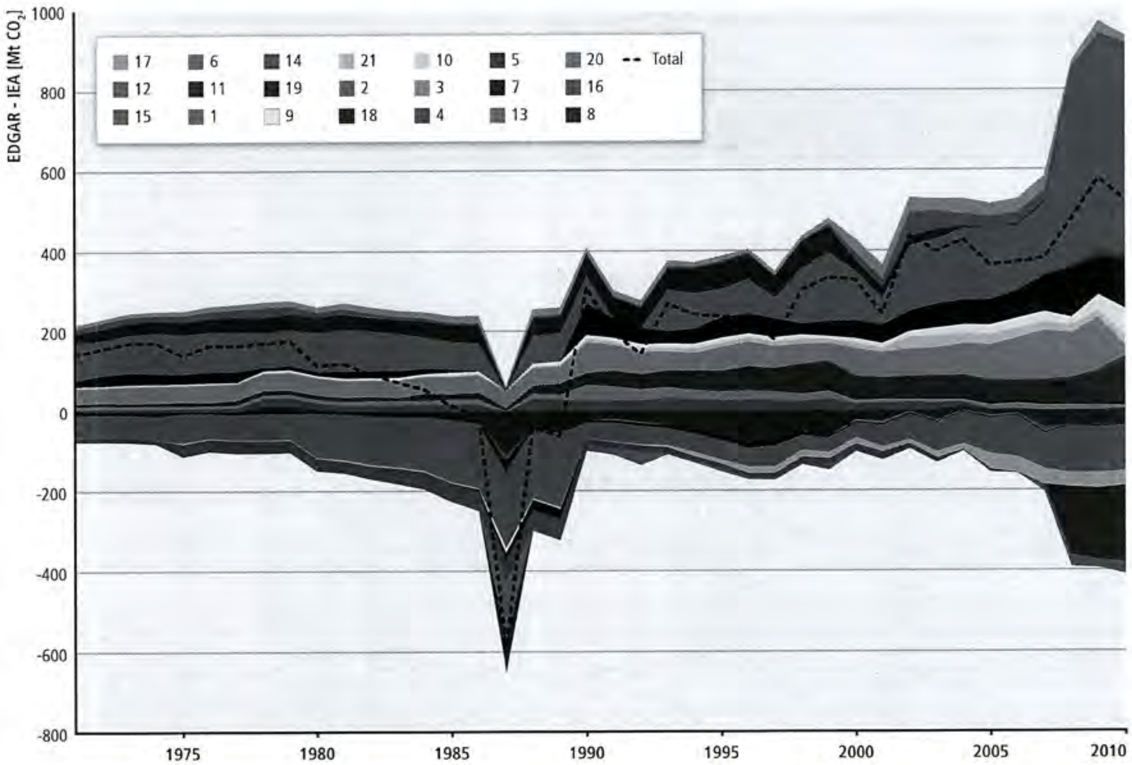

Figure A.II.7 | Difference of CO_2 emissions between analogous IEA (2012c) and EDGAR (JRC/PBL, 2013) categories as detailed in Table A.II.11. (Numbers in key refer to Table A.II.11 Comparison Groups).

A.II.9.2 Historic GDP PPP data

As default dataset for GDP in Purchasing Power Parity (PPP) World Bank data was used (World Bank, 2013). In line with the methodology described in Section A.II.1.3 and by Nordhaus (2007) the initial dataset (1980–2012 PPP in constant Int$_{2011}$[5]) was extended backwards using World Bank GDP growth rates in constant local currency unit[6]. Further data gaps were closed extending World Bank data by applying growth rates as supplied by the IMF (2012) for 1980 and later. For gaps prior to 1980 Penn World Tables (PWT)(Heston et al., 2011) was used. In addition, missing countries were added using PWT (Heston et al., 2011)(Cuba, Puerto Rico, Marshall Islands, Somalia, Bermuda), IMF (2012) (Kosovo, Myanmar, Tuvala, Zimbabwe) and IEA (Dem Rep. Korea, Gibraltar, Netherlands Antilles) GDP data.

A.II.9.3 Lifecycle greenhouse gas emissions

In Chapter 7, Figure 7.6 and 7.7, the lifecycle GHG emissions of different technologies are compared. This section describes how these numbers are derived. The air pollutant emission numbers in Figure 7.8 are from (Hertwich et al., 2013). The assessment of GHG emissions and other climate effects associated with electricity production technologies presented here is based on two distinct research enterprises.

The first effort started with the review of lifecycle GHG emission started for SRREN (Sathaye et al., 2011). This work was extended to a harmonization of LCA studies following the approach by Farrell et al. (2006) and resulted in a set of papers published a special issue of the *Journal of Industrial Ecology* (Brandão et al., 2012; Heath and Mann, 2012). The collected data points of LCA results of GHG emissions of different technologies from this comprehensive review are available online in tabular and chart form at http://en.openei.org/apps/LCA/ and have been obtained from there, but the underlying scientific papers from the peer reviewed literature are referred to here.

The second effort is a broader study of lifecycle environmental impacts and resource requirements under way for the International Resource Panel (Hertwich et al., 2013). The study aims at a consistent technology comparison where lifecycle data collected under uniform instructions in a common format are evaluated in a single assessment model based on a common set of background processes. The model is capable of evaluating environmental impacts in nine different regions and reflecting the background technology at three different points in time (2010/30/50). It addresses more complete inventories than common process-based analysis through the use of hybrid LCA.

5 http://data.worldbank.org/indicator/NY.GDP.MKTP.PP.KD
6 http://data.worldbank.org/indicator/NY.GDP.MKTP.KN

Table A.II.12 | Methane emission (gCH4/MJ_{LHV}) from coal and gas production (Burnham et al., 2012). Based on the minimum, mean, and maximum values provided by Burnham, the parameters μ and σ of a lognormal distribution were estimated. Coal is the weighted average of 60 % from underground mines and 40 % from surface mines.

	Min	Mean	Max	μ	σ
Underground coal mining	0.25	0.34	0.45	−1.09	0.147
Surface coal mining	0.025	0.05	0.068	−3.09	0.291
Natural gas production	0.18	0.52	1.03	−0.75	0.432

Table A.II.13 | Efficiency ranges assumed in power generation assumed in the calculation of fugitive emissions. The best estimate plant efficiency are based on NETL (NETL, 2010a; b; c; d; e) with ranges based (Singh et al., 2011a; Corsten et al., 2013). Note that the min and max efficiencies are not derived from the literature and were not used to calculate direct emissions; rather, they are used only to establish the possible range of fugitive emissions.

	Direct emissions (tCO_2eq/MWh)			Efficiency (% based on LHV)			Infrastructure & Supplies (tCO_2eq/MWh)		
Technology	**Min**	**Average**	**Max**	**Max**	**Average**	**Min**	**Min**	**Average**	**Max**
Gas—Single Cycle	0.621	0.667	0.706	33.1	30.8	29.1	0.001	0.002	0.002
Coal—average	0.913	0.961	1.009	33.3	35.0	36.8	0.010	0.011	0.013
Gas—average	0.458	0.483	0.507	39.9	42.0	44.1	0.001	0.002	0.003
Gas—Combined Cycle	0.349	0.370	0.493	59.0	55.6	41.7	0.001	0.002	0.002
Coal—PC	0.673	0.744	0.868	47.6	43.0	36.9	0.008	0.010	0.012
Coal—IGCC	0.713	0.734	0.762	44.9	43.6	42.0	0.003	0.004	0.006
CCS—Coal—Oxyfuel	0.014	0.096	0.110	35	30.2	27	0.014	0.017	0.023
CCS—Coal—PC	0.095	0.121	0.138	32	29.4	27	0.022	0.028	0.036
CCS—Coal—IGCC	0.102	0.124	0.148	34	32.3	27	0.008	0.010	0.013
CCS—Gas—Combined Cycle	0.030	0.047	0.098	49	47.4	35	0.007	0.009	0.012

The GHG emissions for coal carbon dioxide capture and storage (CCS), PV, concentrating solar power (CSP), and wind power associated with the two different efforts have been compared and have been found to be in agreement. The data has been supplemented by selected literature data where required. The specific numbers displayed come from following data sources.

A.II.9.3.1 Fossil fuel based power

For fossil fuel based power, three different sources of emissions were distinguished: (1) direct emissions from the power plant, (2) emissions of methane from the fuel production and delivery system, and (3) the remaining lifecycle emissions, mostly connected to the infrastructure of the entire energy system including the power plant itself, and supplies such as solvents. Each of these emissions categories was assessed separately, because emerging findings on methane emissions required a reassessment of the lifecycle emissions of established studies, which often use only a generic emissions factor. In our work, probability distributions for emissions from the three different systems were assessed and combined through a Monte Carlo analysis.

Fugitive emissions: The most important source of indirect emissions of fossil fuel based power is the supply of fuel, where fugitive emissions of methane are a major source of GHG gases. We have revisited the issue of fugitive methane emissions given new assessments of these emissions. As described in Section 7.5.1, fugitive emissions were modelled as the product of a log-normal distributions based on the parameters specified in Table A.II.12 and the efficiencies given by a triangular distribution with the parameters specified in Table A.II.13.

The data for the infrastructure component is from Singh et al. (2011a). A uniform distribution was used in the Monte Carlo Analysis. The data is provided in Table A.II.13. Direct emissions and associated efficiency data for Natural Gas Combined Cycle (NGCC) with and without CCS is from Singh et al. (2011b). Minimum and maximum numbers are from Corsten et al. (2013, Table 4), with an assumed direct/indirect share of 40 % and 60 %. For pulverized coal, Corsten et al. (2013, Table 5) reports characterized impacts, with direct and indirect emission shares for pulverized coal with and without CCS. For Integrated Gasification Combined Cycle (IGCC), calculations were performed by Hertwich et al. (2013) based on data obtained from NETL (2010a; d). For oxyfuel, the best estimate is based on a 90 % separation efficiency from Singh et al. (2011a) with the range assuming higher separation efficiency as indicated by Corsten et al. (2013). Ranges are based on Corsten et al. (2013) also considering the ranges reported by NETL (2010a; b; c; d; e). Triangular distributions were used in the Monte Carlo simulation. The contribution analysis shown in Figure 7.6 is based on Singh et al. (2011a) with adjustments to the higher fugitive emissions based on Burnham (2012) and lower average efficiencies and hence direct emissions for gas fired power as obtained from the distributions above.

A log-normal distribution does not have well-defined maximum and minimum values. The range in Figures 7.6 and 7.7 hence shows the 1st to 99th percentile.

A.II.9.3.2 Nuclear power

The data on nuclear power was taken from Lenzen (2008) and Warner and Heath (2012). There is no basis in the literature as far as we know to distinguish between 2nd and 3rd generation power plants.

A.II.9.3.3 Renewable energy

Concentrated solar power: The data range is based on both the assessments conducted for the International Resource Panel (Hertwich et al., 2013) work based on the analysis of Viebahn et al. (2011), Burkhardt et al. (2011), Whitaker et al. (2013), and the review of Burkhardt et al. (2012).

Photovoltaic power: Ranges are based largely on the reviews of Hsu et al. (2012) and Kim et al. (2012). The analysis of newer thin-film technologies analyzed in Hertwich et al. (2013) indicates that recent technical progress has lowered emissions.

Wind power: The data is based on the review of Arvesen and Hertwich (2012) and has been cross-checked with Dolan and Heath (2012) and Hertwich et al. (2013).

Ocean Energy: There have been very few LCAs of ocean energy devices. The numbers are based on the Pelamis (Parker et al., 2007) and Oyster wave energy device (Walker and Howell, 2011), the SeaGen tidal turbine (Douglas et al., 2008; Walker and Howell, 2011), and tidal barrages (Woollcombe-Adams et al., 2009; Kelly et al., 2012). Based on these available assessments, tidal turbines have the lowest GHG emissions and tidal barrages the highest.

Hydropower: The indirect emissions of hydropower are largely associated with fossil fuel combustion in the construction of the plant. The data presented here is based on SRREN (Kumar et al., 2011). The data was cross-checked with a recent review (Raadal et al., 2011) and analysis (Moreau et al., 2012).

The issue of biogenic emissions resulting from the degradation of biomass in reservoirs had been reviewed in SRREN, however, without providing estimates of the size of biogenic GHG emissions per kWh. Please note that only CH_4 emissions are included in the analysis. N_2O emissions have not been broadly investigated, but are assumed to be small (Demarty and Bastien, 2011). Carbon dioxide emissions can be substantial, but these emissions represent carbon that would probably have oxidized elsewhere; it is not clear what fraction of the resulting CO_2 would have entered the atmosphere (Hertwich, 2013). We have hence excluded biogenic CO_2 emissions from reservoirs from the assessment. The distribution of biogenic methane emissions comes from an analysis of methane emissions per kWh of power generated by Hertwich (2013) based on literature data collected and reviewed by Barros et al. (2011). Independent estimates based on recent empirical studies (Maeck et al., 2013) come to similar results. For the maximum number (2 kg CO_2eq/kWh), a specific power station analyzed by Kemenes et al. (2007) was chosen; as it is not clear that the much higher value from the 99th percentile of the distribution determined by Hertwich (2013) is really realistic.

Biomass: Life-cycle direct global climate impacts of bioenergy come from the peer-reviewed literature from 2010 to 2012 and are based on a range of electric conversion efficiencies of 27–50%. The category "Biomass—dedicated and crop residues" includes perennial grasses, like switchgrass and miscanthus, short rotation species, like willow and eucalyptus, and agricultural byproducts, like wheat straw and corn stover. "Biomass—forest wood" refers to forest biomass from long rotation species in various climate regions. Ranges include global climate impacts of CO_2 emissions from combustion of regenerative biomass (i.e., biogenic CO_2) and the associated changes in surface albedo following ecosystem disturbances, quantified according to the IPCC framework for emission metrics (Forster et al., 2007) and using 100-year GWPs as characterization factors (Cherubini et al., 2012).

These impacts are site-specific and generally more significant for long rotation species. The range in "Biomass—forest wood" is representative of various forests and climates, e.g., aspen forest in Wisconsin (US), mixed forest in Pacific Northwest (US), pine forest in Saskatchewan (Canada), and spruce forest in Southeast Norway. In areas affected by seasonal snow cover, the cooling contribution from the temporary change in surface albedo can be larger than the warming associated with biogenic CO_2 fluxes and the bioenergy system can have a net negative impact (i.e., cooling). Change in soil organic carbon can have a substantial influence on the overall GHG balance of bioenergy systems, especially for the case "Biomass—dedicated and crop residues", but are not covered here due to their high dependence on local soil conditions and previous land use (Don et al., 2012; Gelfand et al., 2013).

Additional information on the LCA of bioenergy alternatives is provided in Section 11.A.4.

A.II.10 Scenario data

A.II.10.1 Process

The AR5 Scenario Database comprises 31 models and 1,184 scenarios, summarized in Table A.II.14. In an attempt to be as inclusive as possible, an open call for scenarios was made through the Integrated Assessment Modeling Consortium (IAMC) with approval from the IPCC

Table A.II.14 | Contributing models to the WGIII AR5 Scenario Database.

Model (versions)	Economic coverage and feedback	Myopic/ Foresight	Regional and emissions* detail	Representation of climate and land use	Cost measures	Scenario Publications	Number of Scenarios included in AR5 database
AIM-Enduse (12.1; backcast 1.0)	Partial equilibrium	Myopic	32 regions; 5 substances (v. 12.1)/8 substances (v. backcast 1.0)	None	Energy system cost mark-up (v 12.1; backcast 1.0)/area under marginal abatement cost curve (backcast 1.0)	(Akashi et al., 2014; Kriegler et al., 2014b; Tavoni et al., 2014)	41
BET (1.5)	General equilibrium	Foresight	32 regions; CO_2 only	Climate damages; no land use	Consumption loss, GDP loss, energy system cost mark-up	(Yamamoto et al., 2014)	23
DNE21+ (v.11, v.12)	Partial equilibrium	Foresight	54 regions; 6 substances (v.11)/13 substances (v.12)	Temperature change; no land use	Energy system cost mark-up	(Akimoto et al., 2012; Wada et al., 2012; Kriegler et al., 2014a; Riahi et al., 2014; Sano et al., 2014)	43
EC-IAM 2012	General equilibrium	Foresight	11 regions; 6 substances	Climate damages; no land use	Consumption loss, GDP loss, energy system cost mark-up, welfare loss	(Kriegler et al., 2014c)	21
Ecofys Energy Model	Partial equilibrium	Myopic	1 region; 3 substances	No climate; land use for bioenergy	Energy system cost mark-up	(Deng et al., 2012)	1
ENV-Linkages (WEO2012)	General equilibrium	Myopic	15 regions; 6 substances	No climate; land use for food consumption	Consumption loss, GDP loss, equivalent variation, welfare loss	(Kriegler et al., 2014c)	17
FARM (3.0)	General equilibrium	Myopic	15 regions; CO_2 only	No climate; land use by land type for bioenergy and food consumption	Consumption loss, GDP loss, equivalent variation, welfare loss	(Sands et al., 2014)	12
GCAM (2.0, 3.0, 3.1, MiniCAM)	Partial equilibrium	Myopic	14 regions; 13 substances	Temperature change; Land use by land type for bioenergy and food consumption	Area under marginal abatement cost curve	(Calvin et al., 2009a, 2012, 2013, 2014; Iyer et al., 2014; Kriegler et al., 2014b; Tavoni et al., 2014)	139
GEM-E3-ICCS	General equilibrium	Myopic	37 regions; 11 substances	No climate; land use for food consumption	Consumption loss, GDP loss, equivalent variation	(Kriegler et al., 2014a)	11
GRAPE (ver1998, ver2011)	General equilibrium	Foresight	15 regions; 5 substances	Temperature change; land use by land type for food consumption	Consumption loss, GDP loss	(Calvin et al., 2012; Kriegler et al., 2014c)	14
GTEM REF32	General equilibrium	Myopic	13 regions; 5 substances	No climate; land use for food consumption and crop prices	Consumption loss, GDP loss, welfare loss	(Mi et al., 2012)	4
IEEJ (ver.2011)	Econometric	Foresight	43 regions; CO_2 only	Temperature change; no land use	Energy system cost mark-up	(Matsuo et al.)	2
IGSM	General equilibrium	Myopic	16 regions; 12 substances	Climate damages; land use by land type for bioenergy, food consumption and crop prices	Consumption loss, GDP loss, equivalent variation, welfare loss; area under marginal abatement cost curve; energy system cost mark-up	(Prinn et al., 2011)	5
IMACLIM (v1.1)	General equilibrium	Myopic	12 regions; CO_2 only	Temperature change; no land use	Welfare loss, GDP loss, consumption loss, equivalent variation	(Bibas and Méjean, 2014; Kriegler et al., 2014a; Riahi et al., 2014)	53
IMAGE (2.4)	Partial equilibrium	Myopic	26 regions; 13 substances	Temperature change; land use by land type for bioenergy and food consumption	Area under marginal abatement cost curve	(van Vliet et al., 2009, 2014; van Ruijven et al., 2012; Lucas et al., 2013; Kriegler et al., 2014a; b; Riahi et al., 2014; Tavoni et al., 2014)	79
iPETS (1.2.0)	General equilibrium	Foresight	9 regions; CO_2 only	Land use for food consumption	Consumption loss, GDP loss, welfare loss	(O'Neill et al., 2012)	4
KEI-Linkages	General equilibrium	Myopic	13 regions; CO_2 only	No climate; land use for food consumption and crop prices	Consumption loss, equivalent variation	(Lim and Kim, 2012)	4

Model (versions)	Economic coverage and feedback	Myopic/ Foresight	Regional and emissions* detail	Representation of climate and land use	Cost measures	Scenario Publications	Number of Scenarios included in AR5 database
MARIA23_org	General equilibrium	Foresight	23 regions; 6 substances	Temperature change and climate damage; land use by land type for bioenergy and food consumption	Welfare loss, GDP loss, consumption loss, GDP loss, energy system cost mark-up	(Mori, 2012)	5
MERGE (AME, EMF22, EMF27)	General equilibrium	Foresight	9 (AME)/8 (EMF22) regions; 7 (AME,EMF22) /12 (EMF27) substances	Climate damages; no land use	Consumption loss, GDP loss, welfare loss	(Blanford et al., 2009, 2014b; Calvin et al., 2012)	44
MERGE-ETL (2011)	General equilibrium	Foresight	9 regions; 5 substances	Temperature change; no land use	Consumption loss, GDP loss, welfare loss	(Marcucci and Turton, 2014; Kriegler et al., 2014a; Riahi et al., 2014)	48
MESSAGE (V.1, V.2, V.3, V.4)	General equilibrium	Foresight	11 regions; 10 (V.1)/13 (V.2, V.3, V.4) substances	Temperature change; land use by land type for bioenergy (all versions)	GDP loss, energy system cost mark-up (all versions); area under marginal abatement cost curve (V.1, V.3, V.4); consumption loss (V.3, V.4)	(Krey and Riahi, 2009; Riahi et al., 2011, 2012, 2014; van Vliet et al., 2012; Kriegler et al., 2014a; b; McCollum et al., 2014; Tavoni et al., 2014)	140
Phoenix (2012.4)	General equilibrium	Myopic	24 regions; CO_2 only	Radiative forcing; land as factor of production in agriculture and forestry (including feedstocks for biofuels)	Welfare loss, GDP loss, consumption loss, equivalent variation	(Fisher-Vanden et al., 2012; Kriegler et al., 2014c)	31
POLES (AMPERE, EMF27, AME)	Partial equilibrium/ econometric	Myopic	57 regions (AMPERE, EMF27)/47 regions (AME); 6 substances	No climate; land use by land type for bioenergy (AMPERE, AME)	Area under marginal abatement cost curve	(Dowling and Russ, 2012; Griffin et al., 2014; Kriegler et al., 2014a; Riahi et al., 2014)	79
REMIND (1.1, 1.2, 1.3, 1.4, 1.5)	General equilibrium	Foresight	11 regions; CO_2 only (1.1, 1.2)/4 substances (1.3)/ 6 substances (1.4)/6–9 substances (1.5)	Temperature change; land use emissions via MAC (1.2, 1.3, 1.4) and from a land use model (MAgPIE; 1.5)	Consumption loss, GDP loss, welfare loss	(Leimbach et al., 2010; Luderer et al., 2012a; b; Arroyo-Currás et al., 2013; Bauer et al., 2013; Aboumahboub et al., 2014; Tavoni et al., 2014; Klein et al., 2014; Kriegler et al., 2014a; b; Riahi et al., 2014)	158
SGM	General equilibrium	Myopic	8 regions; CO_2 only	None	Consumption loss, GDP loss, equivalent variation, area under marginal abatement cost curve	(Calvin et al., 2009b)	7
TIAM-ECN	Partial equilibrium	Foresight	15 regions; 3 Substances	Radiative forcing; no land use	Energy cost increase; energy system cost mark-up	(Kober et al., 2014; Kriegler et al., 2014b; Tavoni et al., 2014)	12
TIAM-World (2007, 2012.02, Mar2012)	Partial equilibrium	Foresight	16 regions; 3 Substances	Temperature change; land use for bioenergy	Area under marginal abatement cost curve (all versions); welfare loss (2012.02); energy system cost mark-ups (2007, Mar2012)	(Loulou et al., 2009; Labriet et al., 2012; Kanudia et al., 2014)	41
TIMES-VTT	Partial equilibrium	Foresight	17 regions; 6 Substances	Temperature change; no land use	Consumption loss, energy system cost mark-ups	(Koljonen and Lehtilä, 2012)	6
WITCH (AME, AMPERE, EMF22, EMF27, LIMITS, RECIPE, ROSE)	General equilibrium	Foresight	13 regions/ 12 regions (RECIPE); 6 Substances	Temperature change (AME, AMPERE); climate damages (EMF22, EMF27; no land use	Consumption loss, GDP loss, welfare loss, energy system cost mark-ups	(Bosetti et al., 2009; de Cian et al., 2012; Massetti and Tavoni, 2012; De Cian et al., 2014; Kriegler et al., 2014a; b; Marangoni and Tavoni, 2014; Riahi et al., 2014; Tavoni et al., 2014)	132
WorldScan2	General equilibrium	Myopic	5 regions; 8 Substances	No climate; land use for food consumption	Welfare loss, GDP loss, equivalent variation	(Kriegler et al., 2014a)	8

* The substances reported under emissions detail include GHGs, radiatively and chemically active substances where the reference list includes the following set of 13 substances: CO_2, CH_4, N_2O, CFCs, HFCs, SF_6, CO, NO_x, VOC, SO_2, BC, OC, and NH_3.

Table A.II.15 | Model inter-comparison exercises generating transformation pathway scenarios included in AR5 Scenario Database.

Model Intercomparison Exercise	Year Completed	Number of Models in WGIII AR5 scenario database	Number of Scenarios in WGIII AR5 scenario database	Areas of Harmonization	Lead Institution	Overview Publication
ADAM (Adaptation and Mitigation Strategies—Supporting European Climate Policy)	2009	1	15	Technology availability, Mitigation policy	Potsdam Institute for Climate Impact Research (PIK)	(Edenhofer et al., 2010)
AME (Asian Modeling Exercise)	2012	16	83	Mitigation policy	Pacific Northwest National Laboratories (PNNL)	(Calvin et al., 2012)
AMPERE (Assessment of Climate Change Mitigation Pathways and Evaluation of the Robustness of Mitigation Cost Estimates)	2013	11	378	Technology availability; mitigation policy; GDP; population	Potsdam Institute for Climate Impact Research (PIK)	AMPERE2: (Riahi et al., 2014) AMPERE3: (Kriegler et al., 2014a)
EMF 22 (Energy Modeling Forum 22)	2009	7	70	Technology availability, mitigation policy	Stanford University	(Clarke et al., 2009)
EMF 27 (Energy Modeling Forum 27)	2013	16	362	Technology availability, mitigation policy	Stanford University	(Blanford et al., 2014a; Krey et al., 2014; Kriegler et al., 2014c)
LIMITS (Low Climate Impact Scenarios and the Implications of required tight emissions control strategies)	2014	7	84	Mitigation policies	Fondazione Eni Enrico Mattei (FEEM)	(Kriegler et al., 2014b; Tavoni et al., 2014)
POeM (Policy Options to engage Emerging Asian economies in a post-Kyoto regime)	2012	1	4	Mitigation policies	Chalmers University of Technology	(Lucas et al., 2013)
RECIPE (Report on Energy and Climate Policy in Europe)	2009	2	18	Mitigation policies	Potsdam Institute for Climate Impact Research (PIK)	(Luderer et al., 2012a)
RoSE (Roadmaps towards Sustainable Energy futures)	2013	3	105	Mitigation policy; GDP growth; population growth, fossil fuel availability	Potsdam Institute for Climate Impact Research (PIK)	(Bauer et al., 2013; De Cian et al., 2013; Calvin et al., 2014; Chen et al., 2014; Luderer et al., 2014)

WGIII Technical Support Unit. To be included in the database, four criteria had to be met. First, only scenarios published in the peer-reviewed literature could be considered, per IPCC protocol. Second, the scenario had to contain a minimum set of required variables and some basic model and scenario documentation (meta data) had to be provided. Third, only models with at least full energy system representation were considered given that specific sectoral studies were assessed in Chapters 8–11. Lastly, the scenario had to provide data out to at least 2030. Scenarios were submitted by entering the data into a standardized data template that was subsequently uploaded to a database system[7] administered by the International Institute of Applied System Analysis (IIASA).

[7] https://secure.iiasa.ac.at/web-apps/ene/AR5DB

A.II.10.2 Model inter-comparison exercises

The majority of scenarios (about 95 %) included in the database were generated as part of nine model inter-comparison exercises, summarized in Table A.II.15. The Energy Modeling Forum (EMF), established at Stanford University in 1976, is considered one of the first major efforts to bring together modelling teams for the purpose of model inter-comparison. Since its inception, EMF and other institutions have worked on a large number of model inter-comparison projects with topics ranging from energy and the economy, to natural gas markets, to climate change mitigation strategies. Recent model inter-comparison studies have focused on, for example, delayed and fragmented mitigation, effort sharing, the role of technology availability and energy resources for mitigation and have looked into the role of specific regions (e.g., Asia) in a global mitigation regime.

Table A.II.16 | Scenario classifications.

Name	Climate Category	Carbon Budget 2050 and 2100 Category		Negative Emissions Category	Overshoot Category	Technology Category	Policy Category
Binning criterion	Radiative forcing (total or Kyoto), CO_2 budget	Cumulative CO_2 emissions budget to 2100	Cumulative CO_2 emissions budget to 2050	Maximum annual net negative emissions	Overshoot of 2100 forcing levels	Availability of negative emissions and other technology	Scenario definitions in Model Intercomparison Projects (MIPs)
# of classes	7 classes (1–7)	7 classes (1–7)	7 classes (1–7)	2 classes (N1, N2)	2 classes (O1, O2)	4 classes (T0–T3)	11 classes (P0–P7, P1+, P3+, P4+)
Notes	Extended to models that do not report forcing based on CO_2 budgets. Extrapolated to a subset of 2050 scenarios.		Classes for 2050 budgets cannot be unambiguously mapped to climate outcomes and thus overlap	Only for scenarios that run out to 2100	Only for models that run out to 2100 and report full or Kyoto forcing		

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A.II.10.3 Classification of scenarios

The analysis of transformation pathway or scenario data presented in Chapters 1, 6, 7, 8, 9, 10 and 11 uses a common classification scheme to distinguish the scenarios along several dimensions. The key dimensions of this classification are:

- Climate Target (determined by 2100 CO_2eq concentrations and radiative forcing or carbon budgets)
- Overshoot of 2100 CO_2eq concentration or radiative forcing levels
- Scale of deployment of carbon dioxide removal or net negative emissions
- Availability of mitigation technologies, in particular carbon dioxide removal (CDR) or negative emissions technologies
- Policy configuration, such as immediate mitigation, delayed mitigation, or fragmented participation

Table A.II.16 summarizes the classification scheme for each of these dimensions, which are discussed in more detail in the following sections.

A.II.10.3.1 Climate category

Climate target outcomes are classified in terms of radiative forcing as expressed in CO_2-equivalent concentrations (CO_2eq). Note that in addition to CO_2eq concentrations, also CO_2eq emissions are used in the WGIII AR5 to express the contribution of different radiative forcing agents in one metric. The CO_2-equivalent concentration metric refers to the hypothetical concentration of CO_2 that would result in the same instantaneous radiative forcing as the total from all sources, including aerosols[8]. By contrast, the CO_2eq emissions metric refers to a sum of Kyoto GHG emissions weighted by their global warming potentials (GWPs, see Chapter 3, Section 3.9.6) as calculated in the SAR (IPCC, 1995a), for consistency with other data sources. It is important to note that these are fundamentally different notions of 'CO_2-equivalence'.

There are several reasons to use radiative forcing as an indicator for anthropogenic interference with the climate system and—in the case of climate policy scenarios—mitigation stringency: 1) it connects well to the Representative Concentration Pathways (RCPs) used in CMIP5 (see WGI AR5), 2) it is used as a definition of mitigation target in many modelling exercises, 3) it avoids problems introduced by the uncertainty in climate sensitivity, and 4) it integrates across different radiative forcing agents. These advantages outweigh some difficulties of the radiative forcing approach, namely that not all model scenarios in the WGIII AR5 Scenario Database fully represent radiative forcing, and that there is still substantial natural science uncertainty involved in converting emissions (a direct output of all models investigated in Chapter 6) into global radiative forcing levels.

To rectify these difficulties, the following steps were taken:

1. The emissions of all scenarios in the WGIII AR5 Scenario Database (see following bullets for details) were run through a single climate model MAGICC6.3 (where applicable) to establish comparability between the concentration, forcing, and climate outcome between scenarios. This removes natural science uncertainty due to different climate model assumptions in integrated models. The MAGICC output comes with an estimate of parametric uncer-

8 More technically speaking, CO_2-equivalent concentrations can be converted to forcing numbers using the formula log(CO_2eq / CO_2_preindustrial) / log(2) · RF(2 x CO_2) with $RF(2 \times CO_2) = 3.7\ W/m^2$ the forcing from a doubling of pre-industrial CO_2 concentration.

tainty within the MAGICC framework (Meinshausen et al., 2009, 2011a; b). Calculated MAGICC radiative forcing values are mean values given these uncertainties. MAGICC closely reflects the climate response of General Circulation Model (GCM) ensembles such as studied in CMIP5, and therefore can be considered a useful yardstick for measuring and comparing forcing outcomes between scenarios (Schaeffer et al., 2013). Emissions scenarios were harmonized to global inventories in 2010 to avoid a perturbation of climate projections from differences in reported and historical emissions that were assumed for the calibration of MAGICC (Schaeffer et al., 2013). The scaling factors were chosen to decline linearly to unity in 2050 to preserve as much as possible the character of the emissions scenarios. In general, the difference between harmonized and reported emissions is very small. The MAGICC runs were performed independently of whether or not a model scenario reports endogenous climate information, and both sets of information can deviate. As a result, MAGICC output may no longer fully conform to 'nameplate' targets specified in the given scenarios and as originally assessed by the original authors. Nevertheless, given the benefit of comparability both between AR5 scenarios and with WGI climate projections, scenarios were classified based on radiative forcing derived from MAGICC.

2. As a minimum requirement to apply MAGICC to a given emissions scenario, CO_2 from the fossil fuel and industrial (FF&I) sector, CH_4 from FF&I and land use sectors, and N_2O from FF&I and land use sectors needed to be reported. In case of missing land-use related CO_2 emissions the average of the RCPs was used. If fluorinated gas (F-gas), carbonaceous aerosols and/or nitrate emissions were missing, those were added by interpolating data from RCP2.6 and RCP8.5 on the basis of the energy-related CO_2 emissions of the relevant scenario vis-à-vis these RCPs. If scenarios were part of a model intercomparison project and gases, or forcers were missing, data was used from what was diagnosed as a "central" model for the same scenario (Schaeffer et al., 2013). As a minimum requirement to derive not only Kyoto forcing, but also full anthropogenic forcing, sulfur emissions in addition to CO_2, CH_4, and N_2O needed to be reported. Forcing from mineral dust and land use albedo was fixed at year-2000 values.

3. For the remaining scenarios, which only run to 2050 or that do not fulfill the minimum requirements to derive Kyoto forcing with MAGICC, an auxiliary binning based on cumulative CO_2 emissions budgets was implemented. Those scenarios came from models that only represent fossil fuel and industry emissions or only CO_2 emissions. The categorization of those scenarios is discussed below and includes a considerable amount of uncertainty from the mapping of CO_2 emissions budgets to forcing outcomes. The uncertainty increases significantly for scenarios that only run to 2050. In many cases, 2050 scenarios could only be mapped to the union of two neighbouring forcing categories given the large uncertainty.

The CO_2-equivalent concentrations were converted to full anthropogenic forcing ranges by using the formula in footnote 8, assuming CO_{2}_preindustrial = 278 ppm and rounding to the first decimal. All scenarios from which full forcing could be re-constructed from MAGICC were binned on this basis (Table A.II.17). Those scenarios that only allowed the re-construction of Kyoto forcing were binned on the basis of the adjusted Kyoto forcing scale that was derived from a regression of Kyoto vs. full forcing on the subset of those scenarios that reported both quantities. Thus, the binning in terms of Kyoto forcing already entails an uncertainty associated with this mapping.

We note the following:

- CO_2 equivalent and forcing numbers refer to the year 2100. Temporary overshoot of the forcing prior to 2100 can occur. The overshoot categories (see Section A.II.10.3.3) can be used to further control for overshoot.
- No scenario included in the WGIII AR5 Scenario Database showed lower forcing than 430 ppm CO_2eq and 2.3 W/m^2, respectively, so no lower climate category was needed.
- When labeling the climate categories in figures and text, the CO_2-equivalent range should be specified, e.g., 430–480 ppm CO_2eq for Category 1. If neighbouring categories are lumped into one bin, then the lower and upper end of the union of categories should be named, e.g., 430–530 ppm CO_2eq for Categories 1 & 2 or > 720 ppm CO_2eq for Categories 6 and 7.

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Table A.II.17 | Climate forcing classes (expressed in ppm CO_2eq concentration levels).

Category	Forcing categories (in ppm CO_2eq)	Full anthropogenic forcing equivalent [W/m^2]	Kyoto forcing equivalent [W/m^2]	Centre	RCP (W/m^2)
1	430–480	2.3–2.9	2.5–3.1	455	2.6
2	480–530	2.9–3.45	3.1–3.65	505	-
3	530–580	3.45–3.9	3.65–4.1	555	(3.7)
4	580–650	3.9–4.5	4.1–4.7	650	4.5
5	650–720	4.5–5.1	4.7–5.3		
6	720–1000	5.1–6.8	5.3–7.0	860	6
7	> 1000	> 6.8	> 7.0	-	8.5

Table A.II.18 | 2011–2100 emissions budget binning (rounded to 25 $GtCO_2$).

2100 Emissions Category	Cumulated 2011–2100 CO_2 emissions [$GtCO_2$]	Associated Climate forcing category	Forcing (in ppm CO_2eq)
1	350–950	1	430–480
2	950–1500	2	480–530
3	1500–1950	3	530–580
4	1950–2600	4	580–650
5	2600–3250	5	650–720
6	3250–5250	6	720–1000
7	> 5250	7	> 1000

Table A.II.19 | 2011–2050 emissions budget binning (rounded to 25 $GtCO_2$).

2050 Emissions Category	Cumulated 2011–2050 CO_2 emissions [$GtCO_2$]	Associated Climate forcing category if negative emissions are available (Classes T0 or T2 below)	Associated Climate forcing category if negative emissions are not available (Classes T1 or T3 below)
1	< 825	1	1
2	825–1125	1–2	2
3	1125–1325	2–4	3–4
4	1325–1475	3–5	4–5
5	1475–1625	4–6	5–6
6	1625–1950	6	6
7	> 1950	7	7

A.II.10.3.2 Carbon budget categories

The classification of scenarios in terms of cumulative CO_2 emissions budgets is mainly used as an auxiliary binning to map scenarios that do not allow the direct calculation of radiative forcing (see above) to forcing categories (Tables A.II.18 and A.II.19). However, it is also entertained as a separate binning across scenarios for diagnostic purposes. The mapping between full anthropogenic forcing and CO_2 emissions budgets has been derived from a regression over model scenarios that report both quantities (from the models GCAM, MESSAGE, IMAGE, MERGE, REMIND) and is affected by significant uncertainty (Figure A.II.8). This uncertainty is the larger the shorter the time span of cumulating CO_2 emissions is. Due to the availability of negative emissions, and the inclusion of delayed action scenarios in some studies, the relationship of 2011–2050 CO_2 emissions budgets and year 2100 radiative forcing was weak to the point that a meaningful mapping was hard to identify (Figure A.II.9). As a remedy, a mapping was only attempted for 2050 scenarios that do not include a strong element of delayed action (i.e., scenario policy classes P0, P1, P2 and P6; see Section A.II.10.3.6), and the mapping was differentiated according to whether or not negative emissions would be available (scenario technology classes T0–T3, see Section A.II.10.3.5). As a result of the weak relationship between budgets and radiative forcing, 2050 CO_2 emissions budget categories could only be mapped to the union of neighbouring forcing categories in some cases (Table A.II.19).

CO_2 emissions numbers refer to total CO_2 emissions including emissions from the AFOLU sector. However, those models that only reported CO_2 fossil fuel and industrial emissions were also binned according to this scheme. This can be based on the simplifying assumption that net land use change emissions over the cumulation period are zero.

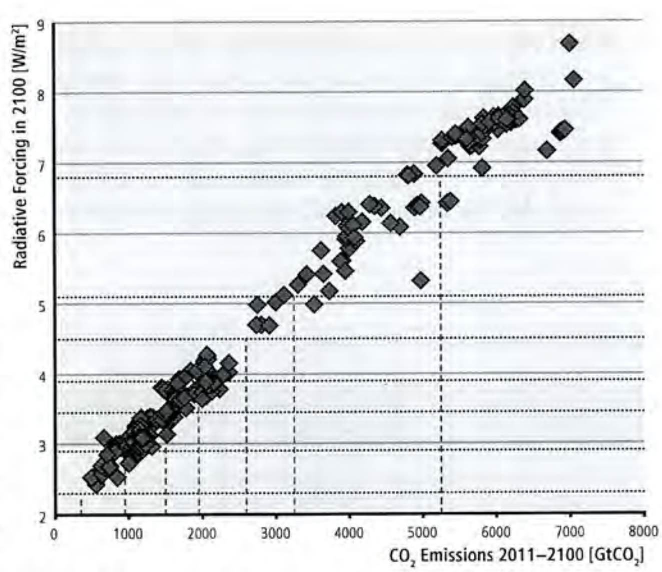

Figure A.II.8 | Regression of radiative forcing against 2011–2100 cumulative CO_2 emissions. Scenarios of full forcing models GCAM, MERGE, MESSAGE, REMIND and IMAGE were used for this analysis. Regression was done separately for each model, and resulting budget ranges averaged across models.

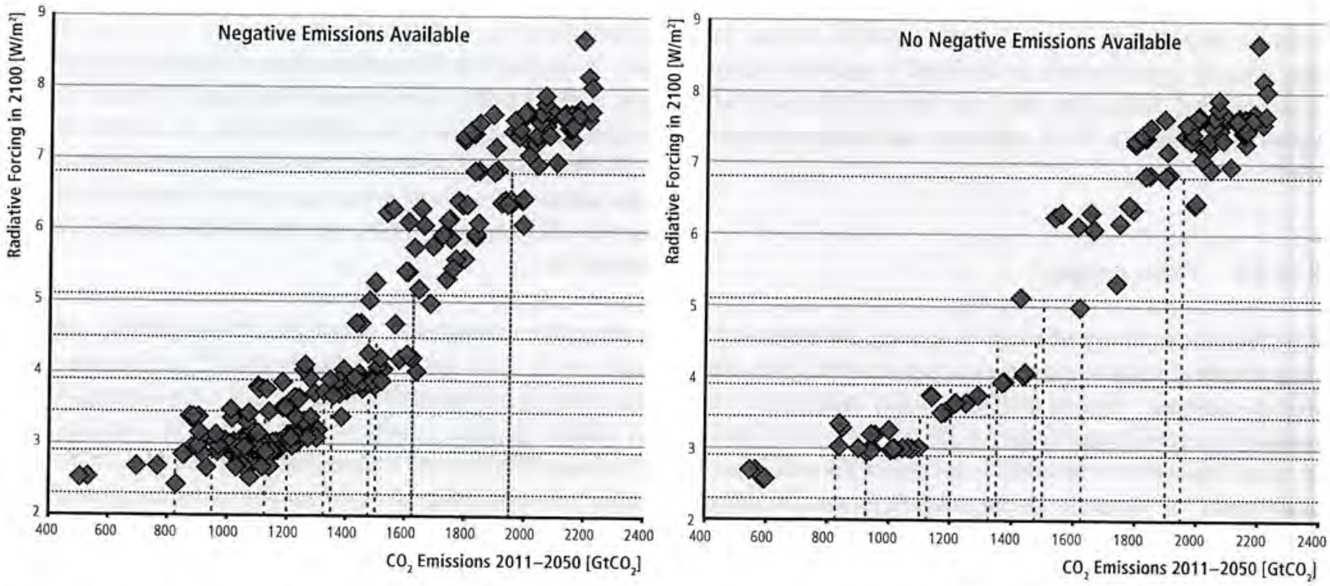

Figure A.II.9 | Regression of radiative forcing against 2011–2050 CO_2 emissions. Red lines show mean results of fit and depend on whether (left panel) or not (right panel) negative emissions are available. Green lines show harmonized bins between both categories for the mapping in Table A.II.19.

A.II.10.3.3 Overshoot category

The overshoot categorization shown in Table A.II.20 applies to the maximum overshoot of the 2100 radiative forcing level before 2100. The binning is only applied to models running until 2100. If full radiative forcing was not available, Kyoto forcing was used. If radiative forcing information was not available, no assignment was made.

A.II.10.3.4 Negative emissions category

The negative emissions categories apply to the maximum amount of net negative CO_2 emissions (incl. land use) in any given year over the 21st century. Scenarios with very large annual fluxes of negative emissions are also able to overshoot strongly, because the overshoot can be compensated with large net negative emissions within a relatively short period of time. Only a small number of scenarios show net negative emissions larger than 20 $GtCO_2$/yr, which was used to separate scenarios with large negative emissions from those with bounded negative emissions (Table A.II.21).

A.II.10.3.5 Technology category

The technology dimension of the categorization scheme indicates the technology availability in a given scenario. We identify two key factors:

1. the availability of negative emissions or CDR technologies that can be either confined by restrictions stipulated in the scenario definition or by the fact that the model does not represent negative emissions technologies, and
2. the restricted use of the portfolio of mitigation technologies that would be available in the model with default technology assumptions.

Combining these two factors lead to four distinct technology categories as shown in Table A.II.22.

Table A.II.20 | Overshoot categories.

Small Overshoot	*Large Overshoot*
< 0.4 W/m²	*> 0.4 W/m²*
O1	O2

Table A.II.21 | Negative emissions categories.

Bounded net negative emissions	*Large net negative emissions*
< 20 $GtCO_2$/yr	*> 20 $GtCO_2$/yr*
N1	N2*

* The GCAM 3.0 scenario EMF27–450-FullTech came in at –19.96 GtCO2/yr and was also included in class N2.

Table A.II.22 | Technology categories.

No restriction Neg. Emissions	**No negative emissions model**	**Restriction, but with negative emissions**	**No negative emissions and (other) restrictions**
T0	T1	T2	T3

Note that some scenarios improve technology performance over the default version (e.g., larger biomass availability, higher final energy intensity improvements, or advanced / expanded technology assumptions). These cases were not further distinguished and assigned to T0 and T1, if no additional technology restrictions existed.

A.II.10.3.6 Policy category

Policy categories are assigned based on scenario definitions in the study protocols of model intercomparison projects (MIPs). The policy categories summarize the type of different policy designs that were investigated in recent studies (Table A.II.23). We stress that the long-term target level (where applicable) is not part of the policy design categorization. This dimension is characterized in terms of climate categories (see above). Individual model studies not linked to one of the larger MIPs were assigned to baseline (P0) and immediate action (P1) categories where obvious, and otherwise left unclassified. The residual class (P7) contains the G8 scenario from the EMF27 study (Table A.II.15), with ambitious emissions caps by Annex I countries (starting immediately) and Non-Annex I countries (starting after 2020), but with a group of countries (fossil resource owners) never taking a mitigation commitment over the 21st century. The RECIPE model intercomparison project's delay scenarios start acting on a global target already in 2020, and thus are in between categories P1 and P2. P0 does not include climate policy after 2010 (it may or may not include Kyoto Protocol commitments until 2012), while P1 typically assumes full 'when', 'where' and 'what' flexibility of emissions reductions in addition to immediate action on a target (so called idealized implementation scenarios). The scenario class P6 characterizes the case of moderate fragmented action throughout the 21st century, without aiming at a long term global target, usually formulated as extrapolations of the current level of ambition. Policy categories P2 to P4 describe variants of adopting a global target or a global carbon price at some later point in the future. With the important exception of the AMPERE2 study, all scenarios in the P2-P4 class assume a period of regionally fragmented action prior to the adoption of a global policy regime. For further details of the scenario policy categories P2-P6, see the individual studies listed in Table A.II.15.

For the policy categories P1 (Idealized), P3 (Delay 2030), and P4 (Accession to Price Regime) subcategories P1+, P3+ and P4+ respectively exist for which in addition to climate policy supplementary policies (Supp.)(e.g., infrastructure polices) that are not part of the underlying baseline scenario have been included. These categories have been assigned to the climate policy scenarios of the IMACLIM v1.1 model from the AMPERE project to distinguish them from similar scenarios (e.g., EMF27) where these supplementary policies were not included and therefore policy costs are generally higher.

A.II.10.3.7 Classification of baseline scenarios

Baseline scenarios used in the literature are often identical or at least very close for one model across different studies. However, in some exercises, characteristics of baseline scenarios, such as population and economic growth assumptions, are varied systematically to study their influence on future emissions, energy demand, etc. Table A.II.24 below provides an overview of unique Kaya-factor decompositions of baseline scenarios in the AR5 scenario database. The results are shown in Figures 6.1 and 6.2 in Chapter 6.

Table A.II.23 | Policy categories.

Category		Target adoption	Staged accession	Long-term frag / Free rider	MIPs
P0	Baseline	None	No	N/A	All
P1	Idealized	Immediate	No	No / No	All
P1+	Idealized + Supp. Policies	Immediate	No	No / No	AMPERE2, AMPERE3
P2	Delay 2020	Model year after 2020	No	No / No	RoSE, LIMITS
P3	Delay 2030	Model year after 2030	No	No / No	RoSE, LIMITS, AMPERE2
P3+	Delay 2030 + Supp. Policies	Model year after 2030	No	No / No	AMPERE2
P4	Accession to Price Regime	None	Yes (2030–2050)	No / No	AMPERE3
P4+	Accession to Price Regime + Supp. Policies	None	Yes (2030–2050)	No / No	AMPERE3
P5	Accession to Target	Yes (starting 2010)	Yes (2030–2070)	No / No	EMF22
P6	Fragmented Ref Pol	No	N/A	Yes / Yes (EMF27)— No (Other)	EMF27, RoSE, LIMITS, AMPERE3
P7	Other cases	N/A	N/A	N/A	EMF27, RECIPE

Table A.II.24 | Classification of unique Kaya factor projections in the baseline scenario literature.

Study	Models Contributing Global Results	Population			Per Capita Income				Energy Intensity		Carbon Intensity
		Harmonized		Unharmonized	Harmonized			Unharmonized	Unharmonized		Unharmonized
		High	Default		High	Default	Low		Default	Fast	
ADAM	1			1				1	1		3
AME	16			16				16	15		15
AMPERE	11		11			10		10	10	9	65
EMF22	7			7			1	7	8		8
EMF27	16			16				31	16	15	119
GEA	1			1				0	0		1
LIMITS	7			7				7	7		7
POeM	1			1				1	1		1
RECIPE	1			1				1	1		1
RCP 8.5	1	1					2		1		1
RoSE	3	3	3		5	3	7		15		31
Other	2			2				2	1		1
	67	4	14	52	5	13	10	76	76	24	253
				= 70				= 104		= 100	

Notes:
All AMPERE scenarios harmonized population along a default trajectory
RoSE specified two harmonized population trajectories: default and high
RCP 8.5 was based on an intentionally high population trajectory
In all other cases, no guidance was given regarding population harmonization
AMPERE scenarios specified a default harmonization of GDP
One model in AMPERE (IMAGE) did not follow GDP harmonization, thus it was classified as unharmonized
AMPERE WP2 (9 of 11 participated) specified an alternative low energy intensity baseline with unharmonized implications for per capita income
One model in EMF22 (MERGE) included an alternative baseline with intentionally low per capita income
EMF27 specified an alternative low energy intensity baseline (15 of 16 ran it) with unharmonized implications for per capita income
ROSE specified several alternative GDP baselines, some run by all three models, others by only one or two
In all other cases, no guidance was given regarding per capita income or GDP harmonization
One study included a model not reporting data for GDP: GEA (MESSAGE)
Three studies included a model not reporting data for total primary energy: AME (Phoenix); AMPERE (GEM-E3); and Other (IEEJ)
No study successfully harmonized energy demand, thus scenarios are classified as default if a low energy intensity baseline was not specifically indicated
Alternative supply technology scenarios generally do not affect energy intensity, thus only default supply technology scenarios are classified

A.II.10.4 Comparison of integrated and sectorally detailed studies

In Section 6.8 of this report, but also in a number of other sections, integrated studies included in the AR5 Scenario Database that is described in Sections A.II.10.1 to A.II.10.3 above are compared to sectorally detailed studies assessed in Chapters 8, 9, and 10 that deal with the end-use sectors transport, buildings and industry respectively. Table A.II.25 provides an overview of the sectorally detailed studies that are included in this comparison. It should be noted that not all studies provide the data necessary to derive final energy demand reduction compared to baseline and low-carbon fuel shares as, for example, shown in Figure 6.37 and 6.38. In addition, some of the sectorally detailed studies do not cover the entire sector, but restrict themselves to the most important services within a sector (e.g., space heating and cooling and hot water provision in the buildings sector).

Table A.II.25 | Sectorally detailed energy end-use studies compared to transformation pathways.

Sector	Study (Literature Reference)	Scenario Name	Scenario Type
Transport (Ch. 8)	World Energy Outlook 2012 (IEA, 2012e)	New Policies	Base
		450 Scenario	Policy
	Energy Technology Perspectives 2008 (IEA, 2008)	Baseline	Base
		ACT Map	Policy
		BLUE Map	Policy
		BLUE conservative	Policy
		BLUE EV	Policy
		BLUE FCV	Policy
	Energy Technology Perspectives 2010 (IEA, 2010b)	Baseline	Base
		BlueMap	Policy
	Energy Technology Perspectives 2012 (IEA, 2012f)	4DS	Policy
		2DS	Policy
	Global Energy Assessment (Kahn Ribeiro et al., 2012)	REF	Base
		GEA-Act	Policy
		GEA-Supply	Policy
		GEA-Mix	Policy
		GEA-Efficiency	Policy
	World Energy Technology Outlook 2050 (EC, 2006)	Hydrogen Scenario	Policy
	World Energy Council 2011 (WEC, 2011)	Freeway	Base
		Tollway	Policy
	Asia/World Energy Outlook 2011 (IEEJ, 2011)	Enhanced Development Scenario	Policy
Buildings (Ch. 9)	World Energy Outlook 2010 (IEA, 2010c)	Current Policies	Base
		450 Scenario	Policy
	Energy Technology Perspectives 2010 (IEA, 2010b)	Baseline	Base
		BlueMap	Policy
	3CSEP HEB (Ürge-Vorsatz et al., 2012)	Frozen efficiency	Base
		Deep efficiency	Policy
	Harvey (Harvey, 2010)	High Slow efficiency no heat pump	Base
		High Fast efficiency with heat pump	Policy
	The Energy Report (WWF/Ecofys/OMA, 2011; Deng et al., 2012)	Baseline	Base
		The Energy Report	Policy
Industry (Ch. 10)	Energy Technology Perspectives 2012 (IEA, 2012f)	6DS Low-demand	Base
		6DS High-demand	Base
		4DS Low-demand	Policy
		4DS High-demand	Policy
		2DS Low-demand	Policy
		2DS High-demand	Policy
	Energy Technology Transitions for Industry (IEA, 2009)	BLUE low	Policy
		BLUE high	Policy
	Global Energy Assessment (Banerjee et al., 2012)	Energy Efficient Scenario	Policy
	Energy [R]evolution 2012 (GWEC et al., 2012)	Reference Scenario	Base
		Energy [R]evolution	Policy
	The Energy Report (WWF/Ecofys/OMA, 2011; Deng et al., 2012)	The Energy Report	Policy

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