Annexes

ANNEX

I

Glossary, Acronyms and Chemical Symbols

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Contents

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).

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 lifecycle 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

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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

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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

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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*.

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.

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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*.

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

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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.

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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*.

AI

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).

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.

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.

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

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

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.

AII

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}.

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

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):

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

(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):

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

$$LCCC = \frac{CRF \cdot \Delta I + \Delta O\&M - \Delta B}{\Delta C}$$ (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.

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.

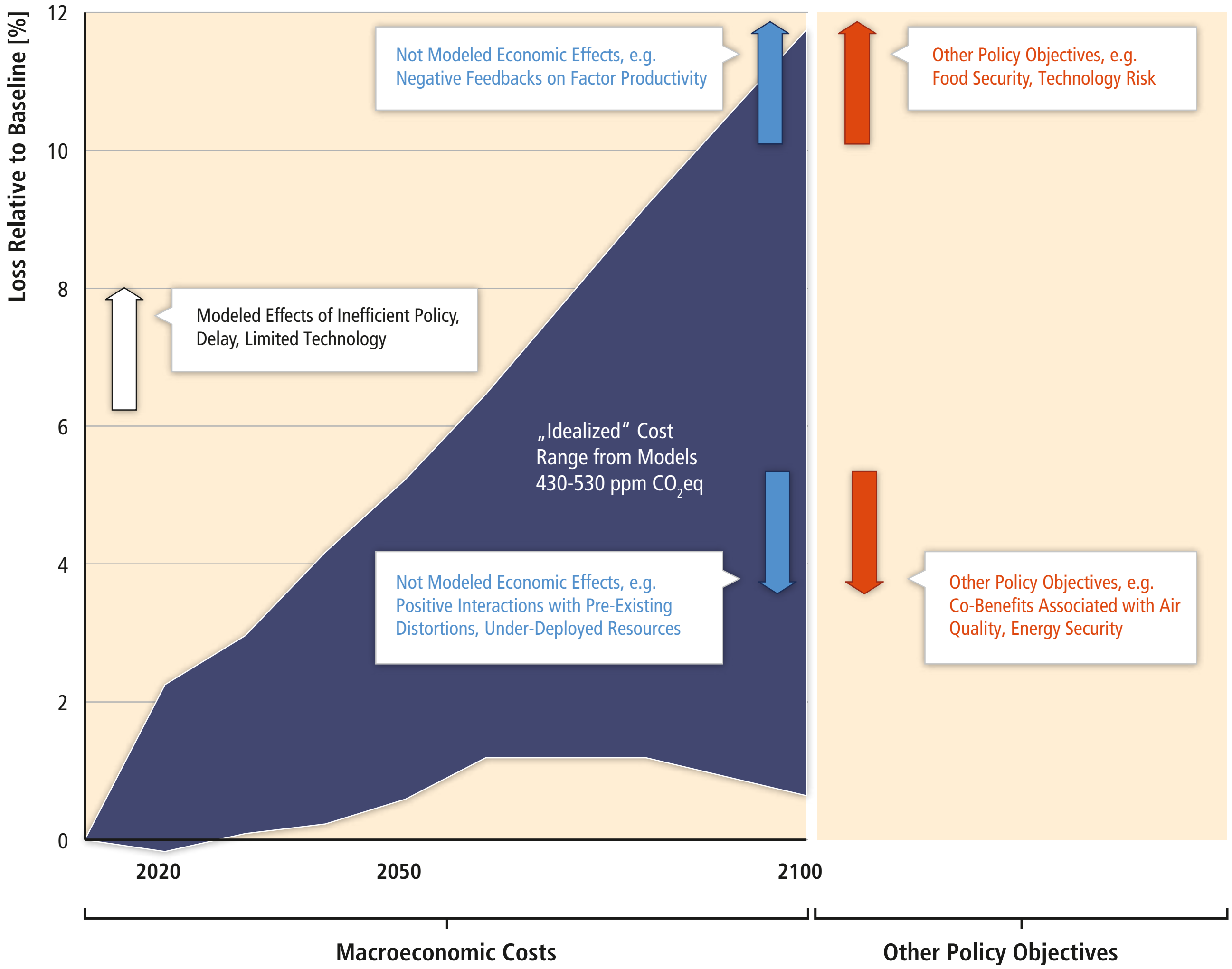

Figure A.II.1 | Modelled policy costs in a broader context. The plotted range summarizes costs expressed as percentage loss relative to baseline across models for cost-effective scenarios reaching 430–530 ppm CO_2eq. Scenarios were sorted by total NPV costs for each available metric (loss in GDP, loss 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.

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- *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.

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).

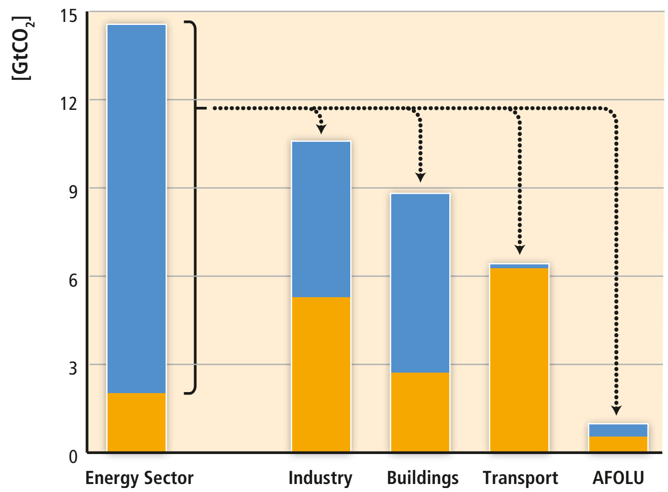

Figure A.II.2 | Energy sector electricity and heat CO_2 emissions calculated for the end-use sectors in 2010. Note that industry sector CO_2 emissions do not include process emissions. Data source: (IEA, 2012b; c).

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.

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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.

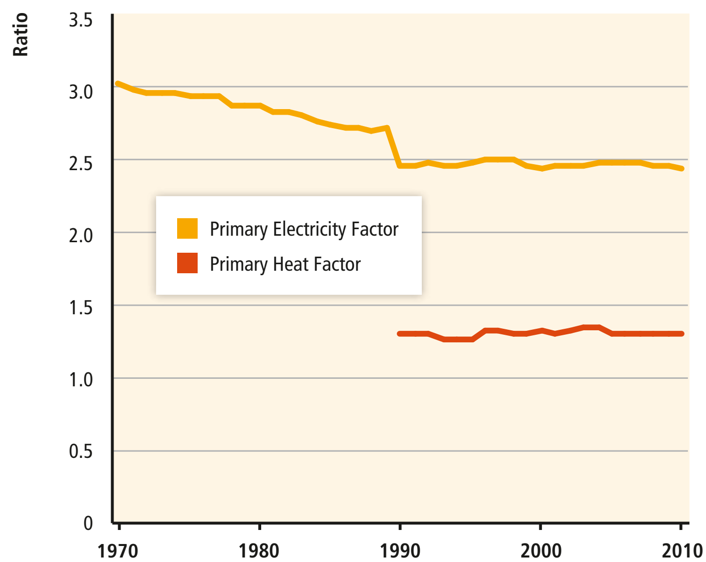

Figure A.II.3 | Historical primary electricity and heat factors. Data source: (IEA, 2012b).

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-

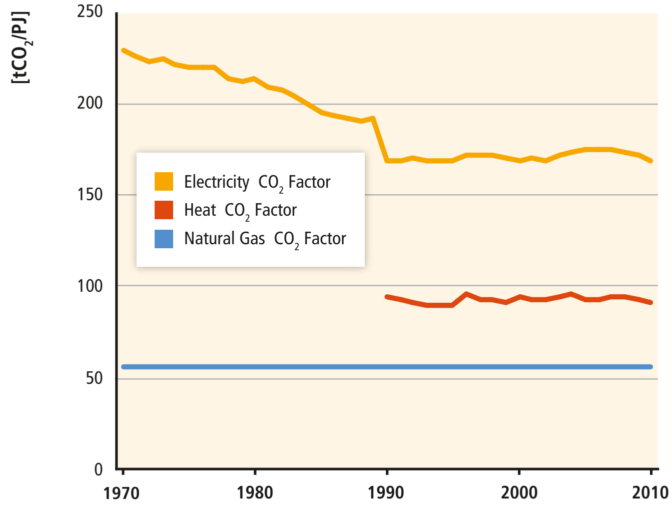

Figure A.II.4 | Historical electricity and heat CO_2 emissions factors. Data source: (IEA, 2012b; c).

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 socioeconomic 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 sociometabolic 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).

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).

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

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,…Xn*, the probability that the sum *X1+…+Xn* exceeds a value *x* becomes identical to the probability that the maximum of *X1,…Xn* exceeds *x*, as *x* gets large. In other words, 'the sum of *X1,… Xn* is driven by the largest of the *X1,…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 $1/(\alpha-1)$. 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).

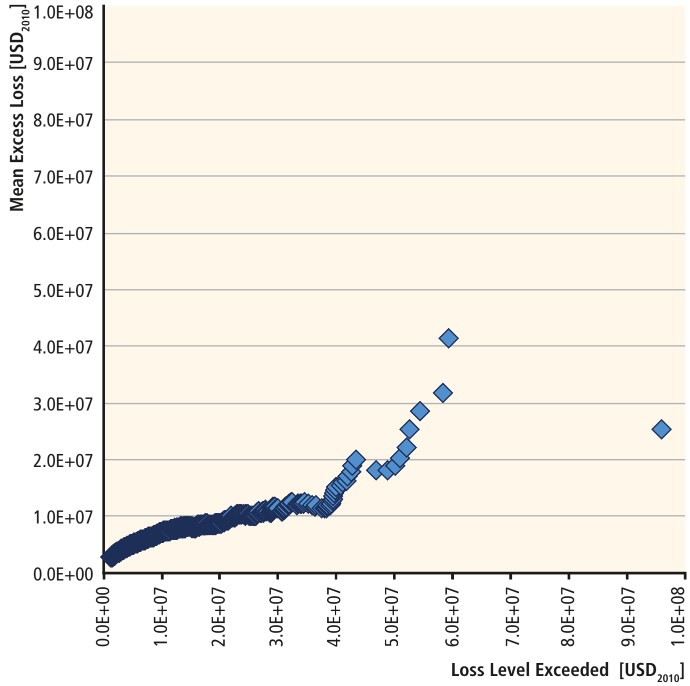

Figure A.II.6 | Mean excess curve of US crop insurance indemnities paid from the US Department of Agriculture's Risk Management Agency, aggregated by county and year for the years 1980 to 2008 in USD_{2010}. Note: The vertical axis gives mean excess loss, given loss at least as large as the horizontal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

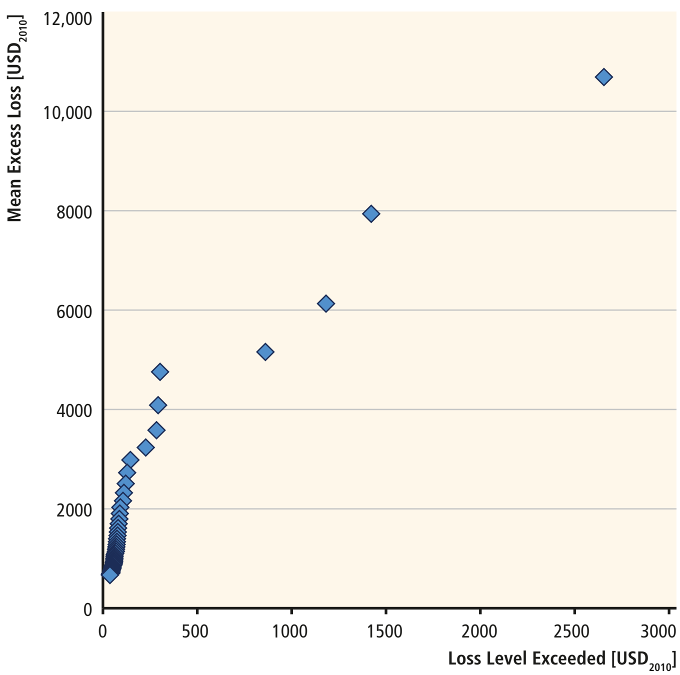

Figure A.II.5 | Mean excess curve for US flood insurance claims from the National Flood Insurance Program per dollar income per county per year for the years 1980 to 2008 in USD_{2010}. Considering dollar claims per dollar income in each county corrects for increasing exposure. Note: The vertical axis 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

AII

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 subsector 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

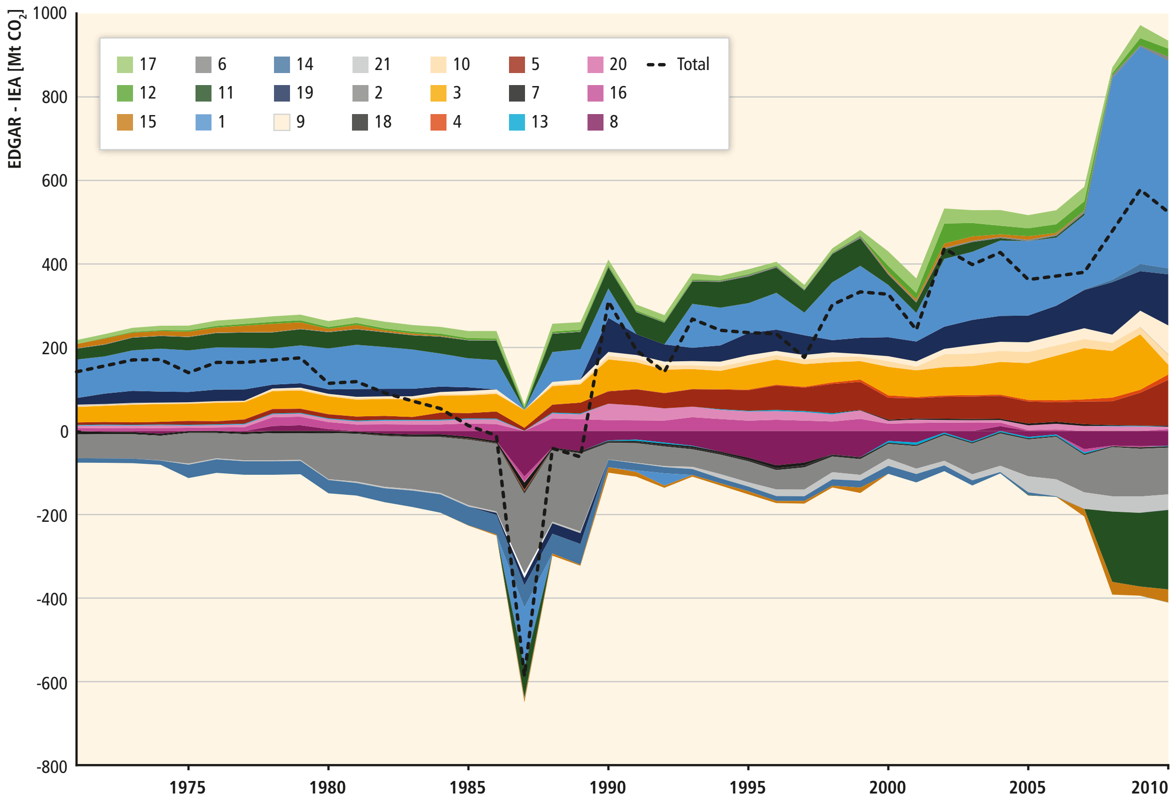

Figure A.II.7 | Difference of CO_2 emissions between analogous IEA (2012c) and EDGAR (JRC/PBL, 2013) categories as detailed in Table A.II.11. (Numbers in key refer to Table A.II.11 Comparison Groups).

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)

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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 x CO_2) = 3.7 W/m²* 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.

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.

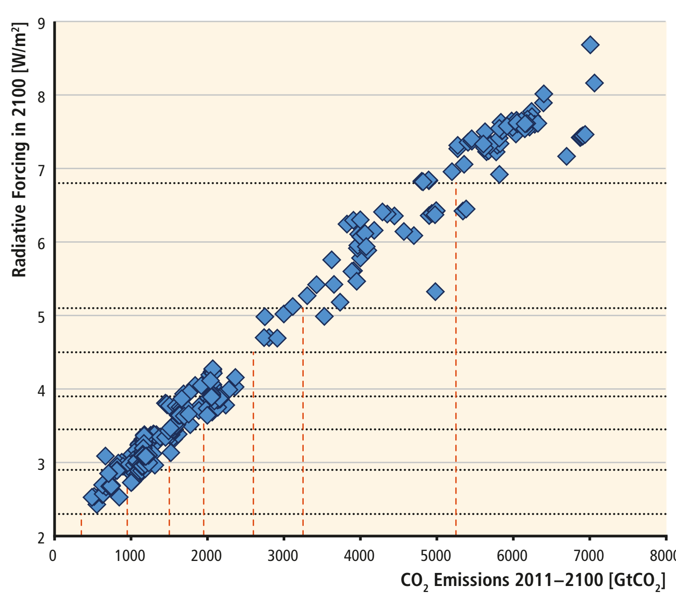

Figure A.II.8 | Regression of radiative forcing against 2011–2100 cumulative CO_2 emissions. Scenarios of full forcing models GCAM, MERGE, MESSAGE, REMIND and IMAGE were used for this analysis. Regression was done separately for each model, and resulting budget ranges averaged across models.

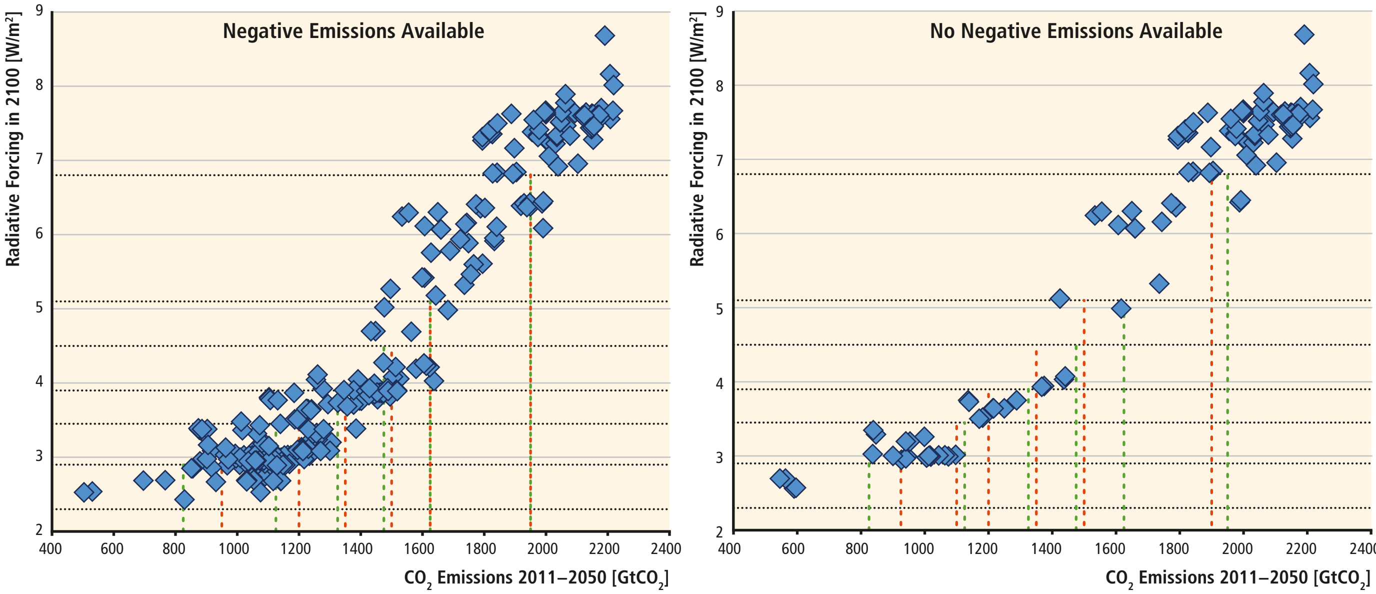

Figure A.II.9 | Regression of radiative forcing against 2011–2050 CO_2 emissions. Red lines show mean results of fit and depend on whether (left panel) or not (right panel) negative emissions are available. Green lines show harmonized bins between both categories for the mapping in Table A.II.19.

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).

AII

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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ANNEX

III

Technology-specific Cost and Performance Parameters

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Contents

A.III.1 Introduction

Annex III contains data on technologies and practices that have been collected to produce a summary assessment of the potentials and costs of selected mitigation options in various sectors as displayed in Figure 7.7, Table 8.3, Figures 10.7, 10.8, 10.9, 10.10, 10.19, 10.21, Figure 11.16 as well as in corresponding figures in the Technical Summary.

The nature and quantity of mitigation options, as well as data availability and quality of the available data, vary significantly across sectors. Even for largely similar mitigation options, a large variety of context-specific metrics is used to express their cost and potentials that involve conversions of input data into particular output formats. For the purpose of the Working Group III (WGIII) contribution to the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5), a limited but still diverse set of sector-specific metrics is used to strike a balance between harmonization of approaches across sectors and adequate consideration of the complexities involved.

Mitigation potentials are approached via product-specific or service-specific emission intensities, i.e., emissions per unit of useful outputs, which are as diverse as electricity, steel, and cattle meat. Mitigation potentials on a product/service level can be understood as the potential reduction in specific emissions that can result from actions such as switching to production processes that cause lower emissions for otherwise comparable products[1] and reducing production/consumption of emission-intensive products.

Mitigation costs are approached via different levelized cost metrics, which share a common methodological basis but need to be interpreted in very different ways. A detailed introduction to the metrics used can be found in the Metrics and Methodology (M&M) Annex (Section A.II.3.1). All of these cost metrics are derived under specific conditions that vary in practice and, hence, need to be set by assumption. These assumptions are not always clear from the literature, where such metrics are presented. Hence, comparison of the same metric taken from different studies is not always possible. For this reason, in the AR5 these metrics are generally re-calculated under specified conditions, e.g., with respect to weighted average cost of capital, based on underlying input parameters that are less sensitive to assumptions. Sensitivities to assumptions made in the AR5 are made explicit. In several cases, however, the availability of data on the parameters needed to re-calculate the relevant cost metric is very limited. In such cases, expert judgment was used to assess information on costs taken directly from the literature.

More detail on sector-specific metrics, the respective input data and assumptions used as well as the conversions required is presented in the sector-specific sections below.

References for data, justifications for assumptions, and additional context is provided in footnotes to the data tables. Footnotes are inserted at the most general level possible, i.e., footnotes are inserted at table headings where they apply to the majority of data, at column/row headings where they apply to the majority of data in the respective column/row, and at individual cells where they apply only to data points or ranges given in individual cells. Input data are included in normal font type, output data resulting from data conversions shown in figures and tables mentioned above are bolded, and intermediate outputs are italicized.

A.III.2 Energy supply

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A.III.2.1 Approach

The emission intensity of electricity production (measured in kg CO_2-equivalents (CO_2eq)/MWh) can be used as a measure to compare the specific greenhouse gas (GHG) emissions of suggested emission mitigation options and those of conventional power supply technologies. With respect to costs, the levelized cost of energy (LCOE), measured in USD_{2010}/MWh, serves the same purpose.[2]

The calculation of LCOE of a technology requires data on all cash flows that occur during its lifetime (see formula in Annex II.3.1.1) as well as on the amount of energy that is provided by the respective technology. Cash flows are usually reported in some aggregate form based on widely deployed monetary accounting principles combining cash flows into different categories of expenditures and revenues that occur at varying points during the lifetime of the investment.

The applied method presents LCOE that include all relevant costs associated with the construction and operation of the investigated power plant in line with the approach in IEA (2010). Taxes and subsidies are excluded, and it is assumed that grids are available to transport the electricity. Additional costs associated with the integration of variable sources are neglected as well (see Section 7.8.2 for an assessment of these costs).

[1] Note that comparability of products is not always given even for seemingly similar ones. For instance, in the case of electricity, the timing of production is crucial for the value of the product and reduces the insights that can be derived from simple comparisons of the metrics used here.

[2] The merits and shortcomings of this method are discussed in detail in the Metrics and Methodology Annex of the WGIII AR5 (Annex II).

The input data used to calculate LCOE are summarized in Table 1 below. The conversion of input data into LCOE requires the steps outlined in the following:

Levelized cost (LCOE) in USD_{2010}/MWh_e

$$LCOE = \frac{\alpha \cdot I + OM + F}{E} \quad \text{(Equation A.III.1)}$$

$$\alpha = \frac{r}{1-(1+r)^{-L_T}} \quad \text{(Equation A.III.2)}$$

$$I = \frac{C}{L_B} \cdot \sum_{t=1}^{L_B} (1+i)^t \cdot \left(1 + \frac{d}{(1+r)^{L_T}}\right) \quad \text{(Equation A.III.3)}$$

$$OM = FOM + (VOM - REV + d_v) \cdot E \quad \text{(Equation A.III.4)}$$

$$E = P \cdot FLH \quad \text{(Equation A.III.5)}$$

$$F = FC \cdot \frac{E}{\eta} \quad \text{(Equation A.III.6)}$$

Where:

- *LCOE* is the levelized cost of electricity.
- α is the capital recovery factor (CRF).
- *r* is the weighted average cost of capital (WACC—taken as either 5 % or 10 %).
- *I* is the investment costs, including finance cost for construction at interest *i*.
- *C* is the capital costs, excluding finance cost for construction ('overnight cost'). In order to calculate the cost for construction, the overnight costs are equally distributed over the construction period.
- *d* represent the decommissioning cost. Depending on the data in the literature, this is incorporated as an extra capital cost at the end of the project duration which is discounted to t = 0 (using a decommissioning factor *d*, as in (Equation A.III.3)), or as a corresponding variable cost (d_v in (Equation A.III.4)). d = 0.15 for nuclear energy, and zero for all other technologies (given the low impact on *LCOE*).
- *OM* are the net annual operation and maintenance costs; summarizing fixed OM (*FOM*), variable OM (*VOM*), and variable by-product revenues (*REV*). As a default and if not stated explicitly otherwise, carbon costs (e. g., due to carbon taxes or emission trading schemes) are not taken into account in calculating the *LCOE* values.
- *E* is the energy (electricity) produced annually, which is calculated by multiplying the capacity (*P*) with the number of (equivalent) full load hours (*FLH*).
- *F* are the annual fuel costs,
  - *FC* are the fuel costs per unit of energy input, and
  - η is the conversion efficiency (in lower heating value—LHV).
- *i* is the interest rate over the construction loan (taken as 5 %).
- L_T is the project duration (in operation), as defined in IEA (2010).
- L_B is the construction period.

Emission Intensities:

For data, see Table AIII.2 below. For methodological issues and literature sources, see Annex II, Section A.II.9.3.

A.III.2.2 Data

Table A.III.1 | Cost and performance parameters of selected electricity supply technologies[i, ii]

Options	*C*	L_B	*FOM*	*VOM*	*REV*	*F*
	Overnight capital expenditure (excl. construction interest) (USD_{2010}/kW)	Construction time (yr)	Fixed annual operation and maintenance cost (USD_{2010}/kW)[iii]	Variable operation and maintenance cost (USD_{2010}/MWh)[iii]	Variable by-product revenue (USD_{2010}/MWh)	Average fuel price (USD_{2010}/GJ)
	Min/Median/Max	Avg	Min/Median/Max	Min/Median/Max	Min/Median/Max	Min/Max
Currently Commercially Available Technologies						
Coal—PC[iv]	380/2200/3900	5	0/23/75	0/3.4/9.0		2.9/5.3
Gas—Combined Cycle[v]	550/1100/2100	4	0/7/39	0/3.2/4.9		3.8/14
Biomass—CHP[vi]	2000/5600/11000	4.5	0/101/400	0/0/56	4/26/93[vii]	3.3/9.3
Biomass—cofiring[vi, viii]	350/900/1800	1	13/20/20	0/0/2		3.3/9.3
Biomass—dedicated[vi]	1900/3600/6500	4.5	42/99/500	0/3.8/34		3.3/9.3
Geothermal[ix, x]	1000/5000/10000	3	0/0/150	0/11/31		
Hydropower[xi, xii]	500/1900/8500	5	5/35/250	0/0/15		
Nuclear[xiii, xiv]	1600/4300/6400	9	0/0/110	1.7/13/30		0.74/0.87

Options	*C* Overnight capital expenditure (excl. construction interest) (USD_{2010}/kW)	L_B Construction time (yr)	*FOM* Fixed annual operation and maintenance cost (USD_{2010}/kW)[iii]	*VOM* Variable operation and maintenance cost (USD_{2010}/MWh)[iii]	*REV* Variable by-product revenue (USD_{2010}/MWh)	*F* Average fuel price (USD_{2010}/GJ)
	Min/Median/Max	Avg	Min/Median/Max	Min/Median/Max	Min/Median/Max	Min/Max
Concentrated Solar Power[xv, xvi]	3700/5100/11000	2	0/50/66	0/0/35		
Solar PV—rooftop[xvii, xviii]	2200/4400/5300	0	17/37/44	0/0/0		
Solar PV—utility[xvii, xviii]	1700/3200/4300	0	12/20/30	0/0/0		
Wind onshore[xix, xx]	1200/2100/3700	1.5	0/0/60	0/14/26		
Wind offshore[xix, xxi]	2900/4400/6500	3.5	0/40/130	0/16/63		
Pre-commercial Technologies						
CCS—Coal—Oxyfuel[xxii]	2800/4000/5600	5	0/58/140	9.1/10/12[xxiii]		2.9/5.3
CCS—Coal—PC[xxii]	1700/3300/6600	5	0/45/290	11/15/28[xxiii]		2.9/5.3
CCS—Coal—IGCC,[xxii]	1700/3700/6600	5	0/23/110	12/13/23[xxiii]		2.9/5.3
CCS—Gas—Combined Cycle[xxii]	1100/2000/3800	4	5/13/73	4.8/8.3/15[xxiii]		3.8/14
Ocean[xxiv, xxv]	2900/5400/12000	2	0/78/360	0/0.16/20		

Table A.III.1 (continued) | Cost and performance parameters of selected electricity supply technologies[i, ii]

Options	η Plant efficiency (%)	*FLH* Capacity utilization /FLH (hr)	*LT* Plant lifetime (yr)	Decommissioning cost[xxvi]	*LCOE* Levelized cost of electricity[i] (USD_{2010}/MWh): 10 % WACC, high FLH, 0 $USD_{2010}/tCO_2eq_{direct}$	5 % WACC, high FLH, 0 $USD_{2010}/tCO_2eq_{direct}$	10 % WACC, low FLH, 0 $USD_{2010}/tCO_2eq_{direct}$	10 % WACC, high FLH, 100 $USD_{2010}/tCO_2eq_{direct}$
	Min/Median/Max	Min/Max	Avg		Min/Median/Max	Min/Median/Max	Min/Median/Max	Min/Median/Max
Currently Commercially Available Technologies								
Coal—PC[iv]	33/39/48	3700/7400	40	See endnote xxvi	**30/78/120**	**27/61/95**	**36/120/190**	**97/150/210**
Gas—Combined Cycle[v]	41/55/60	3700/7400	30		**34/79/150**	**31/71/140**	**43/100/170**	**69/120/200**
Biomass—CHP[vi]	14/29/36	3500/7000	30		**85/180/400**	**71/150/330**	**130/310/610**	**-**[xxvii]
Biomass—cofiring[vi]	38/41/48	3700/7400	40		**65/89/110**	**49/67/88**	**100/140/170**	**160/200/260**[xxviii]
Biomass—dedicated[vi]	20/31/48	3500/7000	40		**77/150/320**	**63/130/270**	**120/230/440**	**–**[xxvii]
Geothermal[ix, x]		5300/7900	30		**18/89/190**	**12/60/130**	**25/130/260**	**18/89/190**
Hydropower[xi, xii]		1800/7900	50		**9/35/150**	**6/22/95**	**40/160/630**	**9/35/150**
Nuclear[xiii, xiv]	33/33/34	3700/7400	60		**45/99/150**	**32/65/94**	**72/180/260**	**45/99/150**
Concentrated Solar Power[xv, xvi]		2200/3500	20		**150/200/310**	**110/150/220**	**220/320/480**	**150/200/310**
Solar PV—rooftop[xvii, xviii]		1100/2400	25		**110/220/270**	**74/150/180**	**250/490/600**	**110/220/270**
Solar PV—utility[xvii, xviii]		1200/2400	25		**84/160/210**	**56/110/130**	**170/310/400**	**84/160/210**
Wind onshore[xx, xx]		1800/3500	25		**51/84/160**	**35/59/120**	**92/160/300**	**51/84/160**
Wind offshore[xxi, xx]		2600/3900	25		**110/170/250**	**80/120/180**	**160/240/350**	**110/170/250**
Pre-commercial Technologies								
CCS—Coal—Oxyfuel[xxii]	32/35/41	3700/7400	40		**90/120/170**	**71/100/130**	**140/180/270**	**92/130/180**
CCS—Coal—PC[xxii]	28/30/43	3700/7400	40		**69/130/200**	**57/110/150**	**97/210/310**	**78/150/210**
CCS—Coal—IGCC[xxii]	30/32/35	3700/7400	40		**75/120/200**	**63/100/150**	**100/180/310**	**85/140/210**
CCS—Gas—Combined Cycle[xxii]	37/47/54	3700/7400	30		**52/100/210**	**45/86/190**	**70/140/270**	**55/110/220**
Ocean[xxiv, xxv]		2000/5300	20		**82/150/300**	**60/110/210**	**200/390/780**	**82/150/300**

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Notes:

[i] General: Input data are included in normal font type, output data resulting from data conversions are bolded, and intermediate outputs are italicized. Note that many input parameters (C, FOM, VOM, and η) are not independent from each other; they come in parameter sets. Parameters that are systematically varied to obtain output values include fuel prices, WACC, and full load hours (FLH). Lifetimes and construction times are set to standard values. The range in levelized cost of electricity (LCOE) results from calculating two LCOE values per individual parameter set, one at a low and one at a high fuel price, for the number of individual parameter sets available per technology. Variation with WACC and with FLHs is shown in separate output columns. This approach is different from the IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN) (IPCC, 2011), where input parameters were considered as independent from each other and the lowest (highest) LCOE value resulted from taking all best-case (worst-case) parameter values.

[ii] General: Comparison of data on capital expenditures with values presented in SRREN (IPCC, 2011) are only possible to limited degrees, since the datasets used in the AR5 reflect a larger sample of projects (including those with more extreme costs) than in the SRREN.

[iii] General: Some literature references only report on fixed OM costs (FOM), some only on variable OM costs (VOM), some on both, and some none. The data in the FOM and VOM columns show the range found in literature. Hence, note that these FOM and VOM values cannot be combined to derive total OM costs. The range of levelized costs of electricity shown in the table is the result of calculations for the individual combinations of parameters found in the literature.

[iv] Coal PC (Pulverized Coal): Black and Veatch (2012), DEA (2012), IEA/NEA (2010), IEA (2013a), IEA-RETD (2013), Schmidt et al. (2012), US EIA (2013).

[v] Gas Combined Cycle: Black and Veatch (2012), DEA (2012), IEA/NEA (2010), IEA (2011),IEA (2013a), IEA-RETD (2013), Schmidt et al. (2012), US EIA (2013).

[vi] Biomass: Black and Veatch (2012), DEA (2012), IPCC-SRREN (2011), IRENA (2012), Augustine et al. (2012), US EIA (2013).

[vii] Biomass CHP (Combined Heat and Power): Revenues from heat from CHP are assumed to be the natural gas price divided by 90% (this is the assumed reference boiler efficiency). It is assumed that one-third of the heat production is marketable, caused by losses and seasonal demand changes. This income is subtracted from the variable operation and maintenance costs (proportional to the amount of heat produced per unit of power), where applicable. Only heat production from biomass-CHP is treated in this manner.

[viii] Biomass Co-firing: Capital costs for co-firing as reported in literature (and the summary table) represent an investment to upgrade a dedicated coal power plant to a co-firing installation. The LCOEs shown in the summary table are those of the total upgraded plant. For the calculation of the LCOEs, the capital costs of the co-firing upgrade are added to the median coal PC capital costs. Fuel costs are obtained by weighting coal and biomass costs with their share in the fuel mix (with biomass shares ranging between 5% and 20%). To calculate specific emissions, the dedicated biomass emissions and (pulverized) coal emissions were added, taking into account biomass shares ranging between 5% and 20%. In the direct emissions coal-related emissions are shown, while the biomass related emissions are shown in column n (Biogenic, geogenic CO_2 and albedo), indicating indirect emissions. We applied an efficiency of 35% to the coal part of the combustion.

[ix] Geothermal: This category includes both flash steam and binary cycle power plants. Data on costs show wide ranges, depending on specific conditions. Geothermal (binary plant) LCOE averages have increased by 39% since the SRREN (BNEF, and Frankfurt and School-UNEP Centre, 2013). Low-end estimate is from Augustine et al. (2012) for a flash plant at higher temperatures; the high-end estimate is from Black and Veatch and based on enhanced geothermal systems, which are not fully commercialized. IRENA (2013) reports values down to 1400 USD_{2011}/kW.

[x] Geothermal: Black and Veatch (2012), IEA (2013a), Augustine et al. (2012), Schmidt et al. (2012), UK CCC (2011), US EIA (2013).

[xi] Hydropower: This includes both run-of-the-river and reservoir hydropower, over a wide range of capacities. Project data from recent IRENA inventories are incorporated, showing a wider range than reported in SRREN. High-end of capital expenditures refers to Japan, but other sources also report these higher values.

[xii] Hydropower: Black and Veatch (2012), IEA (2013a), IEA-RETD (2013), IRENA (2012), Schmidt et al. (2012), UK CCC (2011), US EIA (2013).

[xiii] Nuclear: Limited recent data and/or original data are available in the published literature. More recent, (grey literature) sources provide investment cost and LCOE estimates that are considerably higher than the ones shown here (Brandão et al., 2012). Nuclear fuel prices (per GJ input) are based on fuel cycle costs (usually expressed per MWh generated), assuming a conversion efficiency of 33%. They include the front-end (Uranium mining and milling, conversion, enrichment, and fuel fabrication) and back-end (spent fuel transport, storage, reprocessing, and disposal) costs of the nuclear fuel cycle (see IEA and NEA, 2010).

[xiv] Nuclear: IAEA (2012), EPRI (2011), IEA/NEA (2010), Rangel and Lévêque (2012), UK CCC (2011), US EIA (2013).

[xv] Concentrated Solar Power: This includes both CSP with storage as well as CSP without storage. To prevent an overestimation of the LCOE for CSP with storage, full load hours were used that are directly linked to the design of the system (in- or excluding storage). Project data from recent IRENA inventories are incorporated, showing a wider range than reported in SRREN. High-end value comes from IRENA (solar tower, 6-15 hours of storage). Low-end comes from IEA and is supported by IRENA data.

[xvi] Concentrated Solar Power: Black and Veatch (2012), IEA (2013a), IRENA (2012), US EIA (2013).

[xvii] Solar Photovoltaic: IEA (2013a), IRENA (2013), JRC (2012), LBNL (2013), UK CCC (2011), US EIA (2013).

[xviii] Solar Photovoltaic: Solar PV module prices have declined substantially since the SRREN (IPCC, 2011), accounting for much of the decline in capital costs shown here relative to those used in SRREN. The LCOE of (crystalline silicon) photovoltaic systems fell by 57% since 2009 (BNEF, and Frankfurt and School-UNEP Centre, 2013).

[xix] Wind: Black and Veatch (2012), DEA (2012), IEA (2013a), IEA-RETD (2013), IRENA (2012), JRC (2012), UK CCC (2011), US DoE (2013), US EIA (2013).

[xx] Wind onshore: High-end of capital expenditures is taken from IEA-RETD study (Mostajo Veiga et al., 2013) for Japan. The capital costs presented here show a higher upper end than in the SRREN, and reflect generally smaller wind projects or projects located in remote or otherwise-costly locations. Data from IRENA for Other Asia and Latin America show cost ranges well beyond SRREN. In some regions of the world, wind projects have been increasingly located in lower-quality wind resource sites since the publication of the SRREN (due in part to scarcity of developable higher-quality sites). The FLHs on wind projects, however, have not necessarily decreased -- and in many cases have increased -- due to a simultaneous trend towards longer rotors and higher hub heights. Wind onshore average LCOE have decreased by 15% (BNEF, and Frankfurt and School-UNEP Centre, 2013).

[xxi] Wind offshore: Offshore wind costs have generally increased since the SRREN, partially explaining the higher upper-end of the cost range shown here. Average LCOE of offshore wind have increased by 44% (BNEF, and Frankfurt and School-UNEP Centre, 2013). Higher capital expenditures reported here are in line with market experiences, i.e., a tendency to more remote areas, deeper seas, higher construction costs and higher steel prices.

[xxii] Carbon Dioxide Capture and Storage (CCS): Black and Veatch (2012), DEA (2012), Herzog (2011), IPCC-SRCCS (2005), Klara and Plunkett (2010), US EIA (2013), Versteeg and Rubin (2011), IEA (2011).

[xxiii] Carbon Dioxide Capture and Storage: Includes transport and storage costs of USD_{2010}10/tCO_2.

[xxiv] Ocean: Ocean includes both tidal and wave energy conversion technologies. The high-end of capital expenditures is for wave energy DEA (2012). Since the SRREN, marine wave and tidal average LCOE have increased by 36 and 49% respectively (BNEF, and Frankfurt and School-UNEP Centre, 2013).

[xxv] Ocean: Black and Veatch (2012), DEA (2012), UK CCC (2011).

[xxvi] General: Some literature references report decommissioning costs under VOM. If decommissioning costs are not given, default assumptions are made (see 'Definition of additional parameters').

[xxvii] Biomass: Due to the complexities involved in estimating GHG emissions from biomass, no estimates for LCOE at a positive carbon price are given here.

[xxviii] Biomass co-firing: Only direct emissions of coal share in fuel consumption are considered to calculate LCOE at a carbon price of 100 USD_{2010}/tCO_2eq.

Table A.III.2 | Emissions of selected electricity supply technologies (gCO_2eq/kWh)[i]

Options	Direct emissions	Infrastructure & supply chain emissions	Biogenic CO_2 emissions and albedo effect	Methane emissions	Lifecycle emissions (incl. albedo effect)
	Min/Median/Max	Typical values			Min/Median/Max
Currently Commercially Available Technologies					
Coal—PC	670/760/870	*9.6*	*0*	*47*	**740/820/910**
Gas—Combined Cycle	350/370/490	*1.6*	*0*	*91*	**410/490/650**
Biomass—cofiring	n.a. [ii]	–	–	–	**620/740/890**[iii]
Biomass—dedicated	n.a. [ii]	*210*	*27*	*0*	**130/230/420**[iv]
Geothermal	0	*45*	*0*	*0*	**6.0/38/79**
Hydropower	0	*19*	*0*	*88*	**1.0/24/2200**
Nuclear	0	*18*	*0*	*0*	**3.7/12/110**
Concentrated Solar Power	0	*29*	*0*	*0*	**8.8/27/63**
Solar PV—rooftop	0	*42*	*0*	*0*	**26/41/60**
Solar PV—utility	0	*66*	*0*	*0*	**18/48/180**
Wind onshore	0	*15*	*0*	*0*	**7.0/11/56**
Wind offshore	0	*17*	*0*	*0*	**8.0/12/35**
Pre-commercial Technologies					
CCS—Coal—Oxyfuel	14/76/110	*17*	*0*	*67*	**100/160/200**
CCS—Coal—PC	95/120/140	*28*	*0*	*68*	**190/220/250**
CCS—Coal—IGCC	100/120/150	*9.9*	*0*	*62*	**170/200/230**
CCS—Gas—Combined Cycle	30/57/98	*8.9*	*0*	*110*	**94/170/340**
Ocean	0	*17*	*0*	*0*	**5.6/17/28**

Notes:

i For a comprehensive discussion of methodological issues and underlying literature sources see Annex II, Section A.II.9.3. Note that input data are included in normal font type, output data resulting from data conversions are bolded, and intermediate outputs are italicized.

ii Direct emissions from biomass combustion at the power plant are positive and significant, but should be seen in connection with the CO_2 absorbed by growing plants. They can be derived from the chemical carbon content of biomass and the power plant efficiency. For a comprehensive discussion see Chapter 11, Section 11.13. For co-firing, carbon content of coal and relative fuel shares need to be considered.

iii Indirect emissions for co-firing are based on relative fuel shares of biomass from dedicated energy crops and residues (5-20%) and coal (80-95%).

iv Lifecycle emissions from biomass are for dedicated energy crops and crop residues. Lifecycle emissions of electricity based on other types of biomass are given in Chapter 7, Figure 7.6. For a comprehensive discussion see Chapter 11, Section 11.13.4. For a description of methodological issues see Annex II of this report.

A.III.3 Transport

A.III.3.1 Approach

The following tables provide a limited number of examples of transport modes and technologies in terms of their typical potential CO_2eq emissions per passenger kilometre (p-km) and freight tonne kilometre (t-km), now and in the 2030 timeframe. Estimates of mitigation cost ranges (USD_{2010}/tCO_2eq avoided) are also provided for the limited set of comparisons where data were available. Mitigation cost ranges for HDVs, shipping and air travel were taken directly from the literature. For sport utility vehicles (SUVs) and light duty vehicles (LDVs), specific mitigation costs were re-calculated for well-defined conditions based on basic input parameter sets (see equations and data provided below). The methodology to calculate specific mitigation costs, also called levelized cost of conserved carbon (LCCC), is discussed in Annex II. Future estimates of both emission intensities and specific mitigation costs are highly uncertain and depend on a range of assumptions.

The variation in emission intensities reflects variation in vehicle efficiencies together with narrow ranges for vehicle occupancy rates, or reflects estimates extracted directly from the literature. No cost uncertainty analysis was conducted. As mentioned above, mitigation cost ranges for HDVs, shipping, and air travel were taken directly from the literature. A standardized uncertainty range of +/- 100 USD_{2010}/tCO_2eq was used for SUVs and LDVs. Some parameters such as CO_2eq emitted from electricity generation systems and well-to-wheel CO_2eq emission levels from advanced biofuels should be considered as specific examples only.

This approach was necessary due to a lack of comprehensive studies that provide estimates across the full range of vehicle and technology types. Therefore, possible inconsistencies in assumptions and results mean that the output ranges provided here should be treated with caution. The output ranges shown are more indicative than absolute, as suggested by the fairly wide bands for most emission intensity and mitigation cost results.

The meta-analysis of mitigation cost for alternative road transport options was conducted using a 5 % discount rate and an approximate vehicle equipment life of 15 years. No fuel or vehicle taxes were included. Assumptions were based on the literature review provided throughout Chapter 8 and the estimates shown in Tables 8.1 and 8.2. Changes in assumptions could result in quite different results.

Some of the key assumptions are included in footnotes below the tables. Further information is available upon request from authors of Chapter 8.

Where emission intensities and LCCC were re-calculated based on specific input data, those inputs are summarized in Table 1 below. The conversion of input data into emission intensities and LCCC requires the steps outlined in the following:

Emissions per useful distance travelled (tCO_2eq/p-km and tCO_2eq/t-km)

$$EI = \frac{VEff_i \cdot FCI_i}{OC_i} \cdot \beta \qquad \text{(Equation A.III.7)}$$

Where:

- EI is the emission intensity
- $VEff$ is the typical vehicle efficiency
- FCI is the fuel carbon intensity
- OC is the vehicle occupancy
- ß is a unit conversion factor

Levelized Cost of Conserved Carbon (USD_{2010}/tCO_2eq)

$$LCCC_r = \frac{\Delta E}{\Delta C} \qquad \text{(Equation A.III.8)}$$

$$\Delta E = \alpha \Delta I + \Delta F \qquad \text{(Equation A.III.9)}$$

$$\alpha = \frac{r}{1-(1+r)^{-L}} \qquad \text{(Equation A.III.10)}$$

$$\Delta F = (VEff_i \cdot AD_i \cdot FC_i - VEff_j \cdot AD_j \cdot FC_j) \cdot \gamma \qquad \text{(Equation A.III.11)}$$

$$\Delta C = (VEff_j \cdot FCI_j \cdot AD_j - VEff_i \cdot FCI_i \cdot AD_i) \cdot \eta \qquad \text{(Equation A.III.12)}$$

Where:

- ΔE is the annualized travel cost increment
- ΔC is the difference in annual CO_2eq emissions of alternative i and baseline vehicle j, i.e., the amount of CO_2eq saved
- α is the capital recovery factor (CRF).
- ΔI is the difference in purchase cost of baseline and the alternative vehicle
- ΔF is the difference in annualized fuel expenditures of alternative i and baseline vehicle j
- r is the weighted average cost of capital (WACC)
- L is the vehicle lifetime
- $VEff$ is the typical vehicle efficiency as above, but in calculations for ΔFC and ΔC average typical vehicle efficiency is used.
- AD is the average annual distance travelled
- FC_i is average unit fuel purchase cost (taxes or subsidies excluded) of fuel used in vehicle i
- γ and η are unit conversion factors

Remarks:

Variation in output EI derives from variation of vehicle fuel consumption $VEff$ and vehicle occupancy OC.

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A.III.3.2 Data

Table A.III.3 | Passenger transport—currently commercially available technologies[i]

Option	VEff Vehicle fuel consumption (l/100km for fossil fuel; kWh/km for electricity)[ii]	FCI CO_2eq intensity of fuel[iii]	OC Vehicle occupancy (capita)[iv]	ΔI Vehicle price markup on baseline (Incremental capital expenditure) (USD_{2010})[v]	L Vehicle lifetime (yrs)[vi]	AD Annual distance travelled (km/yr)[vii]
Aviation (commercial, medium to long haul)						
2010 Stock Average	–	73 g/MJ	–	–	–	–
Narrow and Wide Body	–	73 g/MJ	–	baseline	–	–
Rail (Light Rail Car)						
Electric, 600 g CO_2eq/kWh_{el}	1.3–2.0	600 g/kWh	60–80	–	–	–
Electric, 200 g CO_2eq/kWh_{el}	1.3–2.0	200 g/kWh	60–80	–	–	–
Road						
New Buses, Large Size						
Diesel	36–42	3.2 kg/l	40–50	–	–	–
Hybrid Diesel	25–29	3.2 kg/l	40–50	–	–	–
New Sport Utility Vehicles (SUV), Mid-Size						
2010 Stock average SUV	10–14	2.8 kg/l	1.5–1.7	–	15	15,000
Gasoline	9.6–12	2.8 kg/l	1.5–1.7	baseline	15	15,000
Hybrid Gasoline (25 % better)	7.2–9	2.8 kg/l	1.5–1.7	5000	15	15,000
New Light Duty Vehicles (LDV), Mid-Size						
2010 Stock average LDV	8–11	2.8 kg/l	1.5–1.7	–	15	15,000
Gasoline	7.8–9	2.8 kg/l	1.5–1.7	baseline	15	15,000
Hybrid Gasoline (28 % better)	5.6–6.5	2.8 kg/l	1.5–1.7	3000	15	15,000
Diesel	5.9–6.7	3.2 kg/l	1.5–1.7	2500	15	15,000
CNG	7.8–9	2.1 kg/l	1.5–1.7	2000	15	15,000
Electric, 600 g CO_2eq/kWh_{el}	0.24–0.3	600 g/kWh	1.5–1.7	16000	15	15,000
Electric, 200 g CO_2eq/kWh_{el}	0.24–0.3	200 g/kWh	1.5–1.7	16000	15	15,000
New 2-Wheelers (Scooter up to 200 cm^3 cylinder capacity)						
2010 Stock Average	1.5–2.5	2.8 kg/l	1.1–1.3	–	–	–
Gasoline	1.1–1.9	2.8 kg/l	1.1–1.3	–	–	–

Table A.III.3 (continued) | Passenger transport—currently commercially available technologies

Option	FC Average annual fuel purchase cost (USD_{2010}/l for fossil fuel; $UScents_{2010}$/kWh)[viii]	EI Emissions per useful distance travelled (gCO_2eq/p-km)	ΔE Annualized travel cost increment (USD_{2010}/yr)	ΔC Annual CO_2eq savings from vehicle switch (tCO_2eq/yr)	$LCCC_{5\%}$ Levelized cost of conserved carbon at 5 % WACC (USD_{2010}/tCO_2eq)
Aviation (commercial, medium to long haul)					
2010 Stock Average	–	**80–218**[ix]	–	–	–
Narrow and Wide Body	–	**66–95**[x]	–	–	**–200**[xi]
Rail (Light Rail Car)					
Electric, 600 g CO_2eq/kWh_{el}	–	**10–20**	–	–	–
Electric, 200 g CO_2eq/kWh_{el}	–	**3.3–6.7**	–	–	–
Road					
New Buses, Large Size					
Diesel	–	**23–34**	–	–	–
Hybrid Diesel	–	**16–24**	–	–	–
New Sport Utility Vehicles (SUV), Mid-Size					
2010 Stock average SUV	0.81	**160–260**	–	–	–
Gasoline	0.81	**160–220**	*baseline*	*baseline*	**baseline**
Hybrid Gasoline (25 % better)	0.81	**120–170**	*150*	*1.1*	**140**
New Light Duty Vehicles (LDV), Mid-Size					
2010 Stock average LDV	0.81	**130–200**	–	–	–
Gasoline	0.81	**130–170**	*baseline*	*baseline*	**baseline**
Hybrid Gasoline (28 % better)	0.81	**92–120**	*2.5*	*1.0*	**2.6**
Diesel	0.81	**110–150**	*–15*	*0.43*	**–35**
CNG	0.35	**97–130**	*–390*	*0.83*	**–470**
Electric, 600 g CO_2eq/kWh_{el}	0.12	**85–120**	*1000*	*1.1*	**950**
Electric, 200 g CO_2eq/kWh_{el}	0.12	**28–40**	*1000*	*2.7*	**370**
New 2-Wheelers (Scooter up to 200 cm^3 cylinder capacity)					
2010 Stock Average	–	**32–63**	–	–	–
Gasoline	–	**24–47**	–	–	–

Notes:

i Note that input data are included in normal font type, output data resulting from data conversions are bolded, and intermediate outputs are italicized.

ii Vehicle fuel economy estimates for road vehicles based on IEA (2012a) and IEA Mobility Model (MoMo) data values, using averages for stock and new vehicles around the world to establish ranges. For rail, water, and air these estimates are based on a range of studies, see Chapter 8 Section 8.3. Rail estimates were based on expert judgment.

iii CO_2eq fuel intensities are based on IPCC (2006). CO_2eq intensities of electricity based on generic low and high carbon power systems. Well-to-wheel estimates from a range of sources, and specific examples as indicated in tables.

iv Occupancy rates for trains, buses, SUVs, LDVs, and 2-wheelers based on IEA Mobility Model averages from around the world. Bus and rail represent relatively high intensity usage; average loadings in some countries and regions will be lower.

v Vehicle purchase price increments for LDVs based primarily on NRC (2013) and IEA (2012a).

vi For LDVs, vehicle lifetime-kilometres set to 156,000 kms based on discounting 15 years and 15,000 km per year. Other vehicle type assumptions depend on literature. No normalization was attempted.

vi Annual distance travelled as described above.

vii Fuel prices are point estimates based on current and projected future prices in IEA (2012b). Variation in relative fuel prices can have significant impacts on transport costs and LCCC. Though no cost uncertainty analysis was performed, cost ranges were used where available and a standardized $USD_{2010}100/tCO_2eq$ uncertainty range was added around all final point estimates.

ix Current energy consumption per passenger kilometre is 1.1–3 MJ/p-km (IEA, 2009a).

x Based on TOSCA (2011, Table S-1). Slightly wider range for new/very new to account for range of load factors and distances.

xi Based on IEA and TOSCA analysis. IEA based on 30 years, 10% discount rate.

Table A.III.4 | Passenger transport—future (2030) expected technologies[i]

Option	VEff Vehicle fuel consumption (l/100km)	FCI CO_2eq intensity of fuel[ii]	OC Vehicle occupancy (capita)[iii]	ΔI Vehicle price mark-up on baseline (Incremental capital expenditure) (USD_{2010})[iv]	L Vehicle lifetime (yrs)[v]	AD Annual distance travelled (km/yr)[vi]
Aviation						
Narrow Body (20 % better)	–	–	–[vii]	–	15	–
Narrow Body, Open Rotor Engine (33 % better)	–	–	–[vii]	–	15	–
Road						
Optimized Sport Utility Vehicles (SUV), Mid-Size						
Gasoline (40 % better)	5.8–7.2	2.8 kg/l	1.5–1.7	3500[viii], future baseline	15	15,000
Hybrid Gasoline (50 % better)	4.8–6[ix]	2.8 kg/l	1.5–1.7	1200	15	15,000
Optimized Light Duty Vehicles (LDV), Mid-Size						
Gasoline (40 % better)	4.7–5.4[x]	2.8 kg/l	1.5–1.7	2500[viii], future baseline	15	15,000
Hybrid Gasoline (50 % better)	3.9–4.5[xi]	2.8 kg/l	1.5–1.7	1000	15	15,000
Hybrid Gasoline/Biofuel (50/50 share) (Assuming 70 % less CO_2eq/MJ biofuel than/MJ gasoline)	3.9–4.5[xi]	2.8 kg/l	1.5–1.7	1000	15	15,000
Diesel Hybrid	3.3–3.8[xii]	3.2 kg/l	1.5–1.7	1700	15	15,000
CNG Hybrid	3.9–4.5[xi]	2.1 kg/l	1.5–1.7	1200	15	15,000
Electric, 200 g CO_2eq/kWh_{el}	0.19–0.26[xiii]	200 g/kWh	1.5–1.7	3600	15	15,000

Table A.III.4 (continued) | Passenger transport—future (2030) expected technologies[i]

Option	FC	EI	ΔE	ΔC	$LCCC_{5\%}$
	Average annual fuel purchase cost (USD_{2010}/l for fossil fuel; $UScents_{2010}$/kWh)[xiv]	**Emissions per useful distance travelled (gCO_2eq/p-km)**	**Annualized travel cost increment (USD_{2010}/yr)**	**Annual CO_2eq savings from vehicle switch (tCO_2eq/yr)**	**Levelized cost of conserved carbon at 5 % WACC (USD_{2010}/tCO_2eq)**
Aviation					
Narrow Body (20 % better)	–	–	–	–	**0–150**
Narrow Body, Open Rotor Engine (33 % better)	–	**44–63**[xv]	–	–	**0–350**
Road					
Optimized Sport Utility Vehicles (SUV), Mid-Size					
Gasoline (40 % better)	0.93	**94–130**	*–190*[xvi]	*1.8*[xvi]	**–110**[xvi]
Hybrid Gasoline (50 % better)	0.93	**78–110**	*–440*	*2.2*	**–200**
Optimized Light Duty Vehicles (LDV), Mid-Size					
Gasoline (40 % better)	0.93	**76–100**	*–230*[xvii]	*1.4*[xvii]	**–160**[xvii]
Hybrid Gasoline (50 % better)	0.93	**64–83**	*–21*	*0.35*	**– 61**
Hybrid Gasoline/Biofuel (50/50 share) (Assuming 70 % less CO_2eq/MJ biofuel than/MJ gasoline)	0.93	**41–54**	*38*	*1.0*	**39**
Diesel Hybrid	0.93	**63–83**	*–15*	*0.36*	**–43**
CNG Hybrid	0.44	**48–63**	*–310*	*0.77*	**–410**
Electric, 200 g CO_2eq/kWh_{el}	0.13	**23–35**	*86*	*1.4*	**61**

Notes:

i Only those options, where data were available and where significant advances are expected are listed. Other transport options, such as trains, buses and 2-wheelers will remain relevant means of transport in the future but are not covered due to data limitations. Note that input data are included in normal font type, output data resulting from data conversions are bolded, and intermediate outputs are italicized.

ii CO_2eq fuel intensities are based on IPCC (2006). CO_2eq intensities of electricity are based on generic low and high carbon power systems. Well-to-wheel estimates from a range of sources, and specific examples as indicated in tables.

iii Occupancy rates for trains, buses, SUVs, LDVs, 2-wheelers based on IEA Mobility Model averages from around the world. Bus and rail represent relatively high intensity usage; average loadings in some countries and regions will be lower.

iv Future vehicle purchase price mark ups based primarily on NRC (2013) and NRC (2010), also IEA (2009a), TIAX (2011), TOSCA (2011), Horton G. (2010) and other sources.

v For LDVs, vehicle lifetime-kilometres set to 156,000 km based on discounting 15 years and 15,000 km per year. Other vehicle type assumptions depend on literature. No normalization was attempted.

vi Annual distance travelled as described above.

vii Horton G. (2010) gives ranges from 100 to 150 for Boeing 737-800 and 350 to 500 for Airbus A380.

viii Relative to 2010 baseline.

ix Based on NRC (2013) and other studies, see Section 8.3.

x Based on NRC (2013) and other studies, see Section 8.3.

xi Fuel consumption of future hybrid gasoline, hybrid gasoline/biofuel, and hybrid CNG based on NRC (2013) and other studies, see Section 8.3.

xii Fuel consumption of future diesel based on NRC (2013) and other studies, see Section 8.3.

xiii Fuel consumption of future electric based on NRC (2013) and other studies, see Section 8.3.

xiv Future fuel prices based on IEA (2012b). These are point estimates—variation in relative fuel prices can have significant impacts on transport costs and LCCC.

xv Value results from assumption of 33% improvement relative to current new narrow and medium body aircrafts based on TOSCA (2011) and Horton G. (2010).

xvi Relative to 2010 gasoline SUV at 2010 fuel price of 0.81 USD_{2010}/l.

xvii Relative to 2010 gasoline LDV at 2010 fuel price of 0.81 USD_{2010}/l.

Table A.III.5 | Freight transport—currently commercially available technologies[i]

Option	VEff	FCI	OC	ΔI	L	AD
	Vehicle fuel consumption (l/100km)	CO_2eq intensity of fuel[ii]	Vehicle load (t)	Vehicle price markup on baseline (Incremental capital expenditure) (USD_{2010})	Vehicle lifetime	Annual distance travelled (km/yr)
Aviation (commercial, long haul)[iii]						
2010 Stock Average	–	–	–	–	–	–
Dedicated Aircraft	–	–	–	–	–	–
Belly-hold	–	–	–	–	–	–
Rail (freight train) [iv]						
Diesel, light goods	–	–	–	–	–	–
Diesel, heavy goods	–	–	–	–	–	–
Electric, 200g CO_2eq/kWh_{el}	–	–	–	–	–	–
Maritime[v]						
Current Average International Shipping	–	–	–	–	–	–
New Large International Container Vessel[vi]	–	–	–	–	–	–
Large Bulk Carrier/Tanker[vii]	–	–	–	–	–	–
LNG Bulk Carrier[viii]	–	–	–	–	–	–
Road[ix]						
New Medium Duty Trucks						
2010 Stock Average	16–24	3.2 kg/l	1.6–1.9	–	–	–
Diesel	14–18	3.2 kg/l	1.6–1.9	–	–	–
Diesel Hybrid	11–14	3.2 kg/l	1.6–1.9	–	–	–
CNG	18–23	2.1 kg/l	1.6–1.9	–	–	–
New Heavy Duty, Long-Haul Trucks						
2010 Stock Average	28–44	3.2 kg/l	8–12	–	–	–
Diesel	25–32	3.2 kg/l	8–12	–	–	–
CNG	31–40	2.1 kg/l	8–12	–	–	–

Table A.III.5 (continued) | Freight transport—currently commercially available technologies [i]

Option	FC Average annual fuel purchase cost (USD_{2010}/l for fossil fuel; $UScents_{2010}$/kWh)	EI Emissions per useful distance travelled (gCO_2eq/t-km)	ΔE Annualized travel cost increment (USD_{2010}/yr)	ΔC Annual CO_2eq savings from vehicle switch (tCO_2eq/yr)	$LCCC_{5\%}$ Levelized cost of conserved carbon at 5 % WACC (USD_{2010}/tCO_2eq)
Aviation (commercial, long haul) [iii]					
2010 Stock Average	–	550–740	–	–	–
Dedicated Aircraft	–	500–820	–	–	**–200**[x]
Belly-hold	–	520–700[xi]	–	–	–
Rail (freight train) [iv]					
Diesel, light goods	–	26–33	–	–	–
Diesel, heavy goods	–	18–25	–	–	–
Electric, 200g CO_2eq/kWh_{el}	–	6–12	–	–	–
Maritime[v]					
Current Average International Shipping	–	10–40	–	–	–
New Large International Container Vessel[vi]	–	10–20	–	–	–
Large Bulk Carrier/Tanker[vii]	–	3–6	–	–	–
LNG Bulk Carrier[viii]	–	9–13	–	–	–
Road[ix]					
New Medium Duty Trucks					
2010 Stock Average	–	**270–490**	–	–	–
Diesel	–	**240–370**	–	–	–
Diesel Hybrid	–	**180–270**	–	–	–
CNG	–	**200–300**	–	–	–
New Heavy Duty, Long-Haul Trucks					
2010 Stock Average	–	**76–180**	–	–	–
Diesel	–	**70–130**	–	–	–
CNG	–	**60–110**	–	–	–

Notes:

[i] Note that input data are included in normal font type, output data resulting from data conversions are bolded, and intermediate outputs are italicized.

[ii] CO_2eq fuel intensities are based on IPCC (2006). CO_2eq intensities of electricity based on generic low and high carbon power systems. Well-to-wheel estimates from a range of sources, and specific examples as indicated in tables.

[iii] These baseline carbon intensity values for long haul air freight are based on mean estimates from DEFRA (2013). They relate to Boeing 747 and 757 air freight with an average carrying capacity of 84 tonnes and load factor of 69%. High and low estimates set at 15% above and below the means to reflect differences in the energy efficiency of different aircraft types operating with differing load factors.

[iv] The carbon intensity values for rail freight are based mainly on analyses by DEFRA (2013) and EcoTransit (2011). Expert judgment has been exercised to allow for international differences in the age, capacity, and efficiency of railway rolling stock and railway operating practices.

[v] Estimates are derived mainly from DEFRA (2012). This source presents mean carbon intensity values for particular types and size ranges of vessels. The ranges around these means allow for differences in actual vessel size, loading, and energy efficiency on the basis of expert judgment.

[vi] Carrying more than 8000 twenty-foot equivalent units (TEU).

[vii] 100-200,000 dead weight tonnes.

[viii] 100-200,000 cubic metres.

[ix] Truck CO_2eq/t-km ranges estimated from NRC (2010) and IEA Mobility Model data for averages for truck load factors around the world; vehicle efficiency estimates primarily from NRC (2010), IEA (2009a) and TIAX (2011). Baseline estimates derived from DEFRA (2013), EcoTransit (2011) and IEA (2009a). High and low estimates allow for variations in vehicle size, weight, age, operation and loading in different parts of the world.

[x] Aviation freight cost estimates assumptions similar to passenger. Based on IEA and TOSCA analysis, IEA based on 30 years, 10% discount rate.

[xi] The allocation of emissions between passenger and freight traffic on belly-hold services conforms to a standard 'freight weighting' method.

Table A.III.6 | Freight transport—future (2030) expected technologies [i]

Options[ii]	VEff	FCI	OC	ΔI	L	AD	FC	EI	ΔE	ΔC	$LCCC_{5\%}$
	Vehicle fuel consumption (l/100km)	CO_2eq intensity of fuel[iii]	Vehicle load (t)	Vehicle price markup on baseline (Incremental capital expenditure) (USD_{2010})	Vehicle lifetime	Annual distance travelled (km/yr)	Average annual fuel purchase cost (USD_{2010}/l for fossil fuel; $UScents_{2010}$/kWh)	Emissions per useful distance travelled (gCO_2eq/t-km)	Annualized travel cost increment (USD_{2010}/yr)	Annual CO_2eq savings from vehicle switch (tCO_2eq/yr)	Levelized cost of conserved carbon at 5 % WACC (USD_{2010}/tCO_2eq)
Aviation (commercial, long haul)											
Improved Aircraft (25 % better)	–	–	–	–	–	–	–	300–450[v]	–	–	**150**[vi]
Improved, Open Rotor Engine (33 % better)	–	–	–	–	–	–	–	270–400[v]	–	–	**350**[vi]
Maritime											
Optimized Container Vessel	–	–	–	–	–	–	–	7–13[vii]	–	–	**–100**[viii]
Optimized Bulk Carrier	–	–	–	–	–	–	–	2–4[vii]	–	–	**–100**[viii]
Road[iv]											
Optimized Medium Duty Trucks											
Diesel	8–13	3.2 kg/l	1.6–1.9	–	–	–	–	**140–260**	–	–	**–100**
Optimized Heavy Duty, Long-Haul Trucks											
Diesel	15–22	3.2 kg/l	8–12	–	–	–	–	**41–91**	–	–	**–250**
Diesel/Biofuel (50/50 share) (Assuming 70 % less CO_2eq/MJ biofuel than/MJ diesel)	15–22	2.1 kg/l	8–12	–	–	–	–	**26–59**	–	–	**–**

Notes:

i Note that input data are included in normal font type, output data resulting from data conversions are bolded, and intermediate outputs are italicized.

ii No future rail CO_2eq or cost estimates were included due to lack of information.

iii CO_2eq fuel intensities are based on IPCC (2006). CO_2eq intensities of electricity based on generic low and high carbon power systems. Well-to-wheel estimates from a range of sources, and specific examples as indicated in tables.

iv Future truck efficiencies and costs primarily from NRC (2010), Zhao et al (2013).

v These baseline carbon intensity values for long haul airfreight are based on mean estimates from DEFRA (2013). They relate to Boeing 747 and 757 airfreight with an average carrying capacity of 84 tonnes and load factor of 69%. High and low estimates set at 15% above and below the means to reflect differences in the energy efficiency of different aircraft types operating with differing load factors.

vi Projections of the carbon mitigation costs of future aircraft development are based mainly on Tosca. Mitigation costs for future technologies assumed similar to passenger aircraft since the specific large commercial type aircraft are mostly the same configuration.

vii Estimates are derived mainly from DEFRA (2012). This source presents mean carbon intensity values for particular types and size ranges of vessels. The ranges around these means allow for differences in actual vessel size, loading and energy efficiency on the basis of expert judgment.

viii Shipping cost estimates based primarily on Buhaug (2009), Lloyds Register/DNV (2011), and IEA (2009a) (review of literature).

A.III.4 Industry

A.III.4.1 Introduction

The data presented below has been used to assess typical product-specific CO_2eq emissions (i.e., emission per unit of product)[3] for different production practices, which are commercially available today or may become so in the future, and for selected industrial sectors. Both direct and indirect specific emissions are assessed. Specific emissions could be reduced by switching to production processes that cause lower emissions for otherwise comparable products[4] and by reducing production/consumption of emission-intensive products. Some production practices are mutually exclusive; others can be combined to yield deeper reductions in specific emissions. The impact of decarbonizing electricity supplied for industrial processes has been assessed, too, for well-defined exemplary conditions.

For all input parameters and specific CO_2eq emissions global average values are given as a benchmark. Parameters of individual production practices are generally estimates of typical values based on limited studies and expert judgment. Comparisons of input parameters across different individual production practices and with global averages (see Tables A.III.8–A.III.12 below) yields insights into the intermediate effect via which changes in final specific CO_2eq emissions occur for certain production practices.

Estimates of future global averages in specific CO_2eq emissions are derived for long-term scenarios that stabilized GHG concentrations at about 450 ppm CO_2eq and provide data at the necessary level of detail. These can be considered as another rough benchmark for emission intensities that can be achieved with currently available and potential future production practices. Generally, scenarios that provide sufficient detail at the level of industrial subsectors/products are very scarce (2–3 models) and are in many cases derived from the same data source as data for individual production practices (mostly International Energy Agency)[5]. Comparisons of emission intensities in future 450 ppm stabilization scenarios with available production practices can yield rough insights into future trends for production practices with different specific emissions, but need to be considered with caution.

Specific mitigation costs have been assessed for all production practices except for the decarbonization of electricity supply, the costs of which are dealt with in Chapter 7 (Section 7.8). Specific mitigation costs are expressed in USD_{2010}/tCO_2 or USD_{2010}/tCO_2eq and take into account total incremental operational and capital costs. Generally, costs of the abatement options shown vary widely between individual regions and from plant to plant. Factors influencing the costs include typical capital stock turnover rates (some measures can only be applied when plants are replaced), relative energy costs, etc. No meta-analysis of such individual cost components has been attempted, however, due to limited data availability. Estimates are based on expert judgment of the limited data that is available. Hence, the estimates of specific mitigation costs should be considered with care and as indicative only.

Information on specific emissions of different production practices and associated specific mitigation cost is presented in Figures 10.7–10.10 and in Figures 10.19 and 10.20.

A.III.4.2 Approaches and data by industry sector

A.III.4.2.1 Cement

Direct specific emissions of cement (tCO_2/t cement) are derived from technical parameters via the following equation:

$$EI_{direct} = (1 - \lambda) \cdot clc \cdot (e_{n-el} \cdot FCI_{n-el} + CI_{calc}) \qquad \text{(Equation A.III.13)}$$

Where

- λ is the percentage of emissions captured and stored via CCS
- clc is the clinker to cement ratio
- e_{n-el} is the specific non-electric energy use, i.e., the non-electric energy use per unit of clinker
- FCI_{n-el} is the carbon intensity of the non-electric fuel used
- CI_{calc} is the carbon intensity of the calcination process

Indirect specific emissions of cement (tCO_2/t cement) are derived from specific electricity use and the carbon intensity of electricity:

$$EI_{indirect} = e_{el} \cdot FCI_{el} \qquad \text{(Equation A.III.14)}$$

Where

- e_{el} is the specific electric energy use, i.e., the electricity use per unit of cement
- FCI_{el} is the carbon intensity of the electricity used

[3] Emissions cannot always be expressed in product-specific terms. In the case of chemicals, products are too heterogeneous to express emissions per unit of product. Hence, global emissions of different production practices/technologies have been assessed for total global chemicals production.

[4] Note that the extent to which certain production processes can be replaced by others is often constrained by various conditions that need to be considered on a case by case basis. The replacement of blast oxygen steel furnaces by electric arc furnaces, for instance, is limited by availability of scrap.

[5] Further literature sources are assessed in Chapter 10 (Section 10.7). The data sources assessed in 10.7 could, however, often not be used in the summary assessment mainly due to non-comparability of methodological approaches. Chapter 6 presents more comprehensive scenario assessments including all sectors of the economy, which often comes, however, at the expense of sectoral detail. Chapter 10 (Section 10.10) discusses these scenarios from an industry perspective.

Total specific emissions of cement (tCO_2/t cement) are the sum of both direct and indirect specific emissions:

$$EI_{total} = EI_{direct} + EI_{indirect} \qquad \text{(Equation A.III.15)}$$

Remarks:

Variation in emission intensity derives from variation in selected input parameters. Individual input parameters are varied systematically, i.e., in accordance with the definition of each production practice, while all other input parameters are kept at global average values.

Data on technical input parameters is also very limited. Sources are specified in footnotes to data entries.

Specific mitigation costs (cost of conserved carbon) are estimated based on expert assessment of limited selected studies. See footnote ii for details.

Table A.III.7 | Technical parameters and estimates for cost of conserved carbon of cement production processes[i]

Options	clc	$e_{n\text{-}el}$	$FCI_{n\text{-}el}$	CI_{calc}	e_{el}	FCI_{el}	λ	EI_{direct}	$EI_{indirect}$	EI_{total}	$LCCC$
	Clinker to cement ratio (%)	Non-electric fuel intensity (GJ/t clinker)	CO_2 intensity of non-electric fuel (tCO_2/GJ)	CO_2 intensity of calcination process (t CO_2/t clinker)	Electricity intensity (kWh/t cement)	CO_2 intensity of electricity ($kgCO_2$/kWh)	CO_2 capture rate (%)	Direct emission intensity w/CCS (tCO_2/t cement)	Indirect emission intensity (tCO_2/t cement)	Total emission intensity (tCO_2/t cement)	Levelized cost of conserved carbon (USD_{2010}/tCO_2)[ii]
Historical Global Average Data and Future Data for 450 ppm Scenarios from Integrated Models											
Global average (2030) [iii]	–	–	–	–	–	–	–	–	–	**0.38–0.59**	
Global average (2050) [iii]	–	–	–	–	–	–	–	–	–	**0.24–0.39**	
Global average (2010)	0.8	3.9	0.1	0.51	109	0.46[iv]	0	*0.72*	*0.05*	**0.77**	
Currently Commercially Available Technologies											
Best practice energy intensity	0.8	2.9–3.1[v]	0.1	0.51	80–90[vi]	0.46[iv]	0	*0.64–0.66*	*0.037–0.041*	**0.68–0.70**	< 0–150
Best practice clinker to cement ratio	0.6–0.7[vii]	3.9	0.1	0.51	109	0.46[iv]	0	*0.54–0.63*	*0.05*	**0.59–0.68**	< 0–50[viii]
Best practice energy intensity and clinker to cement ratio combined	0.6–0.7[vii]	2.9–3.1[v]	0.1	0.51	80–90[vi]	0.46[iv]	0	*0.48–0.57*	*0.037–0.041*	**0.52–0.62**	< 0–150[viii]
Improvements in non-electric fuel mix[ix]	0.8	3.9	0.056[x]	0.51	109	0.46[iv]	0	*0.58*	*0.05*	**0.63**	< 0–150[viii]
Decarbonization of electricity supply	0.8	3.9	0.1	0.51	109	0–0.39[xi]	0	*0.72*	*0–0.043*	**0,72–0.76**	
Pre-commercial Technologies											
CCS[xii]	0.8	3.9	0.1	0.51	109	0.46[iv]	75–90	*0.072–0.18*	*0.05*	**0.12–0.23**	50–150[xiii]
CCS and fully decarbonized electricity[xiv]	0.8	3.9	0.1	0.51	109	0	75–90	*0.072–0.18*	*0*	**0.072–0.18**	

Notes:

i Note that input data are included in normal font type, output data resulting from data conversions are bolded, and intermediate outputs are italicized.

ii Expert judgment based on McKinsey (2009), 2012, IEA (2009b, 2012a), BEE (2012), and others. The costs of the abatement options shown vary widely between individual regions and from plant to plant. Factors influencing the costs include typical capital stock turnover rates (some measures can only be applied when plants are replaced), relative energy costs, etc.

iii Data range is taken from the following models: AIM Enduse model (Akashi et al., 2013), IEA 2DS low demand (IEA, 2012a).

iv Based on global industry-wide average CO_2eq intensity of primary energy used in electricity and heat supply in 2010 (see Chapter 10. Table 10.2)

v This range is based on best practice operation of 4 to 6 stage pre-heater and pre-calciner kiln technology based on IEA (2009b). Actual operation performance does depend on issues such as moisture content and raw material quality and can be above this range.

vi Best practice electricity consumption is based on IEA (2007).

vii Minimum clinker to cement ratio is for Portland cement according to IEA (2007), which is a globally achievable value taking availability of substitutes into account IEA (2009b). Further reductions in the clinker to cement ratio are possible for other types of cement (e.g., fly ash or blast furnace slag cement).

viii For clinker substitution and fuel mix changes, costs depend on the regional availability and price of clinker substitutes and alternative fuels.

ix This is assuming that only natural gas is used as non-electric fuel. Further reductions in non-electric fuel emission intensity are technically possible, e.g., by increased use of biomass.

x Natural gas fuel emission factor (IPCC, 2006).

xi The upper end of the range is based on natural gas combined cycle (NGCC) with an efficiency of 55 % and fuel emission factors from IPCC (2006).

xii CCS: Carbon dioxide capture and storage. This option assumes no improvements in fuel mix. Feasibility of CCS depends on global CCS developments. CCS is currently not yet applied in the cement sector.

xiii IEA GHG (2008) estimates CCS abatement cost at 63 to 170 USD/tCO_2 avoided.

xiv This option assumes no improvements in non-electric fuel mix.

A.III.4.2.2 Iron and steel

Direct specific CO_2 emissions of crude steel (tCO_2/t steel) are derived from technical parameters via the following equation:

$$EI_{direct} = (1 - \lambda) \cdot EI_{direct,noCCS} \qquad \text{(Equation A.III.16)}$$

Where

- λ is the percentage of emissions captured and stored via CCS
- $EI_{direct,noCCS}$ is the direct emission intensity without CCS

Indirect specific CO_2 emissions of crude steel (tCO_2/t steel) are derived from specific electricity use and the carbon intensity of electricity:

$$EI_{indirect} = e_{el} \cdot FCI_{el} \qquad \text{(Equation A.III.17)}$$

Where

- e_{el} is the specific electric energy use, i.e., the electricity use per unit of crude steel
- FCI_{el} is the carbon intensity of the electricity used

Total specific CO_2 emissions of crude steel (tCO_2/t steel) are the sum of both direct and indirect specific emissions:

$$EI_{total} = EI_{direct} + EI_{indirect} \qquad \text{(Equation A.III.18)}$$

Remarks:

Data on technical input parameters is limited and almost exclusively based on IEA (2007). Emission intensities of the advanced blast furnace route, the natural gas DRI route, and the scrap-based electric arc furnace route are point estimates of global best practice based on IEA (2007). Since no variation in input parameters could be derived from the literature, output ranges have been constructed as an interval around the mean value based on +/-10 % of the respective savings. Where input parameters are set by assumption, they are varied within typical ranges and become the sole source of variation in output values, while all other input parameters are kept at global average values.

Specific mitigation costs (cost of conserved carbon) are estimated based on expert assessment of limited selected studies. See footnote vi for details.

A.III.4.2.3 Chemicals

Global direct CO_2 emissions ($GtCO_2$) of global chemicals production in 2010 are derived from technical parameters via the following equation:

$$CO2_{direct} = (1 - \lambda) \cdot CO2_{direct,noCCS} \qquad \text{(Equation A.III.19)}$$

Where

- λ is the percentage of emissions captured and stored via CCS
- $CO2_{direct,noCCS}$ are global direct CO_2 emissions in chemicals production in 2010 without CCS

Global indirect CO_2 emissions ($GtCO_2$) of global chemicals production in 2010 are derived from global electricity use in chemicals production and the carbon intensity of electricity:

$$CO2_{indirect} = Elec \cdot FCI_{el} \cdot \gamma \qquad \text{(Equation A.III.20)}$$

Where

- $Elec$ is the global electric energy use in the chemicals sector in 2010
- FCI_{el} is the carbon intensity of the electricity used
- γ is a unit conversion factor of 1/1000

Total global CO_2eq emissions ($GtCO_2eq$) of chemicals production in 2010 are the sum of direct and indirect CO_2 emissions and CO_2-equivalents of non-CO_2 emissions:

$$CO2e_{total} = CO2_{direct} + CO2_{indirect} + CO2e_{acid} + CO2e_{HFC-22} \qquad \text{(Equation A.III.21)}$$

Where

- $CO2e_{acid}$ are global direct N_2O emissions from global nitric and adipic acid production expressed in CO_2 equivalents
- $CO2e_{HFC\text{-}22}$ are global direct HFC-23 emissions from HFC-22 production expressed in CO_2 equivalents

Remarks:

For most production practices, only central estimates for technical input parameters could be derived from the available literature. Where input parameters are set by assumption, they are varied within typical ranges and become a source of variation in output values. Where no variation in input parameters could be derived from the literature, output ranges have been constructed as an interval around the mean value based on +/-10 % of the respective savings.

Specific mitigation costs (cost of conserved carbon) are estimated based on expert assessment of limited selected studies. See footnote iv for details.

Table A.III.8 | Technical parameters and estimat+es for cost of conserved carbon of iron and steel production processes[i]

Options[ii]	$EI_{direct,noCCS}$	e_{el}	FCI_{el}	λ	EI_{direct}	$EI_{indirect}$	EI_{total}	$LCCC$
	Specific direct CO_2 emissions w/o CCS[iii] (tCO_2/t steel)	**Specific electricity consumption (kWh/t steel)**	**CO_2 intensity of electricity ($kgCO_2$/kWh)**	**CO_2 capture rate[iv] (%)**	**Specific direct CO_2 emissions w/CCS[v] (tCO_2/t steel)**	**Indirect emission intensity (tCO_2/t steel)**	**Total emission intensity (tCO_2/t steel)**	**Levelized cost of conserved carbon (USD_{2010}/tCO_2)[vi]**
Historical Global Average Data and Future Data for 450 ppm Scenarios from Integrated Models								
Global average (2030)[vii]	–	–	–	–	–	–	0.92–1.36	
Global average (2050)[vii]	–	–	–	–	–	–	0.47–0.84	
Global average (2010)	1.8[viii]	820[ix]	0.46[x]	0	*1.8*	*0.38*	**2.2**	
Currently Commercially Available Technologies								
Advanced blast furnace route[xi]	1.3[xii]	350[xiii]	0.46[x]	0	*1.3*	*0.16*	**1.5**	< 0–150
Natural gas DRI route[xiv, xi]	0.7[xii]	590[xiii]	0.46[x]	0	*0.7*	*0.27*	**0.97**	50–150
Scrap based EAF[xv, xi]	0.25[xii]	350[xiii]	0.46[x]	0	*0.25*	*0.16*	**0.41**	< 0–50[xvi]
Decarbonization of electricity supply	1.8[viii]	820[ix]	0–0.39[xvii]	0	*1.8*	*0–0.32*	**1.8–2.1**	
Pre-commercial Technologies								
CCS[xviii]	1.8[viii]	820[ix]	0.46[x]	75–90	*0.18–0.45*	*0.38*	**0.56–0.82**	50–150
CCS and fully decarbonized electricity[xix]	1.8[viii]	–	0	75–90	*0.18–0.45*	*0*	**0.18–0.45**	

Note:

i Note that input data are included in normal font type, output data resulting from data conversions are bolded, and intermediate outputs are italicized.

ii Non-electric fuel mix improvements are not listed as an abatement option because a large share of the coal use in the iron and steel industry, via the intermediate production of coke, is an inherent feature of the blast furnace technology. The coke is used to reduce iron ore to iron and for structural reasons in the furnace. The limited data availability did not allow assessing the limited potential related to the part of the fuel use that can be substituted.

iii Direct CO_2 emissions contain all emissions from steel production that are unrelated to electricity consumption.

iv As percentage of specific direct CO_2 emissions in steel production.

v Direct CO_2 emissions contain all emissions from steel production that are unrelated to electricity consumption.

vi Expert judgment based on McKinsey (2009; 2010), IEA (2009b, 2012a), BEE (2012) and others. The costs of the abatement options shown vary widely between individual regions and from plant to plant. Factors influencing the costs include typical capital stock turnover rates (some measures can only be applied when plants are replaced), relative energy costs, etc.

vii Data range is provided by AIM Enduse model (Akashi et al., 2013) DNE21+ (Sano et al., 2013a; b) and IEA 2DS low demand (IEA, 2012a).

viii IEA (2012a).

ix Derived from IEA (2012a, 2013b).

x Based on global industry-wide average CO_2eq intensity of primary energy used in electricity and heat supply in 2010 (see Chapter 10, Table 10.2). This is a simplified calculation in line with the method used for other sectors ignoring the practice in many iron and steel plants to use process derived gases (blast furnace gas and basic oxygen furnace gas) for electricity production. The emissions from these derived gases are already included in the direct emissions.

xii Excluding rolling and finishing.

xii Value equals lower bound of total emission intensity in IEA (2007, p. 108, table 5.4) as that is for zero-carbon electricity.

xiii Derived from spread in total emission intensity in IEA (2007, p. 108, table 5.4) and using a typical coal emission factor of 0.85.

xiv DRI: Direct reduced iron.

xv EAF: Electric arc furnace.

xvi Costs depend heavily on the regional availability and price of scrap.

xvii The upper end of the range is based on natural gas combined cycle (NGCC) with an efficiency of 55 % and fuel emission factors from IPCC (2006). The approach taken here is a simplified calculation, consistent with the approach for other sectors and does not explicitly take into account the share of the electricity consumed that is produced with process derived gases (see also footnote ix).

xviii CCS: Carbon dioxide capture and storage. This option assumes no improvements in fuel mix.

xix This option assumes no improvements in non-electric fuel mix.

Table A.III.9 | Technical parameters and estimates for cost of conserved carbon of chemicals production processes [i]

Options	$CO2_{direct,noCCS}$	$CO2e_{acid}$	$CO2e_{HFC-22}$	*Elec*	FCI_{el}	λ	$CO2_{direct}$	$CO2_{indirect}$	$CO2_{total}$	*LCCC*
	Global direct CO_2 emissions w/o CCS ($GtCO_2$)	**Global non-CO_2 emissions from HFC-22 production ($GtCO_2eq$)[ii]**	**Global non-CO_2 emissions from adipic and nitric acid production ($GtCO_2eq$)[ii]**	**Global electricity use (TWh)**	**CO_2 intensity of electricity ($kgCO_2/kWh$)**	**CO_2 capture rate[iii] (%)**	**Global direct CO_2 emissions w/ CCS ($GtCO_2$)**	**Global indirect CO_2 emissions ($GtCO_2$)**	**Global total emissions ($GtCO_2eq$)**	**Cost of conserved carbon (USD_{2010}/tCO_2eq)[iv]**
Historical Data and Future Data from IEA ETP 2DS Scenario										
Global total (2030)[v]	–	–	–	1400	–	–	1.5–1.6	–	–	
Global total (2050)[v]	–	–	–	1400	–	–	1.3	–	–	
Global total (2010)	1.6[vi]	0.13	0.12	1100[vii]	0.46[viii]	0	**1.6**	**0.51**	**2.4**	
Currently Commercially Available Technologies										
Best practice energy intensity	*1.0*[ix]	0.13	0.12	860[x]	0.46[viii]	0	**1.0**	**0.39**	**1.7**	< 0–150
Enhanced recycling, cogeneration and process intensification	*1.3*[xi]	0.13	0.12	1100[vii]	0.46[viii]	0	**1.3**	**0.51**	**2.1**	20–150
Abatement of N_2O from nitric and adipic acid	1.6[vi]	0.13	*0.01*[xii]	1100[vii]	0.46[viii]	0	**1.6**	**0.51**	**2.3**	0–50
Abatement of HFC-23 emissions from HFC-22 production	1.6[vi]	*0*[xiii]	0.12	1100[vii]	0.46[viii]	0	**1.6**	**0.51**	**2.2**	0–20
Improvements in non-electric fuel mix[xiv]	*1.2*[xv]	0.13	0.12	1100[vii]	0.46[viii]	0	**1.2**	**0.51**	**2.0**	< 0–150
Decarbonization of electricity supply	1.6[vi]	0.13	0.12	1100[vii]	0–0.39[xvi]	0	**1.6**	**0–0.44**	**1.8–2.3**	
Pre-commercial Technologies										
CCS for ammonia production[xvii]	1.6[vi]	0.13	0.12	1100[vii]	0.46[viii]	3.5[xviii]	**1.5**	**0.51**	**2,3**	50–150
CCS[xix]	1.6[vi]	0.13	0.12	1100[vii]	0.46[viii]	75–90	**0.16–0.4**	**0.51**	**0.92–1.16**	50–150
CCS and fully decarbonized electricity[xx]	1.6[vi]	0.13	0.12	1100[vii]	0	75–90	**0.16–0.4**	**0**	**0.41–0.65**	

Notes:

- i Note that input data are included in normal font type, output data resulting from data conversions are bolded, and intermediate outputs are italicized.
- ii Based on EPA (2013) unless specified otherwise.
- iii As percentage of global direct CO_2 emissions in chemicals production.
- iv Expert judgment based on McKinsey (2009; 2010), IEA (2009c, 2012a), BEE (2012), and others. The costs of the abatement options shown vary widely between individual regions and from plant to plant. Factors influencing the costs include typical capital stock turnover rates (some measures can only be applied when plants are replaced), relative energy costs, etc.
- v Based on IEA ETP 2DS scenarios with high and low global energy demand (IEA, 2012a).
- vi Based on IEA (2012a).
- vii Based on IEA (IEA, 2013b). IEA (2012a) provided higher values of 1340 TWh.
- viii Based on global industry-wide average CO_2eq intensity of primary energy used in electricity and heat supply in 2010 (see Chapter 10. Table 10.2).
- ix Based on global potential for savings of 35 % in direct emissions in chemicals production as estimated for 2006 (IEA, 2009c) applied to direct emissions in 2010.
- x Based on potential for electricity savings of 0.91 EJ (IEA, 2012a).
- xi Based on global technical potential for saving in primary energy consumption of 4.74 EJ (IEA, 2012a) and assuming that conserved primary energy supply is based on natural gas with an emission factor of 56.2 kg CO_2eq/GJ (2006). This translates into savings in global direct CO_2 emissions of 0.27 $GtCO_2eq$.
- xii Based on a global technical potential to save 85 % of non-CO_2 emissions from HFC-22 production (EPA, 2013).
- xiii Based on a global technical potential to save 100 % of non-CO_2 emissions from production of adipic and nitric acid (Miller and Kuijpers, 2011)
- xiv This is assuming that only natural gas is used as non-electric fuel. Further reductions in non-electric fuel emission intensity are technically possible, e. g., by increased use of biomass.
- xv Based on the assumption that 23 % of direct CO_2 emissions can be saved from a switch to natural gas (IEA, 2009c).
- xvi The upper end of the range is based on natural gas combined cycle (NGCC) with an efficiency of 55 % and fuel emission factors from IPCC (2006).
- xvii Ammonia production was 159 Mt in 2010 (IEA, 2012a). According to Neelis et al. (2005), a best practice gas-based ammonia facility produces 1.6 tCO_2/t ammonia, of which 70 % are pure CO_2 emissions (1.1 t CO_2/t ammonia). 50 % of that pure CO_2 stream is assumed to be used in urea production (0.55 t CO_2/t ammonia). 90 % of the remaining 0.55 tCO_2/t ammonia is assumed to be captured. This results in an effective CO_2 capture rate of 3.5 % of total emissions in chemicals by application of CCS in ammonia production.
- xviii This is the effective rate of CO_2 emissions captured in ammonia production relative to global direct CO_2 emissions in chemicals. See also endnote xvii.
- xix This option assumes no improvements in fuel mix.
- xx This option assumes no improvements in non-electric fuel mix.

A.III.4.2.4 Pulp and paper

Specific direct CO_2 emissions of paper (tCO_2/t paper) are derived from technical parameters via the following equation:

$$EI_{direct} = (1 - \lambda) \cdot EI_{direct,noCCS} \quad \text{(Equation A.III.22)}$$

Where

- λ is the percentage of emissions captured and stored via CCS
- $EI_{direct,noCCS}$ is the direct emission intensity without CCS

Indirect specific CO_2 emissions of paper (tCO_2/t paper) are derived from specific electricity use and the carbon intensity of electricity:

$$EI_{indirect} = e_{el} \cdot FCI_{el} \quad \text{(Equation A.III.23)}$$

Where

- e_{el} is the specific electric energy use, i.e., the electricity use per tonne of paper
- FCI_{el} is the carbon intensity of the electricity used

Total specific CO_2 emissions of paper (tCO_2/t paper) are the sum of both direct and indirect specific emissions:

$$EI_{total} = EI_{direct} + EI_{indirect} \quad \text{(Equation A.III.24)}$$

Remarks:

For most production practices, only central estimates for technical input parameters could be derived from the available literature. Where input parameters are set by assumption, they are varied within typical ranges and become a source of variation in output values. Where no variation in input parameters could be derived from the literature, output ranges have been constructed as an interval around the mean value based on +/-10 % of the respective savings.

Specific mitigation costs (cost of conserved carbon) are estimated based on expert assessment of limited selected studies. See footnote v for details.

A.III.4.2.5 Municipal Solid Waste (MSW)

For waste treatment practices that reduce landfill, specific methane emission (gCH_4/kg MSW) and specific nitrous oxide emissions (gN_2O/kg MSW) are taken directly from the literature. Methane emission intensities (gCH_4/kg MSW) of conventional and improved landfill options are derived from technical parameters given below. CO_2eq emission intensities (tCO_2eq/t MSW) are calculated using global warming potentials (GWP) of methane and nitrous oxide of 21 and 310, respectively.

$$EI_{CH4} = MCF \cdot DOC \cdot DOCf \cdot F \cdot (1 - OX) \cdot (1 - R) \cdot \gamma \cdot \eta \quad \text{(Equation A.III.25)}$$

Where

- *MCF* is the methane correction factor, $Min(MCF) = 0.6$, $Max(MCF) = 1$
- *DOC* is degradable organic carbon (gC/kg MSW)
- *DOCf* is the fraction of *DOC* dissimilated, $DOCf = 0.5$
- *F* is the fraction of methane in landfill gas, $F = 0.5$
- *OX* is oxidation factor (fraction)
- *R* is the fraction of recovered methane
- γ is the unit conversion factor of C into CH_4, $\gamma = 16/12$
- η is a unit conversion factor of 1/1000

Values given above are based on Frøiland Jensen and Pipatti (2001) and Pipatti et al. (2006) default values.

Variation in specific emissions is from maximum to minimum assuming all input parameters are independently distributed.

Cost are taken from EPA (2013) and based on a 10 % WACC.

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Table A.III.10 | Technical parameters and estimates for cost of conserved carbon of pulp and paper production processes[i]

Options	$EI_{direct,noCCS}$	e_{el}	FCI_{el}	λ	EI_{direct}	$EI_{indirect}$	EI_{total}	$LCCC$
	Specific direct CO_2 emissions w/o CCS[ii] (tCO_2/t paper)	Specific electricity consumption (kWh/t paper)	CO_2 intensity of electricity ($kgCO_2$/kWh)	CO_2 capture rate[iii] (%)	Specific direct CO_2 emissions w/CCS[iv] (tCO_2/t paper)	Indirect emission intensity (tCO_2/t paper)	Total emission intensity (tCO_2/t paper)	Cost of conserved carbon (USD_{2010}/tCO_2)[v]
Historical Data and Future Data from IEA ETP 2DS Scenario								
Global average (2030) [vi]	–	*990–1100*[vii]	–	–	**0.26–0.30**[vii]	–	–	
Global average (2050) [vi]	–	*920–950*[vii]	–	–	**0.16–0.20**[vii]	–	–	
Global average (2010)	*0.56*[viii]	*1,200*[ix]	0.46[x]	0	**0.56**	**0.55**	**1,1**	
Currently Commercially Available Technologies								
Best practice energy intensity	*0.48*[xi]	*1,000*[xii]	0.46[x]	0	**0.48**	**0.46**	**0.94**	< 0–150
Co-generation	*0.53*[xiii]	*1,200*[ix]	0.46[x]	0	**0.53**	**0.55**	**1.1**	20–50
Decarbonization of electricity supply	*0.56*[viii]	*1,200*[ix]	0–0.39[xiv]	0	**0.56**	**0–0.47**	**0.56–1,0**	
Pre-commercial Technologies								
CCS[xv]	*0.56*[viii]	*1,200*[ix]	0.46[x]	75–90	**0.056–0.14**	**0.55**	**0.61–0.69**	50–150
CCS and fully decarbonized electricity[xvi]	*0.56*[viii]	*1,200*[ix]	0–0.39	75–90	**0.056–0.14**	**0–0.47**	**0.056–0.14**	

Notes:

i Note that input data are included in normal font type, output data resulting from data conversions are bolded, and intermediate outputs are italicized.

ii Direct CO_2 emissions w/o CCS contain all emissions from paper production that are unrelated to electricity consumption, including those that could be captured and stored.

iii As percentage of specific direct CO_2 emissions in steel production.

iv Direct CO_2 emissions w/CCS contain all non-captured emissions from paper production that are unrelated to electricity consumption.

v Expert judgment based on McKinsey (2009; 2010), IEA (2009b, 2012a), BEE (2012), and others. The costs of the abatement options shown vary widely between individual regions and from plant to plant. Factors influencing the costs include typical capital stock turnover rates (some measures can only be applied when plants are replaced), relative energy costs, etc.

vi Based on IEA ETP 2DS scenarios with high and low global energy demand (IEA, 2012a).

vii Derived from IEA (2012a).

viii Based on global direct emissions of 0.22 $GtCO_2$ and global paper production of 395 Mt (IEA, 2012a).

ix Based on global electricity consumption in pulp and paper production of 1.7 EJ (IEA, 2013b) and global paper production of 395 Mt (IEA, 2012a).

x Based on global industry-wide average CO_2eq intensity of primary energy used in electricity and heat supply in 2010 (see Chapter 10. Table 10.2).

xi Based on technical potential for savings in non-electric fuel input of 1.5 GJ/t paper (IEA, 2012a) and assuming no change in the non-electric fuel emission factor of 51 kg CO_2/GJ (derived from IEA, 2012a). This translates into savings in specific direct CO_2 emissions of 77 kg CO_2/t paper.

xii Based on technical potential for saving electricity of 200 kWh/t paper (IEA, 2012a).

xiii Based on technical potential for savings in non-electric fuel input of 0.6 GJ/t paper (derived from IEA, 2012a) and assuming that conserved fuel is natural gas with an emission factor of 56.2 kg CO_2eq/GJ (IPCC, 2006). This translates into savings in specific direct CO_2 emissions of 34 kg CO_2/t paper.

xiv The upper end of the range is based on natural gas combined cycle (NGCC) with an efficiency of 55 % and fuel emission factors from IPCC (2006).

xv This option assumes no improvements in fuel mix.

xvi This option assumes no improvements in non-electric fuel mix.

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Table A.III.11 | Technical parameters and estimates for cost of conserved carbon of waste treatment practices[i]

Options	*DOC*	*OX*	*R*	*EI_{CH4}*	*EI_{N2O}*	*EI_{CO2eq}*	*LCCC*
	Degradable organic carbon (g C/kg MSW) [ii, iii]	**Oxidation factor (fraction)**	**Fraction of recovered CH_4**	**CH_4 emission intensity of MSW (gCH_4/kg MSW)** [ii, iv]	**N_2O emission intensity of MSW (g N_2O/kg MSW)** [ii, iv]	**CO_2eq emission intensity of MSW (tCO_2eq/t MSW)** [ii]	**Levelized cost of conserved carbon at 10 % WACC (USD_{2010}/tCO_2eq)** [v]
	min/max			**min/max**	**min/max**	**min/max**	**min/max**
Reference: Landfill at MSW disposal site	*140/210*	0	0	*42/110*	~0	**0.58/1.5**	
Reducing MSW landfill							
Composting	–	–	–	0.0/8	0.06/0.6	**0.019/0.35**	– 140/470
Anaerobic digestion	–	–	–	0/1/8	~0	**0/0.17**	150/590
Improving MSW landfill practices							
Biocover	*140/210*	0.8[vi]	0	*8.5/21*	~0	**0.12/0.19**	99/100
In-situ aeration	*140/210*	0.9	0	*4.2/11*	~0	**0.058/0.10**	99/130
Flaring	*140/210*	0	0.6/0.85	*6.4/43*	~0	**0.087/0.35**	5.0/58
CH_4 capture for power generation	*140/210*	0	0.6/0.9	*4.2/43*	~0	**0.058/0.35**	–37/66
CH_4 capture for heat generation	*140/210*	0	0.6/0.9	*4.2/43*	~0	**0.058/0.35**	–70/89

Notes:

i Note that input data are included in normal font type, output data resulting from data conversions are bolded, and intermediate outputs are italicized.

ii On wet weight basis.

iii Total DOC derived from estimates for regional composition of wastes and fraction of DOC in each type of waste (Pipatti et al., 2006, Tables 2.3 and 2.4).

iv Methane emissions intensity of reference and improved landfill practices is based on Frøiland Jensen and Pipatti (2001, Table 3) and approach above, which is based on equation 1 of aforementioned source. Methane emission intensity and nitrous oxide emissions intensity of reduced landfill options is based on IPCC (2006).

v Based on EPA (2013).

vi Based on EPA (2006).

A.III.4.2.6 Domestic wastewater

Specific CO_2eq emissions of wastewater (tCO_2/t BOD_5) are based on IPCC (2006) using the following equation to convert methane emissions.

$$EI_{CO2e} = MAX_{CH4} \cdot MCF \cdot GWP_{CH4} \quad \text{(Equation A.III.26)}$$

Where

- MAX_{CH4} is the maximum CH_4 production
- MCF is the methane correction factor
- GWP_{CH4} is the global warming potential of methane, $GWP_{CH4} = 21$

The levelized cost of conserved carbon is taken directly from EPA (2013). The discount rate used by EPA (2013) to derive these values was 10 %.

A.III.5 AFOLU

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A.III.5.1 Introduction

Figure 11.16 shows ranges for baseline emission intensities of selected agricultural and forestry commodities, emission intensities after application of mitigation options, and specific mitigation costs.

A.III.5.2 Approach

Commodity definitions are taken from the FAOSTAT (2013) database, where 'cereals' is the aggregation of 16 cereal crops, 'rice' is paddy rice, 'milk' is whole, fresh milk from dairy cows, 'meat' is meat from cattle only, and wood is 'roundwood'.

A.III.5.2.1 Baseline Emission Intensities

Baseline emission intensities represent the minimum and maximum of regional averages for five world regions. For agricultural commodities (rice, cereals, milk, and meat), they are calculated based on 11-year averages (2000–2010) of total annual CO_2eq emissions and total annual production volumes per region taken from (FAOSTAT, 2013). The following emission categories are considered for the calculation of baseline emission intensities: 'synthetic fertilizer' for cereals, 'rice cultivation' for paddy rice, and 'enteric fermentation' and 'manure management' for milk and meat.

For production of roundwood only afforestation and reforestation of idle land is considered. Hence, baseline emission intensities are set to zero.

A.III.5.2.2 Improved emission intensities

Improved emission intensities are derived by deducing product-specific mitigation potentials from baseline emission intensities.

Table A.III.12 | Technical parameters and estimates for cost of conserved carbon of wastewater treatment practices.[i]

Options	*MAX_{CH4}* Maximum CH_4 production (kg CH_4/kg BOD_5[ii])[iii]	*MCF* Methane Correction Factor (fraction) [iii]	*EI_{CO2e}* CO_2eq emission intensity (tCO_2/t BOD_5)	*LCCC* Levelized cost of conserved carbon (USD_{2010}/tCO_2eq)[iv]
Untreated system: Stagnant sewer (open and warm)[v]	0.6	0.4–0.8	**5–10**	–
Aerobic wastewater plant (WWTP)[vi]	0.6	0.2–0.4	**2.5–5**	0–530
Centralized wastewater collection and WWTP[vii]	0.6	0–0.1	**0–1.3**	0–530
Aerobic biomass digester with CH_4 collection[viii]	0.6	0–0.1	**0–1.3**	0–530

Notes:

i Note that input data are included in normal font type, output data resulting from data conversions are bolded, and intermediate outputs are italicized.

ii BOD: Biochemical Oxygen Demand. The amount of dissolved oxygen that biological organisms need in order to break down organic material into CH4. For domestic wastewater this value is in the range of 110–400 mg/l.

iii Based on IPCC (2006). N2O emission are neglected, since they do not play a significant role in emissions from domestic wastewater.

iv These values are directly taken from EPA (2013). They are relative to regional baselines.

v Untreated wastewater that is stored in a stagnant sewer under open and warm conditions.

vi Aerobic wastewater treatment refers to the removal of organic pollutants in wastewater by bacteria that require oxygen to work. Water and carbon dioxide are the end products of the aerobic wastewater treatment process.

vii Centralized wastewater collection improves the reduction efficiency. Processes are the same as for the aerobic treatment plant. Centralized collection of wastewater assumes that in general an infrastructure was established that ensures local wastewater storage in closed tanks and secures (emission impermeable) transport from production site to treatment plant.

viii Anaerobic wastewater treatment is a process whereby bacteria digest bio-solids in the absence of oxygen.

Mitigation options considered in the derivation of product-specific mitigation potentials include 'improved agronomic practices', 'nutrient management', 'tillage and residue management' and 'agroforestry' for cereals; 'rice land management' for rice; 'feeding' and 'dietary additives' for milk and meat production; and 'afforestation and reforestation' for roundwood production.

For cereals and paddy rice, data on mitigation potentials is provided by Smith et al. (2008) as average amount of CO_2eq sequestered per land area for four climate zones. These values are converted into amounts of CO_2eq sequestered per product by multiplication with global average product yields per land area based on FAOSTAT (2013).

For meat and milk, mitigation potentials are provided by Smith et al. (2008) as percentage reductions in emissions per mitigation option (see above) and region for five geographical regions. Minimum, average, and maximum of five regional values per mitigation option are taken and converted into amounts of CO_2eq sequestered per product by multiplication with an unweighted average of regional averages of emissions from enteric fermentation per product derived from FAOSTAT (2013). The derivation of the latter is done by dividing the 11-year (2000–2010) regional averages of emissions from enteric fermentation per commodity by the corresponding 11-year regional averages of the total number of producing animals for five geographical regions and by subsequently taking the unweighted average of those five regional averages. For roundwood, the carbon sequestration potential is calculated for representative tree species (based on FAO (2006) and IPCC (2006)) which match the rotation periods for short-term rotations given by Sathaye et al. (2006) for ten geographical regions. Regional and country averages are calculated based on the highest and lowest values for the ten geographical regions.

A.III.5.2.3 Levelized cost of conserved/sequestered carbon

Mitigation costs for agricultural mitigation options are taken from Smith et al. (2008) for cereals and paddy rice, and from US-EPA (2013) for milk and meat. For the livestock mitigation options, only the low end of the given cost range is considered. Costs for afforestation and reforestation are based on Sathaye et al. (2006).

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ANNEX

IV

Annex IV: Contributors to the IPCC WGIII Fifth Assessment Report

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ANNEX

V

Annex V: Expert Reviewers, Government Reviewers and Other Scientific Advisors of the IPCC WGIII Fifth Assessment Report

This annex should be cited as:

IPCC, 2014: Annex V: Expert Reviewers, Government Reviewers and Other Scientific Advisors of the IPCC WGIII Fifth Assessment Report. In: ***Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*** [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

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ANNEX

VI

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*Note: * indicates the term also appears in the Glossary (Annex I). Bold page numbers indicate page spans for entire chapters. Italicized page numbers denote tables, figures and boxed material.*

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