Chapter 13
Scopes 1, *2*, and *3* Industry Emissions and Future Pathways

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Abstract The *Scope 1*, *2*, and *3* emissions analysed in the OECM are defined and are presented for the 12 sectors analysed: (1) energy, (2) power and gas utilities, (3) transport, (4) steel industry, (5) cement industry, (6) farming, (7) agriculture and forestry, (8) chemical industry, (9) aluminium industry, (10) construction and buildings, (11) water utilities, and (12) textiles and leather industry. The interconnections between all energy-related CO_2 emissions are summarized with a Sankey graph.

Keywords Scope 1, 2, and 3 emissions · Industry · Service · Transport · Buildings steel · Cement · Aluminium · Chemicals agriculture · Forests water utilities · Textile and leather

13.1 Introduction

The OECM methodology has been presented in previous chapters, based on which energy consumption and supply concepts for sectorial pathways were developed. All 12 sectors analysed have been described, the assumptions presented, and the derivations of the energy pathways explained in detail. The resulting energy-related CO_2 levels for the sectors are described in Chap. 12. The present chapter focuses on the results of the calculated *Scope 1*, *2*, and *3* emissions for all the sectors analysed.

The industry-specific emission budgets are further subdivided into so-called *Scope 1*, *2*, and *3* emissions, which define the responsibility for those emissions. So far, this system has only been applied to companies, and not yet to entire industry

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sectors or regions. For a better overview, the OECM definitions of *Scopes 1*, *2*, and *3*, which are explained in detail in Chap. 4, are shown again in Box 13.1.

Box 13.1: OneEarth Climate Model: Definitions of Scope 1, 2, and 3 Emissions

Scope 1 – All direct emissions from the activities of an organization or under their control. Including on-site fuel combustion, such as gas boilers, fleet vehicles, and air-conditioning leaks. For this analysis only, the economic activities covered under the sector-specific GICS classification that are counted under the sector are included. All the energy demands reported by the International Energy Agency (IEA) Advanced World Energy Balances (IEA, 2020, 2021) for a specific sector are included.

Scope 2 – Indirect emissions from electricity purchased and used by an organization. Emissions are created during the production of this energy, which is eventually used by the organization. For reasons of data availability, the calculation of these emission focuses on the electricity demand and 'own consumption', e.g. reported for power generation.

Scope 3 – Greenhouse gas (GHG) emissions caused by the analysed industry, limited to sector-specific activities and/or products, as classified in the GICS. The OECM only includes sector-specific emissions. Traveling, commuting, and all other transport-related emissions are reported under *transport*. The lease of buildings is reported under *buildings*. All other finance activities, such as 'capital goods', are excluded because no data are available for the GICS industry sectors, and their inclusion would lead to double counting. The OECM analysis is limited to energy-related CO_2 and energy-related methane (CH_4) emissions. All other GHGs are calculated outside the OECM model by Meinshausen and Dooley (2019).

The results and key parameters for the primary and secondary energy sectors are presented first, followed by those for the *industries* and *services*, *buildings*, and *transport* sectors.

13.2 Scope 1, 2, and 3: Energy and Utilities

The *energy* sector includes the primary production of energy from oil, gas, hard coal, and lignite, and all renewable energies. This includes the exploration for all types of fossil fuels; the operation of oil and gas drilling facilities, mining equipment, and fossil fuel transport to refineries; and further processing facilities, as defined under GICS Sector *10 Energy*. To remain within the defined carbon budget, no new oil, gas, or coal-mining projects can be opened up, an assumption that is

Table 13.1 GICS Sector 10 *energy*

10 Energy	
1010 10	Energy equipment and services
	1010 1010 Oil and gas drilling
	1010 1020 Oil and gas equipment and services
1010 20	Oil, gas, and consumable fuels
	1010 2010 Integrated oil and gas
	1010 2020 Oil and gas exploration and production
	1010 2030 Oil and gas refining and marketing
	1010 2040 Oil and gas storage and transportation
	1010 2050 Coal and consumable fuels

consistent with the recommendations of the IEA NetZero by 2050 report (IEA-NZ 2050) (Table 13.1).

As documented in section 10, the OECM 1.5 °C trajectory requires a phase-out of brown coal (lignite) and hard coal by 2030 in all Organization for Economic Cooperation and Development (OECD) countries and in all other regions thereafter by 2050, at the very latest. The phase-out of brown coal has priority over that of hard coal, because its specific CO_2 emissions are higher. For the oil and gas sector, it is assumed that existing mines will wind-down, with an average decline in production of minus 2% per year for coal, minus 4% per year for onshore oil fields and 6% per year offshore oil fields, and minus 4% per year on- and offshore gas fields, which represent the average industry standards on the global scale (see Chap. 10). However, the production decline rates will differ significantly by region and geological formation. It is assumed that natural gas will be phased out by 2050 and partly replaced by alternative fuels, such as hydrogen and/or synthetic fuels, from 2025 onwards. The *energy* sector is also assumed to transition to utility-scale renewable energy projects and therefore to maintain its core business of energy production. Utility-scale renewables are defined as power plants that produce bulk power that is sold to utilities or end-use customers in the *industry* or *service* sector, such as offshore and onshore wind farms, solar farms, and geothermal and biomass power plants (including combined heat and power) with over 1 megawatt installed capacity.

A significant part of the renewable energy production by this sector under the 1.5 °C pathway will be from offshore wind, both to supply utilities with electricity and to produce hydrogen and other synthetic fuels. Figure 13.1 shows the global amounts of annual energy production in petajoules (PJ). The renewable energy production level will reach parity with those of oil and gas by 2030 and will continue to grow throughout the next two decades. The remaining oil and gas production shown for 2050 is for non-energy use.

Energy—Scope 1 emissions are defined as the direct emissions related to the extraction, mining, and burning of fossils fuels. This analysis covers both the

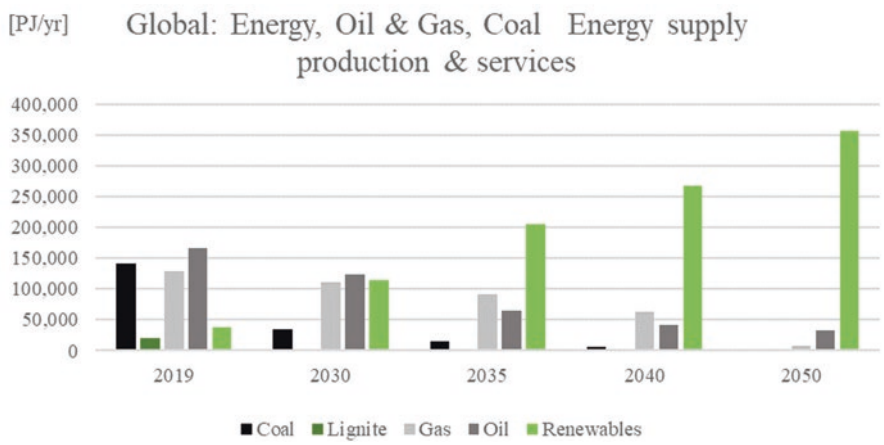

Fig. 13.1 Global primary energy sector—energy production under the OECM 1.5 °C pathway

energy-related CO_2 emissions and non-energy GHGs, such as methane (CH_4) emissions from mining and fossil fuel production.

Energy—Scope 2 emissions are indirect emissions from the electricity used for the operation of mining equipment, oil and gas rigs, refineries, and other equipment required in the primary energy sector. Their calculation is based on statistical information ('own consumption') from the IEA Advanced Energy Balances. The OECM assumes the global average carbon intensity of electricity generation for each calculated year according to the OECM power scenario, which will reach 100% renewables by 2050 (for details, see Chap. 12).

Energy—Scope 3 emissions are embedded CO_2 emissions, which occur when the fossil fuel produced by the primary energy industry is burnt by end users.

Table 13.2 shows the *scope 1*, *2*, and *3* emissions for coal, oil, and gas and the development of the fuel intensity of the global economy. In 2019, as a global average, 1.25 PJ of coal was used for each billion US$ of gross domestic product ($GDP). This coal intensity is assumed to halve by 2025 and to drop by 85% by 2030. The global economy will grow independently of coal use under the OECM 1.5 °C pathway (Table 13.3).

The *utilities* sector covers energy transport and the operation and maintenance of power- and heat-generating equipment and is responsible for the energy transport infrastructure, such as power grids and pipelines to the end user. In this analysis, the *utilities* sector is a secondary energy service provider, whose core function is the generation and distribution of electricity and the distribution of natural gas, as well as hydrogen and synthetic fuels, beyond 2030. It operates and maintains power and cogeneration plants, power grids (all voltage levels), and pipelines and provides energy services, such as balancing, demand-side management, and storage. 'Utilities' are energy service companies linking the primary energy supply with consumers.

Electricity and gaseous fuel supplies are the core commodities of gas and power utilities. With the increased electrification of the transport and heating sectors, the

Table 13.2 Global *energy* sector—*scopes 1*, *2*, and *3* for coal, oil, and gas

Sub-sector	Units	2019	2025	2030	2035	2040	2050
			Projections				
Coal (hard and brown)							
Coal *Scope 1*:	[$MtCO_2eq/yr$]	2434	1419	583	270	93	0
Compared with 2019	[%]		−42%	−76%	−89%	−96%	−100%
Coal Scope 2:	[$MtCO_2eq/yr$]	260.4	127.3	56.5	24.4	7.9	0.0
Compared with 2019	[%]		−51%	−78%	−91%	−97%	−100%
Coal *Scope 3*:	[$MtCO_2eq/yr$]	15,328.7	7864.3	3272.1	1327.6	290.7	0.0
Compared with 2019	[%]						
Total non-energy GHG:	[$MtCO_2eq/yr$]	111	67	37	27	12	0
Compared with 2019	[%]		−40%	−67%	−76%	−89%	−100%
Coal intensity of economy	[PJ/bn$GDP]	1.25	0.52	0.19	0.07	0.02	0.00
Compared with 2019	[%]		−59%	−85%	−94%	−98%	−100%
Oil							
Oil *Scope 1*:	[$MtCO_2eq/yr$]	990.3	918.5	732.3	383.6	251.1	191.0
Compared with 2019	[%]		−94%	−95%	−97%	−98%	−99%
Oil *Scope 2*:	[$MtCO_2eq/yr$]	165.6	153.5	122.4	64.1	42.0	31.9
Compared with 2019	[%]		−41%	−53%	−75%	−84%	−88%
Oil *Scope 3*:	[$MtCO_2eq/yr$]	10,416.1	9580.3	7162.7	2766.7	1051.1	0.0
Compared with 2019	[%]		−8%	−31%	−73%	−90%	−100%
Total non-energy GHG:	[$MtCO_2eq/yr$]	96	98	94	60	43	0
Compared with 2019	[%]		156%	147%	58%	11%	−100%
Gas							
Gas *Scope 1*:	[$MtCO_2eq/yr$]	1103.2	1062.8	949.0	778.5	535.2	71.1
Compared with 2019	[%]		−93%	−94%	−95%	−96%	−100%
Gas *Scope 2*:	[$MtCO_2eq/yr$]	60.7	58.4	52.2	42.8	29.4	3.9
Compared with 2019	[%]		−78%	−80%	−84%	−89%	−98%
Gas *Scope 3*:	[$MtCO_2eq/yr$]	8,082.4	7515.9	6608.3	5428.2	3792.6	478.2
Compared with 2019	[%]		−7%	−18%	−33%	−53%	−94%
Total non-energy GHG:	[$MtCO_2eq/yr$]	85	91	104	140	175	0
Compared with 2019	[%]		139%	172%	267%	357%	−100%

Table 13.3 Global *energy* sector—*scopes 1*, *2*, and *3*

Total energy, gas, oil, and coal sector						
Energy sector—*scope 1*:	[$MtCO_2eq/yr$]	4527	3400	2265	880	262
	[%]	0%	−25%	−50%	−81%	−94%
Energy sector—*scope 2*:	[$MtCO_2eq/yr$]	487	339	231	79	36
	[%]	0%	−30%	−53%	−84%	−93%
Energy sector—*cope 3*:	[$MtCO_2eq/yr$]	33,827	24,960	17,043	5134	478
	[%]	0%	−26%	−50%	−85%	−99%

electricity demand—and therefore the potential market value of power utilities—will increase significantly. Renewable electricity will overtake global coal- and gas-fuelled power generation combined by 2025. By 2045, the market volume of hydrogen and synthetic fuels will be as high as that of natural gas for gas utilities, making them important new products.

Utilities—Scope 1 emissions are defined as the direct emissions from fuels related to the generation and transmission of electricity and the distribution of fossil fuels and/or renewable gas.

Utilities—Scope 2 emissions are indirect emissions from the electricity used for the production of a sector's core product. This includes the electricity consumption of power plants, losses by power grids, and the operation of pumps for gas pipelines, etc. Their calculations are based on statistical information listed under 'self-consumption' of the IEA Advanced Energy Balances plus the global average power grids losses, which are assumed to be 7.5%.

Utilities—Scope 3 emissions are embedded CO_2 emissions that occur with the use of electricity or gaseous fuels by end users. Table 13.4 shows all *scope 1*, *2*, and *3* emissions for the *utilities* sector by sub-sector and in total.

Table 13.4 Global *utilities* sector—*scopes 1*, *2*, and *3*

Sub-sector	Units	2019	2025	2030	2035	2040	2050
			Projections				
Power							
Power—*scope 1*:	[$MtCO_2eq/yr$]	1292	741	596	522	479	469
Compared with 2019	[%]		−43%	−54%	−60%	−63%	−64%
Power—*scope 2*:	[$MtCO_2eq/yr$]	112	86	54	24	11	0
Compared with 2019	[%]		−23%	−52%	−78%	−91%	−100%
Power—*scope 3*:	[$MtCO_2eq/yr$]	14,722	9124	5337	3110	1919	469
Compared with 2019	[%]		−38%	−64%	−79%	−87%	−97%
Gas							
Gas—*scope 1*:	[$MtCO_2eq/yr$]	1243	917	694	522	341	43
Compared with 2019	[%]		−26%	−44%	−58%	−73%	−97%
Gas—*scope 2*:	[$MtCO_2eq/yr$]	175	140	125	103	71	9
Compared with 2019	[%]		−20%	−29%	−41%	−60%	−95%
Gas—*scope 3*:	[$MtCO_2eq/yr$]	7,183	7009	6278	5151	3414	24
Compared with 2019	[%]		−2%	−13%	−28%	−52%	−100%
Total CH_4 emissions	[$MtCH_4/yr$]	14.9	14.4	12.9	10.5	7.3	1.0
Compared with 2019	[%]		−4%	−14%	−29%	−51%	−94%
Utilities							
Utilities—*scope 1*:	[$MtCO_2eq/yr$]	2535	1659	1289	1044	819	512
Compared with 2019	[%]		−35%	−49%	−59%	−68%	−80%
Utilities—*scope 2*:	[$MtCO_2eq/yr$]	287	226	179	127	81	10
Compared with 2019	[%]		−21%	−38%	−56%	−72%	−97%
Utilities—*scope 3*:	[$MtCO_2eq/yr$]	21,905	16,134	11,615	8,261	5333	493
Compared with 2019	[%]		−26%	−47%	−62%	−76%	−98%

13.3 *Scopes 1*, *2*, and *3*: *Industry*

All results for the *scope* 1, *2*, and *3* emissions for the five main energy-intensive industry sectors are based on the energy demand assessment documented in Chap. 5.

13.3.1 Scopes 1, 2, *and 3: Chemical Industry*

The *chemical industry* is the most complex industry of all the sectors analysed, and the data available on its energy demand are less detailed than for, for example, the steel industry. Furthermore, the production of chemical commodities (see Sect. 5.1) is energy intensive, and they are used not only across the chemical industry but also in other sectors. Therefore, the calculation results shown in Table 13.5 are subject to uncertainties resulting from the paucity of detailed data. The global energy demand data for, for example, the pharmaceuticals industry are not available, and the calculations are based upon sector-specific energy intensities and the market shares of the pharmaceuticals industry in 2019 (see Sect. 5.1.3).

Chemicals—Scope 1 emissions are defined as the direct emissions related to the production of raw materials for the chemical industry from natural gas, ethane, oil-refining by-products (such a propylene), and salt, which are used to manufacture bulk chemicals, such as sulfuric acid, ammonia, chlorine, industrial gases, and basic polymers, such as polyethylene and polypropylene.

Chemicals—Scope 2 emissions are indirect emissions from the electricity used for the production and processing of chemical products and the manufacture of goods that fall under *chemicals*, as classified under GICS 1510 10.

Chemicals—Scope 3 emissions are all non-energy-related GHG emissions and aerosols that fall under the Montreal Protocol (UNEP MP, 2021). Montreal Protocol gases are mainly propellants, foams, or liquids and gases used for cooling and refrigeration that are produced by the chemical industry. More details about these gases are given in Chap. 11.

Scope 1 and *2* emissions will reach zero by 2050, whereas *Scope 3* emissions will only be reduced by 73% compared with 2019 due to the nature of those substances.

13.3.2 Scope 1, 2 *and* 3*:* Cement Industry

The energy intensity of the cement production processes is well-documented, and data for the energy demands and process emissions are available. This analysis includes all steps in cement production, from quarrying the raw materials to its storage in cement silos. However, the further processing of cement for construction, for example, is not included but is included in the *buildings and construction* sector (Sect. 13.4).

Table 13.5 Global *scope 1*, *2*, and *3* emissions of the *chemical industry*

Chemical industries	Units	2019	2025	2030	2035	2040	2050
Scope 1:	[$MtCO_2eq$/yr]	1257	994	707	554	323	0
Compared with 2019	[%]		−21%	−44%	−56%	−74%	−100%
Scope 2:	[$MtCO_2eq$/yr]	761	499	263	114	57	0
Compared with 2019	[%]		−34%	−66%	−85%	−93%	−100%
Scope 3:	[$MtCO_2eq$/yr]	2520	1852	1220	991	775	682
Compared with 2019	[%]		−27%	−52%	−61%	−69%	−73%
Chemical industries—sub-sectors	**Units**	**2019**	**2025**	**2030**	**2035**	**2040**	**2050**
Pharmaceutical industry—*scope 1*	[$MtCO_2eq$/yr]	230	181	129	101	59	0
Pharmaceutical industry—*scope 2*	[$MtCO_2eq$/yr]	202	133	70	31	15	0
Pharmaceutical industry—*scope 3*	[$MtCO_2eq$/yr]	0	0	0	0	0	0
Agricultural chemicals—*scope 1*	[$MtCO_2eq$/yr]	270	213	151	119	69	0
Agricultural chemicals—*scope 2*	[$MtCO_2eq$/yr]	111	73	38	17	8	0
Agricultural chemicals—*scope 3*	[$MtCO_2eq$/yr]	0	0	0	0	0	0
Inorganic chemicals and consumer products—*scope 1*	[$MtCO_2eq$/yr]	229	181	128	101	59	0
Inorganic chemicals and consumer products—*scope 2*	[$MtCO_2eq$/yr]	205	134	71	31	15	0
Inorganic chemicals and consumer products—*scope 3*	[$MtCO_2eq$/yr]	0	0	0	0	0	0
Manufactured fibres and synthetic rubber—*scope 1*	[$MtCO_2eq$/yr]	301	237	169	132	77	0
Manufactured fibres and synthetic Rubber—*scope 2*	[$MtCO_2eq$/yr]	39	25	13	6	3	0
Manufactured fibres and synthetic rubber—*scope 3*	[$MtCO_2eq$/yr]	0	0	0	0	0	0
Bulk petrochemicals and intermediates, plastic resins—*scope 1*	[$MtCO_2eq$/yr]	229	181	129	102	59	0
Bulk petrochemicals and intermediates, plastic resins—*scope 2*	[$MtCO_2eq$/yr]	205	133	70	30	15	0
Bulk petrochemicals and intermediates, plastic resins—*scope 3*	[$MtCO_2eq$/yr]	0	0	0	0	0	0

Table 13.6 Global *scope 1*, *2*, and *3* emissions for the *cement industry*

Total materials/cement	Units	2019	2025	2030	2035	2040	2050
Scope 1:	[$MtCO_2eq/yr$]	1731	1609	1388	1217	1044	734
Compared with 2019	[%]		−7%	−20%	−30%	−40%	−58%
Scope 2:	[$MtCO_2eq/yr$]	248	116	54	21	10	0
Compared with 2019	[%]		−53%	−78%	−92%	−96%	−100%
Scope 3:	[$MtCO_2eq/yr$]	9685	6085	3039	1416	746	0
Compared with 2019	[%]		−37%	−69%	−85%	−92%	−100%

Cement—Scope 1 emissions are defined as the direct energy-related CO_2 emissions related to all steps of cement production, from mining to the final raw product that is used in further processes and applications. The fuels for mining vehicles are included, as well as the process heat for clinker production in kilns, etc. Emissions from the calcination process—the decomposition of limestone into quick lime and carbon dioxide (Kumar et al., 2007)—are also included.

Cement—Scope 2 emissions are the indirect emissions from the electricity used across all steps of the value chain of the cement industry.

Cement—Scope 3 emissions of the cement industry are *scope 2* emissions of the *buildings* sector, according to the World Business Council for Sustainable Development's Cement Sector Reporting Guidance (WBCSD, 2016).

By 2050, there will be no energy-related CO_2 emissions from the cement industry under the OECM 1.5 °C pathway (Sect. 5.2). Process emissions from calcination are assumed to decline from 0.4 tCO_2 per tonne of clinker to 0.24 tCO_2—an assumption based on the IEA Technology Roadmap (IEA, 2018). Table 13.6 and Fig. 13.2 show the calculated results for the *scope 1*, *2*, and *3* emission of the global cement industry.

13.3.3 Scopes 1, 2, *and* 3*:* Aluminium Industry

As for the cement industry, all aluminium production processes are well-documented. The processes and their energy demand for each step of aluminium production, from bauxite mining to aluminium sheets or aluminium blocks, which are then delivered to other industries for further processing, are available in the literature. The recycling of aluminium for the production of secondary aluminium is also included. All assumptions for the projected development of the aluminium industry—including bauxite mining—are documented in Sect. 5.3.

Aluminium—Scope 1 emissions are defined as the direct energy-related CO_2 emissions related to the use of fuels for bauxite mining, alumina processing, and all steps of the production of primary and secondary aluminium. The process emissions from anode or paste (IAI, 2006) consumption, which lead to CO_2 emissions that are not energy related, are included.

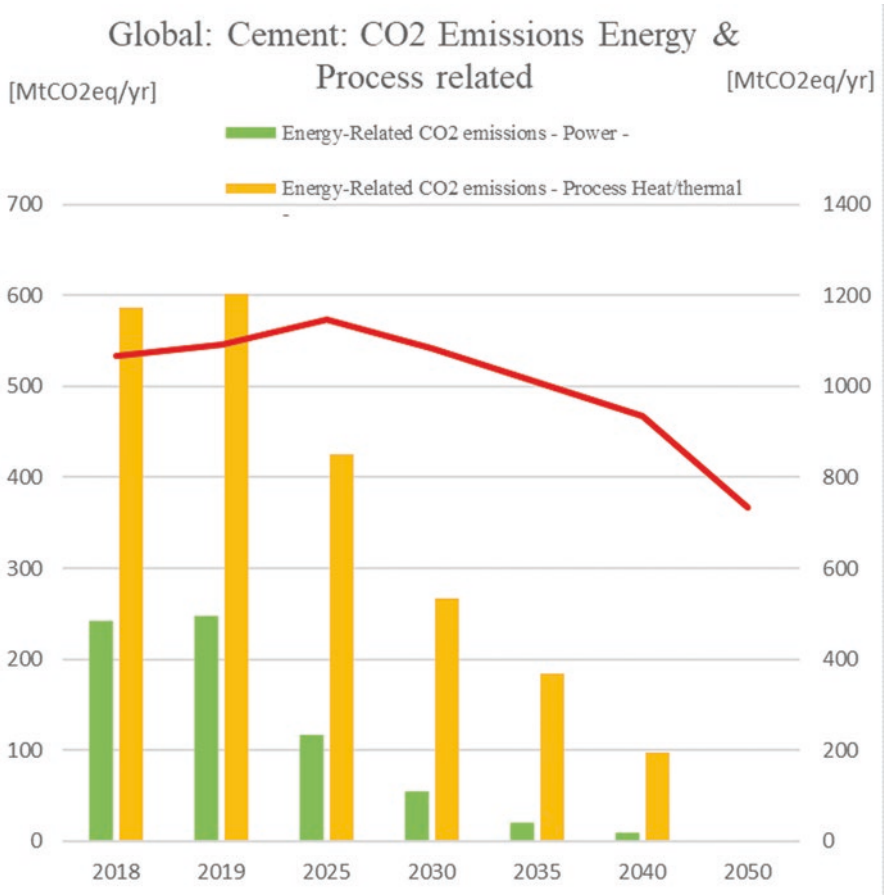

Fig. 13.2 Global *cement* sector—energy- and process-related CO_2 under the OECM 1.5 °C pathway

Aluminium—Scope 2 emissions are the indirect emissions from the electricity used across all the steps of the value chain of the aluminium industry.

Aluminium—Scope 3 emissions are solely those emissions caused by tetrafluoromethane, a strong GHG that is produced in certain aluminium production processes. A recent study published in Nature highlights the increased emissions of this gas, which probably derive from aluminium production facilities in Asia (Nature 8/2021). We decided to include tetrafluoromethane emissions in this OECM analysis to highlight the importance of this finding.

By 2050, all energy-related CO_2 emissions of the aluminium industry will be zero and the industry will be fully decarbonized. However, process-related GHG emissions are not expected to be completely phased out (Table 13.7).

Table 13.7 Global *scope 1*, *2*, and *3* emissions for the *aluminium industry*

Aluminium industry	Units	2019	2025	2030	2035	2040	2050
Scope 1:	[$MtCO_2eq/yr$]	401	337	308	297	282	270
Compared with 2019	[%]		−16%	−23%	−26%	−30%	−33%
Scope 2:	[$MtCO_2eq/yr$]	522	305	144	57	26	0
Compared with 2019	[%]		−42%	−72%	−89%	−95%	−100%
Scope 3:	[$MtCO_2eq/yr$]	72	47	15	13	14	18
Compared with 2019	[%]		−35%	−79%	−82%	−81%	−75%

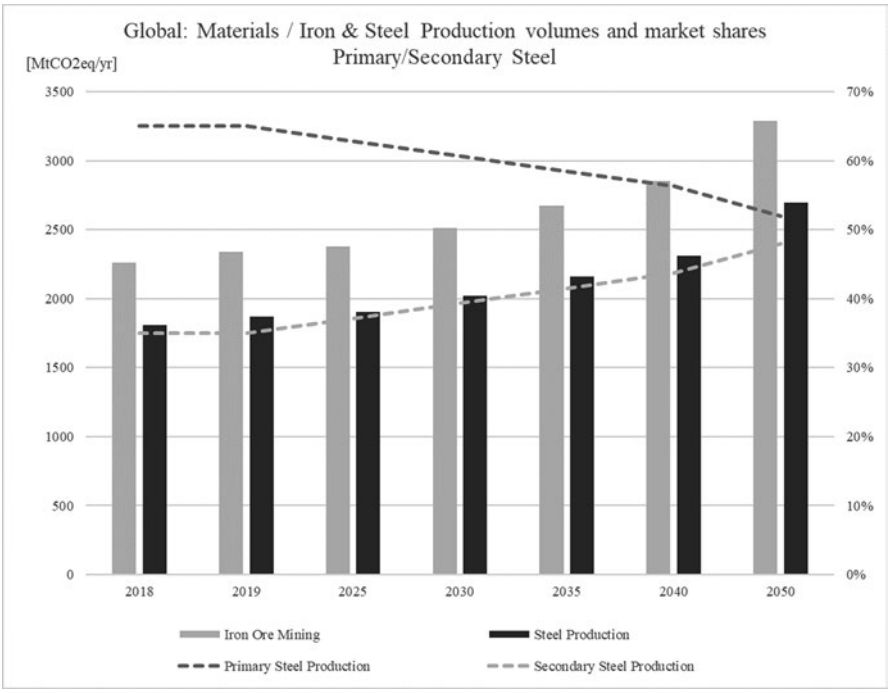

Fig. 13.3 Global *steel* sector—iron-ore mining and steel production under the OECM 1.5 °C pathway

13.3.4 Scope 1, 2, *and* 3*:* Steel Industry

Global and regional steel industry emissions are among the most discussed of all industry emissions. Various industry- and science-based working groups have developed relevant scenarios over the past decade. However, most of them are consistent with the Iron and Steel Technology Roadmap of the IEA (IEA, 2020). The OECM 1.5 °C pathway for the *steel industry* is based to a large extent on the IEA assumptions for the energy demand side but has added a more ambitious decarbonization scenario for the energy *supply* side. Figure 13.3 shows the development of

iron-ore mining and primary and secondary steel production assumed for the global market between 2019 and 2050. The increase in secondary steel—recycled steel, mainly from scrap—will increase from 35% in 2019 to 48% in 2050, leading to a reduction in the iron and mining demands and the process emissions that are only related to primary steel production. Therefore, a high recycling rate will directly affect process emissions, which are not related to the actual energy supply but to the steel-making process itself. Further information about the assumptions for the *steel industry* is documented in Chap. 5 (Sect. 5.4).

The OECM analysis includes energy-related CO_2 emissions that occur from iron-ore mining across all steps of the steel manufacturing processes for primary and secondary steel but exclude manufacturing processes that use steel for product manufacture, such as the automotive industry.

Steel—Scope 1 emissions are defined as the direct energy-related CO_2 emissions related to the use of fuels for iron-ore mining and the production of primary and secondary steel. Process emissions from anode or paste (IAI, 2006) consumption, which lead to CO_2 emissions that are not energy related, are included.

Steel—Scope 2 emissions are the indirect emissions from the electricity used across all steps of the value chain of the steel industry.

Steel—Scope 3 emissions are only process-related emissions, as defined in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). It is assumed that process emissions will decline significantly from 0.92 tCO_2 per tonne currently to 0.08 tCO_2 by 2050 as a result of the transition to electric-furnace-based steel production (see Sect. 5.4.3) (Table 13.8).

13.3.5 Scopes 1, 2, *and* 3*:* Textile and Leather Industry

The *textile and leather industry* is part of the IEA *industry* sector but is not part of the GICS (15) *materials* group (see Chap. 4). The *textile and leather industry* is closely associated with the *chemicals industry*, from which synthetic fibres and plastic for accessories are sourced, and with the *agriculture* sector, for cotton and other natural fibres. The production of leather depends on animal farms, especially those that produce meat. The assumptions made for the calculation of the energy-related CO_2 emissions of this industry are documented in Sect. 5.5.

Table 13.8 Global *scope 1*, *2*, and *3* emissions for the *steel* industry

Total materials/steel	Units	2019	2025	2030	2035	2040	2050
Scope 1:	[$MtCO_2eq/yr$]	1073	762	489	353	187	0
Compared with 2019	[%]		−29%	−54%	−67%	−83%	−100%
Scope 2:	[$MtCO_2eq/yr$]	645	459	222	95	48	0
Compared with 2019	[%]		−29%	−66%	−85%	−93%	−100%
Scope 3:	[$MtCO_2eq/yr$]	1980	1757	1219	804	542	216
Compared with 2019	[%]		−11%	−38%	−59%	−73%	−89%

Table 13.9 Global *scope 1*, *2*, and *3* emissions for the *textile and leather industry*

Textile and leather industry	Units	2019	2025	2030	2035	2040	2050
Scope 1:	[$MtCO_2eq/yr$]	178	151	109	87	51	0
Compared with 2019	[%]		−15%	−39%	−51%	−71%	−100%
Scope 2:	[$MtCO_2eq/yr$]	181	127	68	30	15	0
Compared with 2019	[%]		−30%	−62%	−83%	−92%	−100%
Scope 3:	[$MtCO_2eq/yr$]	38	30	24	22	22	20
Compared with 2019	[%]		−23%	−37%	−43%	−44%	−48%

Textile and Leather—Scope 1 emissions are defined as the direct energy-related CO_2 emissions associated with all the steps of textile and leather production that require process heat or fuels. It covers leather production, but not the production of fibres, which is part of the *chemicals* sector. The calculation of these emissions includes the value chain until delivery to retail.

Textile and Leather—Scope 2 emissions are the indirect emissions from the electricity used for the production of textile and leather products, excluding fibres manufacture and retail.

Textile and Leather—Scope 3 emissions include 25% of all CH_4 emissions from the agricultural sector to reflect the non-energy-related GHG emissions associated with the production of natural fibres and animal skins (Table 13.9).

13.4 *Scope 1*, *2*, and *3*: *Services*

All the results for the *scope 1*, *2*, and *3* emissions of the four *service* sectors analysed are based on the energy demand assessment documented in Chap. 6. Non-energy-related GHG emissions form the majority of the *service* sector emissions, whereas energy-related CO_2 is a relatively small component compared with that in other sectors, such as *industry* and *transport*. These non-energy-related GHG emissions—referred to as agriculture, forestry, and other land-uses (AFOLU) in climate science—are among the main emitters of non-energy CO_2, CH_4, and nitrous oxide (N_2O). The *service* sectors analysed, *agriculture and food*, *forestry and wood*, *fisheries*, and *water utilities*, are described and the assumptions are documented in Chaps. 6, 11, and 14. Therefore, in this section, we focus solely on the presentation of their calculated *scope 1*, *2*, and *3* emissions.

13.4.1 Scope 1, 2, *and* 3*:* Agriculture and Food *Sector*

The *agriculture and food* sector includes all economic activities from ‘the field to the supermarket’. With regard to the energy used, this sector is a combination of the service sector *agriculture* and the industry sub-sector *food and tobacco*. Therefore,

it includes crop and animal farming and the processing of all commodities into food, beverages, and tobacco products.

Agriculture and Food—Scope 1 emissions are related to fuel used in agricultural vehicles, such as tractors, machinery for harvesting and other equipment used on farms, as well as heat for food and tobacco processing and packaging.

Agriculture and Food—Scope 2 emissions include those for electricity purchased from utilities for either farming or any step in food processing or packaging. On-site electricity generation (e.g. on farms via solar photovoltaic, wind power, or bioenergy from residuals) will reduce *scope 2* emissions, but sub-sector-specific on-site generation is not assumed in this analysis.

Agriculture and Food—Scope 3 emissions include AFOLU emissions, N_2O, and ammonia emissions from fertilizers and CH_4 emissions (see Chaps. 11 and 14).

All energy-related CO_2 emissions of the *agriculture and food* sector will be reduced by half by 2030 and phased out entirely by 2050. However, it is assumed that AFOLU emissions from agriculture cannot be reduced to zero, because the demand for food for the growing global population will increase (Table 13.10).

13.4.2 Scopes 1, 2, and 3: Forestry and Wood *Sector*

Like the *agriculture and food* sector, the *forestry and wood* sector contains to subsectors: *forestry*, which is part of the IEA's *other sectors*, and the IEA industry subsector *wood and wood products*, which includes the pulp and paper industry. Details of the energy demand of this sector are provided in Sect. 6.2.

Forestry and Wood—Scope 1 emissions include those from heavy machinery for wood harvesting, all-terrain vehicles, power tools, chainsaws, etc.

Forestry and Wood—Scope 2 emissions are the indirect emissions from electricity. Like the agricultural sector, the forestry sector has significant potential for on-site power and heat generation, e.g. from forestry residuals, which can lower its *scope 2* emissions, but this is not assumed under the OECM 1.5 °C pathway.

Table 13.10 Global *scope 1*, *2*, and 3 emissions for the *agriculture and food* sector (including tobacco)

Agriculture, food, and tobacco	Units	2019	2025	2030	2035	2040	2050
Agriculture, food processing—*scope 1*:	[$MtCO_2eq$/yr]	355	272	184	134	95	0
Compared with 2019	[%]		−24%	−48%	−62%	−73%	−100%
Agriculture, food processing—*scope 2*:	[$MtCO_2eq$/yr]	975	632	324	138	67	0
Compared with 2019	[%]		−35%	−67%	−86%	−93%	−100%
Agriculture, food processing—*scope 3*:	[$MtCO_2eq$/yr]	6,837	5413	4515	4243	4205	3994
Compared with 2019	[%]		−21%	−34%	−38%	−38%	−42%

Forestry and Wood—Scope 3 emissions are forestry-related AFOLU emissions. The transition towards sustainably managed forests, the cessation of deforestation, and the commencement of reforestation are integral parts of the OECM 1.5 °C pathway as 'carbon sinks'. Therefore, *scope 3* emissions will become negative by 2030 (see Chaps. 11 and 14) (Table 13.11).

13.4.3 Scopes 1, 2, *and* 3*:* Fisheries *Sector*

The majority of all energy-related *scope 1* and *2* emissions in this industry are from fishing vessels and other equipment directly related to wild catches and aquaculture fish farms. Whereas the energy demand for fishing vessels is documented in the literature (see Sect. 6.3), no statistical data on the global energy demand for aquaculture and fish farming are available. Instead, only accumulated data on the GHG emissions for the global aquaculture sector have been published and have been used to calculate the *scope 3* emissions (MacLeod et al., 2020). Therefore, the energy demand of the fishing industry in 2019 and its projection until 2050 are estimates with uncertainties.

Fisheries—Scope 1 emissions are defined as the direct energy-related CO_2 emissions related to the use of fuels for fishing vessels and directly related to the infrastructure, such as refrigerators and freezers for fish on board fishing vessels.

Fisheries—Scope 2 emissions are the indirect emissions from the electricity used for cooling devices as part of the cooling chain for fish, from 'dock to supermarket'.

Fisheries—Scope 3 emissions are emissions from aquaculture as defined by MacLeod et al. (2020) as 'emissions arising from fishmeal production, feed blending, transport … and non-feed emissions from the nitrification and denitrification of nitrogenous compounds in the aquatic system ('aquatic N_2O')'. Also included are the estimated energy-use emissions, mainly for pumping water.

Table 13.12 shows the results for all the calculated emissions in this industry. It is assumed that about one-quarter of aquaculture *scope 3* emissions are directly related to energy use and will therefore be reduced to zero with the use of 100% renewable energy.

Table 13.11 *Global scope 1*, *2*, and *3* emissions for the *forestry and wood* sector

Forestry and wood	Unit	2019	2025	2030	2035	2040	2050
Forestry, wood products—*scope 1*:	[$MtCO_2eq$/yr]	196	155	105	76	54	0
Compared with 2019	[%]		−21%	−47%	−61%	−73%	−100%
Forestry, wood products—*scope 2*:	[$MtCO_2eq$/yr]	344	184	97	42	21	0
Compared with 2019	[%]		−46%	−72%	−88%	−94%	−100%
Forestry, wood products—scope 3:	[$MtCO_2eq$/yr]	2648	1164	−619	−1241	−835	−1359
Compared with 2019	[%]		−56%	−123%	−147%	−132%	−151%

Table 13.12 Global *scope 1*, *2*, and *3* emissions for the *fisheries* sector

Fishery	Units	2019	2025	2030	2035	2040	2050
Fishing industry—*scope 1*:	[$MtCO_2eq/yr$]	29	28	25	21	16	0
Compared with 2019	[%]	0%	−4%	−15%	−29%	−47%	−100%
Fishing industry—*scope 2*:	[$MtCO_2eq/yr$]	4	3	1	1	0	0
Compared with 2019	[%]	0%	−32%	−63%	−82%	−88%	−100%
Fishing industry*scope 3*:	[Mt CO_2eq/yr]	250	239	227	215	202	178
Compared with 2019	[%]	0%	−4%	−9%	−14%	−19%	−29%

Table 13.13 Global *scope 1*, *2*, and *3* emissions for *water utilities*

Water utilities	Unit	2019	2025	2030	2035	2040	2050
Water utilities—*scope 1*:	[$MtCO_2eq/yr$]	77	53	33	22	15	0
Compared with 2019	[%]	0%	−32%	−57%	−71%	−81%	−100%
Water utilities—*scope 2*:	[$MtCO_2eq/yr$]	27	14	7	3	1	0
Compared with 2019	[%]	0%	−47%	−74%	−90%	−95%	−100%
Water utilities—*scope 3*:	[$MtCO_2eq/yr$]	830	881	925	971	1020	1125
Compared with 2019	[%]	0%	6%	11%	17%	23%	35%

13.4.4 Scopes 1, 2, *and* 3*:* Water Utilities

Only 13% of the GHG emission from *water utilities* are related to energy use. The bulk of GHG emissions are related to CH_4 and N_2O emission from sewers or the treatment of biological wastewater and the resulting sludge. Chapter 6 documents all the assumptions and input data used to calculate the *scope 1*, *2*, and *3* emissions for water utilities.

Water Utilities—Scope 1 emissions are defined as the direct energy-related CO_2 emissions associated with the supply of the low- and medium-temperature process heat used in all steps of wastewater treatment.

Water Utilities—Scope 2 emissions are the indirect emissions from the electricity used across all steps of wastewater treatment processes.

Water Utilities—Scope 3 emissions are the CH_4 and N_2O emissions from sewers or biological wastewater treatment. They are calculated with average global emission factors of 0.17 kg CO_2 equivalents per cubic metre ($kgCO_2eq/m^3$) for CH_4 emissions and 0.033 $kgCO_2eq/m^3$ for N_2O emissions.

Water utilities have significant potential to use the CH_4 from sewage and wastewater treatment for on-site power and heat generation. The identified *scope 2* emissions for water utilities do not include the implementation of this technology. The *scope 3* emissions shown in Table 13.13 are entirely related to CH_4 and N_2O emissions and are projected to increase with the growing global population. The use of on-site CH_4 emissions with a global warming potential (GWP) of 25 (see Chap. 11) for electricity and heat generation would result in CO_2 (GWP = 1), instead of CH_4 emissions, and would therefore significantly reduce the *scope 3* emissions.

Therefore, we strongly recommend the utilization of on-site CH_4 emissions for energy generation.

13.5 *Scopes 1*, *2*, and *3*: *Buildings*

The *buildings* sector is further broken down into residential and commercial buildings and is based on calculations that include construction. The energy demand for construction is taken from the IEA World Energy Balances, and the demand includes the *construction of buildings* (ISIC Rev. 4, Div. 41), c*ivil engineering* (ISIC Rev. 4, Div. 42), and s*pecialized construction activities* (Div. 43), as documented in Chap. 4. It is assumed that 60% of the energy used for construction is for buildings. The energy demands calculated for residential and commercial buildings are based on a separate research project under the leadership of the Central European University (Chatterjee et al., 2021) and are documented in Chaps. 3 and 7.

Buildings—Scope 1 emissions are defined as direct energy-related CO_2 emissions associated with the construction of those buildings.

Buildings—Scope 2 emissions are indirect emissions from the residential and commercial use of electricity and energy for space heating. The commercial electricity demand is the remaining electricity that is not allocated elsewhere in the *service*, *industry*, *transport*, or *residential* sectors, to avoid double counting.

Buildings—Scope 3 emissions are the *scope 1* emissions of the *cement industry* to capture the embedded building emissions from construction materials.

There are no *scope 3* emissions calculated for construction to avoid double counting with the remaining *buildings* sector. Table 13.14 shows the global *scope 1*, *2*, and *3* emissions for all sub-sectors and for the overall *buildings* sector.

13.6 Scope *1*, *2*, and *3*: *Transport*

The *transport* sector includes all travel modes (aviation, shipping, and road transport), and passenger and freight transport have been calculated separately on the basis of current and projected passenger-kilometres (pkm) and tonne-kilometres (tkm), as documented in Chap. 8. The *transport* sector includes the manufacture of vehicles and other transport equipment, as defined in GICS group 2030 (see Chap. 4) and documented in Sect. 8.9.

Transport—Scope 1 emissions are defined as the direct energy-related CO_2 emissions associated with the manufacture of road and rail vehicles, planes, and ships.

Transport—Scope 2 emissions are the indirect emissions from electricity used for all from the electric drives in vehicles and the electricity required for hydrogen or synthetic fuel production. The emission factors for this electricity—as in all other *scope 2* emission calculations—are based on the OECM 1.5 °C pathway for power

Table 13.14 Global *scope 1*, *2*, and *3* emissions for *buildings*

Residential and commercial Buildings and construction	Units	2019	2025	2030	2035	2040	2050
Buildings—*scope 1*:	[$MtCO_2eq$/yr]	128	81	54	38	23	0
Compared with 2019	[%]	0%	−37%	−58%	−71%	−82%	−100%
Buildings—*scope 2*:	[$MtCO_2eq$/yr]	9685	6085	3039	1416	746	0
Compared with 2019	[%]	0%	−37%	−69%	−85%	−92%	−100%
Buildings—*scope 3*:	[$MtCO_2eq$/yr]	1,690	1959	1609	1388	1217	884
Compared with 2019	[%]	0%	16%	−5%	−18%	−28%	−48%
Buildings—sub-sectors							
Residential buildings—*scope 1*:	[$MtCO_2eq$/yr]	83	52	34	23	14	0
Compared with 2019	[%]	0%	−38%	−60%	−72%	−83%	−100%
Residential buildings—*scope 2*:	[$MtCO_2eq$/yr]	4578	2830	1343	605	320	0
Compared with 2019	[%]	0%	−38%	−71%	−87%	−93%	−100%
Residential buildings—*scope 3*:	[$MtCO_2eq$/yr]	1120	1023	860	739	623	428
Compared with 2019	[%]	0%	−9%	−23%	−34%	−44%	−62%
Commercial buildings—*scope 1*:	[$MtCO_2eq$/yr]	45	30	21	15	9	0
Compared with 2019	[%]	0%	−35%	−54%	−67%	−80%	−100%
Commercial buildings—*scope 2*:	[$MtCO_2eq$/yr]	5107	3255	1696	810	425	0
Compared to 2019	[%]	0%	−36%	−67%	−84%	−92%	−100%
Commercial buildings—*scope 3*:	[$MtCO_2eq$/yr]	611	586	528	478	421	305
Compared with 2019	[%]	0%	−4%	−13%	−22%	−31%	−50%
Construction of buildings—*scope 1*:	[$MtCO_2eq$/yr]	128	81	54	38	23	0
Compared with 2019	[%]	0%	−37%	−58%	−71%	−82%	−100%
Construction buildings—*scope 2*:	[$MtCO_2eq$/yr]	63	36	20	9	5	0
Compared with 2019	[%]	0%	−43%	−69%	−86%	−93%	−100%

generation, with an emission factor of 0.5 kg CO_2 per kilowatt-hour in 2019, which will decline to zero by 2050.

Transport—Scope 3 emissions are all the emissions caused by the utilization of all vehicles, planes, and ships for passenger and freight transport by end users. These emissions are not further allocated to other sectors in which vehicles are used to avoid double counting. Data are unavailable on how freight kilometres are distributed to, for example, the cement or steel industry.

Table 13.15 provides the global *scope 1*, *2*, and *3* emissions for the *transport* sector. Specific emissions from, for example, airports or single airline offices, as

Table 13.15 Global *scope* 1, 2, and 3 emissions for the transport sector

Total transport sector	Units	2019	2025	2030	2035	2040	2050
Aviation: transport —*scope 1*:	[$MtCO_2eq$/yr]	16	10	6	4	2	0
Compared with 2019	[%]	0	−39%	−62%	−76%	−86%	−100%
Aviation: transport—*scope 2*:	[$MtCO_2eq$/yr]	0.4	14.7	25.9	62.0	35.2	0.0
Compared with 2019	[%]	0	0%	0%	0%	0%	0%
Aviation: transport—*scope 3*:	[$MtCO_2eq$/yr]	936.1	1439.0	1193.3	459.4	96.0	0.0
Compared with 2019	[%]	0	54%	27%	−51%	−90%	−100%
Navigation: transport—*scope 1*:	[$MtCO_2eq$/yr]	23	14	9	6	3	0
Compared with 2019	[%]	0	−38%	−61%	−75%	−86%	−100%
Navigation: transport—*scope 2*:	[$MtCO_2eq$/yr]	1.7	20.4	144.9	56.4	68.9	0.0
Compared with 2019	[%]	0%	0%	0%	0%	0%	0%
Navigation: transport—*scope 3*:	[$MtCO_2eq$/yr]	793.8	3645.2	2601.8	2624.9	510.6	0.0
Compared with 2019	[%]	0%	359%	228%	231%	−36%	−100%
Road: transport—*scope 1*:	[$MtCO_2eq$/yr]	183	111	70	44	25	0
Compared with 2019	[%]	0	−39%	−62%	−76%	−86%	−100%
Road: transport—*scope 2*:	[$MtCO_2eq$/yr]	34.5	157.8	119.7	287.8	138.1	0.0
Compared with 2019	[%]	0%	0%	0%	0%	0%	0%
Road: transport—*scope 3*:	[$MtCO_2eq$/yr]	7223.4	6010.9	4769.2	1410.2	643.8	0.0
Compared with 2019	[%]	0%	−17%	−34%	−80%	−91%	−100%
	Units	2019	2025	2030	2035	2040	2050
Transport—*scope 1*:	[$MtCO_2eq$/yr]	223	136	85	53	30	0
Compared with 2019	[%]	0	−38%	−61%	−75%	−86%	−100%
Transport—*scope 2*:	[$MtCO_2eq$/yr]	36.6	192.8	290.4	406.2	242.2	0.0
Compared with 2019	[%]	0	445%	721%	1049%	585%	−100%
Transport—*scope 3*:	[$MtCO_2eq$/yr]	8953.2	11095.2	8564.3	4494.5	1250.5	0.0
Compared with 2019	[%]	0	27%	−2%	−49%	−86%	−100%

defined under GICS 2030 5010, cannot be assessed on a global scale because of lack of data. Furthermore, these emissions are allocated under ‘commercial buildings’. *Scope 3* emissions are the ‘classic’ emissions when consumers drive a car or use a plane. The OECM deliberately includes electricity emissions from, for example, electric cars under *scope 2* emissions, because car manufacturers today include the charging infrastructure in their value chain and are therefore responsible for it.

13.7 *Scopes 1*, *2*, and *3*: Global Summary

A global assessment of *scopes 1*, *2*, and *3* for the whole *industry* sector is a new research area, and changes had to be made to the method for determining those emissions, which was originally developed by the World Resource Institute (WRI), as documented in Chap. 4.

The OECM methodology differs from the original concept primarily insofar as the interactions between industries and/or other services are kept separate. A primary class is defined for the primary energy industry, a secondary class for the supply utilities, and an end-use class for all the economic activities that consume energy from the primary- or secondary-class companies, to avoid double counting. All the emissions by defined industry categories (e.g. with GICS) are also separated, streamlining the accounting and reporting systems. The volume of data required is reduced, and reporting is considerably simplified with the OECM methodology.

Figure 13.4 shows the global energy-related *scope 1*, *2*, and *3* CO_2 emissions in 2019 as a Sanky flow chart. The primary energy emissions are on the left and the end-use-related emissions are on the right. The carbon budgets remain constant, from production to end use, apart from losses and statistical differences. A simplified description is that all *scope 1* emissions are on the left, with the primary energy industry as the main emitter, and all *scope 3* emissions are on the right, with the consumers of all forms of energy and for all purposes as the main emitters. In the secondary energy industry, utilities are the link between the demand of end users

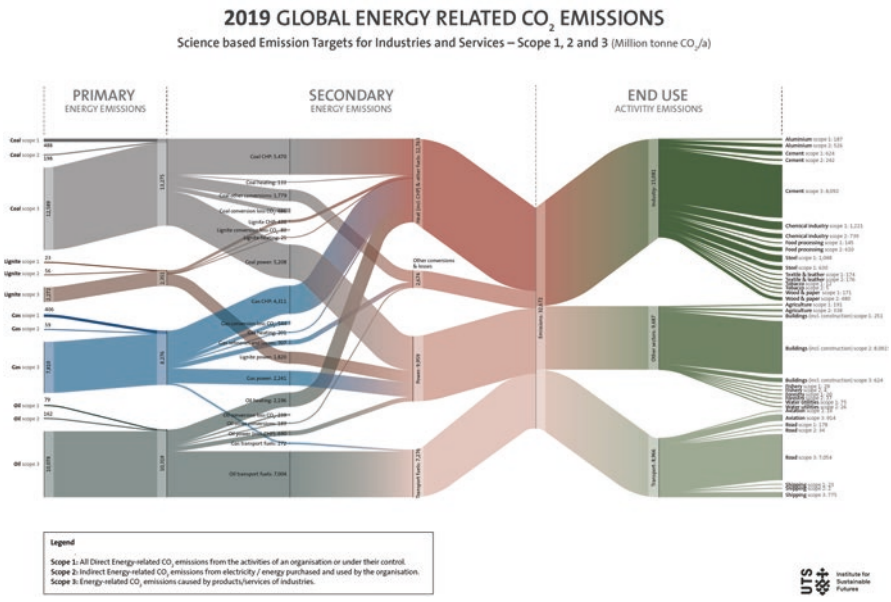

Fig. 13.4 Global *scope 1*, *2*, and *3* energy-related CO_2 emissions in 2019

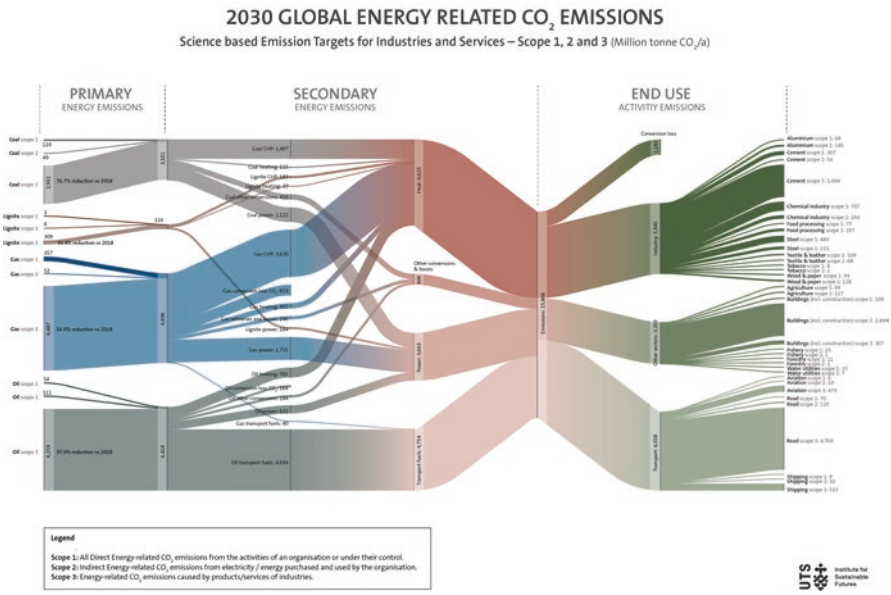

Fig. 13.5 Global *scope 1*, *2*, and *3* energy-related CO_2 emissions in 2030 under the OECM 1.5 °C pathway

and the supply by the primary energy industry. The figure also shows the complex interconnections between demand and supply.

Figure 13.5 shows the energy-related CO_2 emissions and the interconnections between various sectors and consumers in 2030 under the global 1.5 °C pathway.

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