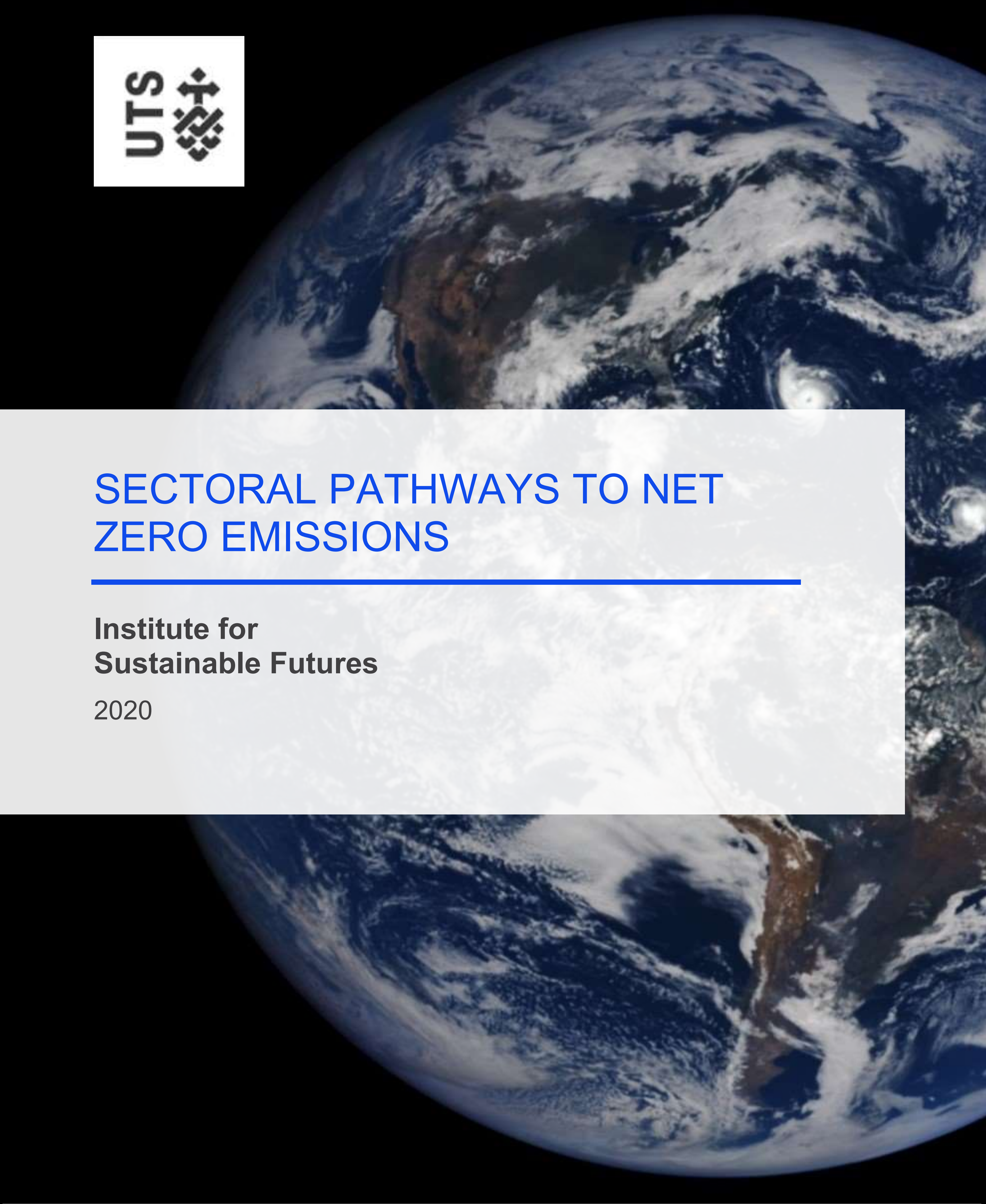

SECTORAL PATHWAYS TO NET ZERO EMISSIONS

Institute for
Sustainable Futures

2020

Prepared for U.N.-Convened Net Zero Asset Owner Alliance

isf.uts.edu.au

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About the authors

The Institute for Sustainable Futures (ISF) is an interdisciplinary research and consulting organisation at the University of Technology Sydney. ISF has been setting global benchmarks since 1997 in helping governments, organisations, businesses, and communities to achieve change to support sustainable futures.

ISF acknowledges and respects the Aboriginal and Torres Strait Islander custodians of Australia and the Gadigal people, custodians of the land upon which the UTS City Campus now stands. We continue to value the generations of knowledge that Aboriginal and Torres Strait Islander peoples embed within our university, and we pay our respect to their elders past, present and emerging.

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Foreword from the Climate Champions

In the last year the world has seen an unprecedented acceleration towards a net-zero economy. Governments, companies, financial institutions, cities and regions are joining forces and 'racing to zero', aiming to entirely transform the energy system - in just three decades.

To date, more than half of the world's GDP, or almost USD 46 trillion, is presently estimated to be under or currently considering a net-zero by 2050 commitment. While non-state actors covering more than 25% of global CO2 emissions have made net-zero commitments under the *Race to Zero*. The number is growing, critical mass is within sight.

To enable this rapid transition, all actors need clear-eyed intelligence on how the transition might be achieved. Technologies need to be research and developed, policies need to be adjusted, business operations need to evolve, and exponential rates of change must be realised. How an entire global economy transforms will need to be understood from a variety of vantage points and may take myriad trajectories, but all must end in one destination - net-zero by 2050.

These 'roadmaps' or 'sector pathways' provide information on the routes we can travel as a global community. The knowledge and rigor of the scientific community, the strategic direction of governments and the know-how of industry all provide data points on this global map.

In November 2020, the United Nations Framework Convention on Climate (UNFCCC) Marrakech Partnership for Global Climate Action, that works to accelerate the implementation of the Paris Agreement by enabling collaboration between governments and the cities, regions, businesses and investors, launched the "Climate Action Pathways" which outline sectoral visions for 1.5-degree climate-resilient world. These Pathways provide an overview of the transformational actions and milestones needed for systems transformations within sectors. They are supported and enhanced by the growing body of sectoral decarbonization pathways developed by the scientific community and others built from industry intelligence. One such effort, a collaboration between the scientific community and shared with investors, is contained within this report.

This report represents a detailed assessment of key high emitting sectors and their potential for decarbonization in the near and longer term. In what may be the first ever translation of a global energy systems model into financial sector classifications, this novel approach is framed from the perspective of an international investor, classifying sectors as one might find in a portfolio. Such an approach allows investors and real economy actors to engage with a common map and work together towards change.

We need to make use of all the intelligence at our disposal to move this critical mass of actors towards the finish line.

Nigel Topping **Gonzalo Muñoz**

High Level Climate Action Champions

Reviewers

A panel of experts reviewed the methodology, assumptions, data input, and results of this study. The panel included the following members:

Name	Official Title	Official Name of Institution
Faustine De La Salle	Director	Energy Transition Commission
Aparajit Pandey	Associate	Energy Transition Commission
Laetitia de Villepin	Associate	Energy Transition Commission
Johan Falk	Senior Innovation Fellow	Exponential Roadmap
Magnus Jiborn	Researcher and Consultant	Exponential Roadmap
Owen Gaffney	Analyst and Author	Exponential Roadmap
Jérôme Hilaire	Scientist	Potsdam Institute for Climate Impact Research

Additional input and review were provided by the following experts:

Name	Official Title	Official Name of Institution
Jean Francois Coppenolle	Head of Credit and Sustainability Risk	Aviva
Marcus Bruns	Nordic Head of Sustainability	Storebrand
Thiviya Rajendran	Actuarial Manager	Aviva
Thomas Liesch	Climate Lead Integration	Allianz
David Knewitz	Senior Manager Sustainable Finance	WWF Germany
Andres Chang	Senior Technical Officer, Science Based Targets	CDP
Fernando Angel	Senior Technical Manager	WWF Mexico
Nate Aden	Senior Associate	World Resources Institute
Estefania Marchan	Senior Associate	Rocky Mountain Institute
James Mitchell	Climate Finance Practitioner	Rocky Mountain Institute
Nathan Fabian	Chief Responsible Investment Officer	UN-backed Principles for Responsible Investment
Elke Pfeiffer	Senior Specialist	UN-backed Principles for Responsible Investment
Jesica Andrews	Senior Project Manager	United Nations Environment Programme Finance Initiative

Other experts and asset owners had opportunities to provide input during review meetings, as detailed in the section below on the peer review process.

Contents

Preface

The *IPCC Special Report on the impacts of global warming of 1.5°C* highlights the critical importance of keeping global warming below 1.5°C to keep within the safe operating boundaries of the planet and avoid catastrophic impacts of climate change.

In support of 1.5°C ambition, the Paris Climate Agreement aims to hold global warming to well below 2°C and to "pursue efforts" to limit it to 1.5°C. Countries have also agreed the following under Article 2.1.c of the Paris Agreement:

> *Paris Agreement - Article 2*
>
> *1. This Agreement, in enhancing the implementation of the Convention, including its objective, aims to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty, including by:*
> *..*
> *(c) Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development.*

Representing to date more than USD 5 trillion in assets under management, the United Nations-convened Net Zero Asset Owner Alliance (Alliance) is an international group of over 30 institutional investors who have committed to transition their investment portfolios to net zero GHG emissions by 2050. The Alliance demonstrates united investor action to align portfolios with a 1.5°C scenario, addressing Article 2.1.c, especially by emphasizing GHG emission reductions outcomes in real-world economy. Members of the Alliance commit to the following at the highest levels of their organisations:

> *"The members of the Alliance commit to transitioning their investment portfolios to net-zero GHG emissions by 2050 consistent with a maximum temperature rise of 1.5°C above pre-industrial temperatures, taking into account the best available scientific knowledge including the findings of the IPCC, and regularly reporting on progress, including establishing intermediate targets every five years in line with Paris Agreement Article 4.9.*
> *In order to enable members to meet their fiduciary duty to manage risks and achieve target returns, this Commitment must be embedded in a holistic ESG approach, incorporating but not limited to, climate change, and must emphasize GHG emissions reduction outcomes in the real economy.*
> *Members will seek to reach this Commitment, especially through advocating for, and engaging on, corporate and industry action, as well as public policies, for a low-carbon transition of economic sectors in line with science and under consideration of associated social impacts.*
> *This Commitment is made in the expectation that governments will follow through on their own commitments to ensure the objectives of the Paris Agreement are met."*

The Alliance must therefore pursue active dialogue with investee companies to encourage them to adopt low-carbon business models and achieve Alliance member's own net zero commitments. To support productive and informed dialogue, the Alliance needs comprehensive information on the current situation within each relevant sector, the potential realistic pathways to decarbonize and the required pathway to get to net zero by 2050.

The Alliance noted a dearth of sectoral pathways available at 1.5°C necessary to support its 5-year intermediary target setting commitment described in the initial Alliance 2025 Target Setting Protocol. Therefore, in the first quarter of 2020, the Alliance set out to identify possible models which could describe in decision-useful terms for financial actors' sectoral pathways.

The Alliance reviewed work and scenarios by IEA, NGFS, Transition Pathway Initiative, CICERO, Energy Transitions Commission, Potsdam Institute for Climate Impact Research, and IIASA database[1] for the appropriate sector granularity under a 1.5°C model. The One Earth Climate Model (OECM) emerged as the most suitable model as determined by an interdisciplinary group of reviewers on behalf of the Alliance, due to the fact that the OECM model:

- is a 1.5°C model readily translatable to granular sector pathways
- uses assumptions suited to the needs of the Alliance
- is able to report on absolute carbon emission and carbon / energy intensity reduction needs in 5-year steps
- is able to report on financial sectors as usually used by investors (GICs, BICs, NACE)
- is a not an overshoot scenario, meaning it does not rely on high levels of unproven BECCS/CCUS

The Alliance then commissioned the Institute for Sustainable Futures (ISF) at the University of Technology Sydney (UTS) to apply their model to sectors as defined by sector classification schemes commonly used in finance (GICs, BICs, and NACE). The aim was to develop sectoral pathways to net zero by 2050 with carbon emissions (scope 1-2)[2] and energy intensity and carbon intensity (scope 1-2) milestones in 5-year intervals for agreed high emitting sectors. The Alliance aims to continue its pursuit of sector pathways, expanding the number of sectors and regions covered. Once a sufficient number of sectors are included in the pathway coverage from any one model, it is possible to account for Scope 3 in full. It should be noted however that scope 1 or 2 of the some of the sectors below would constitute the scope 3 of other sectors highlighted below (for example, transport constitutes a high portion of oil and gas' scope 3). Therefore, expansion and growth of sector pathways is critical to guide the Alliance in accomplishing its dual goals of engaging to promote emission reduction in the real economy and achieving portfolio emission reductions.

The work was based on a previously concluded interdisciplinary project (running from 2017 to 2019) that had developed practical pathways to achieve the Paris climate goals based on a detailed bottom-up examination of the decarbonization potential of the energy sector, in order to avoid reliance on net negative emissions later. The study focuses on anthropogenic emission, specifically energy related emissions, because energy-related carbon dioxide (CO2) emissions are the main driver of climate change. A group of reviewers as listed in the table on page 3 oversaw the application of the OECM model to financial sector allocations and reviewed the final results and methodology.

The resulting modelling effort is described in this report, and the accompanying data sheets are made available to the members of the Alliance as well as to investee companies and the general public. This report describes one such set of sector pathways derived from consistent assumptions underpinning the One Earth Climate Model. The OECM assumptions and resulting sector pathways represent one such option for transition to a net-zero future. Investors may use the set of sector pathways described herein to support engagement with investee companies, gauge individual corporate pathways against this benchmark and as a guide to establishing their sector targets or rely on current or future sector pathways as they develop. The Alliance welcomes the contribution of OECM to scientific work and calls on climate and energy modelers, including the IEA, to continue to advance 1.5C aligned sectoral pathways to inform the energy transition.

[1] Since the review in the first quarter of 2020 the Alliance has also noted and welcomed the introduction of the UNFCCC Climate Action Pathways Climate Action Pathways | UNFCCC, the 1.5C sectoral pathways contained in the Cambridge E3ME model, and the IEA NZE2050 scenario.
[2] Phase I of OECM work covered Alliance priority sectors only. Without full sectoral coverage it is not possible to include Scope 3.

Glossary

BECCS	Bioenergy with carbon capture and storage
BICS	The Bloomberg Industry Classification System, a proprietary hierarchical classification system that classifies the general business activities of firms
CAPEX	Capital expenditures
CCS	Carbon capture and storage
CO_2	Carbon dioxide
CO_4	Methane, greenhouse gas (GHG) with high global warming potential[3]
CSP	Concentrated solar power
CHP	Combined heat and power generation (also called '*co-generation or 'cogen*')
Energy-related emissions	Emissions caused by the burning of fossil fuels for electricity and heat, electricity-related emissions, and energy losses during transport (e.g. gas leakages)
GICS	Global Industry Classification Standard
GHG	Greenhouse gases
GWP	Global warming potential
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
LAZARD	An institute based in the USA—publishes Levelized Cost of Energy Analysis
Lignite	Brown coal
Energy model	Computer program to calculate energy-system interactions
NACE	Financial classification system
OECM	One Earth Climate Model
OECD North America	Canada, USA, and Mexico
OECD Europe	Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Israel, Luxembourg, the Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, and the United Kingdom
PV	Photovoltaic
pkm	Person kilometre
RE	Renewable energy
REN21	Renewable Energy Policy Network for the 21st Century
Scenario	Coherent set of assumptions about a possible system
tkm	ton kilometre
WEO	The World Energy Outlook (WEO), published annually by the IEA

[3] GHG Protocol (2016). Global Warming Potential Values. https://www.ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf

Executive Summary

The U.N.-convened Net Zero Asset Owners Alliance (*the Alliance*) is a Principles for Responsible Investment (PRI) and UNEP FI-supported initiative. The members of the Alliance have committed to:

i) transitioning their investment portfolios to net zero GHG emissions by 2050, consistent with a maximum temperature rise of 1.5°C above pre-industrial levels;

ii) establishing intermediate targets every 5 years; and

iii) regularly reporting on progress.

The first set of intermediate targets for the year 2025 is based on the latest available research and proven available technologies.

The Alliance commissioned the Institute for Sustainable Futures (ISF) at the University of Technology Sydney (UTS) to utilise their pre-existing 1.5°C model to derive decarbonization pathways for five key high-emitting sectors, on a global level and for two regions (Europe and North America), to achieve net zero emissions by 2050, and to inform the development of sector-based targets for decarbonization. This report presents the results of that research, which it is hoped will provide initial insight to clarify investor expectations for decarbonization strategies for the sectors in which they invest. A more comprehensive analysis for further sectors and regions could be conducted, but due to time limitations, this analysis focuses on the sectors and regions that are currently the most relevant for the Alliance.

Identification of Priority Sectors

The sectors were determined by the Alliance in a two-step process.

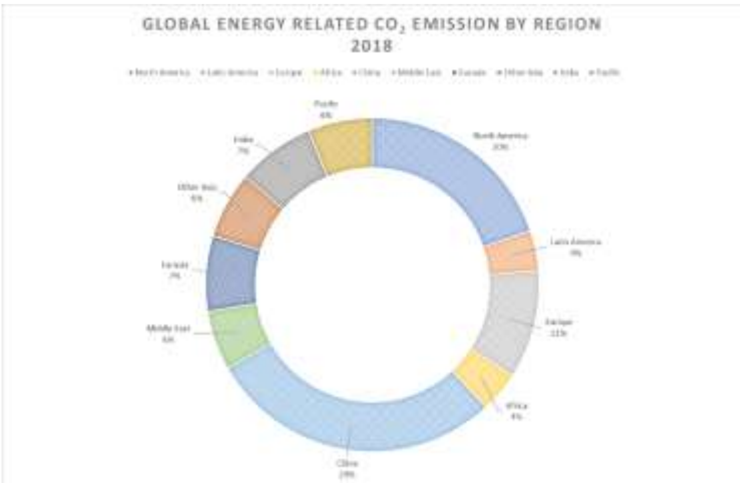
First, the Alliance surveyed the landscape of financial- and private-sector initiatives that addressed sector-specific decarbonization, including Science Based Targets, World Economic Forum Mission Possible, and the Rocky Mountain Institute.

Second, the Alliance determined the highest-emitting sectors as they relate to financial portfolios. The Alliance then took a decision to prioritise a subset of these sectors based on the expected impact of their engagement.

The priority sectors are:

- *Energy, including coal, oil, and gas;*
- *Utilities, with a focus on power and gas supply;*
- *Materials in specific steel and cement;*
- *Transport, including aviation, shipping, and heavy- and light-duty road travel.*

The Alliance seeks and expects to include more such ‘sector decarbonization pathways’ from a variety of models and welcomes the availability for inclusion and comparison of a growing range of sector pathways from multiple sources.



Methodology overview

This study builds on a previous 2-year (2017–2019) interdisciplinary project led by ISF that modelled sectoral and regional decarbonization pathways to achieve the Paris climate goals—to hold global warming to well below 2 °C and to "pursue efforts" to limit it to 1.5 °C. That project produced the One Earth Climate Model (OECM), a detailed bottom-up examination of the potential to decarbonize the energy sector. The study focused on the ways in which humans produce energy, because energy-related carbon dioxide (CO_2) emissions are the main driver of climate change.

The present study uses the OECM to provide sectoral pathways to net zero emissions by 2050. It provides carbon emissions milestones (*Scopes 1* and *2*) and energy intensity and carbon intensity milestones in 5-yearly intervals for five sectors—*Energy*, *Utilities*, *Steel*, *Cement*, and *Transport*; and for three regions—OECD Europe, OECD North America, and Global. This study provides updated baseline data, updated input data across sectors, and new in-depth research and modelling for two industry sectors—*Steel* and *Cement*.

Key results

Global Scopes 1 and 2 Emissions by financial sector in CO_2 equivalents (CO_2e)* (includes energy-related CO_2 and CH_4 emissions only)	**Scope 1**		**Scope 2**	
	2025 [MtCO_2e]	Required reduction 2019–2025 [%]	2025 [Mt CO_2 e]	Required reduction 2019–2025 [%]
Energy (Oil & Gas, Coal)	24,660	−30%	328	−33%
Utilities	12,772	−37%	193	−24%
Transport (Aviation)	269	−34%	39.5	(†) see below
Transport (Shipping)	144	−6%	21.2	(†) see below
Transport (Heavy-duty road/Freight)	1,912	−27%	127	(†) see below
Transport (Light-duty road/Passenger)	2,735	−32%	147	(†) see below
Steel	3,313	−22%	389	−37%
Cement	1,701	−13%	113	−50%

*CO_2e, CO_2 equivalents

The table shows the key results for all the financial sectors analysed. Provided are *Scope 1* and *Scope 2* emissions in CO_2 equivalents (CO_2e), which include energy-related CO_2 and CH_4 emissions. Based on the methodology used for Sector 1 and 2 emissions, the emissions cannot be summed. The calculation of *Scope 3* emissions was not possible because this would require an analysis of all sectors.

(†) The implementation of new hydrogen and synthetic fuels and increased electrification will increase the *Scope 2* emissions, while the *Scope 1* emissions will decrease. The share of electric vehicles in road transport and the use of hydrogen and synthetic fuels in aviation and shipping are currently almost zero on a global scale, so the increase in emissions from 2019 to 2025 cannot be provided as a percentage.

Cumulative energy-related CO_2 emissions [$GtCO_2$] Note (A): Energy statistics and financial sectoral breakdowns differ—emissions therefore do not add up	Global 2017–2030	Global 2017–2050	Sector Share of cumulative emissions in 2015–2050 [%]
Industry	71.7	94.2	24%
- Cement	8.3	11.4	3%
- Steel	21.9	27.2	7%
Transport	78.0	90.7	23%
- Aviation	4.1	4.9	1%
- Navigation	2.0	2.6	1%
- Road	67.2	77.7.6	20%
Power	113.2	137.5	35%
- Utilities	192.7	261.4	66%
- Energy Sector	345.0	421.3	106%
Buildings/Other Sectors	36.6	46.5	12%
Other Conversions	20.3	27.2	7%
Total Actual CO_2 Emissions	**320.0**	**396.0**	**100%**

Global weighted investments requirement by sector in [billion US$]

Total Energy, Gas, Oil, & Coal Sector -		2021–2025	2026–2030	2031–2035	2036–2040	2041–2045	2046–2050	2021–2050 [Average]
Scope 1: Energy Sector - weighted investment (energy)	[billion US$/a]	497	734	739	643	675	674	660
Scope 2: Energy Sector - weighted investment (power)	[billion US$/a]	22	22	10	4	2	1	10
Total Utilities Sector		2021–2025	2026–2030	2031–2035	2036–2040	2041–2045	2046–2050	2021–2050 [Average]
Scope 1: Utilities Sector - weighted investment (energy)	[billion US$/a]	355	542	571	532	524	506	505
Scope 2: Utilities Sector - weighted investment (power)	[billion US$/a]	7	8	4	1	1	0	4
Total Transport Sector		2021–2025	2026–2030	2031–2035	2036–2040	2041–2045	2046–2050	2021–2050 [Average]
Scope 1: Transport Sector - weighted investment (energy)	[billion US$/a]	9	16	20	27	27	21	20
Scope 2: Transport Sector - weighted investment (power)	[billion US$/a]	3	13	41	64	71	67	43
Total Materials–Steel		2021–2025	2026–2030	2031–2035	2036–2040	2041–2045	2046–2050	2021–2050 [Average]
Scope 1: Steel Sector - weighted investment (energy)	[billion US$/a]	133	213	231	222	255	282	223
Scope 2: Steel Sector - weighted investment (power)	[billion US$/a]	17	27	26	23	22	22	23
Total Materials–Cement		2021–2025	2026–2030	2031–2035	2036–2040	2041–2045	2046–2050	2021–2050 [Average]
Scope 1: Cement Sector - weighted investment (energy)	[billion US$/a]	48	73	74	69	77	80	70
Scope 2: Cement Sector - weighted investment (power)	[billion US$/a]	7	8	6	5	4	3	5

'Weighted investments' are calculated on the assumption that new power-generation capacities are added to supply electricity for industrial, business, or private consumers. The investment is divided equally between the energy suppliers and the industrial and private consumers. The *Steel* sector, for example, only covers one third of the investments required to install renewable energy capacities to supply carbon-free energy and electricity.

Key findings

This study achieves net zero CO_2 emissions based on a carbon budget to maintain the temperature increase below 1.5°C with 66% probability, corresponding to a global energy-related CO_2 emission budget of around 450 Gt[4]. The decarbonization of the financial sectors—*Energy*, *Utilities*, *Transport*, *Steel*, and *Cement*—to achieve the Paris Climate Agreement target is achievable based on current technologies. It is economically viable and cost competitive in the mid to long term.

- **Global and regional *Scope 1* and *Scope 2* emissions** must decrease between 2021 and 2025 by around 28% (± 5%), with some differences across sectors. The rapid and consequent decarbonization of the power sector is vital to achieve the 1.5°C pathway. Renewables-based power generation is the backbone of decarbonization for all the financial sectors analysed as fossil fuels are replaced by increased electrification.
- There is **no alternative to a phase-out of coal** power and coal-based heat generation in OECD Europe or OECD North America by 2030. The delayed phase-out of coal will put the Paris Climate Agreement beyond reach.
- The ***Energy* and *Utility* sectors play key roles in allowing all other industries to meet the 1.5°C target.** Whereas the *Steel* and *Cement* industries might be able to set up their own renewable energy and power supply or acquire power with power purchase agreements (PPA), the *Transport* sector is dependent on the *Energy* and *Utility* sectors to provide sufficient amounts of renewable electricity and bio- and synthetic fuels to supply airlines, shipping, and road vehicles for passenger and freight transport.
- The ***Energy* and *Utility* sectors must be the first movers** to decarbonize energy for their customers, to allow them to fulfil their emissions reduction targets.
- The key responsibility of the *Transport* sector is to move to electric vehicles, biofuels, and renewably produced synthetic fuels. Manufacturers of road vehicles, planes, and ships are required to phase-out fossil-fuel-based combustion engines over the next two decades.
- The **market share of electric road vehicles**—for passenger and freight transport—must increase from currently around 2% globally **to 30% by 2030**. The increased electricity demand must be met by renewably generated electricity.
- The rapid electrification of road transport has cross benefits for the *Energy* sector and especially for the *Utilities* sector, because increased numbers of electric vehicles will come with higher storage capacities for electricity and significant demand-side-management possibilities to integrate high shares of variable solar and wind generation. An increasing charging infrastructure is a pre-condition for mainstreaming electric vehicles (EV).
- The estimated investments in new power- and heat-generation capacities and in bio- and synthetic fuel production are calculated to be **US$60 trillion between 2021 and 2050** under the 1.5°C pathway—an average of US$2 trillion annually or around 1.5% of global GDP. This does not include investments in new energy infrastructure.
- **Fuel cost savings will more than compensate for the increased investment** required in renewable power and heat generation by all industries.
- Whereas early action in the *Energy*, *Utilities*, and *Transport* sectors is required and technologies are available to avoid process-related emissions, the *Steel* and *Cement* industries will require more time. In this analysis, we recommend that the renewable energy supply for the production processes of steel and cement be implemented first. The reduction in process emissions is calculated for the period after 2030 and requires a gradual change in production processes.
- The ***Steel* industry must move to electricity-based steel-making processes,** such as electric arc furnace (EAF) and hydrogen-based steel production, by 2035. The latter is currently still in its demonstration phase and must move into mainstream steel manufacturing within the next 15 years.
- Based on current technologies, the process emissions of the *Cement* industry cannot be reduced to zero. Therefore, nature-based carbon sinks—mainly forests—are factored in to compensate for the residual cement emissions in 2050. The authors of this analysis recommend that the *Cement* industry—among all other industries—support projects to expand nature-based solutions for negative emissions

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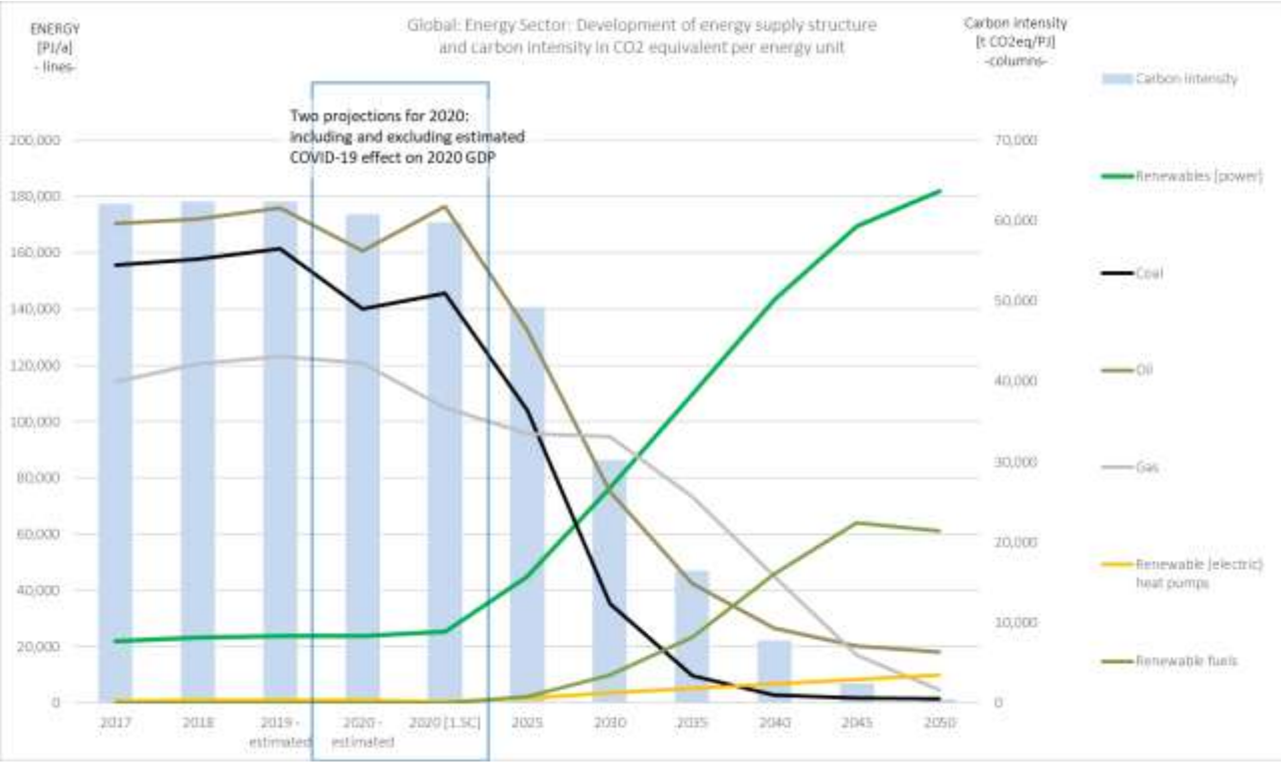
[4] Energy-related cumulative carbon budget in $GtCO_2$ between 2015 and 2050

(i.e., carbon sinks) on both global and regional levels. Furthermore, the replacement of steel and cement with alternative building materials is vital to reducing emissions.



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Under the 1.5°C pathway, 18% of those investments must go to solar photovoltaic and 28% to wind power (onshore and offshore). A significant share of solar and wind electricity is used in this pathway to produce synthetic fuels and hydrogen for industrial processes, heat, and fuels for aviation and shipping.

Between 2021 and 2025, approximately 2,500 GW solar photovoltaic, 1000 GW onshore wind, and 150 GW offshore wind power plants must be installed globally. Compared with the market volumes in 2019, solar photovoltaic must increase from 115 GW per year (GW/a) to 500 GW/a; onshore wind from 54 GW/a to 200 GW/a; and offshore wind from 6 GW/a to 30 GW/a.

[5] Note in the chart above the blue box contains two values; the estimated effect of COVID-19 lockdowns in 2020 and the 2020 value as seen originally in the 1.5C scenario. It should be interpreted as an increase.

Policy Development

The basic principles for the development of the 1.5°C pathway derive from the long-term experiences of the authorship team with scenario development, and have led to a 'seven-step logic'. This logic extends from the definition of the final state of the energy systems in the long-term future to the key drivers of the energy demand and the energy efficiency potentials; a technological analysis of supply and demand and the market development potential; and the specific policy measures required to implement a theoretical concept in the real market place.

The seven steps are:

1. Definition of the maximum carbon budget, milestones, and constraints to achieve the climate goal;
2. Definition of the renewable energy resource potentials for each sector;
3. Identification of the economic and societal drivers of demand;
4. Definition of the efficiency potentials and energy intensities for each sector;
5. Establishment of time lines and narratives for the technology implementation on the end-user and supply sides;
6. Estimation of the infrastructure needs, generation costs, and other effects;
7. Identification of the policies required and discussion of the policy options.

Policy recommendations

On the basis of the Paris Agreement goal of holding the increase in the average global temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, the following high-level policy recommendations form the basis of sector-specific policies:

- Introduction of carbon pricing;
- Phase-out of global fossil fuel subsidies;
- Implementation of reforestation policies.

Energy and *Utilities* Sectors

The *Energy* and *Utilities* sectors can form separate categories for the financial sector, but for the *Energy* sector, they are two sides of the same coin. The 1.5°C pathway does not allow the *Energy* sector to invest in any new oil or gas extraction projects or new coal-mining projects. Instead, security of supply will rely on new renewable energy projects, such as offshore wind and solar power projects, and renewable fuel production facilities. In this regard, the *Energy* sector must work closely with the *Utilities* sector, which covers the distribution and operation of renewable-energy-generating equipment.

Decarbonized electricity will replace the use of fossil fuels in the transport and heating sectors

The following high-level policy measures are required:

- Binding CO_2 emission targets towards a total phase-out of fossil fuels by 2050 in 5-year steps;
- Legally binding renewable energy targets for power, heating, and renewable fuels in 5-year steps;
- Gradual and reliable **discontinuation of direct and indirect subsidies for fossil energy investments;**
- Streamlined processes for the issue of construction permits for all renewable-energy-related projects (power, heat, and fuels);
- Guaranteed, mandatory access to the power grids for renewables, with priory dispatch for all renewable power generators;
- Changes in national taxation systems strictly towards renewable energy projects.

Transport

Road transport must move towards the resolute electrification of passenger and—within some limits—freight vehicles. Synthetic and biofuels will complement the transition away from fossil fuels. The *Transport* sector is primarily responsible for the design, manufacture, and operation of new vehicles. However, the fuel and electricity supply (and the charging and energy supply infrastructure required) is a joint task with the *Energy* and Utilities sectors and cannot be seen—or handled by policy makers—in isolation. However, the transport transition is not only a technical process. The aim should be to promote the use of less ecologically problematic transport modes, and public transport wherever possible.

Road transport

- Global phase-out of internal combustion engines for passenger vehicles by 2030;
- Incentivize of the construction of the infrastructure required for the operation of electric vehicles;
- Incentivize of public transport.

Aviation

- Implement a carbon tax;
- Complete the fuel switch from fossil fuels to renewables-based fuels between 2030 and 2040.

Shipping

- Implementation of carbon tax;
- Completion f the fuel switch from fossil fuels to renewables-based fuels between 2030 and 2040;
- Incentivize of a switch in the freight transport mode from roads to ships wherever possible.

Steel

The policy recommendations for the *Steel* industry are two-fold:

1. Support the **decarbonization** of the thermal and electrical energy supply until 2030 via **steel tax mechanisms**;
2. Support the expansion of new production processes to decarbonize steel manufacture towards
   - EAF processes;
   - Hydrogen-based steel production.

Research and development (R&D) grants are required, as well as product certification schemes, to financially encourage the changes towards new production lines. Steel-processing industries, such as the automotive and construction sectors, require binding purchase quotas for CO_2-neutral steel. CO_2-intensive steel should gradually be made more expensive with a special 'steel tax' to further promote the production of 'green steel'.

Cement

The reduction of process emissions requires increased efficiency at all steps of the cement production line. However, to date, no processes are available that produce emissions-free cement. Therefore, measures to establish nature-based carbon sinks should be supported to compensate for the residual process emissions in the *Cement* industry.

- Reduce emissions in cement and concrete production;
- Reduce demand by promoting design and different materials (e.g., wood);
- Improve material and construction efficiencies and standards;
- Re-use whole concrete structures;
- Design for disassembly and the re-use of elements.

Introduction and Scope of the study

This analysis aimed to develop sector-based targets for the U.N.-convened Net Zero Asset Owner Alliance. The key elements are:

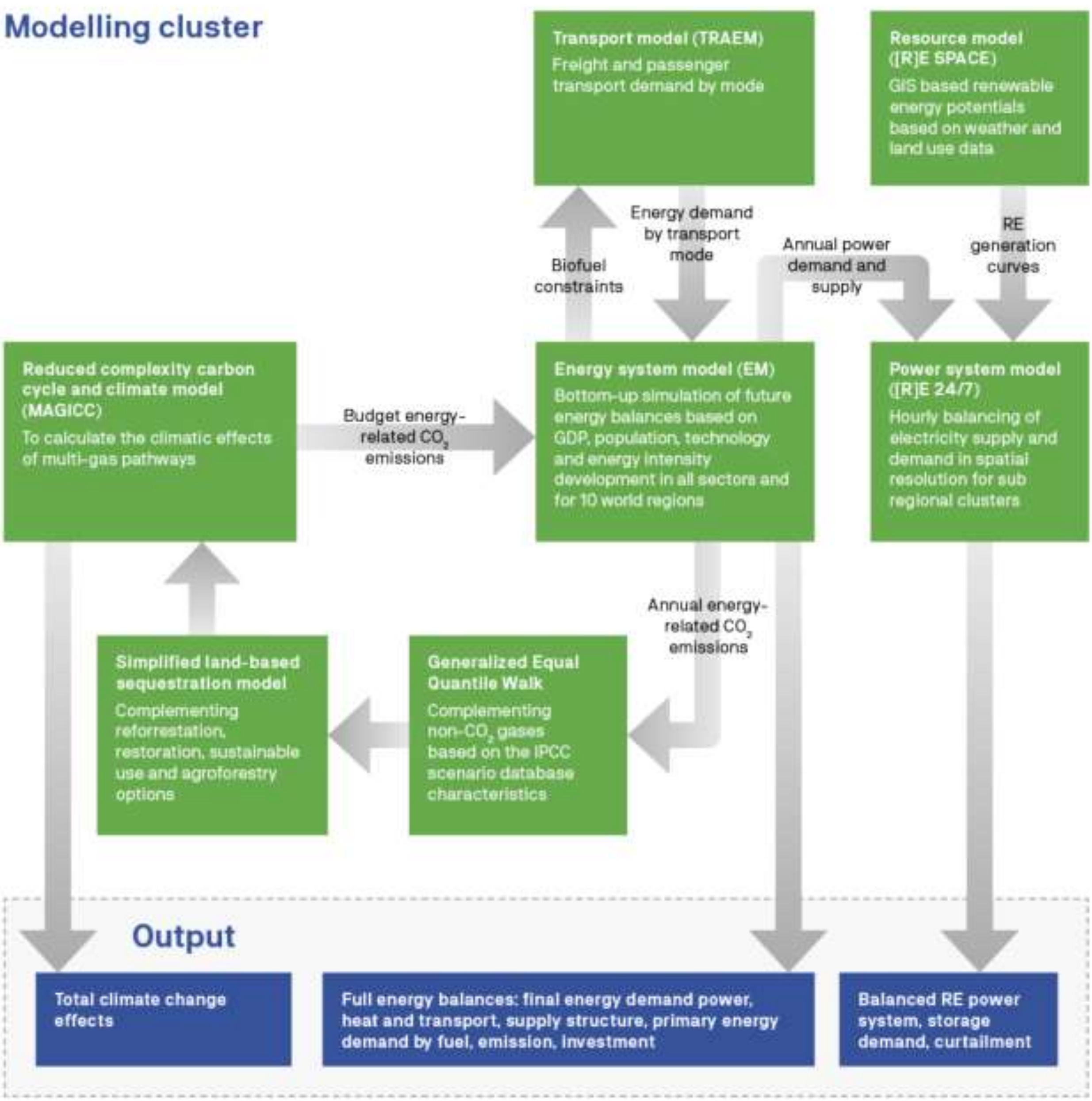
- Net zero emissions and 100% renewable energy by 2050;
- This is based on a carbon budget to maintain temperatures below 1.5°C with 66% probability, with a global energy-related CO_2 emission budget of around 450 Gt, accumulated between 2015 and 2050;
- Decarbonization pathways for five high-emitting economic sectors (below) are defined with reference to the three main industry classifications, NACE, BICS, and GICS (see Table 1), that are used by financial institutions for financial sector classification. The emissions pathways are provided for OECD North America, OECD Europe, and the world (Global):
    - *Energy* (Oil & Gas)
    - *Utilities*
    - *Steel*
    - *Cement*
    - *Transport*
- *Scope 1* and *Scope 2* emissions.
  Scope 3 emissions were beyond the scope of this research because they include all indirect emissions that are not included in *Scope 2* and that occur in the value chains of the reporting companies, including both upstream and downstream emissions. To calculate the *Scope 3* emissions would first require an analysis of all sectors.
- The research covers energy-related CO_2 and CH_4 and the process emissions for coal, oil, and natural gas, as well as for the steel and cement industries. Data are presented in CO_2 equivalents (for CO_2 and CH_4, but does not include any other GHG).
- The base year is actually 2018, plus 2019 and two estimates for 2020 (including and excluding possible COVID-19 effects).
- Total emissions and emission intensities, and total energy and energy intensities are given in 5-year intervals to 2050.
- CAPEX are given in US$ and in the additional energy-generation capacities required for the *Energy* sector.
- The technology mix is given every 5 years until 2050, with percentages of renewable energy.
- Efficiency requirements are given every 5 years until 2050.
- The research incorporates technologies currently available or under development, excluding bioenergy with carbon capture and storage (BECCS) and nuclear energy. The analysis excludes theoretical technologies and includes only technologies that have a demonstrated proof of concept.
- It includes nuclear plants currently under production but no future nuclear plants, given the prohibitive cost estimates and the availability of more economical alternatives.
- The analysis incorporates reforestation requirements but does not include the afforestation of lands that are not optimally suited for forestry.

Methodology

This study builds on the 2017–2019 study led by UTS and undertaken in partnership with the University of Melbourne, the German Aerospace Center (DLR), and the Graduate School of Energy Science, Kyoto University. The 2017–2019 study produced the One Earth Climate Model (OECM), which combines a set of existing models and was based on the scenario modelling used for the Energy [R]evolution scenario series developed by the authors of the present study between 2004 and 2015.

The OECM model developed decarbonization pathways for power, heat, and fuel supply in 5-year steps. Scenario building was complemented by a simulation with hourly resolution to calculate the electricity storage demand. Another significant improvement over previous studies was its combination with a climate model. The interaction between non-energy GHG pathways and a high-resolution integrated energy assessment model provided additional information on how to achieve the Paris goals. The diagram below illustrates the interactions between the models used in the OECM.

Figure 1 Interactions between the models used in the One Earth Climate Model (OECM)



Scenario narrative

This study presents one possible pathway to the achievement of net zero emissions by 2050 for the sectors and regions covered. It is important to acknowledge that there are other potential pathways. This study incorporates a set of core assumptions—different assumptions would result in many other different pathways and potentially different outcomes. A core assumption of the OECM project and this study is that CO_2 emissions must be reduced to zero. Otherwise, cumulative emissions and global warming will continue to increase.

There is no viable alternative to the swift and complete cessation of all fossil fuel use. Crucially, the OECM is not an overshoot scenario and therefore it avoids shifting the responsibility of reducing GHG emissions to the next generation. The OECM is a technical pathway, based on measures and options that are technically possible today, without taking into account political or societal barriers.

The assumptions of this study are set out in detail in this report. Below is a high-level overview of the core assumptions. The implementation of new renewable-energy technologies, energy efficiency measures, and the infrastructure required to connect the supply and demand sides are assumed to be non-linear and take the socio-economic situation of the analysed region into account.

Global socio-economic developments until 2050—assumptions for the 1.5°C scenario

- GDP projections for OECD North America, OECD Europe and globally are based on World Bank projections, with an average annual growth of 3.2% over the period 2015–2050.
- The impact of the COVID-19 pandemic in 2020 has been taken into account—two different GDP developments have been calculated: one growth case and a GDP decline, as projected by the OECD.
- Population growth projections are based on UN projections: the global average annual growth over the modelling period is 0.8%, increasing from 7.7 billion in 2020 to 9.7 billion in 2050. The population of OECD North America is estimated to grow from 0.5 billion to 0.6 billion (2050); and OECD Europe from 0.58 billion to 0.6 billion.

High-level assumptions across scenarios

- The methodology of the OECM model is consistent with the methodology of the models used for the IPCC Assessment Report (AR). The OECM model has been pre-reviewed and parts of it have been used for AR5 and currently AR6.
- The assumptions for the OECM 1.5°C pathway are consistent with the 1.5°C (66% likelihood) carbon budget of 450 $GtCO_2$ (2015–2050)) identified by the IPCC.
- Cost assumptions: fuel costs are based on IEA projections; current technology costs are based on actual market prices (LAZARD, IRENA, and REN21); projections of technology costs are based on learning curves.
- The OECM scenarios have higher technology resolution than most other IPCC/AR scenarios.
- The OECM is NOT an overshoot scenario that moves the responsibility for GHG emissions to the next generation.
- Large-scale reforestation is assumed, particularly in the sub-tropics and tropics; the sustainable use of existing forests, i.e., reduced logging; median assumed sequestration pathways of 151.9 GtCO2 approximately equivalent to all historical land-use-related CO_2 emissions, indicating substantial challenges with sequestration pathways.

High-level technical assumptions across scenarios

- Decarbonization of the entire global energy sector by 2050.
- BECCS and nuclear energy are excluded or phased-out due to significant uncertainties about the techno-economic, societal, and/or environmental risks associated with these technologies.
- High-energy efficiency across all sectors.
- New renewable power generation—mainly new solar and wind—will contribute around 65% of the total *electricity* generated by 2050.
- Renewables will provide 100% of the total *heat* demand in 2050.
- Sustainable use of biomass will partly substitute for fossil fuels in all energy sectors—limited to an annual global energy potential of less than 100 EJ per year.
- Accelerated uptake of renewable energies—100% renewable *primary* energy supply by 2050.
- Significantly higher global electricity demand due to: the electrification of the transport and heating sectors; a moderate increase in the electricity demand from "classical" electrical devices; and the generation of hydrogen (for transport and high-temperature process heat) and the manufacture of synthetic fuels for transport.
- Transport: electrification, the use of biofuels and synthetically produced fuels, modal shifts. The general limitation of further pkm and tkm growth in the OECD countries; internal combustion engines will be almost entirely phased out by 2050; modal shifts from domestic aviation to rail and from road to rail; hydrogen used as a complementary renewable option in the transport sector.[6]
- Process emissions from the steel and cement industries will be reduced but not entirely phased-out by 2050 and will be offset by negative emissions from reforestation.

Updates and new research undertaken for this study

This study focuses on a subset of three regions covered by the OECM model, as outlined in the 'Scope of the study' section. Whereas the OECM model covered a broad 'industry' sector, this study provides a comprehensive analysis of the steel and cement industry sub-sectors. New research has been undertaken in this study to identify and understand the potential decarbonization pathways for these sectors. This includes research on production, energy use, and efficiency as well as the options for the decarbonization of process emissions. The *Energy*, *Utilities*, and *Transport* sectors in this study have also been aligned with industry classifications that are more relevant for asset owners.

In this study, the baseline has been updated from 2017 to 2018 (the most-recent IEA data available) and baselines have been estimated for 2019 and 2020 to allow the easier comparison of baselines for the targets set by asset owners.

All the data used in this study have been updated to incorporate the most recently available data sources.

Peer review process

An integral element of this study is the peer review process. The Alliance engaged a group of partner organisations to provide a review of the methodology, assumptions, data input, and results. Throughout the course of the study, the review group met seven times to discuss its core elements. The reviewers provided further detailed comments and input between meetings. A full list of the reviewers is provided in Appendix C. Asset owners were also invited to review and provide input through meetings and via email.

[6] This analysis assumes a maximum amount of sustainable biofuels of 80 EJ per year. Sustainable fuels are made out of agricultural residuals and other bio waste – it does not include large bio crop plantations – therefore the biofuels are carbon neutral.

Limitations

The 1.5°C scenario may seem more difficult than scenarios with similarly ambitious assumptions that were made 10 to even 20 years ago. However, the opportunities to respond to climate change have been largely wasted in the last two decades, and all transition processes have faced huge obstacles in the past, arising from the inertia and conflicting aims of societies, governments, and most relevant stakeholders. Too often, more attention has been paid to doubters than to facts. Therefore, the scenarios also show that the longer governments wait, the more difficult it will be to prevent severe climate damage and the greater will be the technical and economic challenges encountered in the transformation of the energy system.

The coarse regional resolution of such global scenarios does not allow sufficient account to be taken of sub-regional differences in energy demand and the characteristic and favourable possibilities of sustainable supply. However, it can provide rather fundamental insight into the basic technical and structural possibilities and requirements of a target-oriented pathway. Our results clearly reveal and quantitatively describe that the coming years will be most critical for a successful energy transition because for both parts of the energy transition (efficiency improvement/demand reduction and the implementation of new technologies), huge investments and fundamental changes in producing, distributing, and consuming energy will be required. Such transformation processes must be analysed and planned carefully under the complex economic and societal framework conditions of each region, down to the country, sub-country, and community levels. Such analyses can then form the basis for further investigation of the economic implications of these pathways.

Another limitation of this approach is that the consistency of the economic, technical, and market assumptions made is probably limited. Carbon, fuel, and technology costs are assumed independently of the assumptions regarding overall economic development and the final energy demand. It also remains unclear to what extent the energy transition will change the overall material demands and activities of the manufacturing industry. Furthermore, the economic framework conditions and market mechanisms that will be necessary for rapid decarbonization remain largely unclear, as is whether the current market mechanisms are capable of supporting the fundamental paradigm shifts in this target-oriented energy transition.

Sectoral pathways for the *Cement* and *Steel* industries are based on literature research and input during the Peer review process. Global and regional market volumes for the future *Steel* and *Cement* industries are unclear, but will have significant impacts on the calculated process emissions for decades to come. New production processes for the steel industry and possible alternatives to cement have not been studied in depth because it they were beyond the scope of this project.

A number of limitations are associated with the non-energy-related emission trajectories derived. Possibly the most important opportunity for future research will involve a more fine-grained look at land-use-based sequestration options in various countries and biomes. This study assumed only rather coarse approximations of the available land areas, sequestration rates, and cumulative changes in land carbon stocks to estimate the potential and time trajectories for reforestation, forest restoration, agroforestry, and other land-based sequestration options.

In terms of the non-CO_2 emission trajectories, this study relied heavily on the collective wisdom embodied within a large set of literature-reported scenarios. Although we have designed probably the most advanced method yet to distil that knowledge into emission trajectories that are consistent with our energy-related pathways, this meta-analytical approach is not without its limitations. In particular, a bottom-up energy-system and land-use/agricultural model must be able to estimate methane and N_2O emissions from various agricultural activities in a more coherent way, which could provide results on a regional level. Such regional and sector-specific information would, in turn, allow the examination of various mitigation options for non-CO_2 emissions. This bottom-up modelling capacity is missing from our meta-analytical approach.

Further Research Needs

The statistical databases on the transport activities and fleet and powertrain shares for several world regions are limited, and in those cases, projections, conclusions by analogy, and estimates were required in our modelling. Therefore, further studies should focus on improving these databases and specify the modelling in more detail. This research could also include case studies of countries instead of regions, to better address spatial particularities in the transport models. Detailed investigations of mode shift potentials, based on the constraints on infrastructure capacities, were considered to some extent, but deserve more in-depth modelling in future works. Further research is required to refine the coupling of renewable energy potentials, transport infrastructure upgrades, and the expansion of on-board energy storage usage.

Overview of Financial Sector Classification

In this analysis, we developed sector-based targets with carbon emissions, energy intensity, and carbon intensities. The sector specifications for the financial sector vary. Table 1 shows the three main categorisation systems: NACE, BICS–Bloomberg, and GICS–S&P and MSCI.

Table 1: Financial classification systems – NACE, BICS, and GICS

Financial Sector	NACE	BICS– Bloomberg	GICS– S&P and MSCI
Energy–Oil & Gas	B - Mining and quarrying B5 - Mining of coal and lignite B6 - Extraction of crude petroleum and natural gas	1. Energy 1.1 Coal 1.2 Oil & Gas 1.3 Renewables	1010 Energy 101020 Oil, Gas & Consumable Fuels 10102010 Integrated Oil & Gas 10102020 Oil & Gas Exploration & Production 10102050 Coal & Consumable Fuels
Utilities Electricity Generation & Distribution Gas distribution	D - Electricity, gas, steam, and air-conditioning supply D35.1 - Electric power generation, transmission, and distribution	2. Utilities 2.1 Electric 2.1.1 Distribution 2.1.2 Generation 2.1.3 Integrated 2.2 Gas 2.2.1 Distribution	5510 Utilities 551010 Electric Utilities 551020 Gas Utilities 551050 Independent Power and Renewable Electricity Producers
Transport Airlines Light and Heavy Road Transport Shipping	H - Transporting and storage H50 - Water transport H51 - Air transport	4. Consumer, Cyclical 4.1 Airlines 4.2 Auto Manufacturers 4.2.1 Auto–Cars/Light Trucks 4.2.2 Auto–Medium- & Heavy-Duty Trucks	2030 Transportation 203010 Air Freight & Logistics 203020 Airlines 203030 Marine (Commercial Shipping) 25102010 Automobile Manufacturers
	C - Manufacturing C29.1 - Manufacture of motor vehicles C30.1 - Building of ships and boats C30.3 - Manufacture of air and spacecraft	4.3 Industrial 4.3.1 Shipbuilding 4.3.2 Transport–Marine	203050 Transportation Infrastructure 20305030 Marine Ports & Services
Materials–Steel	C - Manufacturing C24.1 - Manufacture of basic iron, steel, and ferro-alloys C24.2 - Manufacture of tubes, pipes, hollow profiles and related fittings of steel C24.3 - Manufacture of other products of the first processing of steel	3. Basic Materials 3.1 Iron/Steel 3.1.1 Metal–Iron 3.1.2 Steel Producers	15104050 Steel
Materials–Cement	C - Manufacturing C23.5.1 - Manufacture of cement	5. Industrial 5.1 Building Materials 5.2 Building Products-Cement/Aggregated	1510 Materials 15102010 Construction Materials (Cement only)

To reflect all three finance categorisation systems in this analysis, we developed a categorisation system for the Alliance, which is used to calculate and present the results throughout this research (Table 2).

Table 2: Financial sectors used in the Alliance analysis

Financial Sector	NZAOA Sector	Definition	Scope—Analysis
Energy–Oil & Gas/Coal > Primary Energy Sector	> Extraction of oil > Extraction of gas > Mining of coal > Mining of lignite	The **Oil, Gas, Coal and Renewables** Sector covers the production of primary energy up to the transfer point, for transport via pipeline, power plant, or power grid: > oil > gas > coal/lignite > all renewable energies	Scope 1: Direct emissions related to extraction, mining, and burning of fossils fuels. This analysis only covers the two main GHGs, CO_2 and CH_4. For CO_2, the potential emissions content of the produced primary energy is provided in order to take into account that the sector does not use energy itself, but extracts, mines, and/or produces the energy to sell to customers. Scope 2: Indirect emissions from electricity used for the production of the core product of the sector. Calculation based on statistical information ('own consumption') of IEA Advanced Energy Balances.
The **Energy–Oil & Gas/Coal Sector** ('primary energy') covers all activities required for the primary energy production of fuel and electricity			
Utilities > Energy Service Sector: Electric Generation & Distribution Gas Distribution	Operation & Maintenance of > Power plants/co-generation plants > Power grids (transmission to distribution) > Energy service infrastructure, e.g., smart grid and storage > pipeline for gas transport	The **Utilities** Sector covers energy transport, the operation and maintenance of power/heat-generating equipment, and the transport infrastructure (grid- and pipe-bound infrastructure): Utilities are energy services and link production with the costumer	Scope 1: Direct emissions related to the generation and transmission of electricity and the distribution of fossil and/or renewable gas. This analysis only covers the two main GHGs, CO_2 and CH_4. For CO_2, the potential emissions content of the produced electricity/transported gases is provided in order to take into account that the sector does not use energy itself, but provides energy services for energy consumers. Scope 2: Indirect emissions from electricity used for the production of the core product of the sector. Calculation based on statistical information for 'self-consumption power plants and energy infrastructure', of IEA Advanced Energy Balances.
The **Utilities Sector** ('energy services') connects electricity and fuel gas production with the consumer.			
Transport > Transport Equipment & Services: Civil Aviation Road Transport Shipping	Civil Aviation > Passenger planes > Airline services/aeroplane operation Shipping > Ships > Shipping line services/ship operation Road Transport > Light- and heavy-duty vehicles > Car services/car operation > Truck/bus services, truck/bus operation	The **Transport** Sector cover aviation, shipping, and road transport. For each transport mode, there are two main sub-sectors: 1. Design, manufacture, and sale of planes, ships, and road vehicles for transportation of passengers and freight; 2. Operation and maintenance of vehicles to provide transport services for passengers and freight.	Scope 1: Direct emissions related to the operation of vehicles, not the energy required to manufacture those vehicles because data are not available (IEA statistics). For CO_2, the potential emissions content of the consumed transport energy (electricity/fuels) is provided in order to take into account that the sector does not use the transport service itself, but provides transport services for consumers. Scope 2: Indirect emissions from electricity or electricity-produced fuels (hydrogen, synthetic fuels) used for transportation services.
The **Transport Sector** ('transport equipment & services') develops, manufactures, and/or operates technical equipment to provide transport services in aviation, navigation, and on roads (excluding rail).			
Materials–Steel	Steel Manufacturing > Mining iron ore > Primary steel processes > Manufacture of basic iron and steel	The **Materials–Steel** Sector covers the manufacture of steel. It does not include the further processing of steel, e.g., in the car or construction industry. The Steel Sector includes three sub-sectors: 1. Mining iron ore 2. Processing iron ore to primary steel 3. Production of secondary steel using scrap or recycled primary steel	
The **Materials–Steel Sector** ('steel') covers all activities required to produce steel: from mining iron ore to the final steel product.			
Materials–Cement	Manufacture of cement > Mining > Clinker > Cement production	The **Materials–Cement** Sector covers the manufacture of cement but does not include the further processing of cement, e.g., in the construction industry. 1. Mining limestone and clay (= marl) 2. Processing marl to clinker 3. Production of cement	
The **Material–Cement** sector ("Cement") covers all activities required to produce cement: from mining limestone and clay to the final cement product.			

Definition of Scope 1 and Scope 2 Emissions

The concepts of *Scope 1* and *Scope 2* emissions have been developed from the *Greenhouse Gas Protocol Initiative*[7], a multi-stakeholder partnership of businesses, non-governmental organizations (NGOs), governments, and others convened by the World Resources Institute (WRI), a U.S.-based environmental NGO, and the World Business Council for Sustainable Development (WBCSD), a Geneva-based coalition of 170 international companies. The GHG Protocol Initiative comprises two separate but linked standards:

- GHG Protocol Corporate Accounting and Reporting Standard
- GHG Protocol Project Quantification Standard

The GHG Protocol Corporate Standard classifies a company's GHG emissions into three 'scopes'.

- *Scope 1*: Emissions are direct emissions from owned or controlled sources.
- *Scope 2*: Emissions are indirect emissions from the generation of purchased energy.
- *Scope 3*: Emissions are all indirect emissions (not including those in *Scope 2*) that occur in the value chain of the reporting company, including both upstream and downstream emissions.

These definitions have been developed for specific companies and not for whole industry sector or individual regions. Therefore, the definitions for *Scope 1* and *Scope 2* emissions require some minor changes.

Because the scope of this analysis is limited to five financial sectors, *Scope 3* emissions of the individual sectors cannot be calculated because they would include emissions from the industry sector and GHGs (other than CO_2 and CH_4), which are not part of this research project.

Table 3: GHGs emissions and what is covered in this analysis

Analysis includes the following GHG gases:			
Greenhouse Gas (GHG)	Main source of emission (hyperlinks to IPCC reports)	CO_2 equivalents	Covered by this analysis
CO_2 - Carbon dioxide	Energy industry/burning fossil fuels	1	**YES**
CH_4 - Methane	Extraction and mining of fossil fuels	25	**YES**
	Livestock, fertilizer	25	NO
N_2O - Nitrous Oxide	Fertilizer/Agricultural sector	298	NO
HFCs - Hydrofluorocarbons	Refrigerants/Production of refrigerants	53–14,800	NO
PFCs - Perfluorocarbons	Primary aluminium production process	7,390–12,200	NO
SF_6 - Sulfur Hexafluoride	Electrical equipment	22,800	NO
NF_3 - Nitrogen Trifluoride	Chemical released in high-tech industries, such as electronics	17,200	NO

[7] The Greenhouse Gas Protocol - A Corporate Accounting and Reporting Standard; World Resource Institute, World Business Council for Sustainable Development, 2004, SBN 1-56973-568-9, https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf

Overview of Scope 1 and Scope 2 Emissions in this Analysis

***Scope 1*: Includes** all direct emissions from the activities of an organisation or under its control, including fuel combustion on site, such as in gas boilers, fleet vehicles, and air-conditioning leaks.

Limitations for this analysis: Only sector-specific emissions are used, as opposed to company-specific *Scope 1* emissions, which would include, for example, the emissions of vehicles used by the sector or sub-sector analysed. These emissions are provided in the *Transport* sector analysis.

Scope 2: Includes indirect emissions from electricity purchased and used by the organisation. Emissions are created during the production of the energy that is eventually used by the organisation.

Limitations for this analysis: Because of limited data availability, the actual electricity demand is not reported for most industry sectors or sub-sectors. Therefore, the *Scope 2* emissions focus on projected future electricity consumption under the assumed electricity-generation mix. For example, the current electricity demand of the car manufacturing industry is not published in the IEA World Energy Balances used here. Therefore, *Scope 2* emissions for road transport only include the electricity demand of electric vehicles.

Scope 3: Includes all other indirect emissions from the activities of the organisation, arising from sources that they do not own or control. These are usually the greatest share of the carbon footprint.[8]

Limitations for this analysis: The project scope is limited to five industry sectors and two GHGs (CO_2 and CH_4). Therefore, other indirect emissions for the five sectors analysed cannot be provided. However, the industries analysed must require that all business partners comply with the 1.5°C pathway.

[8] It should be noted that while it is not currently possible to calculate for each individual sector, if taking a value chain approach some of the scope 1 and 2 of the sector's covered in this report, constitute the scope 3 of other sectors covered in this report.

Overview of Scenarios and Technology Storylines

Energy Scenario Narratives and Assumptions for the World

The scenario-building process involves many assumptions and explicit, but also implicit, narratives about how future economies and societies, and ultimately energy systems, will develop under the overall objective of ‘deep and rapid decarbonization’ by 2050. These narratives depend on three main strategic pillars:

- Efficiency improvement and demand reduction leading to a continuous reduction in both the final and primary energy consumption. In the 1.5°C scenario, these measures must be supplemented with responsible energy consumption behaviour by the consumer.
- Deployment of renewable energies: the massive implementation of new technologies for the generation of power and heat in all sectors.
- Sector coupling: stringent direct electrification of heating and transport technologies in order to integrate renewable energy in the most efficient way. Because this strategy has its limitations, it will be complemented by the massive use of hydrogen (generated by electrolysis) or other synthetic energy carriers.

Some alternative or probably complementary future technical options are explicitly excluded from the scenario. In particular, those options with large uncertainties in terms of the technical, economic, societal, and environmental risks, such as large hydro and nuclear power plants, unsustainable biomass use, carbon capture and storage (CCS), and geo-engineering, are not considered on the supply side as mitigation measures or—in the case of hydro power—are not expanded in the future. The sustainable use of biomass will partly substitute for fossil fuels in all energy sectors. However, this use will be limited to an annual global energy potential of less than 100 EJ per year for sustainability reasons, according to the calculations of Seidenberger et al. (2008), Thrän et al. (2011), and Schueler et al. (2013).

The following storylines and assumptions used in this project are based on the following book publication:

Achieving the Paris Climate Agreement Goals — Global and Regional 100% Renewable Energy Scenarios with Non-energy GHG Pathways for +1.5°C and +2 °C:

Chapter 5

Main Assumptions for Energy Pathways: Thomas Pregger, Sonja Simon, Tobias Naegler, Sven Teske.

The scenario modelling follows a hybrid bottom-up/top-down approach, with no objective cost-optimising functions. The analysis considers key technologies for successful energy transitions and focuses on the role and potential utility of efficiency measures and renewable energies. Wind and solar energies have the highest economic potential and dominate the pathways on the supply side. However, the variable renewable power from wind and solar voltaic remains limited to a maximum of 65%, because sufficient secured capacity must always be maintained in the electricity system. Therefore, we also consider concentrated solar power (CSP), with high-temperature heat storage, as a solar option that promises large-scale dispatchable and secured power generation.

Socio-Economic Assumptions

Population Growth

Population growth is an important driver of energy demand, directly and through its impact on economic growth and development. The assumptions made in this study up to 2050 are based on United Nations Development Programme (UNDP) projections for population growth (UNDP 2017 [medium variant]). Table 4 shows that according to the UNDP, the world's population is expected to grow by 0.8% per year on average over the period 2015–2050. Satisfying the energy needs of a growing population in the developing regions of the world in an environmentally friendly manner is the fundamental challenge in achieving a sustainable global energy supply.

Table 4: Population growth projections. UN World Population Prospects—2017 revision, medium variant

Million	2020	2025	2030	2035	2040	2045	2050	Change 2015–2050
OECD North America	**503**	**524**	**543**	**560**	**575**	**588**	**599**	**+24%**
OECD Pacific	208	208	208	206	204	201	198	-4%
OECD Europe	**582**	**587**	**592**	**596**	**598**	**599**	**598**	**+5%**
Eastern Europe/Eurasia	346	347	346	345	343	341	339	−1%
Middle East	254	276	295	314	331	348	363	+56%
Latin America	531	552	571	587	599	609	616	+22%
China	1,433	1,447	1,450	1,442	1,426	1,403	1,374	−2%
Africa	1,353	1,522	1,704	1,897	2,100	2,312	2,528	+112%
India	1,383	1,452	1,513	1,565	1,605	1,636	1,659	+27%
Non-OECD Asia	1,203	1,269	1,329	1,382	1,428	1,467	1,499	+32%
Global	**7,795**	**8,185**	**8,551**	**8,893**	**9,210**	**9,504**	**9,772**	**+32%**

GDP Development

Economic growth is a key driver of energy demand. **Since 1971, each 1% increase in the global GDP has been accompanied by a 0.6% increase in primary energy consumption**. Therefore, the decoupling of energy demand and GDP growth is a pre-requisite for the rapid decarbonization of the global energy industry. In this study, the economic growth in the model regions is measured in GDP, expressed in terms of purchasing power parity (PPP) exchange rates.

Table 5: GDP development projections based on the average annual growth rates for 2015–2040 from IEA (WEO 2016) and on our own extrapolations for 2040–2050

Billion $ PPP	2020	2025	2030	2035	2040	2045	2050	Change 2015-/2050
OECD North America	**27,542**	**30,723**	**33,904**	**37,820**	**41,735**	**46,305**	**50,875**	**+107%**
OECD Pacific	9,866	10,715	11,564	12,361	13,158	13,846	14,535	+58%
OECD Europe	**26,537**	**28,973**	**31,410**	**33,931**	**36,452**	**38,761**	**41,070**	**+71%**
Eurasia	7,508	8,799	10,090	11,630	13,170	14,932	16,695	+135%
Middle East	7,005	8,033	9,841	11,650	13,458	16,911	19,541	+227%
Latin America	8,303	9,785	11,268	13,279	15,290	18,259	20,749	+160%
China	31,741	42,219	52,696	62,452	72,207	83,229	94,250	+320%
Africa	7,909	10,274	12,640	16,041	19,442	24,389	29,337	+351%
India	12,795	18,982	25,169	33,676	42,184	51,133	60,082	+574%
Other Asia	12,623	16,197	19,771	24,261	28,751	33,395	38,038	+240%
Global	**151,829**	**184,700**	**218,352**	**257,100**	**295,848**	**341,161**	**385,173**	**+201%**

Purchasing power parity compares the costs of fixed baskets of traded and non-traded goods and services in different currencies. GDP PPP is a widely used measure of living standards and is independent of the currency exchange rates, which might not reflect a currency's true value (purchasing power) within a country. Therefore, GDP PPP is an important basis of comparison when analysing the main drivers of energy demand or when comparing the energy intensities of countries. Although PPP assessments are still relatively imprecise compared with statistics based on national incomes, trade, and national price indices, it is argued that they provide a better basis for global scenario development.

Impact of COVID-19 on GDP projections

The 2019 data are based on a global GDP increase of 2.4% (Worldbank 2020). Due to the significant impact of the pandemic, we have included two different estimates of GDP development for the ongoing year 2020.

Global: The 1.5°C case is calculated with an GDP increase of 1.5%, as estimated before the COVID-19 crisis or with the IEA Global Energy Review estimate of −8% as a result of the COVID-19 crisis. The following years are based on the assumption that the economy will recover, and that by 2025, GDP will be as high as that projected before COVID-19 and will be back on a constant growth trajectory.

Regions: The 1.5°C case is calculated with an GDP increase (see Table 5) and the estimates for the COVID-19 crisis are based on the OECD Economic Outlook (June 2020)[9], which assumes −9% for the European region and −8.5% for OECD North America.

Fuel Price Projections

Although fossil fuel price projections have seen considerable variations, as described above, we based our fuel price assumptions up to 2040 on WEO 2017 (IEA 2017). Beyond 2040, we extrapolated from the price developments between 2035 and 2040. Although these price projections are highly speculative, they provide a set of prices consistent with our investment assumptions.

Table 6: Development projections for fossil fuel prices in US$2015 (IEA 2017)

Development projections for fossil fuel prices							
			2015	2020	2030	2040	2050
Oil	All	$/GJ	8.5	12.3	21.5	24.2	35.1
Gas	OECD North America	$/GJ	2.5	3.3	5.5	6.2	8.9
	OECD Europe	$/GJ	6.6	7.2	9.2	10.0	12.9
	China	$/GJ	9.2	9.5	10.3	10.5	11.4
	OECD Pacific	$/GJ	9.8	10.0	10.7	10.9	11.8
	Others	$/GJ	2.5	3.3	5.5	6.2	8.9
Coal	OECD North America	$/GJ	2.3	2.5	2.9	3.0	5.3
	OECD Europe	$/GJ	2.6	3.1	4.1	4.3	5.3
	China	$/GJ	3.2	3.5	4.3	4.5	5.3
	OECD Pacific	$/GJ	2.6	3.3	4.4	4.5	5.3
	Others	$/GJ	2.9	3.3	4.2	4.4	5.3
Nuclear	All	$/GJ	1.1	1.2	1.5	1.8	2.1

[9] OECD Economic Outlook, June 2020, viewed in August 2020, https://www.oecd.org/economic-outlook/

CAPEX Projections

Table 7: Investment cost assumptions for power-generation plants (in US$2015/kW) in all scenarios until 2050

Investment costs for power generation plants						
		2015	**2020**	**2030**	**2040**	**2050**
CHP Coal	US$/kW	2,500	2,500	2,500	2,500	2,500
CHP Gas	US$/kW	1,000	1,000	1,000	1,000	1,000
CHP Lignite	US$/kW	2,500	2,500	2,500	2,500	2,500
CHP Oil	US$/kW	1,310	1,290	1,240	1,180	1,130
Coal power plant	US$/kW	2,000	2,000	2,000	2,000	2,000
Diesel generator	US$/kW	900	900	900	900	900
Gas power plant	US$/kW	670	500	500	500	670
Lignite power plant	US$/kW	2,200	2,200	2,200	2,200	2,200
Nuclear power plant	US$/kW	6,600	6,000	5,100	4,500	4 ,500
Oil power plant	US$/kW	950	930	890	860	820
CHP Biomass	US$/kW	2,550	2,500	2,450	2,350	2,250
CHP Fuel cell	US$/kW	5,000	5,000	2,500	2,500	1,120
CHP Geothermal	US$/kW	13,200	11,190	8,890	7,460	6,460
Biomass power plant	US$/kW	2,400	2,350	2,300	2,200	2,110
Geothermal power plant	US$/kW	12,340	2,800	2,650	2,500	2,400
Hydro power plant**	US$/kW	2,650	2,650	2,650	2,650	2,650
Ocean energy power plant	US$/kW	6,950	6,650	4,400	3,100	2,110
Photovoltaic power plant	US$/kW	1,300	980	730	560	470
CSP power plant*	US$/kW	5,700	5,000	3,700	3,050	2,740
Wind turbine offshore	US$/kW	4,000	3,690	3,190	2,830	2,610
Wind turbine onshore	US$/kW	1,640	1,580	1,510	1,450	1,400
Hydrogen production	US$/kW	1,380	1,220	920	700	570

*Costs for a system with solar multiple of two and thermal storage for 8 h of turbine operation
**Values apply to both run-of-the-river and reservoir hydro power

Table 8: Specific investment cost assumptions (in US$2015) for heating technologies in all scenarios until 2050

Investment costs for heat-generation plants							
			2015	**2020**	**2030**	**2040**	**2050**
Geothermal		US$/kW	2,390	2,270	2,030	1,800	1,590
Heat pumps		US$/kW	1,790	1,740	1,640	1,540	1,450
Biomass heat plants		US$/kW	600	580	550	510	480
Residential biomass stoves	Industrialized countries	US$/kW	840	810	760	720	680
Residential biomass stoves	Developing countries	US$/kW	110	110	110	110	110
Solar collectors	Industry	US$/kW	850	820	730	650	550
	Heat grids	US$/kW	970	970	970	970	970
	Residential	US$/kW	1,060	1,010	910	800	680

Sector-based 1.5°C Target–Overview Results by Region

Global: Key Sector-based Results for 1.5°C Target

The global *Scope 1* and *Scope 2* emissions for 2018 were calculated with the latest published statistical data from IEA in August 2020[10]. The 2019 data are based on a global GDP increase of 2.4% (Worldbank 2020)[11], whereas we include two different estimates of GDP development for the ongoing year 2020: an increase of 1.5%, as estimated before the COVID-19 crisis, and with the IEA Global Energy Review estimate of −8%. The subsequent years are based on the assumption that the economy will recover and that by 2025, GDP will be on a constant growth trajectory.

The COVID-19 crisis led to an overall reduction in oil production of 8% (IEA, 2020)[12] in the first half of 2020. The oil price became negative in April 2020. In response, the USA, Russia, and Saudi Arabia agreed to reduce daily production by 10 million barrels per day (approximately −10%) from 1 May until 30 June 2020 (OPEC, 2020). In this analysis, we assume that the increases in the oil demand in the second half of 2020 is only minor, but jumps by 6% again in 2021. For coal, the estimated decline in 2020 (−8%) due to the COVID-19 crisis (IEA 2020)[12] will remain and production will not jump back to the production volumes of 2019 because profitability will decline (LAZARD 2020)[13].

According to this first analysis, lockdown measures have significantly reduced the electricity demand. Although residential demand increased, the reductions in commercial and industrial operations were significantly higher. The IEA calculated that on average, every month of full lockdown reduced the demand by 20%, or by > 1.5% on an annual basis. In this analysis, we assume a global decrease of 7% for the 2020 demand under the 2020 estimate, whereas the demand under the 2020 (1.5 °C) projection (for comparison) decreases by 2% due to technical efficiency measures.

Figure 2 shows the global *Scope 1* emissions in CO_2 equivalents for energy-related CO_2 and CH_4 emissions—no other GHGs are included in this analysis. The *Energy* sector includes all CO_2 and CH_4 emissions related to the extraction of fossil fuels, the production of secondary products in refineries, coal products, and the transport of fuel to utilities for re-sale or use in power plants. The *Energy* sector includes renewable energy generation, but not its operation or re-sale.

The *Utilities* sector covers electricity and gas re-sale and the resulting CO_2 and CH_4 emissions. Therefore, emissions under the *Scope 1* methodology count emissions twice; natural gas CO_2 emissions are accounted for in the *Energy* sector (for extraction), for the *Utility* sector (for distribution and re-sale), and for the end-users of the gas or gas-generated electricity. Therefore, *Scope 1* emissions of different sectors do not add up to the actual global emissions.

The *Transport* sector includes aviation, shipping, and road transport and focuses on the operation of planes, ships, and road vehicles, but excludes the energy required to manufacture these because no data are available. Finally, the *Cement* and *Steel* sectors covers energy-related CO_2 and CH_4 emissions for the energy consumed and process-related emissions.

A 1.5°C climate mitigation pathway requires that we remain within a cumulative carbon budget of 450 $GtCO_2$ between 2015 and 2050. The annual global energy-related CO_2 emissions in 2019 were 33 $GtCO_2$—about the same level as in 2018[14]. Without rapid reduction measures, the budget will be used up in around 10 years. The average annual budget for energy-related carbon emission for the *Energy* sector between 2020 and 2050 will be around 10 $GtCO_2$. Therefore, early action is required to remain within this benchmark.

Therefore, the OECM-derived 1.5°C mitigation pathway requires the energy sectors to reduce their energy-related carbon emissions by 26%–37% until 2025, with a similar drastic reduction for the following 5-year period until 2030. These significant reductions will be achieved almost exclusively with two measures:

1. A rapid increase in cost-competitive renewable power generation to replace fossil fuel—mainly brown- and hard-coal-based power generation—to decarbonize the electricity sector.
2. Decarbonized electricity will replace fossil fuels in the *Transport* and *Heating* sectors. The two most important measures to achieve high electrification shares are the uptake of electric mobility and electricity-based heating systems (mainly heat pumps). Both technology groups (electric vehicles

[10] IEA—Advanced World Energy Balances—release August 2020
[11] Worldbank 2020, https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG
[12] IEA 2020, Global Energy Review 2020, https://www.iea.org/reports/global-energy-review-2020
[13] LAZARD 2020, Levelized Cost of Energy and Levelized Cost of Storage—2020, October 2020; website viewed 26th October 2020, https://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2020/
[14] IEA website, viewed August 2020; https://www.iea.org/articles/global-co2-emissions-in-2019

and electricity-based heating systems) will increase the availability of electricity storage and demand-side management (charging and heating concepts), which will be used for the integration of large shares of variable solar and wind power generation.

The reduction in process-related emissions will require structural changes in the industry itself—with a change in manufacturing processes—and will require long-term investment planning. Therefore, these measures are taken into account for emission reductions after 2030.

Figure 2: Global: Scope 1 emissions in CO_2 equivalents

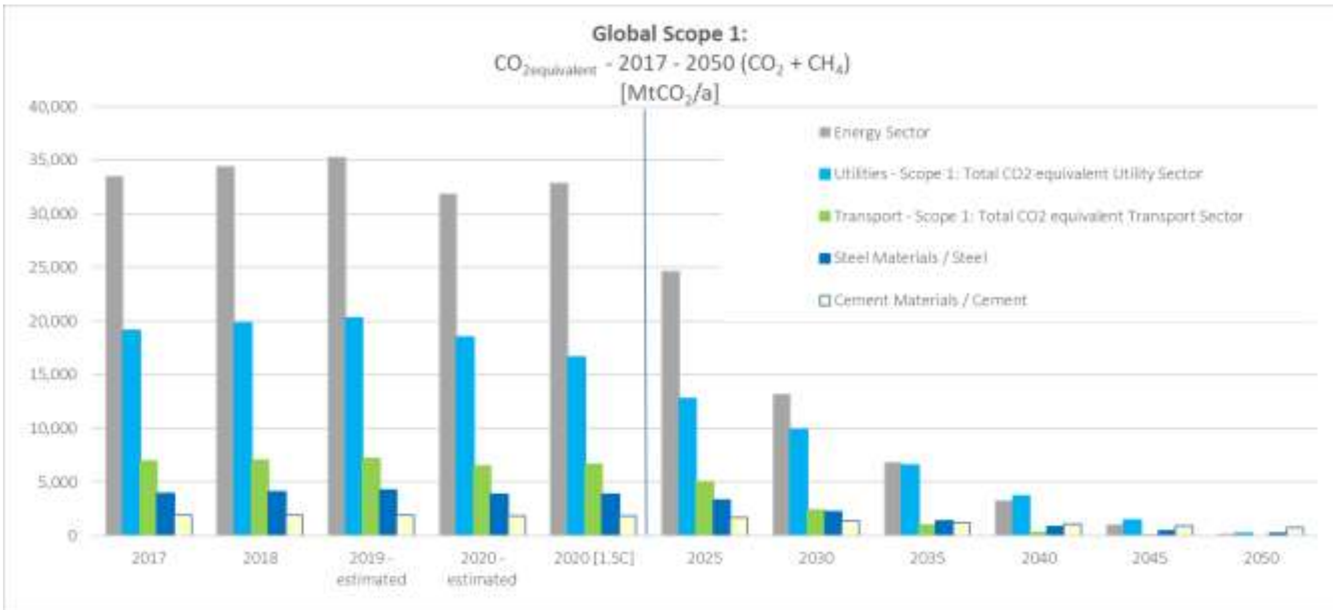


Figure 3 shows the global *Scope 2* emissions in CO_2 equivalents, which cover the emissions related to electricity consumption in each analysed sector. *Scope 2* emissions in the *Energy* and the *Utilities* sectors cover only the electricity demand for the sector itself: internal electricity consumption for power plants ('own consumption') and electricity used for fossil fuel extraction and transport. They do not include the overall electricity generated and distributed in both sectors. For example, a coal power plant generates electricity for consumers. The power plant itself requires electricity to operate. The *Scope 2* emissions for this power plant only include the self-consumed amount, whereas the actual electricity generated will be transported to consumers, e.g., the steel industry, to which these emissions are then assigned.

Under the 1.5°C pathway, the *Transport* sector will replace fossil fuels with electricity to a large extent. The electrification of road vehicles is a core measure to significantly reduce the demand for oil and increase the demand for electricity in the sector. Thus, *Scope 1* emissions will drop sharply between 2020 and 2035, whereas *Scope 2* emissions will nearly quadruple between 2020 and 2025. Therefore, the decarbonization of the electricity sector with increased shares of renewable power generation is vital to achieve the reduction targets for the *Transport* sector and for the other two sectors analysed–*Steel* and *Cement.*

Therefore, the *Utilities* sector has a key responsibility to shift electricity generation from fossil-fuel-based to renewable-based power generation to allow other industries, the financial sector, and consumers to achieve the Scope 1 and *Scope 2* emission targets. Another option to achieve these targets for the sectors analysed is to purchase renewable electricity directly from renewable power producers via power purchase agreements (PPA) or to invest in their own power generation and move away from fossil-fuel-dominated utilities.

Between 2035 and 2045, the carbon intensity of electricity will drop sharply, and by 2050, global electricity generation will be carbon-free. Therefore, the increased electricity demand will have no effect on the *Scope 2* emissions of any industry sector.

Figure 3: Global Scope 2 emissions in CO_2 equivalents—emissions from the use of electricity

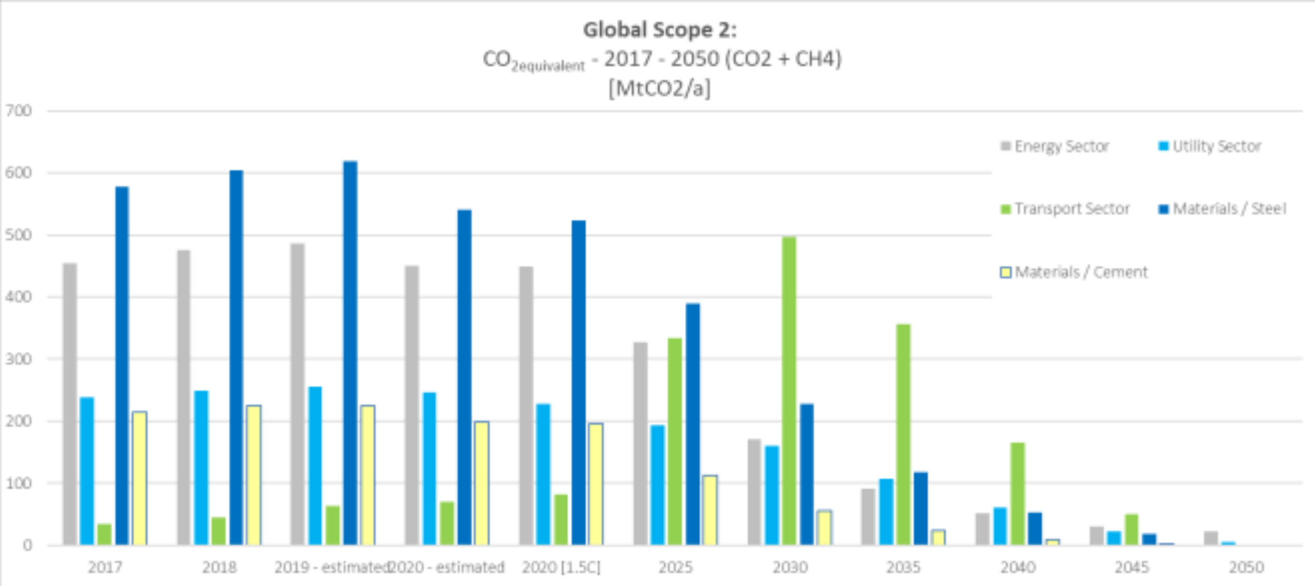


Figure 4 shows the development of the global energy supply structure under the 1.5°C pathway. Energy supply by source in petajoules per year [PJ/a] is shown on the left axis and the carbon intensity of the overall *Energy* sector—across all sources—in tons of CO_2 per petajoule [tCO_2/PJ] is shown on the right axis. Carbon intensity will halve from around 60,000 tCO_2/PJ to 30,000 tCO_2/PJ between 2020 and 2030.

Lignite and hard coal will decrease fastest, at 5% per year [%/a] between 2020 and 2025 and 13%/a between 2025 and 2030. Oil will follows, with the slightly lower rates of decrease: 3%/a in 2020–2025 and 8%/a over the following decade (until 2035). Gas is the last fossil fuel to be phased out, with production volumes remaining at the 2020 level until 2030 and decreasing at 5%/a towards 2035 and at 8%/a in 2035–2040. The generation of renewable electricity will increase annually by 15% until 2030 to supply the increased electrification rates in the *Transport* and (industrial) *Heating* sectors, and to replace coal-based power generation. The increase in *Scope 2* emissions in the *Transport* sector will be due to electrification, which will replace fuels and therefore reduce *Scope 1* emissions. Power generation for the additional electricity required for the *Transport* sector will contain some fossil-fuel-based power plants in 2030, which will decrease constantly thereafter, towards a fully renewable power supply by 2050.

Renewable fuels—hydrogen and synthetic fuels—will increase to 2,500 PJ by 2025 and quadruple between 2025 and 2030.

The increase in renewable energy—both electricity and synthetic fuels—must go hand in hand with the increased electrification of road transport and heating in order to replace fossil fuels. The *Energy* and *Utilities* sectors play important roles in organizing the transition, especially in supporting the road *Transport* sector and supplying sufficient amounts of renewable electricity. However, both the *Steel* and *Cement* industry sectors have the option to purchase renewable energy—both for process heat and for electricity—from either independent power producers or by investing in their own capacities, if utilities are unable to supply the required low-carbon energy.

Figure 4: Global development of the energy supply structure

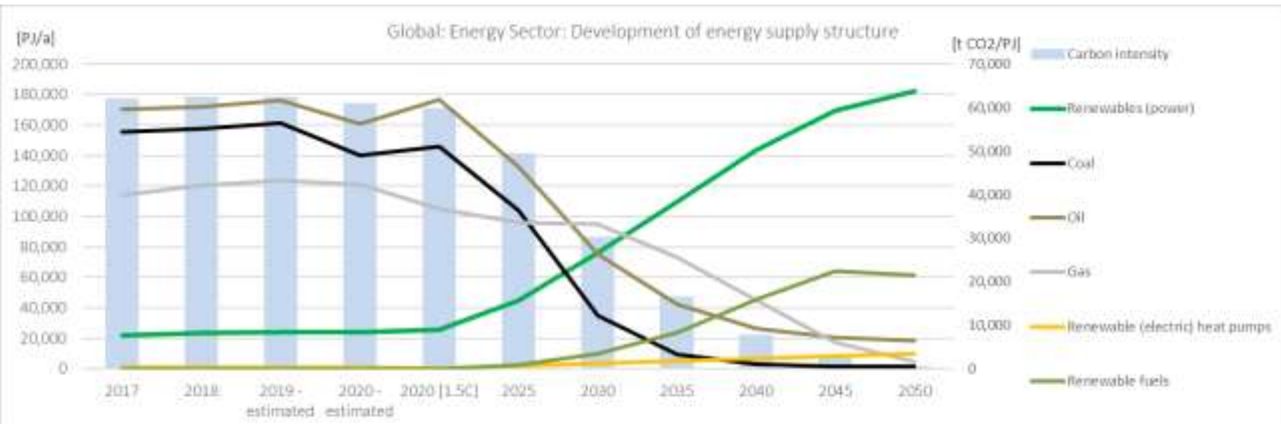


Table 9: Global: Key Results—*Energy*, *Utilities*, and *Transport* sectors

Sub-sector	Units	2018	2019	2020	2020	2025	2030	2035	2040	2045	2050
World		Base year	[estimated]	[estimated]	[1.5 °C]	Projection					
Total Energy, Gas, Oil & Coal Sector -											
Total CO_2 Emissions	[$MtCO_2$/a]	32,635	33,410	30,232	31,076	23,311	12,474	6,393	2,997	854	48
Variation compared with 2019	[%]				−7%	−30%	−63%	−81%	−91%	−97%	−100%
Energy Sector - Scope 1: Total CO_2 equivalents (CO_2e)	[**$MtCO_2e$**]	34,422	35,240	31,861	32,818	24,660	13,200	6,790	3,232	997	157
Change to 2019	[%]				−7%	−30%	−63%	−81%	−91%	−97%	−100%
Energy Sector - Scope 2: Total CO_2 equivalents	[**$MtCO_2e$**]	475	487	450	449	328	171	91	51	30	22
Change to 2019	[%]				−8%	−33%	−65%	−81%	−89%	−94%	−96%
Total Energy Production	[PJ/a]	552,496	565,655	524,822	549,519	501,175	437,483	415,300	418,325	421,520	422,668
Variation compared with 2019	[%]				−3%	−11%	−23%	−27%	−26%	−25%	−25%
Intensities											
Sector CO_2 Intensity	[$MtCO_2$/PJ]	0.06	0.06	0.06	0.06	0.05	0.03	0.02	0.01	0.00	0.00
Variation compared with 2019	[%]				−4%	−21%	−52%	−74%	−88%	−97%	−100%
Sector **CO_2 equivalent** Intensity (CO_2 + CH_4)	[$MtCO_2$/PJ]	0.06	0.06	0.06	0.06	0.05	0.03	0.02	0.01	0.00	0.00
Variation compared with 2019	[%]				96%	79%	48%	26%	12%	4%	1%
Regional Energy Intensity	[PJ/$GDP]	7.2	7.2	6.4	6.7	4.9	3.6	2.8	2.3	2.0	1.7
Variation compared with 2019	[%]				−6%	−31%	−50%	−62%	−67%	−73%	−76%
Total Utilities Sector											
Total CO_2 Emissions	[$MtCO_2$/a]	18,961	19,416	17,614	15,933	12,164	9,144	5,879	3,143	1,060	0
Variation compared with 2019	[%]				−18%	−37%	−53%	−70%	−84%	−95%	-100%
Utilities - Scope 1: Total CO_2 equivalents	[**$MtCO_2e$**]	19,854	20,331	18,511	16,630	12,772	9,886	6,577	3,737	1,457	265
Change to 2019	[%]				−18%	−37%	−51%	−68%	−82%	−93%	−99%
Utilities - Scope 2: Total CO_2 equivalents	[**$MtCO_2e$**]	249	255	247	228	193	160	107	61	22	5
Change to 2019	[%]				−11%	−24%	−37%	−58%	−76%	−91%	−98%
Total Energy Production	[PJ/a]	201,394	206,228	197,269	193,272	200,681	235,183	262,759	295,640	314,329	313,275
Variation compared with 2019	[%]				−6%	−3%	14%	27%	43%	52%	52%
Intensities											
Sector CO_2 Intensity	[$MtCO_2$/PJ]	0.09	0.09	0.09	0.08	0.06	0.04	0.02	0.01	0.00	0.00
Variation compared with 2019	[%]				−12%	−36%	−59%	−76%	−89%	−96%	−100%
Sector **CO_2 equivalent** Intensity (CO_2 + CH_4)	[**$MtCO_2e$**/PJ]	0.10	0.10	0.09	0.09	0.06	0.04	0.03	0.01	0.00	0.00
Variation compared with 2019	[%]				87%	65%	43%	25%	13%	5%	1%
Regional Energy Intensity	[PJ/$GDP]	2.64	2.61	2.42	2.37	1.97	1.91	1.74	1.65	1.47	1.26
Variation compared with 2019	[%]				−9%	−25%	−27%	−33%	−37%	−44%	−52%
Total Transport Sector		2018	2019	2020	2020	2025	2030	2035	2040	2045	2050
Transport - Scope 1: Total CO_2 equivalents	[**$MtCO_2e$**]	7,015	7,204	6,494	6,631	5,052	2,404	997	305	42	0
Change to 2019	[%]	0	0	0	-5%	-28%	-66%	-86%	-96%	-99%	-100%
Transport - Scope 2: Total CO_2 equivalents	[**$MtCO_2e$**]	44.7	63.9	70.6	82.4	333.3	494.8	354.9	165.6	49.6	0.0
Change to 2019	[%]										
Total Sector Energy Demand	[PJ/a]	102,023	104,894	95,110	97,517	87,025	65,751	57,115	51,886	46,493	42,005
Variation compared with 2019	[%]				-4%	-15%	-36%	-44%	-49%	-54%	-59%
Intensities											
Air Passenger Transport											
Emission Intensity	[gCO_2/pkm]	125.57	117.20	117.20	117.20	97.00	73.59	63.03	46.74	13.81	0.00
Emission Intensity reduction compared with 2019	[%]				0%	-17%	-37%	-46%	-60%	-88%	-100%
Energy Intensity	[MJ/pkm]	1.7	1.6	1.6	1.6	1.5	1.4	1.3	1.3	1.3	1.2
Emission Intensity reduction compared with 2019	[%]				0%	-6%	-14%	-17%	-20%	-21%	-23%
Air Freight Transport											
Emission Intensity	[gCO_2/tkm]	2360.26	2237.12	2237.12	2237.12	1878.36	1458.28	1260.69	944.10	280.15	0.00
Emission intensity reduction compared with 2019	[%]				0%	-16%	-35%	-44%	-58%	-87%	-100%
Energy Intensity	[MJ/tkm]	32.2	30.52	30.52	30.52	29.12	27.16	26.46	25.76	25.48	25.2
Emission Intensity reduction compared with 2019	[%]				0%	-5%	-11%	-13%	-16%	-17%	-17%
Navigation: Passenger Transport											
Emission Intensity	[gCO_2/pkm]	4.55	4.55	4.55	4.51	3.93	2.96	1.75	0.00	0.00	0.00
Emission intensity reduction compared with 2019	[%]				−1%	−14%	−35%	−62%	−100%	−100%	−100%
Energy Intensity	[MJ/pkm]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Emission intensity reduction compared with 2019	[%]				−1%	−2%	−3%	−4%	−5%	−6%	-7%
Navigation: Freight Transport											
Emission Intensity	[gCO_2/tkm]	15.35	15.35	15.35	15.35	13.28	9.94	5.83	0.00	0.00	0.00
Emission intensity reduction compared with 2019	[%]				0%	−13%	−35%	−62%	−100%	−100%	−100%
Energy Intensity	[MJ/tkm]	0.19	0.19	0.19	0.19	0.19	0.18	0.18	0.18	0.17	0.17
Emission Intensity reduction compared with 2019	[%]				0%	−2%	−3%	−5%	−7%	−8%	-9%
ROAD: Light Duty Vehicles / Passenger Transport											
Emission Intensity	[gCO_2/pkm]	718.91	738.66	752.82	753.40	620.34	288.45	111.08	34.16	4.72	0.00
Emission intensity reduction compared with 2019	[%]				−2%	−15%	−43%	−68%	−79%	−83%	−85%
Energy Intensity	[MJ/pkm]	1.5	1.3	1.3	1.3	1.2	0.9	0.7	0.6	0.5	0.5
Emission intensity reduction compared with 2019	[%]				−2%	−12%	−30%	−44%	-−53%	−59%	−61%
ROAD: Trucks / Freight Transport											
Emission Intensity	[gCO_2/tkm]	874	940	954	884	767	426	200	63	9	0
Emission Intensity reduction compared with 2019	[%]				−1%	−19%	−56%	−87%	−97%	−100%	−100%
Energy Intensity	[MJ/tkm]	1.3	1.3	1.3	1.3	1.2	0.9	0.8	0.6	0.6	0.5
Emission Intensity reduction compared with 2019	[%]				0%	−9%	−26%	−41%	−49%	−55%	−57%

Table 10: Global: Key Results—*Steel* and *Cement* sectors

Sub-sector	Units	2018	2019	2020	2020	2025	2030	2035	2040	2045	2050
World		Base year	[estimated]	[estimated]	[1.5 °C]	Projection					
Total Materials–Steel											
Scope 1: Total direct emissions in CO_2 equivalents	[$MtCO_2e/a$]	4,113	4,231	3,873	3,855	3,313	2,224	1,386	845	470	216
Change to 2019	[%]				−9%	−22%	−47%	−67%	−80%	−89%	−95%
Scope 2: Electricity generation for steel production	[tCO_2/ton steel]	604	619	541	523	389	228	117	53	18	0
Change to 2019	[%]				−16%	−37%	−63%	−81%	−91%	−97%	−100%
Specific energy related CO_2 emissions per ton of steel	[tCO_2/ton steel]	2.27	2.26	2.14	2.13	1.74	1.10	0.64	0.37	0.19	0.08
Deviation compared with 2019	[%]				−6%	−23%	−51%	−72%	−84%	−92%	−96%
Specific process-related CO_2 emissions per ton of steel	[tCO_2/ton steel]	1.06	1.06	1.02	1.02	0.92	0.60	0.37	0.23	0.15	0.08
Deviation compared with 2019	[%]				−55%	−59%	−73%	−84%	−90%	−93%	−96%
Total Final Energy Demand	[PJ/a]	30,398	31,128	28,861	32,235	33,399	34,638	36,059	37,510	39,351	41,247
Deviation in energy demand compared with 2019	[%]				4%	7%	11%	16%	21%	26%	33%
Product Energy Intensity	[GJ/ton steel]	18.6	18.6	18.6	18.0	17.5	17.2	16.7	16.2	15.8	15.3
Deviation compared with 2019	[%]				−3%	−6%	−8%	−10%	−13%	−15%	−18%
Total Materials–Cement											
Scope 1: Total direct emissions in CO_2 equivalents	[$MtCO_2e/a$]	1,920	1,946	1,847	1,862	1,701	1,407	1,209	1,082	940	807
Change to 2019	[%]				−4%	−13%	−28%	−38%	−44%	−52%	−59%
Scope 2: Emissions—Electricity generation for cement production	[$MtCO_2e/a$]	225	225	199	198	113	55	24	9	3	0
Change to 2019	[%]				−12%	−50%	−76%	−89%	−96%	−99%	−100%
Total CO_2 Emissions	[$MtCO_2/a$]	854.2	853.6	780.9	723.5	525.2	324.7	201.4	146.3	105.3	73.0
CO_2 emissions reduction compared with 2019	[%]				−15%	−38%	−62%	−76%	−83%	−88%	−91%
Specific energy-related CO_2 emissions per ton of clinker	[tCO_2/ton clinker]	0.236	0.230	0.218	0.185	0.140	0.092	0.059	0.045	0.033	0.024
Deviation compared with 2019	[%]				−20%	−39%	−60%	−74%	−81%	−85%	−90%
Specific energy-related CO_2 emissions per ton of cement	[tCO_2/ton cement]	0.291	0.284	0.267	0.230	0.165	0.104	0.064	0.046	0.034	0.024
Deviation compared with 2019	[%]				−19%	−42%	−63%	−77%	−84%	−88%	−92%
Total Energy Demand	[PJ/a]	11,801	11,762	11,107	11,585	11,469	11,144	11,199	11,303	11,119	10,924
Deviation in energy demand compared with 2019	[%]				−2%	−2%	−5%	−5%	−4%	−5%	−7%
Product Energy Intensity (thermal + electricity)	[GJ/ton cement]	2.9	2.8	2.7	2.6	2.5	2.4	2.4	2.3	2.2	2.1
Deviation compared with 2019	[%]				−6%	−10%	−13%	−16%	−17%	−20%	−23%

OECD Europe: Key Sector-based Results for 1.5°C Target

OECD Europe's *Scope 1* and *Scope 2* emissions for 2018 were calculated with the latest published statistical data from IEA, August 2020[15]. The 2019 data are based on the GDP increase of 1.5% for Europe (OECD 2020)[16]. For the ongoing year 2020, two different GDP developments are included: an increase of 1.5%, estimated before the COVID-19 crisis, and the OECD Economic Outlook (June 2020)[17] estimate of −9% for the European region. The subsequent years are based on the assumptions that the economy will recover and that by 2025, GDP will be on a constant growth trajectory.

On the global level, the COVID-19 crisis led to an overall reduction in oil production of 8% (IEA, 2020)[18] in the first half of 2020; for the whole year, we assume a drop of 8%. For coal, the estimated decline in 2020 of −8% due to the COVID-19 crisis (IEA, 2020)[18] will remain and production will not jump back to the production volumes of 2019. The IEA calculated that on average, every month of full lockdown reduced demand by 20%, or by over 1.5% on an annual basis. In this analysis, we assume a global decline of 7% in the 2020 demand under the 2020 estimate, whereas the demand under the 2020 (1.5 °C) projection (for comparison) decreased by 2% in response to technical efficiency measures. Detailed regional estimates for 2020 were not available at the time of writing, so we extended the global decline rates to the European region.

Figure 5 shows the global *Scope 1* emissions in CO_2 equivalents for energy-related CO_2 and CH_4 emissions (no other GHG is included in this analysis). The *Energy* sector includes all CO_2 and CH_4 emissions related to the extraction of fossil fuels, the production of secondary products in refineries, coal products, and the transport of fuel to utilities for re-sale or use in power plants. The *Energy* sector includes renewable energy generation, but not its operation or re-sale.

The *Utilities* sector covers electricity and gas re-sale and the resulting CO_2 and CH_4 emissions. Therefore, emissions under the methodology count emissions twice: natural gas CO_2 emissions are accounted for in the *Energy* sector (for its extraction), in the *Utility* sector (for its distribution and re-sale), and for end-users of gas or gas-generated electricity. Therefore, *Scope 1* emissions of different sectors do not add up.

The *Transport* sector includes aviation, shipping, and road transport and focuses on the operation of planes, ships, and road vehicles, but excludes the energy required to manufacture these because no data are available.

Finally, the *Cement* and *Steel* sectors comprise energy-related CO_2 and CH_4 emissions for the energy consumed and process-related emissions.

A 1.5°C climate mitigation pathway requires that we remain within a cumulative global carbon budget of 450 $GtCO_2$ between 2015 and 2050. Based on this, the European carbon budget for energy-related CO_2 emissions within the same time frame is 40.5 $GtCO_2$—or an average of 1.2 $GtCO_2$ per year until 2050. OECD Europe's energy-related CO_2 emissions in 2019 were at about 3.5 $GtCO_2$.

The OECM-derived 1.5°C mitigation pathway for OECD Europe requires a phase-out of brown and hard coal by 2030. Therefore, a very significant rate reduction of −46% is required for CO_2 in the *Energy* sector between 2019 and 2025. In their latest analysis (CA 2020), *Climate Analytics,* an internationally recognized think tank with offices in Europe, Australia, and the Americas*,* confirmed our estimate that the OECD region must phase-out coal by 2031[19]. Current political agreements (e.g., in Germany) to phase-out coal by 2038 are therefore insufficient to achieve the 1.5°C target.

Because coal must be phased-out within 10 years, the *Utilities* sector must also implement the rapid decarbonization of power generation. Europe's CO_2 emissions from electricity generation must decrease from 1.1 $GtCO_2$ in 2019 to 0.5 $GtCO_2$ in 2025. This reduction is based entirely on the assumption that the coal phase-out is well underway and will be successfully implemented by 2030. The overall energy-related CO_2 emissions from the *Utilities* sector—for electricity and gas—must decrease by 35%, from around 1.8 $GtCO_2$ in 2019 to 1.35 $GtCO_2$ in 2025.

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[15] IEA–Advanced World Energy Balances–released August 2020
[16] OECD 2020, Online Statistic, viewed in August 2020, https://stats.oecd.org/index.aspx?queryid=60703
[17] OECD Economic Outlook, June 2020, viewed in August 2020, https://www.oecd.org/economic-outlook/
[18] IEA 2020, Global Energy Review 2020, https://www.iea.org/reports/global-energy-review-2020
[19] CA 2020, Climate Analytics Briefings—Coal Phase-Out, website, viewed in September 2020, https://climateanalytics.org/briefings/coal-phase-out/

As with the Global scenario, these significant reductions will be achieved almost exclusively with two measures:

1. A rapid increase in cost-competitive renewable power generation to replace fossil fuels—mainly brown- and hard-coal-based power generation—to decarbonize the electricity sector.
2. Decarbonized electricity will replace fossil fuels in the *Transport* and *Heating* sectors. The two most important measures for high electrification shares are the uptake of electric mobility and electricity-based heating systems (mainly heat pumps). Both technology groups (electric vehicles and electricity-based heating systems) will increase the availability of electricity storage and demand-side management (charging and heating concepts), which will be used for the integration of large shares of variable solar and wind power generation.

The reduction of process-related emissions requires structural changes in the industry itself—with a change in manufacturing processes—and long-term planning. Therefore, these measures are taken into account for emission reductions after 2030.

The *Steel* and *Cement* industry sectors in Europe are currently responsible for around 0.5 $GtCO_2$ equivalents. More than half those emissions are process-related, and are not related to the energy used for production.

Figure 5: OECD Europe: Scope 1 emissions in CO_2 equivalents

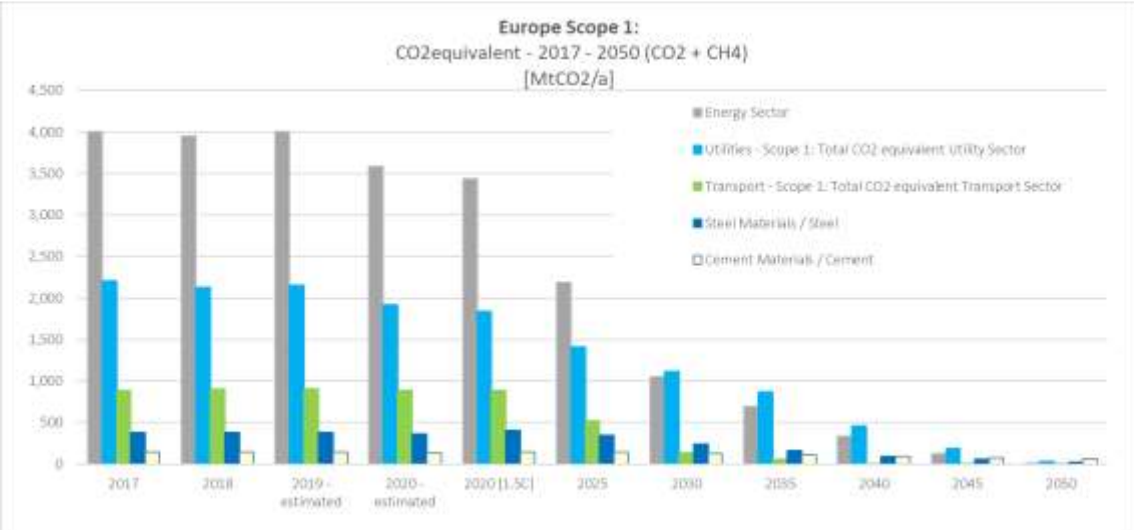


Figure 6 shows Europe's *Scope 2* emissions in CO_2 equivalents, which cover the emissions related to the electricity consumption of each sector analysed. The *Scope 2* emissions of the *Energy* and *Utilities* sectors cover only the electricity demand of the sector itself: internal electricity consumption for power plants ('own consumption') and the electricity used for fossil fuel extraction and transport. It does not cover the overall electricity generated and distributed by either sector. For example, a coal power plant generates electricity for consumers. The power plant itself requires electricity to operate. The *Scope 2* emissions of this power plant only include those produced by the self-consumed energy, whereas the actual electricity generated will be transported to consumers (e.g., the *Steel* industry), to which these emissions are then assigned.

Under the 1.5°C pathway, the *Transport* sector will replace fossil fuels with electricity to a large extent. The electrification of road vehicles is a core measure to significantly reduce the oil demand and increase the electricity demand for the sector. Therefore, the *Scope 1* emissions will drop sharply between 2020 and 2035, whereas the *Scope 2* emissions will nearly quadruple between 2020 and 2025. The decarbonization of the *Electricity* sector, with increased shares of renewable power generation, is vital to achieve the reduction targets for the *Transport* sector and for the other two sectors analysed, *Steel* and *Cement.*

Therefore, the *Utilities* sector has a key responsibility to shift electricity generation from fossil fuels to renewables-based power generation to allow other industries, financial sectors, and consumers to achieve their *Scope 1* and *Scope 2* emission targets. Another option to achieve the targets for the analysed sector is to purchase renewable electricity directly from renewable power producers via power purchase agreements (PPA) or to invest in its own power generation, thus moving away from fossil-fuel-dominated utilities.

Between 2035 and 2045, the carbon intensity of electricity will drop sharply and by 2050, Europe's electricity generation will be carbon-free. The increased electricity demand will have no effect on the *Scope 2* emissions of any industry sector.

Figure 6: OECD Europe Scope 2 emissions in CO_2 equivalents—emissions from the use of electricity

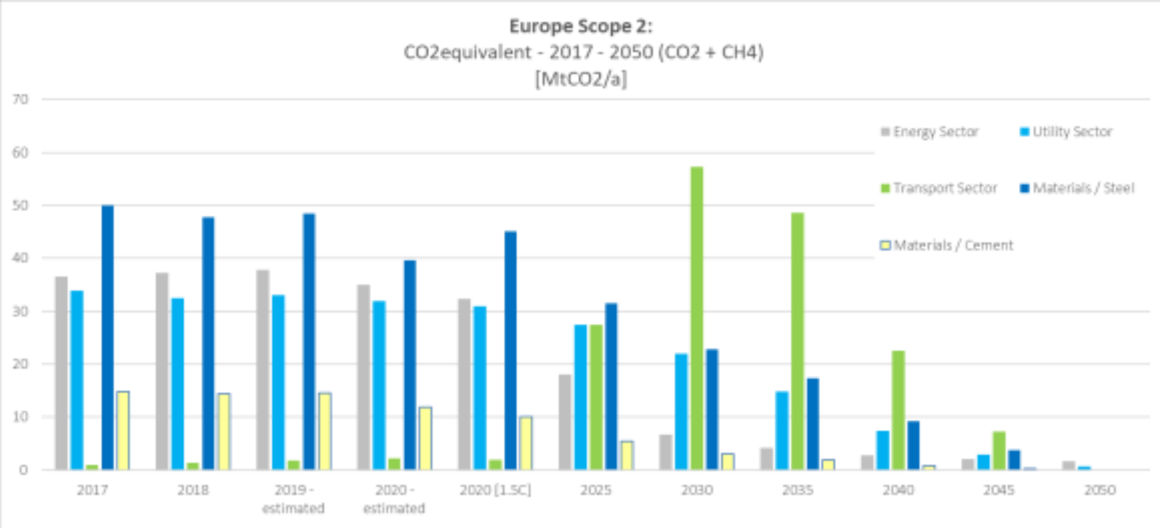


Figure 7 shows the development of Europe's energy supply structure under the 1.5°C pathway. The energy supply by source in petajoules per year [PJ/a] is shown on the left axis and the carbon intensity of the overall energy sector—across all sources—in tons CO_2 per PJ [tCO_2/PJ] is shown on the right axis. Carbon intensity will decline by 57%, from around 53,000 tCO_2/PJ in 2019 to 30,000 tCO_2/PJ in 2030, due to the required European coal phase-out by 2030.

Lignite and hard coal will decrease fastest, at 12% per year [%/a] between 2020 and 2025 and by 17%/a between 2025 and 2030. Oil will follow, with lower decrease rates of 8%/a in 2020–2025 and 12%/a in 2025–2030. Gas is the last fossil fuel to be phased out, with production volumes decreasing by around 2%/a until 2030 and by 5%/a towards 2035. The generation of renewable electricity will increase annually by 10% until 2030 to supply the increased electrification rates in the *Transport* and (industrial) *Heating* sectors and to replace coal-based power generation.

Renewable fuels (hydrogen and synthetic fuels) will increase to 170 PJ by 2025 and to 1,400 PJ by 2030.

The increase in renewable energy—both electricity and synthetic fuels—must go hand in hand with the increased electrification of road transport and heating in order to replace fossil fuels. The *Energy* and *Utilities* sectors will play important roles in organizing the energy transition, especially in supporting the road *Transport* sector and supplying sufficient amounts of renewable electricity. However, both the *Steel* and *Cement* industry sectors have the option to purchase renewable energy—for both process heat and electricity—either from independent power producers or by investing in their own capacities, if utilities are unable to supply the required low-carbon energy.

Figure 7: OECD Europe's development of the energy supply structure under the 1.5°C pathway

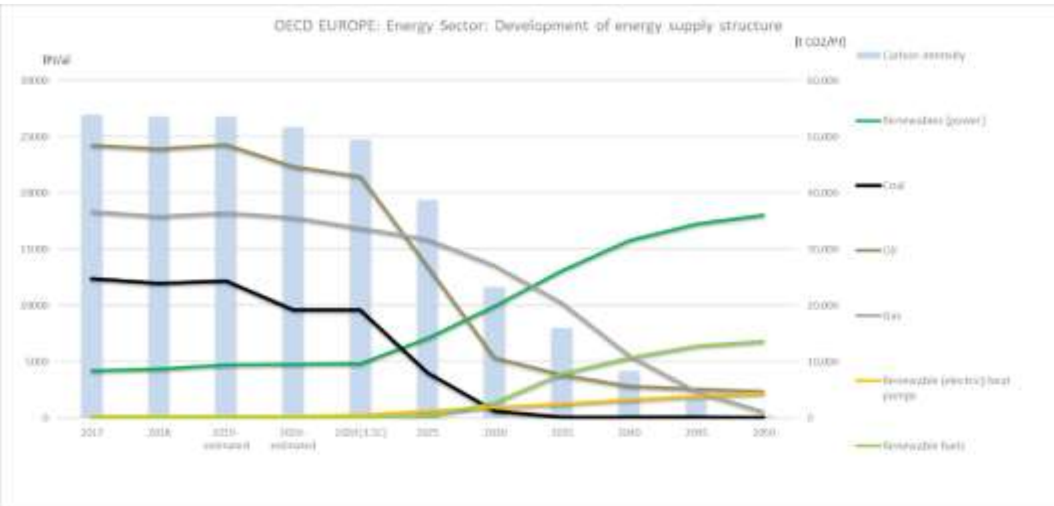


Table 11: OECD Europe: Key Results—*Energy*, *Utilities*, and *Transport* sectors

OECD Europe		2018	2019	2020	2020	2025	2030	2035	2040	2045	2050
Sub-sector	Units	Base year	[estimated]	[estimated]	[1.5 °C]	Projection					
Total Energy, Gas, Oil & Coal Sectors -											
Total CO_2 Emissions	[$MtCO_2$/a]	3,712	3,767	3,371	3,218	2,040	971	631	297	106	3
Variation compared with 2019	[%]				−15%	−46%	−74%	−83%	−92%	−97%	−100%
Energy Sector - Scope 1: Total CO_2 equivalents (CO_2e)	[$MtCO_2e$]	3,950	4,008	3,586	3,433	2,189	1,054	691	333	129	17
Change to 2019	[%]				−14%	−45%	−74%	−83%	−92%	−97%	−100%
Energy Sector - Scope 2: Total CO_2 equivalents	[$MtCO_2e$]	37	38	35	32	18	7	4	3	2	2
Change to 2019	[%]				−15%	−52%	−82%	−89%	−93%	−95%	−96%
Total Energy Production	[PJ/a]	73,686	74,778	69,319	69,309	56,512	45,249	42,974	39,648	37,928	37,336
Variation compared with 2019	[%]				93%	76%	61%	57%	53%	51%	50%
Intensities											
Sector CO_2 Intensity	[$MtCO_2$/PJ]	0.05	0.05	0.05	0.05	0.04	0.02	0.01	0.01	0.00	0.00
Variation compared with 2019	[%]				−8%	−28%	−57%	−71%	−85%	−94%	−100%
Sector **CO_2 equivalent** Intensity (CO_2 + CH_4)	[$MtCO_2$/PJ]	0.05	0.05	0.05	0.05	0.04	0.02	0.02	0.01	0.00	0.00
Variation compared with 2019	[%]				−8%	−28%	−57%	−70%	−84%	−94%	−99%
Regional Energy Intensity	[PJ/$GDP]	3.2	3.2	2.9	2.9	2.2	1.6	1.4	1.2	1.1	1.0
Variation compared with 2019	[%]				91%	68%	50%	44%	38%	34%	32%
Total Utilities Sector											
Total CO_2 Emissions	[$MtCO_2$/a]	2,072	2,104	1,863	1,790	1,357	1,035	765	380	136	0
Variation compared with 2019	[%]				−15%	−35%	−51%	−64%	−82%	−94%	−100%
Utilities - Scope 1: Total CO_2 equivalents	[$MtCO_2e$]	2,125	2,157	1,916	1,837	1,408	1,112	867	461	185	33
Change to 2019	[%]				−15%	−35%	−48%	−60%	−79%	−91%	−98%
Utilities - Scope 2: Total CO_2 equivalents	[$MtCO_2e$]	33	33	32	31	27	22	15	7	3	1
Change to 2019	[%]				−6%	−17%	−33%	−55%	−78%	−91%	−98%
Total Energy Production	[PJ/a]	29,666	30,111	28,810	28,587	28,548	30,116	32,416	31,230	30,594	30,327
Variation compared with 2019	[%]				−5%	−5%	0%	8%	4%	2%	1%
Intensities											
Sector CO_2 Intensity	[$MtCO_2$/PJ]	0.07	0.07	0.06	0.06	0.05	0.03	0.02	0.01	0.00	0.00
Variation compared with 2019	[%]				−10%	−32%	−51%	−66%	−83%	−94%	−100%
Sector **CO_2 equivalent** Intensity (CO_2 + CH_4)	[**$MtCO_2e$**/PJ]	0.07	0.07	0.07	0.06	0.05	0.04	0.03	0.01	0.01	0.00
Variation compared with 2019	[%]				90%	69%	52%	37%	21%	8%	2%
Regional Energy Intensity	[PJ/$GDP]	1.29	1.28	1.21	1.20	1.09	1.07	1.06	0.95	0.88	0.82
Variation compared with 2019	[%]				−7%	−15%	−17%	−17%	−26%	−32%	−36%
Total Transport Sector											
Transport - Scope 1: Total CO_2 equivalents	[$MtCO_2e$]	903	901	891	891	524	135	57	8	0	0
Change to 2019	[%]	0	0	0	-1%	-42%	-85%	-94%	-99%	-100%	-100%
Transport - Scope 2: Total CO_2 equivalents	[$MtCO_2e$]	1.3	1.8	2.2	1.9	27.5	57.3	48.5	22.5	7.2	0.0
Change to 2019	[%]										
Total Sector Energy Demand	[PJ/a]	12,919	12,894	12,804	13,172	8,985	6,113	6,044	5,151	4,558	4,131
Variation compared with 2019	[%]				2%	-30%	-53%	-53%	-60%	-65%	-68%
Intensities											
Air Passenger Transport											
Emission Intensity	[gCO_2/pkm]	125.57	117.20	117.20	117.20	97.00	75.34	45.58	0.00	0.00	0.00
Emission intensity reduction compared with 2019	[%]				0%	-17%	-36%	-61%	-100%	-100%	-100%
Energy Intensity	[MJ/pkm]	1.7	1.6	1.6	1.6	1.5	1.4	1.3	1.3	1.3	1.2
Emission intensity reduction compared with 2019	[%]				0%	-6%	-14%	-17%	-20%	-21%	-23%
Air Freight Transport											
Emission Intensity	[gCO_2/tkm]	2360.26	2237.12	2237.12	2237.12	1878.36	1493.12	911.57	0.00	0.00	0.00
Emission intensity reduction compared with 2019	[%]				0%	-16%	-33%	-59%	-100%	-100%	-100%
Energy Intensity	[MJ/tkm]	32.2	30.52	30.52	30.52	29.12	27.16	26.46	25.76	25.48	25.2
Emission intensity reduction compared with 2019	[%]				0%	-5%	-11%	-13%	-16%	-17%	-17%
Navigation: Passenger Transport											
Emission Intensity	[gCO_2/pkm]	4.55	4.55	4.55	4.51	3.93	2.96	1.75	0.00	0.00	0.00
Emission intensity reduction compared with 2019	[%]				−1%	−14%	−35%	−62%	−100%	−100%	−100%
Energy Intensity	[MJ/pkm]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Emission intensity reduction compared with 2019	[%]				−1%	−2%	−3%	−4%	−5%	−6%	−7%
Navigation: Freight Transport											
Emission Intensity	[gCO_2/tkm]	15.35	15.35	15.35	15.35	13.28	9.94	5.83	0.00	0.00	0.00
Emission intensity reduction compared with 2019	[%]				0%	−13%	−35%	−62%	−100%	−100%	−100%
Energy Intensity	[MJ/tkm]	0.19	0.19	0.19	0.19	0.19	0.18	0.18	0.18	0.17	0.17
Emission Intensity reduction compared with 2019	[%]				0%	−2%	−3%	−5%	−7%	−8%	−9%
Road: Light-Duty Vehicles/Passenger Transport											
Emission Intensity	[gCO_2/pkm]	98.17	100.11	111.53	105.64	66.40	17.05	6.90	0.94	0.00	0.00
Emission intensity reduction compared with 2019	[%]				−12%	−26%	−62%	−85%	−93%	−95%	−95%
Energy Intensity	[MJ/pkm]	1.5	1.5	1.5	1.3	1.2	0.9	0.7	0.6	0.5	0.5
Emission intensity reduction compared with 2019	[%]				−12%	−22%	−38%	−50%	−58%	−63%	−65%
Road: Trucks/Freight Transport											
Emission Intensity	[gCO_2/tkm]	112	112	112	120	80	23	11	2	0	0
Emission intensity reduction compared with 2019	[%]				−6%	−22%	−73%	−97%	−100%	−100%	−100%
Energy Intensity	[MJ/tkm]	1.3	1.3	1.3	1.3	1.2	0.9	0.8	0.6	0.6	0.5
Emission intensity reduction compared with 2019	[%]				0%	−9%	−26%	−41%	−49%	−55%	−57%

Table 12: OECD Europe: Key Results—*Steel* and *Cement* sectors

OECD Europe		2018	2019	2020	2020	2025	2030	2035	2040	2045	2050
Sub-sector	Units	Base year	[estimated]	[estimated]	[1.5 °C]	Projection					
Total Materials–Steel											
Scope 1: Total direct emissions in CO_2 equivalents (CO_2e)	[$MtCO_2e/a$]	447	450	425	406	346	238	157	95	57	26
Change to 2019	[%]				−10%	−23%	−47%	−65%	−79%	−87%	−94%
Scope 2: Electricity generation for steel production	[tCO_2/ton steel]	48	48	40	45	31	23	17	9	4	0
Change to 2019	[%]				−7%	−35%	−53%	−64%	−81%	−92%	−100%
Specific energy-related CO_2 emissions per ton of steel	[tCO_2/ton steel]	2.06	2.07	1.96	1.93	1.55	0.97	0.60	0.34	0.19	0.08
Deviation compared with 2019	[%]				−7%	−25%	−53%	−71%	−83%	−91%	−96%
Specific process-related CO_2 emissions per ton of steel	[tCO_2/ton steel]	1.06	1.06	1.06	1.06	0.92	0.58	0.36	0.22	0.15	0.08
Deviation compared with 2019	[%]				−49%	−55%	−72%	−83%	−89%	−93%	−96%
Total Final Energy Demand	[PJ/a]	3,764	3,821	3,560	3,696	3,693	3,889	3,933	3,965	4,017	4,055
Deviation energy demand compared with 2019	[%]				−3%	−3%	2%	3%	4%	5%	6%
Product Energy Intensity	[GJ/ton steel]	18.6	18.6	18.6	17.6	16.6	15.9	15.1	14.3	13.4	12.6
Deviation compared with 2019	[%]				−6%	−11%	−15%	−19%	−23%	−28%	−32%
Total Materials–Cement											
Scope 1: Total direct emissions in CO_2 equivalents	[$MtCO_2$ equiv./a]	148	142	138	140	141	127	109	93	76	62
Change to 2019	[%]				−2%	−1%	−11%	−23%	−35%	−47%	−57%
Scope 2: Emissions - Electricity generation for cement production	[$MtCO_2$ equiv./a]	14	15	12	10	5	3	2	1	0	0
Change to 2019	[%]				−31%	−63%	−80%	−87%	−94%	−98%	−100%
Total CO_2 Emissions	[mio. tCO_2/a]	58.2	52.8	48.1	45.5	42.0	36.0	24.5	14.1	5.3	0.0
CO_2 emissions reduction compared with 2019	[%]				−14%	−20%	−32%	−54%	−73%	−90%	−100%
Specific energy-related CO_2 emissions per ton of clinker	[tCO_2/ton clinker]	0.195	0.170	0.162	0.150	0.148	0.133	0.090	0.051	0.019	0.000
Deviation compared with 2019	[%]				−12%	−13%	−22%	−47%	−70%	−89%	−100%
Specific energy-related CO_2 emissions per ton of cement	[tCO_2/ton cement]	0.237	0.213	0.196	0.177	0.162	0.141	0.094	0.053	0.020	0.000
Deviation compared with 2019	[%]				−17%	−24%	−34%	−56%	−75%	−91%	−100%
Total Energy Demand	[PJ/a]	965	979	921	963	963	938	943	951	936	919
Deviation in energy demand compared with 2019	[%]				−2%	−2%	−4%	−4%	−3%	−4%	−6%
Product Energy Intensity (thermal + electricity)	[GJ/ton cement]	2.8	2.8	2.7	2.6	2.5	2.4	2.4	2.3	2.2	2.1
Deviation compared with 2019	[%]				−7%	−11%	−15%	−17%	−18%	−21%	−24%

OECD North America: Key Sector-based Results for 1.5°C Target

OECD North America's *Scope 1* and *Scope 2* emissions for 2018 were calculated with the latest published statistical data from IEA, August 2020[20]. The 2019 data are based on the increase in GDP of 2.0% for OECD North America (1.7% for Canada. 2.2% for USA, and −0.1% for Mexico) (OECD 2020)[21]. For the ongoing year 2020, two different GDP developments are included: an increase of 2.1%, estimated before the COVID-19 crisis, and the OECD Economic Outlook (June 2020)[22] estimate of −8.5% for the North American region. The subsequent years are based on the assumption that the economy will recover and that by 2025, GDP will be on a constant growth trajectory.

On the global level, the COVID-19 crisis led to an overall reduction in oil production of 8% (IEA, 2020)[23] in the first half of 2020; for the whole year, we assume a drop of 8%. For coal, the estimated decline in 2020 of −8% due to the COVID-19 crisis (IEA, 2020)[23] will remain and production will not jump back to the production volumes of 2019. The IEA found that on average, every month of full lockdown reduced demand by 20%, or over 1.5% on an annual basis. In this analysis, we assume a global decline of 7% for the 2020 demand under the 2020 estimate, whereas the demand under the 2020 (1.5 °C) projection (for comparison) decreased by 2% due to technical efficiency measures. No detailed regional estimates for 2020 were available at the time of writing, so we extended the global decline rates to the North American region.

Figure 8 shows the global *Scope 1* emissions in CO_2 equivalents for energy-related CO_2 and CH_4 emissions—no other GHGs are included in this analysis. The *Energy* sector covers all CO_2 and CH_4 emissions related to the extraction of fossil fuels, the production of secondary products in refineries, coal products, and the transport of fuel to utilities for re-sale or use in power plants. The *Energy* sector includes renewable energy generation but not its operation or re-sale.

The *Utilities* sector covers electricity and gas re-sale and the resulting CO_2 and CH_4 emissions. Therefore, emissions under the *Scope 1* methodology count emissions twice; natural gas CO_2 emissions are accounted for in the *Energy* sector (for its extraction), in the *Utility* sector (for its distribution and re-sale) and for the end-users of gas or gas-generated electricity. Therefore, the *Scope 1* emissions of different sectors do not add up.

The *Transport* sector includes aviation, shipping, and road transport and focuses on the operation of planes, ships, and road vehicles, but excludes the energy required for the manufacture of those because no data are available. Finally, the *Cement* and *Steel* sectors cover energy-related CO_2 and CH_4 emissions for the energy consumed and process-related emissions.

A 1.5°C climate mitigation pathway requires that we remain within a global cumulative carbon budget of 450 $GtCO_2$ (2015–2050). Based on this, the North American carbon budget for energy-related CO_2 emissions for this time frame is 57 $GtCO_2$—or an average of 1.7 $GtCO_2$ per year until 2050. OECD North America's energy-related CO_2 emissions in 2019 were around 5.9 $GtCO_2$.

The OECM-derived 1.5°C mitigation pathway for OECD North America requires a phase-out of brown and hard coal by 2030. Therefore, the very significant CO_2 reduction rate for the *Energy* sector in 2019–2025 is −43%. In their latest analysis (CA 2020), *Climate Analytics,* an internationally recognized think tank with offices in Europe, Australia, and the Americas, confirmed our estimates that the OECD region must phase-out coal by 2031[24]. Whereas over 300 coal power plants have been retired for economic reasons and/or because they had reached the end of their technical lifetime in the USA, over 200 coal power plants are still active, with no political agreement for their shut down until 2030[25].

Because coal must be phased out within 10 years, the *Utilities* sector must also implement a rapid decarbonization of power generation. North America's CO_2 emissions from electricity generation must decrease from 2.2 $GtCO_2$ in 2019 to 1.01 $GtCO_2$ in 2025. This reduction is entirely based on the assumption that the coal phase-out is well underway and will be successfully implemented by 2030. The overall energy-related CO_2 emissions from the *Utilities* sector—for electricity and gas—must decrease by 36%, from around 3.5 $GtCO_2$ in 2019 to 2.5 $GtCO_2$ in 2025.

These significant reductions will be achieved almost exclusively with two measures:

1. A rapid increase in cost-competitive renewable power generation to replace fossil fuel—mainly brown- and hard-coal-based power generation—to decarbonize the electricity sector.

[20] IEA—Advanced World Energy Balances–released August 2020
[21] OECD 2020, Online Statistic, viewed in August 2020, https://stats.oecd.org/index.aspx?queryid=60703
[22] OECD Economic Outlook, June 2020, viewed in August 2020, https://www.oecd.org/economic-outlook/
[23] IEA 2020, Global Energy Review 2020, https://www.iea.org/reports/global-energy-review-2020
[24] CA 2020, Climate Analytics Briefings—Coal Phase-Out, website, viewed in September 2020, https://climateanalytics.org/briefings/coal-phase-out/
[25] Sierra Club – Beyond Coal website, viewed September 2020, https://coal.sierraclub.org/

2. Decarbonized electricity will replace the use of fossil fuels in the *Transport* and *Heating* sectors. The two most important measures to achieve high electrification shares are the uptake of electric mobility and electricity-based heating systems (mainly heat pumps). Both technology groups (electric vehicles and electricity-based heating systems) will increase the availability of electricity storage and demand-side management (charging and heating concepts), which will be used for the integration of large shares of variable solar and wind power generation.

The reduction in process-related emissions requires structural changes in the industry itself—with a change in manufacturing processes—and requires long-term planning. Therefore, these measures are taken into account for the emission reductions after 2030. The *Steel* and *Cement* industry sectors in North America are currently responsible for around 0.3 $GtCO_2$ equivalents—about half are process emissions, which are not related to the energy used for production.

Figure 8: OECD North America: Scope 1 emissions in CO_2 equivalents

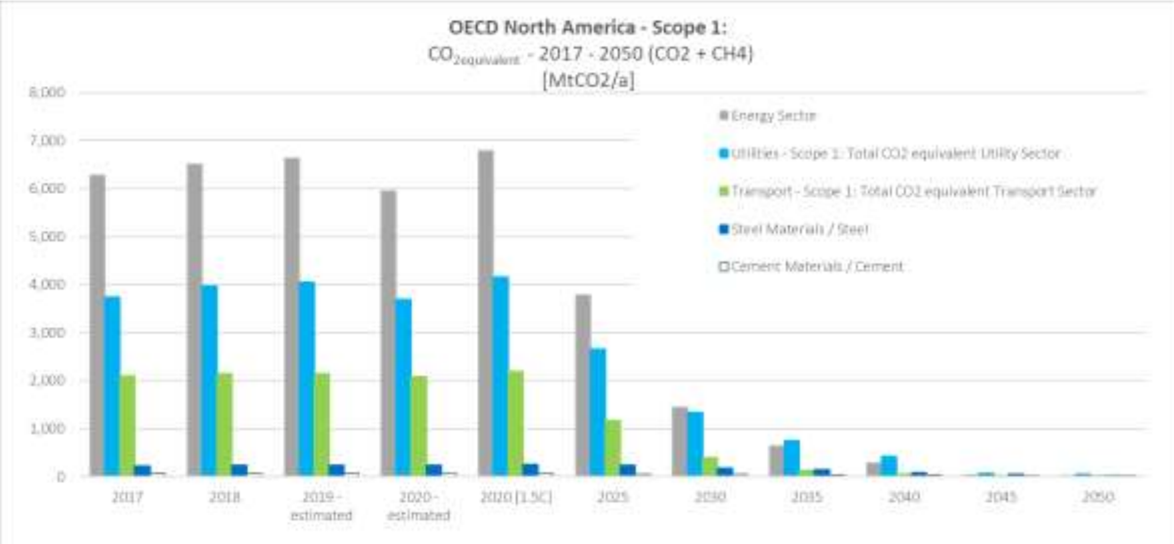


Figure 9 shows North America's *Scope 2* emissions in CO_2 equivalents, which cover emissions related to the electricity consumption of each sector analysed. The *Scope 2* emissions of the *Energy* and *Utilities* sectors include only the electricity demand for the sector itself: internal electricity consumption for power plants ('own consumption') and the electricity used for fossil fuel extraction and transport. They do not cover the overall electricity generated and distributed in either sector. For example, a coal power plant generates electricity for consumers. The power plant itself requires electricity to operate. The *Scope 2* emissions for this power plant only include the self-consumed amount, whereas the actual electricity generated will be transported to consumers (e.g., the steel industry) to which these emissions are then assigned.

Under the 1.5°C pathway, the *Transport* sector will replace fossil fuels with electricity to a large extent. The electrification of road vehicles is a core measure to significantly reduce the demand for oil and increase the electricity demand of the sector. Thus, the *Scope 1* emissions will drop sharply between 2020 and 2035, whereas *Scope 2* emissions will nearly quadruple between 2020 and 2025. Therefore, the decarbonization of the *Electricity* sector with increased shares of renewable power generation is vital to achieve the reduction targets for the *Transport* sector and for the other two sectors analysed—*Steel* and *Cement.*

Therefore, the *Utilities* sector has a key responsibility to shift electricity generation from fossil fuels to renewables-based power generation to allow other industries, financial sectors, and consumers to achieve their *Scope 1* and *Scope 2* emission targets. Another option for the analysed sectors to achieve these targets is to purchase renewable electricity directly from renewable power producers via power purchase agreements (PPAs) or to invest in their own power generation and move away from fossil-fuel-dominated utilities.

Between 2035 and 2045, the carbon intensity of electricity will drop sharply and by 2050, North America's electricity generation will be carbon-free. The increased electricity demand will have no effect on the *Scope 2* emissions of any industry sector.

Figure 9: OECD North America Scope 2 emissions in CO_2 equivalents—emissions for the use of electricity

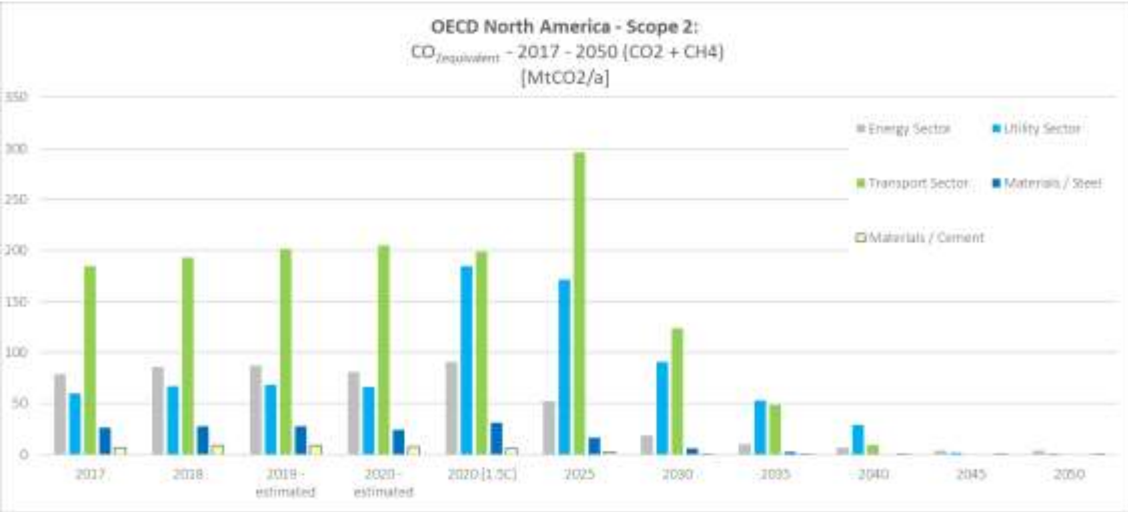


Figure 10 shows the development of North America's energy supply structure under the 1.5°C pathway. The energy supply by source in petajoules per year [PJ/a] is shown on the left axis and the carbon intensity of the overall energy sector—across all sources—in tons CO_2 per PJ [tCO_2/PJ] is shown on the right axis. The carbon intensity declines by 66%, from around 58,000 tCO_2/PJ in 2019 to 20,000 tCO_2/PJ in 2030, due to the required coal phase-out by 2030.

Lignite and hard coal decrease fastest, at 12% per year [%/a] between 2020 and 2025 and by 20%/a between 2025 and 2030. Oil follows, with lower decrease rates of 8%/a in 2020–2025 and 11%/a in 2025–2030. Gas is the last fossil fuel to be phased out, with production volumes decreasing by around 2%/a in 2020–2025 and by 9%/a in 2030–2040.

The generation of renewable electricity will double between 2020 and 2025, and again in the following 5 years to 2030, to supply the increased electrification rates in the *Transport* and (industrial) *Heating* sectors and to replace coal-based power generation.

Renewable fuels—hydrogen and synthetic fuels—will increase to 460 PJ by 2025 and to 3,600 PJ by 2030.

The increase in renewable energy—both electricity and synthetic fuels—must go hand in hand with the increased electrification of road transport and heating in order to replace fossil fuels. The *Energy* and *Utilities* sectors will play important roles in organizing the transition, especially to support the road *Transport* sector and supply sufficient amounts of renewable electricity. However, both the *Steel* and *Cement* industry sectors have the option to purchase renewable energy—for both process heat and electricity—either from independent power producers or by investing in their own capacities, if the *Utilities* sector is unable to supply the required low-carbon energy.

Figure 10: OECD North America's development of its energy supply structure

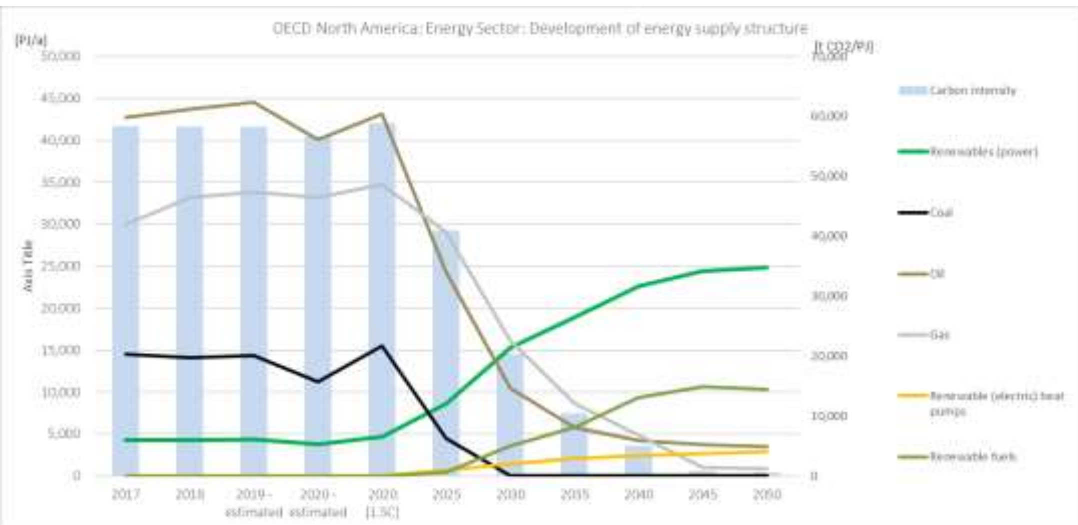


Table 13: OECD North America: Key Results—*Utilities* and *Transport* sectors

OECD North America		2018	2019	2020	2020	2025	2030	2035	2040	2045	2050
Sub-sector	Units	Base year	[estimated]	[estimated]	[1.5 °C]	Projection					
Total Energy, Gas, Oil & Coal Sector -											
Total CO_2 Emissions	[$MtCO_2$/a]	6,266	6,389	5,742	6,408	3,513	1,326	562	247	22	7
Variation compared with 2019	[%]				0%	−45%	−79%	−91%	−96%	−100%	−100%
Energy Sector - Scope 1: Total CO_2 equivalents (CO_2e)	[Mt**CO_2e**]	6,505	6,633	5,947	6,652	3,648	1,373	588	266	40	24
Change to 2019	[%]				0%	−45%	−79%	−91%	−96%	−99%	−100%
Energy Sector - Scope 2: Total CO_2 equivalents	[Mt**CO_2e**]	86	88	81	90	51	18	10	6	4	4
Change to 2019	[%]				2%	−42%	−80%	−89%	−93%	−95%	−96%
Total Energy Production	[PJ/a]	111,913	114,131	105,226	113,386	90,304	70,234	60,336	59,004	56,387	55,513
Variation compared with 2019	[%]				99%	79%	62%	53%	52%	49%	49%
Intensities											
Sector CO_2 Intensity	[$MtCO_2$/PJ]	0.06	0.06	0.05	0.06	0.04	0.02	0.01	0.00	0.00	0.00
Variation compared with 2019	[%]				1%	−31%	−66%	−83%	−93%	−99%	−100%
Sector **CO_2 equivalent** Intensity (CO_2 + CH_4)	[$MtCO_2$/PJ]	0.06	0.06	0.06	0.06	0.04	0.02	0.01	0.00	0.00	0.00
Variation compared with 2019	[%]				101%	69%	34%	17%	8%	1%	1%
Regional Energy Intensity	[PJ/$GDP]	4.7	4.7	4.2	4.6	3.3	2.3	1.8	1.6	1.4	1.2
Variation compared with 2019	[%]				97%	69%	49%	38%	33%	29%	26%
Total Utilities Sector											
Total CO_2 Emissions	[$MtCO_2$/a]	3,778	3,854	3,512	3,866	2,352	1,059	511	236	15	0
Variation compared with 2019	[%]				0%	−39%	−73%	−87%	−94%	−100%	−100%
Utilities - Scope 1: Total CO_2 equivalents	[Mt**CO_2e**]	3,963	4,043	3,697	4,032	2,535	1,271	705	408	62	48
Change to 2019	[%]				0%	−37%	−69%	−83%	−90%	−98%	−99%
Utilities - Scope 2: Total CO_2 equivalents	[Mt**CO_2e**]	67	68	66	65	49	23	10	5	1	1
Change to 2019	[%]				−4%	−28%	−67%	−85%	−92%	−98%	−99%
Total Energy Production	[PJ/a]	52,358	53,405	51,253	51,771	47,271	42,186	40,514	45,686	45,953	45,998
Variation compared with 2019	[%]				−3%	−11%	−21%	−24%	−14%	−14%	−14%
Intensities											
Sector CO_2 Intensity	[$MtCO_2$/PJ]	0.07	0.07	0.07	0.07	0.05	0.03	0.01	0.01	0.00	0.00
Variation compared with 2019	[%]				3%	−31%	−65%	−83%	−93%	−100%	−100%
Sector **CO_2 equivalent** Intensity (CO_2 + CH_4)	[Mt**CO_2e**/PJ]	0.08	0.08	0.07	0.08	0.05	0.03	0.02	0.01	0.00	0.00
Variation compared with 2019	[%]				103%	71%	40%	23%	12%	2%	1%
Regional Energy Intensity	[PJ/$GDP]	7.92	7.78	7.20	7.27	5.11	3.71	2.81	2.61	2.09	1.74
Variation compared with 2019	[%]				−7%	−34%	−52%	−64%	−66%	−73%	−78%
Total Transport Sector											
Transport - Scope 1: Total CO_2 equivalents	[Mt**CO_2e**]	2,138	2,142	2,077	2,192	1,175	396	135	58	1	0
Change to 2019	[%]	0	0	0	3%	-45%	-81%	-94%	-97%	-100%	-100%
Transport - Scope 2: Total CO_2 equivalents	[Mt**CO_2e**]	1.8	3.1	4.7	6.1	65.5	57.1	30.6	7.8	0.2	0.0
Change to 2019	[%]										
Total Sector Energy Demand	[PJ/a]	32,214	32,351	31,672	32,304	26,727	19,336	15,068	12,035	10,425	9,532
Variation compared with 2019	[%]				0%	-17%	-40%	-53%	-63%	-68%	-70%
Intensities											
Air Passenger Transport											
Emission Intensity	[gCO_2/pkm]	125.57	117.20	117.20	117.20	92.87	59.27	28.61	0.00	0.00	0.00
Emission intensity reduction compared with 2019	[%]				0%	-21%	-49%	-76%	-100%	-100%	-100%
Energy Intensity	[MJ/pkm]	1.7	1.6	1.6	1.6	1.5	1.4	1.3	1.3	1.3	1.2
Emission intensity reduction compared with 2019	[%]				0%	-6%	-14%	-17%	-20%	-21%	-23%
Air Freight Transport											
Emission Intensity	[gCO_2/tkm]	2360.26	2237.12	2237.12	2237.12	1798.31	1174.59	572.16	0.00	0.00	0.00
Emission intensity reduction compared with 2019	[%]				0%	-20%	-47%	-74%	-100%	-100%	-100%
Energy Intensity	[MJ/tkm]	32.2	30.52	30.52	30.52	29.12	27.16	26.46	25.76	25.48	25.2
Emission intensity reduction compared with 2019	[%]				0%	-5%	-11%	-13%	-16%	-17%	-17%
Navigation: Passenger Transport											
Emission Intensity	[gCO_2/pkm]	4.55	4.55	4.55	4.51	3.97	3.25	2.62	0.00	0.00	0.00
Emission intensity reduction compared with 2019	[%]				−1%	−13%	−29%	−42%	−100%	−100%	−100%
Energy Intensity	[MJ/pkm]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Emission intensity reduction compared with 2019	[%]				−1%	−2%	−3%	−4%	−5%	−6%	−7%
Navigation: Freight Transport											
Emission Intensity	[gCO_2/tkm]	15.35	15.35	15.35	15.35	13.43	10.90	8.74	0.00	0.00	0.00
Emission intensity reduction compared with 2019	[%]				0%	−13%	−29%	−43%	−100%	−100%	−100%
Energy Intensity	[MJ/tkm]	0.19	0.19	0.19	0.19	0.19	0.18	0.18	0.18	0.17	0.17
Emission intensity reduction compared with 2019	[%]				0%	−2%	−3%	−5%	−7%	−8%	−9%
Road: Light -Duty Vehicles/Passenger Transport											
Emission Intensity	[gCO_2/pkm]	227.01	231.98	258.10	252.96	146.74	48.85	15.92	6.68	0.08	0.01
Emission intensity reduction compared with 2019	[%]				−2%	−9%	−43%	−66%	−78%	−83%	−84%
Energy Intensity	[MJ/pkm]	1.5	1.5	1.5	1.4	1.4	1.0	0.8	0.6	0.5	0.5
Emission Intensity reduction compared with 2019	[%]				−2%	−6%	−30%	−46%	−58%	−63%	−65%
Road: Trucks/Freight Transport											
Emission Intensity	[gCO_2/tkm]	231	232	231	261	157	60	23	10	0	0
Emission intensity reduction compared with 2019	[%]				5%	−40%	−86%	−109%	−102%	−102%	−99%
Energy Intensity	[MJ/tkm]	1.3	1.3	1.3	1.3	1.2	0.9	0.8	0.6	0.6	0.5
Emission intensity reduction compared with 2019	[%]				0%	−9%	−26%	−41%	−49%	−55%	−57%

Table 14: OECD North America: Key Results—*Steel* and *Cement* sectors

OECD North America		2018	2019	2020	2020	2025	2030	2035	2040	2045	2050
Sub-sector	Units	Base year	[estimated]	[estimated]	[1.5°C]	Projection					
Total Materials–Steel											
Scope 1: Total direct emissions in CO_2 equivalents (CO_2e)	[MtCO_2e/a]	233	240	235	253	235	185	143	88	51	15
Change to 2019	[%]				6%	−2%	−23%	−40%	−63%	−79%	−94%
Scope 2: Emissions - Electricity generation for steel production	[tCO_2/ton steel]	28	28	24	31	16	6	3	1	0	0
Change to 2019	[%]				11%	−42%	−79%	−90%	−97%	−100%	−100%
Specific energy-related CO_2 emissions per ton of steel	[tCO_2/ton steel]	1.94	1.93	1.89	2.10	1.84	1.32	0.96	0.55	0.30	0.08
Deviation compared with 2019	[%]				9%	−4%	−32%	−50%	−71%	−85%	−96%
Specific process-related CO_2 emissions per ton of steel	[tCO_2/ton steel]	1.06	1.06	1.06	1.06	1.13	0.95	0.79	0.49	0.29	0.08
Deviation compared with 2019	[%]				−45%	−41%	−51%	−59%	−74%	−85%	−96%
Total Final Energy Demand	[PJ/a]	1,801	1,837	1,752	2,168	2,222	2,383	2,458	2,532	2,626	2,720
Deviation in energy demand compared with 2019	[%]				18%	21%	30%	34%	38%	43%	48%
Product Energy Intensity	[GJ/ton steel]	18.6	18.6	18.6	18.0	17.5	17.0	16.5	15.9	15.4	14.8
Deviation compared with 2019	[%]				−3%	−6%	−9%	−12%	−14%	−17%	−20%
Total Materials–Cement											
Scope 1: Total direct emissions in CO_2 equivalents	[MtCO_2e/a]	72	71	69	63	60	50	41	34	29	25
Change to 2019	[%]				−11%	−15%	−30%	−43%	−52%	−60%	−65%
Scope 2: Emissions - Electricity generation for cement production	[MtCO_2e/a]	9	9	7	6	3	1	0	0	0	0
Change to 2019	[%]				−27%	−69%	−91%	−97%	−99%	−100%	−100%
Total CO_2 Emissions	[MtCO_2/a]	36.5	35.1	32.4	25.0	20.5	13.3	6.7	2.5	0.5	0.0
CO_2 emissions reduction compared with 2019	[%]				−29%	−42%	−62%	−81%	−93%	−98%	−100%
Specific energy-related CO_2 emissions per ton of clinker	[tCO_2/ton clinker]	0.311	0.293	0.276	0.197	0.180	0.127	0.063	0.024	0.005	0.000
Deviation compared with 2019	[%]				−33%	−39%	−57%	−78%	−92%	−98%	−100%
Specific energy-related CO_2 emissions per ton of cement	[tCO_2/ton cement]	0.373	0.357	0.330	0.241	0.198	0.132	0.065	0.024	0.005	0.000
Deviation compared with 2019	[%]				−32%	−45%	−63%	−82%	−93%	−99%	−100%
Total Energy Demand	[PJ/a]	507	517	490	389	393	384	382	380	374	368
Deviation in energy demand compared with 2019	[%]				−25%	−24%	−26%	−26%	−26%	−28%	−29%
Product Energy Intensity (thermal + electricity)	[GJ/ton cement]	3.7	3.7	3.5	2.7	2.6	2.5	2.4	2.3	2.2	2.1
Deviation compared with 2019	[%]				−29%	−31%	−34%	−36%	−38%	−41%	−43%

Key Sector-based Results for 1.5°C Target—Regional Differences between Europe and North America

The carbon budget for energy-related CO_2 emissions between 2015 and 2050 will differ significantly between OECD Europe (40.5 $GtCO_2$) and OECD North America (57 $GtCO_2$). The reason for the higher carbon budget for North America is the different starting points of the current energy system. The European energy intensity is currently at 3.2 PJ per dollar GDP [PJ/$GDP], whereas OECD North America requires 4.7 PJ for the same economic activity. By 2035, the energy intensities of both regions will be within the same range, at around 1.6 PJ/$GDP. These different energy intensities are not only based on the energy supply structures but also on the different industry structures. North America's *Energy* sector produces significantly more oil and gas than Europe's.

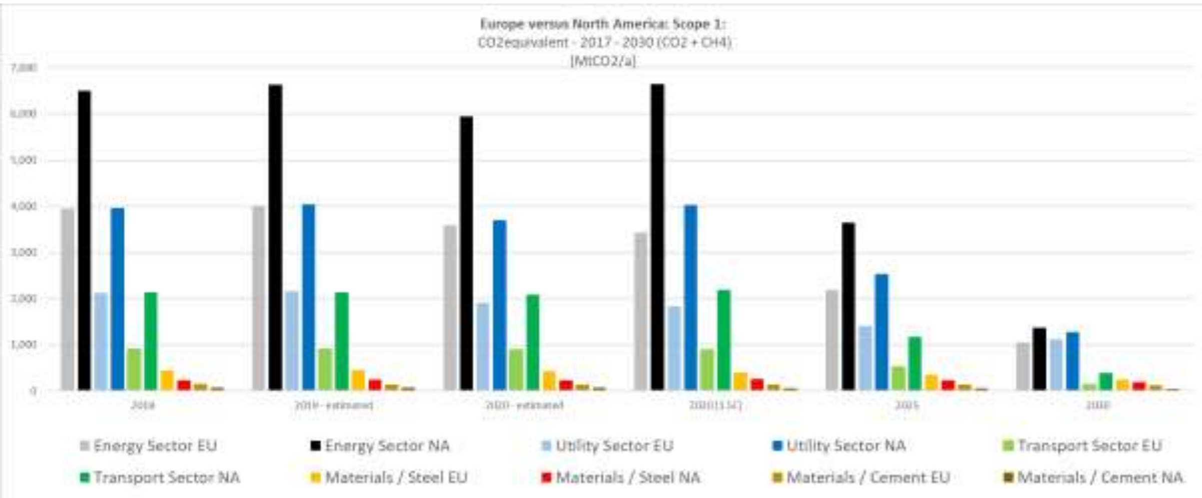
However, the CO_2 reduction rate for the *Energy* sectors in both regions are similar under the 1.5°C pathway between 2019 and 2025, at −46% for Europe and −43% in North America. To achieve this, a phase-out of thermal hard coal and brown coal for energy production until 2030 is required, with no alternative. Whereas several European countries either already have a political commitment to phase-out coal or have started the discussion, none of the North American countries have political agreements for a coal shut-down until 2030.

Although the total electricity demand in North America is 5,432 TWh (2019), significantly higher than in Europe (3,300 TWh), the overall amount of renewable electricity is almost identical: 1,370 TWh in Europe and 1,330 TWh in North America. Under the 1.5°C pathway, the share of renewable energy must increase to around 80% by 2030 in both regions. Therefore, North America will have a higher amount of renewable electricity than Europe by 2030.

The *Steel* and *Cement* industry sectors are currently responsible for around 0.5 $GtCO_2$ equivalents in Europe and 0.3 $GtCO_2e$ in North America. Process related emissions—independent of the energy supply—make up about half the total emissions from both sectors of the industry in both regions.

Figure 11 shows the significant differences between OECD Europe and OECD North America in *Scope 1* emissions across all sectors until 2025. By 2030, all sectors will have similar values and the economies of both regions will be well underway towards decarbonization under the 1.5°C pathway.

Figure 11: OECD Europe (EU) versus OECD North America (NA)—Scope 1 emissions in CO_2 equivalents



Key Results by Sector

Energy Sector—Key Results and Assumptions

The *Energy* sector (see Table 2) covers the primary energy production of oil, gas, hard coal and lignite, and all renewable energies.

Scope 1 emissions are defined as the direct emissions related to the extraction, mining, and burning of fossils fuels. This analysis only covers the two main GHGs, CO_2 and CH_4. For CO_2, the potential emission content of the primary energy produced is provided so that we can take into account that the sector does not use the transport services itself, but extracts it from mines and/or produces the energy to sell to customers.

Scope 2 emissions are indirect emissions from the electricity used for the production of the sector's core product. Calculations are based on statistical information ('own consumption') from IEA Advanced Energy Balances.

Figure 12, Figure 13, and Figure 14 show the development of the energy supply production and services for all four fossil fuel sources (oil, gas, hard coal and lignite) and all utility-scale renewables for *OECD Europe* and *North America* and *Globally*. Utility-scale renewables are defined as power plants that produce bulk power sold to end-use customers, such as offshore and onshore wind farms, solar farms, and geothermal and biomass power plants (including CHP) with over 1 megawatt capacity.

Globally, the current production levels of oil, gas, and coal (including lignite) are within the same range, between 120EJ/a (gas) and 175 EJ/a (oil). Hard and brown coal (160 EJ/a) dominates the *Electricity* sector, whereas oil dominates the *Transport* sector. Gas is mainly used for heating and electricity generation. In OECD North America and OECD Europe, gas dominates heating and power generation. The 1.5°C pathway leads to equal production volumes of renewables and oil between 2025 and 2030 in all regions. After 2030, renewable energy will dominate the *Energy* sector.

COAL

On average, the global energy demand for mining operations in 2018 accounted for 1.84%[26] of total hard coal and 0.1% of lignite production and is assumed to be stable throughout the entire modelling period until 2050. For OECD North America and OECD Europe, own energy consumption for hard coal is below the global average (1.59% and 0.75%, respectively), but is above it for lignite (both 0.3%).

The energy demand for secondary hard coal products ranges from 2% of total hard coal production in OECD North America to 4% in OECD Europe, and the global average is calculated to be 3%. It is assumed to remain stable until 2050 for each region.

For lignite secondary products, such as brown coal briquette (BKBs), the global average share of production is 1% while it is 4% in OECD Europe. This source[26] does not provide any value for OECD North America. Power plants and co-generation plants are assumed to consume 7.3% of their gross electricity production in internal processes and distribution losses for all the years and regions examined.

The CO_2 emission factor for hard coal is calculated to be 93[27] kilotons CO_2 per PJ [ktCO_2/PJ] for hard coal and 111 ktCO_2/PJ for lignite/brown coal. The specific CH_4 emissions for hard coal (upstream) are calculated to be 271 tons of CH_4 per PJ [tCH_4/PJ] based on the IEA World Energy Outlook 2019. The specific CH_4 emissions for brown coal mining are not available.

Import and Export

In 2018, 14% of the consumed hard coal in OECD North America was imported, whereas 54% was exported—this included non-energy-use coal and coking coal. In OECD Europe, 70% of coal was imported and 7% exported. On a global level, around 25% of the coal produced was exported from producing countries to consuming countries (→ imported). The import and export rates remained stable over time and for each region. The long-distance transport of coal—for importation and exportation—is assumed to be by ships, whereas 30% of short-distance transport within a country is assumed to be by train, with only 1% by road. The rest is transported by barges and ships. Lignite cannot be exported and is used in power plants next to the actual mines. Transport is assumed to be predominately by conveyer belts and rail.

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[26] Calculated with IEA Advanced World Energy Balances, released August 2020
[27] Umweltbundesamt, Climate Change 28/2016, CO_2 Emission Factors for Fossil Fuels, page 46, https://www.umweltbundesamt.de/sites/default/files/medien/1968/publikationen/co2_emission_factors_for_fossil_fuels_correction.pdf

Figure 12: Global: Key indicators of the Energy, Oil, Gas, and Coal sector—production by fuel

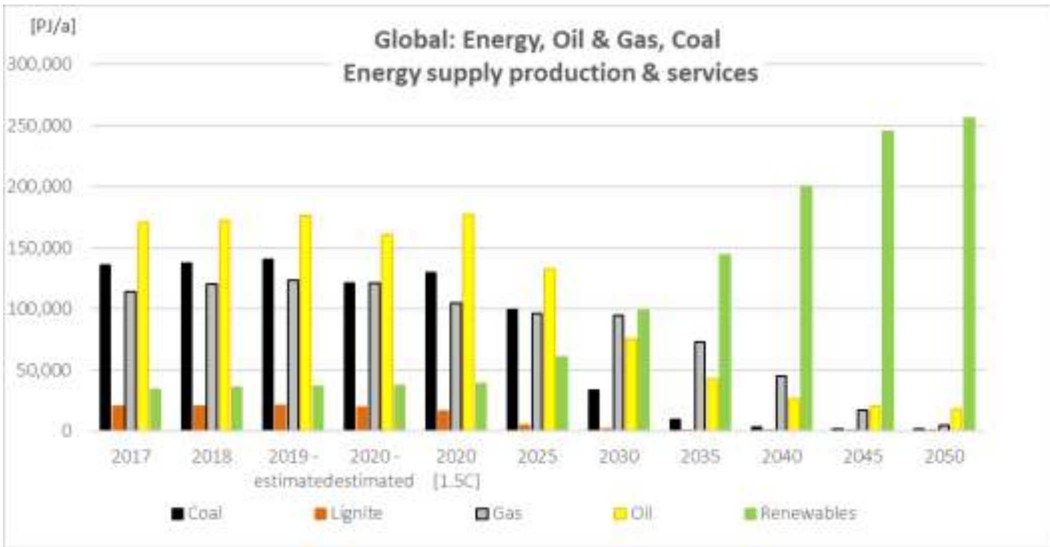


Figure 13: OECD Europe: Key indicators of the Energy, Oil, Gas, and Coal sector—production by fuel

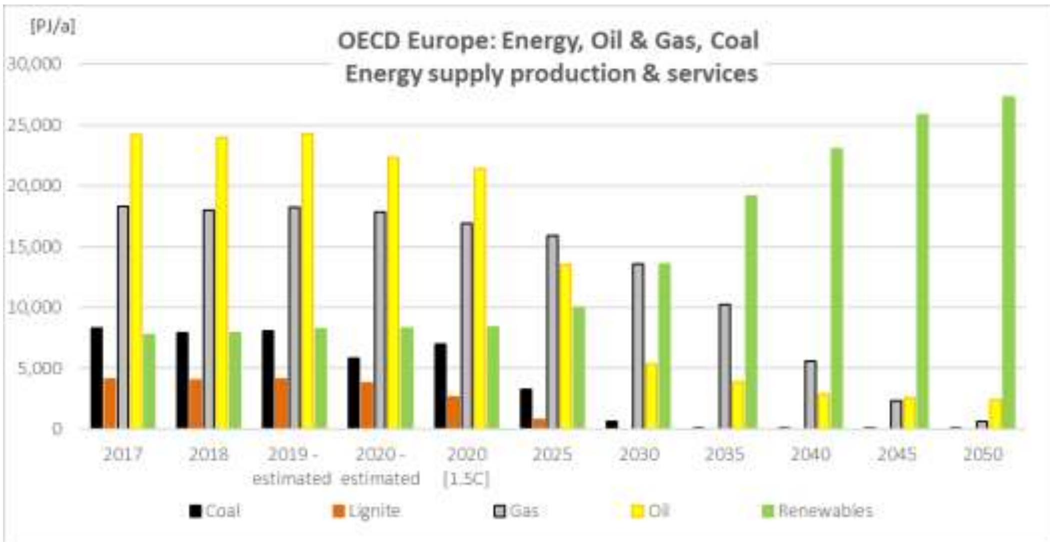
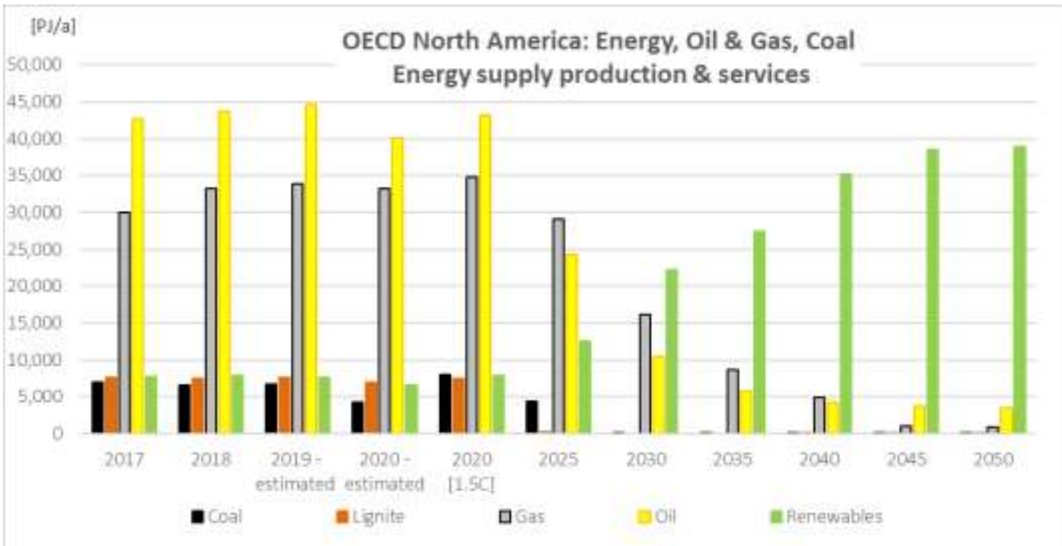


Figure 14: OECD North America: Key indicators of the Energy, Oil, Gas, and Coal sector—production by fuel



OIL

Global oil extraction processes consume 0.3% of the production volume on average, and around 0.2% in OECD Europe and 0.5% in OECD North America. The energy consumption of refineries ranges from 0.2% in OECD North America to 0.4% in OECD Europe—0.3% on average globally. All values are calculated on the basis of the IEA Advanced World Energy Balances 2020.

Electricity requirements for all oil-production-relevant processes are calculated to be 1.27% of total production globally, 4.17% for OECD Europe and 1.42% for OECD North America.

The calculated emission factor for oil across all regions and for each year is 75 $ktCO_2/PJ$ (Umweltbundesamt, 2016). According to the IEA 2020 Methane Tracker, in 2019, the upstream CH_4 emissions associated with global oil production accounted for 37.8 $MtCH_4$ and the emissions for downstream processes accounted for 0.222 $MtCH_4$ (IEA, 2019). The average specific CH_4 emissions were 219 tCH_4/PJ upstream and 1.28 tCH_4/PJ downstream. The share of flaring in global gross oil production is integrated as a figure under 'global natural gas production'.

70% of crude oil transport is assumed to be by pipeline, 23% is transported by marine transport (tankers), and the remaining 7% is transported by land transport. We assume these figures will remain consistent between 2019 and 2050.

Under the 1.5°C pathway, the oil market in 2050 will be 18,000 PJ—90% below the market volume in 2018—to supply non-energy uses, such as the basic material for plastic production.

Import and Export

All the oil consumed in OECD Europe is currently imported, 94.6% of the energy-related oil demand (EC 2018)[28]. Based on IEA statistics, 31% of the oil consumed in OECD North America is exported and 43% is imported, including the oil for non-energy uses, such as petrochemical processes. Globally, almost 60% of all oil produced is not produced where it is consumed. All shares are assumed to remain stable.

GAS

On average, gas extraction processes consume 6% of the production volume globally, 10% in OECD North America, and 2.5% in OECD Europe. The other processes combined, such as gas blending, gas-to-liquefaction plants, and liquefied natural gas (LNG) regasification, are assumed to remain stable at 0.2% of the overall volume. The electricity required for gas extraction processes is currently just under 1%.

It is estimated that the global consumption and worldwide grid losses (for *Scope 2* emissions) associated with power and co-generation based on natural gas accounted for 2% in 2019 and are expected to decrease to 4.3% in 2030 and decline further to 1.1% in 2050. The values for the period 2019–2025 are based on current average values, and future projections for 2030–2050 are drawn from UTS/ISF.

For every unit of primary energy produced from natural gas, 56 kilotons of CO_2 are emitted; the emission factor is 56 $ktCO_2/PJ$ (Umweltbundesamt, 2016). According to the IEA 2020 Methane Tracker, in 2018, the upstream methane emissions associated with global natural gas production accounted for 28.16 $MtCH_4$ and downstream methane emissions were 15.32 $MtCH_4$ (IEA, 2019). The average natural-gas-specific upstream methane emissions accounted for 212 $MtCO_4$ and the downstream methane emissions for 115 $MtCO_4$ in 2018.

In the base year 2019, flaring emissions accounted of 3.7% of global gas production. We assume that this share will reach 0% by 2030. This development is based on the World Bank's "Zero Routine Flaring by 2030" initiative (World Bank, 2019).

Import and Export

In 2018, around 35%[29] of global gas production was exported to and imported by non-producing countries. The import–export balance of OECD North America was positive and more gas was exported than imported, whereas in OECD Europe, almost all natural gas was imported (98%).

In this analysis, we assume that 98% of all gas produced is transported by pipeline, 1% by marine tanker, and 1% by tankers on rail and roads. The gas transport losses are estimated to be 2% of the gross consumption and will remain stable until 2050 (DLR/UTS)[30]

[28] European Commission 2018, 94.6% of net imports in gross available energy (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Oil_and_petroleum_products_-_a_statistical_overview&oldid=315177#Trade_in_petroleum_products)
[29] Calculated with IEA Advanced World Energy Balances, released August 2020
[30] DLR/UTS, Achieving the Paris Climate Agreement

Utilities Sector—Key Results and Assumptions

The *Utilities* sector covers energy transport and the operation and maintenance of power- and heat-generating equipment and the transport infrastructure (grid- and pipe-bound infrastructure).

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 (and hydrogen and synthetic fuels beyond 2030). It operates and maintains power and co-generation 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 energy supply with consumers.

Scope 1 emissions are defined as direct emissions related to the generation and transmission of electricity and the distribution of fossil fuels and/or renewable gas. This analysis only covers the two main GHGs, CO_2 and CH_4. For CO_2, the potential emissions content of the electricity produced and gases transported are included in order to take into account that the sector does not use energy itself, but provides energy services for energy consumers.

Scope 2 emissions are indirect emissions from the electricity used for the production of a sector's core product. Calculations are based on statistical information for ′self-consumption in power plants and energy infrastructure′, of IEA Advanced Energy Balances.

Globally, renewable electricity generation provides around 33% of all the electricity consumed, with significant regional differences. To supply increased electrification for the *Transport* and *Industry* sectors during the replacement of fossil fuels, the *Utilities* sector must double its renewable electricity generation every 5 years between 2020 and 2030 and again between 2030 and 2040 (Figure 15, Figure 16, and Figure 17). The transition of the *Utilities* sector towards renewable-energy-driven industry is key to achieving the Paris Climate Agreement. If the *Utilities* sector fails to restructure, the 1.5°C target will not be reached.

Although the electricity shares of fossil, nuclear, and renewable electricity differ in OECD North America and OECD Europe today, the renewable electricity share must exceed 75% by 2030 in all the regions analysed. By 2040, renewable electricity must reach a share of well over 90% in order to provide low-carbon electricity for all sectors to achieve the required *Scope 1* and *Scope 2* emissions.

The supply of natural gas will gradually decrease globally under the 1.5°C pathway, as well as in OECD North America and OECD Europe, and synthetic fuels and hydrogen will increase to over 50% of the total supply volume by 2040 in all the regions analysed.

Table 15: Utilities sector—Scope 1 and 2 emissions: Global, OECD North America, and OECD Europe

Utilities Sector		2019	2020 Estimated reduced GDP	2020 Estimated GDP stable	2025	2030	2040	2050
Global: Scope 1	[$MtCO_2e$]	20,331	18,511	16,630	12,772	9,886	3,737	265
Global: Scope 2	[$MtCO_2e$]	249	255	247	228	193	107	22
Europe: Scope 1	[$MtCO_2e$]	2,157	1,916	1,837	1,408	1,112	461	33
Europe: Scope 2	[$MtCO_2e$]	33	32	31	27	22	7	1
North America: Scope 1	[$MtCO_2e$]	4,043	3,697	4,032	2,535	1,271	408	48
North America: Scope 2	[$MtCO_2e$]	68	66	65	49	23	5	1

Table 15 shows the *Scope 1* and *2* emissions for the *Utilities* sector for all regions analysed. *Scope 1* emissions must decrease by 35% within the next 5 years in order to reduce global energy-related CO_2 emissions according to the Paris Climate Agreement goals. This reduction is based on the phase-out of coal for electricity generation and the shift to renewable electricity, mainly cost-effective solar photovoltaic and onshore wind.

Figure 15: Global: Key indicators for the Utilities sector—production by fuel

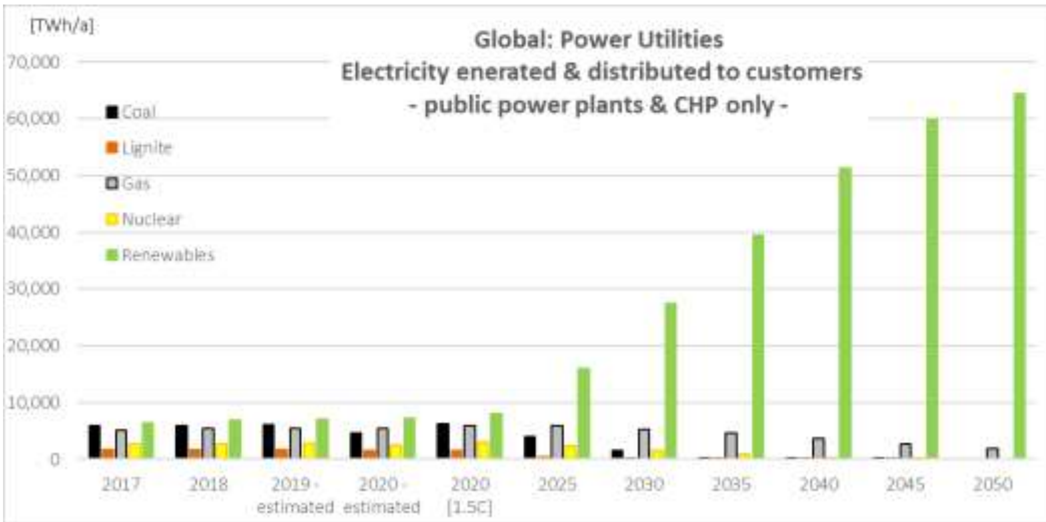


Figure 16: OECD Europe: Key indicators for the Utilities sector—production by fuel

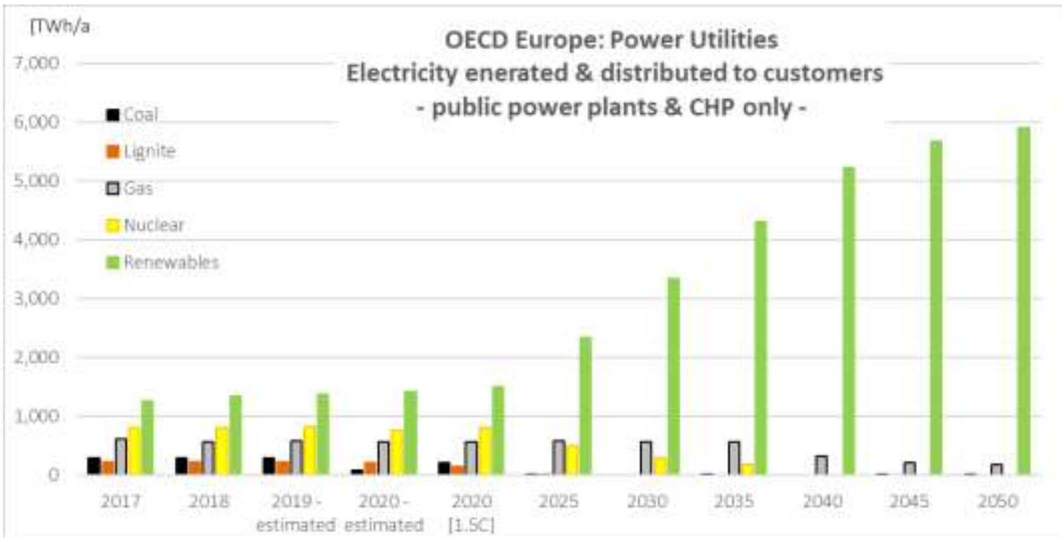
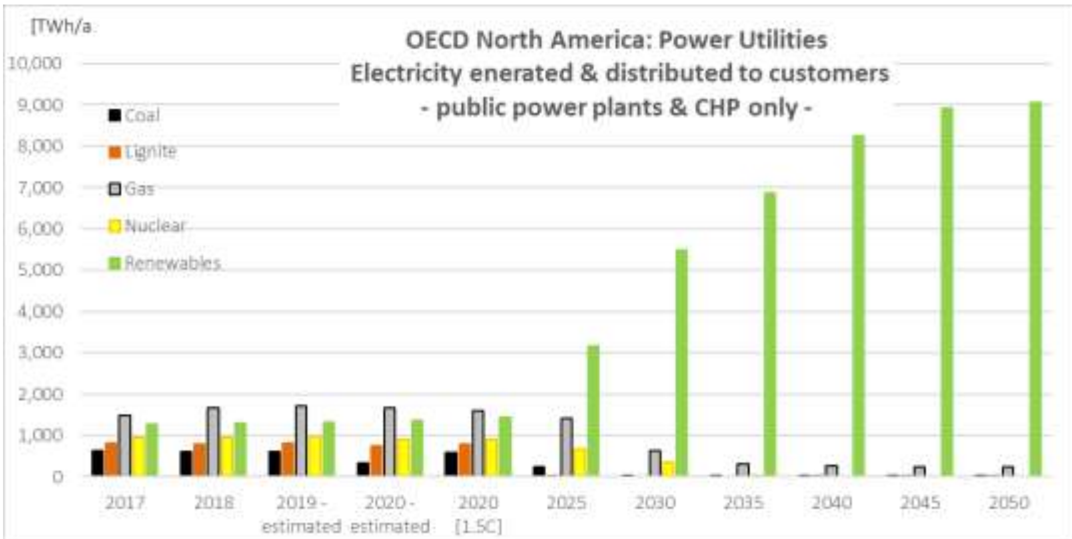


Figure 17: OECD North America: Key indicators for the Utilities sector —production by fuel



Transport Sector—Key Results and Assumptions

The financial sector *Transport* sector spans civil aviation, shipping, and road transport, including passenger and freight transport and all related services. For each transport mode, there are two main sub-sectors:

1. Design, manufacture, and sales of planes, ships, and road vehicles for the transportation of passengers and freight;
2. Operation and maintenance of vehicles to provide transport services for passengers and freight.

Scope 1 emissions are the direct emissions associated with the operation of vehicles, not the energy required to manufacture those vehicles because these data are not available (IEA statistics). For CO_2, the potential emissions content of the transport energy consumed (electricity and fuels) is provided so that we can take into account that the sector does not use the transport services itself, but provides transport services for consumers.

Scope 2 emissions are indirect emissions from the electricity or electricity-produced fuels (hydrogen, synthetic fuels) used for transportation services.

In 2018, transport consumed 71% of the total oil demand globally. Therefore, the transition from oil to electric drives, or synthetic fuels and biofuels is key to achieving the Paris Climate Agreement. A rapid uptake of electric mobility, combined with a renewable power supply, is the single most important measure to maintain with the carbon budget of the 1.5°C pathway.

AVIATION

The 2020 pandemic led to significant travel restrictions and significantly affected global and domestic aviation demands[31]. The International Air Transport Association expects flight capacity utilisation to be, on average, 65% below the 2019 level in the second quarter (Q2) of 2020, 40% below in Q3 2020, and 10% below in Q4 2020[32]. Data show that the global flight numbers were down by 70% at the start of April 2020 relative to the previous year. The consumption of kerosene in the whole of 2020 is expected to be reduced by 26% (IEA GER 2020).[33]

The energy intensity for aviation freight transport is assumed to be 30.5 MJ/ton kilometre (tkm) in 2019[34], decreasing by 1% per year until 2025. By 2050, the energy intensity for freight planes is estimated to be 25.2 MJ/tkm, 17% below today's value.

The energy intensity for aviation passenger transport will decrease from 1.6 MJ per passenger kilometre to 1.2 MJ/tkm between 2020 and 2050. For both freight and passenger planes, technical improvements in aerodynamic, materials, weight, and more efficient turbines are assumed[34]. The volume of freight (in tkm) and the amount of passenger kilometres is assumed to drop by 30% globally between 2019 and 2050, an average reduction of around 1% per year.

The emissions factor for kerosene is calculated to be 73.3 g of CO_2 per MJ [gCO_2/MJ] (UBA 2016)[35]. The specific CO_2 emissions for aviation freight will decrease from 2.2 $kgCO_2$/tkm to 1.8 $kgCO_2$/tkm in 2025. By 2040, the specific emissions will halve to 0.9 $kgCO_2$/tkm, and will be completely decarbonized by 2050.

In passenger aviation transport, specific CO_2 emissions will decrease from 117 gCO_2/passenger kilometre (pkm) in 2019 to 97 gCO_2/pkm in 2025, will halve by 2040, and will be CO_2-free by 2050 – analogous to freight transport. Both reduction trajectories will be achieved by the gradual replacement of fossil kerosene with organic kerosene and after 2040, with synthetic kerosene that is generated with renewable electricity (Figure 20 and Figure 21). Because aviation is a truly global sub-sector, the assumptions for aviation are the same for all regions.

[31] IEA, Global Energy Review 2020, The impacts of the COVID-19 crisis on global energy demand and CO_2 emissions, April 2020, https://www.iea.org/reports/global-energy-review-2020
[32] IATA, April 2020, website viewed in April and August 2020, https://www.iata.org/en/iata-repository/publications/economic-reports/covid-fourth-impact-assessment/
[33] IEA, 2020. Global Energy Review 2020. Oil. https://www.iea.org/reports/global-energy-review-2020/oil#abstract
[34] Teske et al. 2019, Springer; Achieving the Paris Climate Agreements; Chapter 6, Transport Transition Concepts, Pagenkopf et al.
[35] UBA 2016, Umweltbundesamt, Umweltbundesamt, Climate Change 28/2016, CO_2 Emission Factors for Fossil Fuels, page 46, https://www.umweltbundesamt.de/sites/default/files/medien/1968/publikationen/co2_emission_factors_for_fossil_fuels_correction.pdf

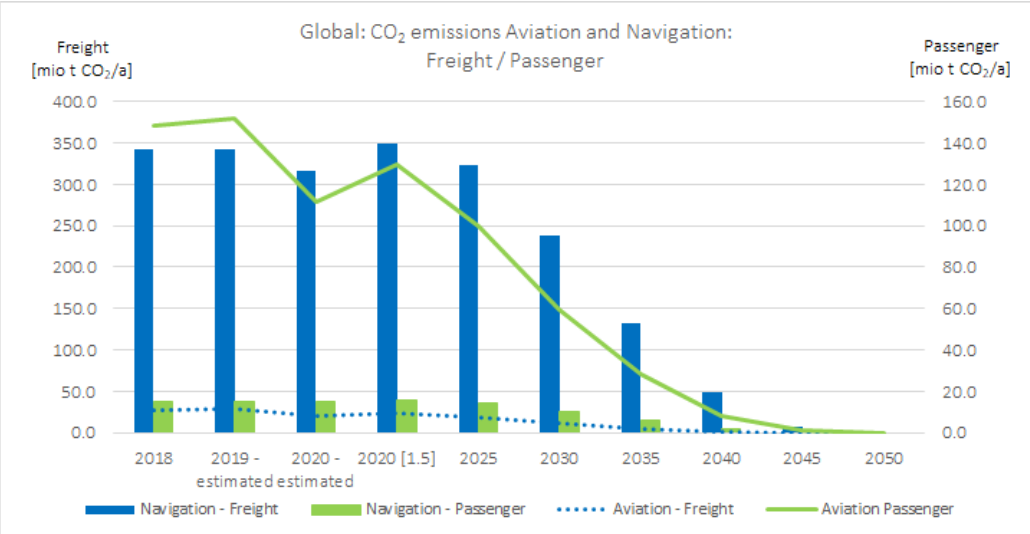
SHIPPING

Ninety (90%) per cent of the global energy demand for shipping is for freight transport, and only around 10% is for passenger transport (mainly cruise ships and ferries). In 2018, the worldwide cruise ship passenger capacity was 537,000 passengers on 314 ships, and 26 million passenger were transported in 2018 (CMW 2020)[36]. In comparison, around 53,000 merchant ships were registered globally in January 2019: approximately 17,000 cargo ships, 11,500 bulk cargo carriers, 7,500 oil tankers, 5,700 chemical tankers, and 5,150 container ships. The remaining ships included roll-on, roll-off passenger and freight transport ships and LNG tankers (Statista 2020)[37].

The energy intensity for freight transport by ship was assumed to be 0.19 MJ/tkm in 2019[38], and will decrease only slightly to 0.18 MJ/tkm in 2030 and 0.17 MJ/tkm in 2050. An equal trajectory is assumed for shipping passengers, from 0.056 MJ/pkm to 0.054 MJ/pkm in 2030 and 0.052 MJ/pkm in 2050. Shipping is already by far the most efficient transport mode. However, further technical improvements, especially for ship engines, are required[34]. The volume of freight (in tkm) is assumed to increase by around 0.5% per year globally until 2050, whereas passenger transport volumes will remain at today's levels over the entire modelling period.

The emissions factor for heavy fuel oil is calculated to be 81.3 grams CO_2 per MJ [gCO_2/MJ] (UBA 2016)[39]. The specific CO_2 emissions for shipping freight will decrease from 15 gCO_2/tkm to 10 $kgCO_2$/tkm in 2030. By 2040, freight shipping will be completely decarbonized. The specific CO_2 emissions for passenger shipping transport will decrease from 5 gCO_2/pkm in 2019 to 3 gCO_2/pkm in 2030, and analogous to freight shipping, passenger transport by ship will be carbon neutral by 2040. Both reduction trajectories will be achieved by the gradual replacement of fossils with biofuels and after 2040, with renewables-generated synthetic fuels (Figure 20 and Figure 21).

Figure 18: Global: CO_2 emissions from aviation and navigation



ROAD

Road transport is the single largest consumer of oil. In 2018, 64% of the global demand was attributed to road transport vehicles, for freight and passenger transport. The pandemic in 2020 led to a unique development: as a consequence of global lockdown measures, mobility (57% of the global oil demand) declined at an unprecedented rate. Road transport in regions in lockdown decreased by 50%–75%, with the global average road transport activity falling to almost 50% of the 2019 level by the end of March 2020 (IEA GER 2020)[40].

Whereas electric-powered planes or ships are still in the early stages of development, there are no technical barriers to the phasing-out of internal combustion engines (ICEs) or the move to efficient electric vehicles

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[36] CMW 2020, Cruise Market Watch, website viewed in September 2020, https://cruisemarketwatch.com/capacity/
[37] Statistia 2020, Number of ships in the world merchant fleet as of January 1, 2019, by type, https://www.statista.com/statistics/264024/number-of-merchant-ships-worldwide-by-type/
[38] Teske et al. 2019, Springer; Achieving the Paris Climate Agreements; Chapter 6, Transport Transition Concepts, Pagenkopf et al.
[39] UBA 2016, Umweltbundesamt, Umweltbundesamt, Climate Change 28/2016, CO_2 Emission Factors for Fossil Fuels, page 46, https://www.umweltbundesamt.de/sites/default/files/medien/1968/publikationen/co2_emission_factors_for_fossil_fuels_correction.pdf
[40] IEA, Global Energy Review 2020, The impacts of the COVID-19 crisis on global energy demand and CO_2 emissions, April 2020

(EVs) for passenger transport and to hydrogen or synthetic biofuels for heavy-duty vehicles (HDV). The vehicle technology is widely available and market shares are rising sharply. In 2012, only 110,000 battery electric vehicles (BEVs) had been sold worldwide. Since then, sales have almost doubled every year, reaching 1.18 million BEVs in 2016, 3.27 million in 2018, and 4.79 million in 2019 (IEA GEV 2020)[41].

Electric vehicles are significantly more efficient than vehicles with ICEs that use gas, oil, or biofuels. For this analysis, we calculated energy intensities of 0.55 MJ/pkm for EVs and 1.31 MJ/pkm for oil-based ICE vehicles, with efficiency potential for all engine technologies. However, the increased efficiency of ICEs is not an alternative to EVs, because the ICEs will still emit carbon, whereas renewable-electricity-powered EVs are carbon free.

However, the overall share of EVs in the global car fleet is currently only 1%. To meet the goal of the 1.5°C pathway, manufacturers of road vehicles must commit to a phase-out of oil-fuelled ICEs over the next 25–30 years. Figure 19 shows the development of the global market share for passenger vehicles, with ICEs versus EVs. Between 2030 and 2035, EVs must take over more than half the global passenger car market if we are to remain within the carbon budget. Operators of vehicles and transport service providers must predominately purchase EVs by 2025.

Figure 19: Global: Market shares of ICEs and EVs (no values beyond 2045 = ICEs phased-out)

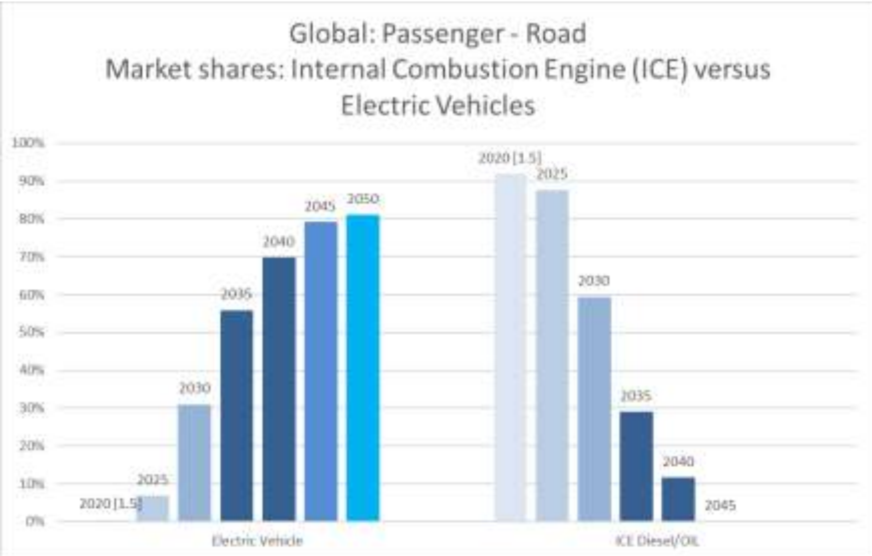


Figure 20: Global: Key indicators for freight transport–emission intensities [gCO_2/tkm] (no values beyond 2040 = decarbonized)

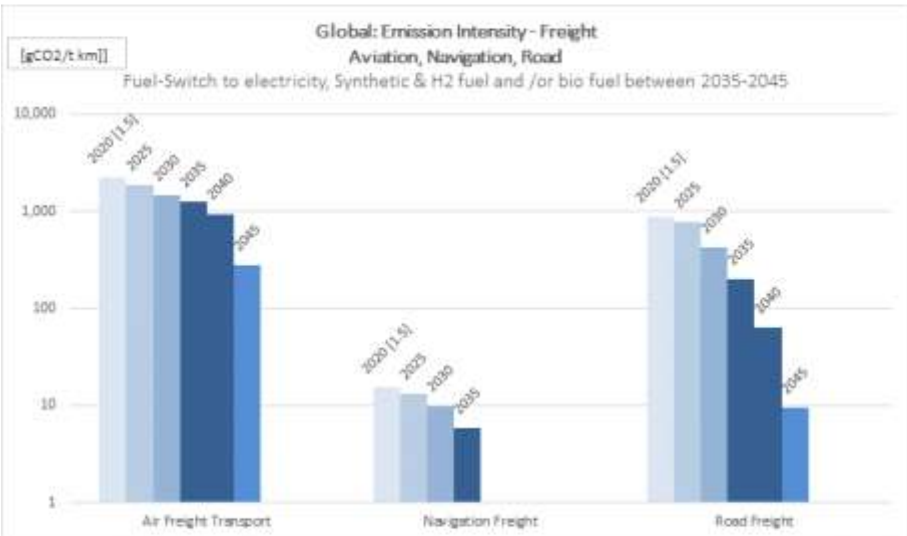
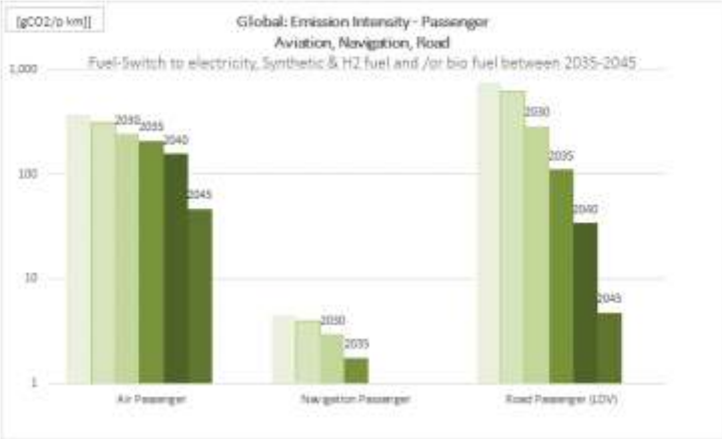


Figure 21: Global: Key Indicators for passenger transport—emission intensities [gCO_2/pkm] (no values beyond 2040 = decarbonized)

[41] IEA GEVO 2020, IEA Global Electric Vehicle Outlook 2020, https://www.iea.org/reports/global-ev-outlook-2020



Under the 1.5°C pathway, the global average carbon intensity for all passenger road transport vehicles will decrease from 97 gCO_2/pkm in 2018 to 73 gCO_2/pkm in 2025, and to almost half that (39 gCO_2/pkm) in 2030 (Figure 21). OECD North America will reduce its specific emissions more slowly than the OECD Europe because its regional car fleet is more inefficient.

Table 16 shows the *Scope 1* and *Scope 2* emissions for the *Transport* sector for all the regions analysed. *Scope 1* emissions must decrease by 28% within the next 5 years in order to reduce the global energy-related CO_2 emissions according to the Paris Climate Agreement goals. This reduction is based on the rapid electrification of road transport, which will be powered by renewable electricity. The two most important measures will be the increased manufacture EVs to achieve economies of scale for electric mobility and the expansion of the charging infrastructure. The road transport sector must co-operate with the *Utilities* sector to upgrade the infrastructure for electric charging and to ensure a sufficient supply of renewables-based power generation.

The *Scope 2* emissions for electricity do not include the power required to manufacture vehicles because this information is not available but include only the electricity required for the operation of EVs or the production of synthetic fuels. Because electricity will not be entirely derived from renewable sources in the next decade, the *Scope 2* emissions will increase—although not as much as the *Scope 1* emissions decline—before they decrease again.

Table 16: Transport sector—Scope 1 and 2 emissions: Global, OECD North America, and OECD Europe

Transport Sector		2019	2020 Estimated reduced GDP	2020 Estimated GDP stable	2025	2030	2040	2050
Global: Scope 1	[$MtCO_2e$]	7,204	6,494	6,637	5,060	2,414	311	0
Global: Scope 2	[$MtCO_2e$]	64	71	82	334	497	166	0
Europe: Scope 1	[$MtCO_2e$]	901	891	891	524	135	8.0	0
Europe: Scope 2	[$MtCO_2e$]	1.8	2.2	1.9	27.5	57.3	22.5	0
North America: Scope 1	[$MtCO_2e$]	2,142	2,077	2,192	1,175	396	58	0
North America: Scope 2	[$MtCO_2e$]	3.1	4.7	6.1	65.5	57.1	7.8	0

Steel Sector—Key Results and Assumptions

The *Steel* industry sector covers the entire process of steel manufacture, from mining iron ore to the production of raw steel, but does not include the further processing of steel to products, such as cars or frames for the construction industry. The steel sector covers three sub-sectors:

1. Mining iron ore;

2. Processing iron ore to primary steel;

3. Production of secondary steel using scrap or recycled primary steel.

The *Scope 1* emissions are all direct energy- and process-related emissions (CO_2 and CH_4 only) from iron ore mining and the steel production processes under the control of the *Steel* industry sector. These include fuel combustion on site, such as gas boilers, coking coal use, and the process heat and power generation required for these processes.

The *Scope 2* emissions are the indirect emissions from electricity purchased and/or generated to power iron ore mining and steel production processes.

Iron ore and steel demand development

The global annual iron ore mining volume reached 2,262 million tons in 2018 and will develop according to the global steel market, which is expected to increase by around 1.5% per year over the entire modelling period. With this assumed growth rate, the global steel market will reach 2,700 million tons per year—around 800 million tons above the market volume of 2019. The market data for 2017–2019 and the projection for 2020 (−3%) are based on information of the World Steel Association (WSA 2020)[42], and future market projections (2025 to 2050) are based on Xylia et al. (2018)[43]. The current steel market shares of OECD North America (7%) and OECD Europe (12%) are assumed to remain the same until 2050.

Besides the actual projection of the steel market volume, the share of secondary steel (scrap) for steel production is very important for both future energy (heat and power)- and process-related emissions. Globally, secondary steel is assumed to have a current share of 25%, on average, slightly higher than the estimate (20%) of the IEA tracking process (IEA 2018)[44].

On the global level, an increase in secondary steel production to 48% by 2050 is assumed. In OECD Europe, the current secondary rate will increase from 30% in 2019 to 70% in 2050, and in OECD North America, from 25% to 52% in the same period (Figure 22). These rates have been discussed with the stakeholder review group (see Reviewers).

Intensities

Figure 23 shows the global energy and electricity intensities, taken from the IEA tracking process[44], for primary and secondary steel. Globally, the average energy intensity for primary steel production was 31 GJ/t in 2018, decreasing to 28 GJ/t in 2050 (Xylia et al., 2018; Yellishetty et al., 2011). For secondary steel production, this parameter was 12.5 GJ/t in 2018, and will decrease to 9 GJ/t in 2050 (Xylia et al., 2018; Yellishetty et al., 2011). The average energy intensity of global steel production (primary and secondary) for the base year is drawn from the IEA's most recent iron and steel report (IEA, 2020).

For OECD North America and OECD Europe, the average energy intensity in steel production (including primary and secondary steel) was 18.6 GJ/t in the base year 2017. Based on the assumption of higher secondary steel shares, the intensity will decrease to 14.8 GJ/t in OECD North America and to 12.6 GJ/t in OECD Europe. Secondary steel production will remain stable at 9 GJ/t. These calculations are based on mini mills (basic oxygen furnaces, BOFs) in the USA (U.S. Department of Energy, 2015).

Globally, the share of electricity used in primary steel production was 2% of the total electricity consumed by the steel industry in 2019. This figure is assumed to remain stable until 2050 and is based on information from the Energy Transition Commission (ETC)[45]. In 2019, 91% of the total electricity consumed by the steel industry was used in secondary steel production (ETC) [45].

Davis et al. (2018) stated that the specific process emissions in steel production range from 3.1 (maximum) to 1.6 (minimum) tons CO_2 per ton of crude steel produced. These figures are based on the IEA report on

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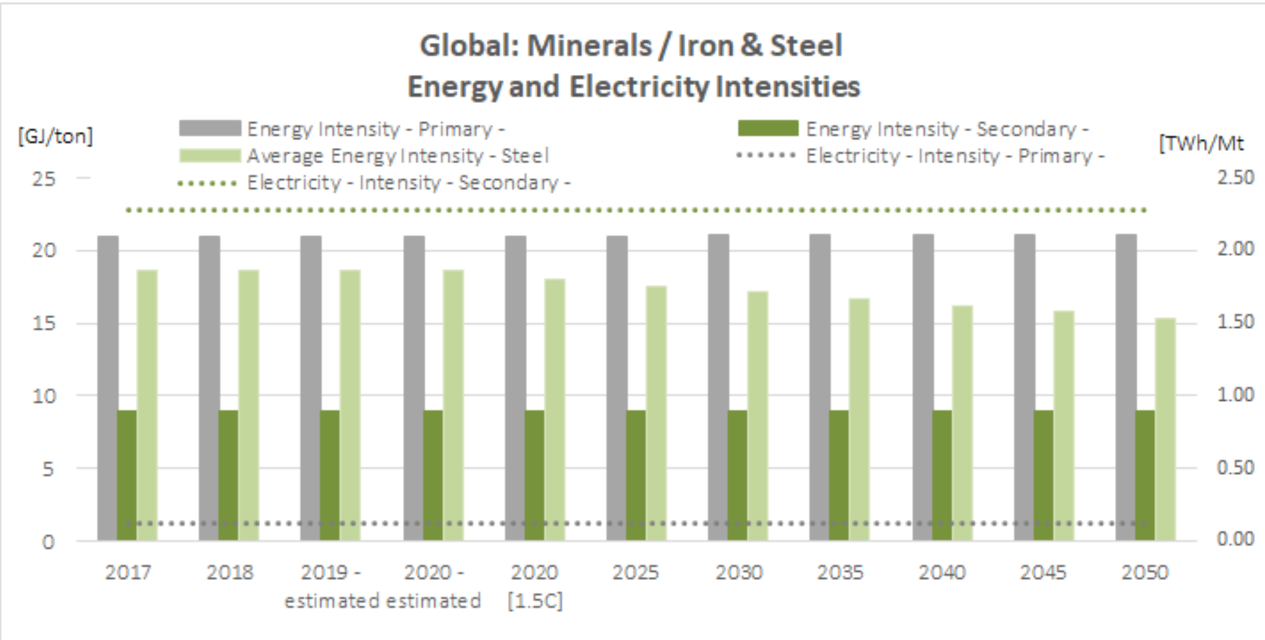
[42] WSA 2020, https://www.worldsteel.org/media-centre/press-releases/2020/Global-crude-steel-output-increases-by-3.4--in-2019.html
[43] Xylia et al. 2018, Weighing regional scrap availability in global pathways for steel production processes, Maria Xylia et al., Energy Efficiency (2018) 11:1135–1159; https://doi.org/10.1007/s12053-017-9583-7
[44] IEA Tracking Process Industry, https://www.iea.org/reports/iron-and-steel
[45] Energy Transition Commission (ETC), http://energy-transitions.org/

Greenhouse Gas Emissions from Iron and Steel Production (IEA, 2000). In 2018, the production of 1 ton of steel led to the emission of 1.85 tons of CO_2 (MK 2018)[46].

Figure 22: Global: Iron & Steel sector—production volumes, primary versus secondary steel

Figure 23: Global: Iron & Steel sector—energy and electricity Intensities



[46] McKinsey 2019, (https://www.mckinsey.com/industries/metals-and-mining/our-insights/decarbonization-challenge-for-steel#)

Process emissions

The basic oxygen furnace (BOF) is used in primary steel making, for the process in which carbon-rich molten pig iron is converted to steel. For every ton of steel, 1.46 tCO_2 is emitted (IPCC 2006)[47]. The share of BOF in global steel production is 65%; under the 1.5°C scenario, the share of the BOF process will be reduced to 35% in 2030 and phased-out by 2050. The share of the BOF production process varies regionally and will decrease faster in OECD Europe than in OECD North America.

Open hearth furnace (OHF) is the most emission-insensitive process. It is used in secondary steel making, in a process that converts scrap into steel by burning gas. The emissions factor for this process is 1.72 CO_2 for every ton of steel. The share of OHF in global steel production ranges between 3% and 5% by region, but will be phased out globally around 2040 under the 1.5°C pathway.

The share of the electric arc furnace (EAF) process in global steel production is 30%. It is used in secondary steel making, when high-voltage electrified arcs melt scrap into steel. The emission factor for this process is much lower than those for BOF and OHF, and only 0.08 tCO_2 is emitted for every ton of steel. Under the 1.5°C scenario, the share of the EAF process will increase to 38% in 2030. By 2050, the EAF process, together with hydrogen-based steel processes, will make up 100% of secondary steel manufacture.

Globally, the average process emissions for steel production will decline from 1.06 tCO_2 per ton of steel to 0.92 tCO_2/t steel in 2025, and decrease further to 0.6 tCO_2/t steel in 2030. By 2050, the average process emissions for each ton of steel will decrease to 0.08 tCO_2 and these will be EAF emissions.

Table 17 shows the *Scope 1* and *Scope 2* emissions for the *Steel* sector for all the regions analysed. The *Scope 1* emissions must decrease by 22% within the next 5 years in order to reduce the global energy-related CO_2 emissions according to the Paris Climate Agreement goals. This reduction is based on the rapid phase-out of fossil fuel for process heat and electricity generation. Changing the energy supply is the most important measure for decarbonizing the steel industry over the next decade towards 2035. Changing the production processes, such as increasing the electric processes, including EAF and hydrogen-based steel production, are only taken into account after 2030 because the transition will take several years.

The decarbonization of the energy supply for the *Steel* industry is possible with current technologies and is therefore prioritized, but further reductions of process emissions are required. Electricity (EAF)- and hydrogen-based steel-making processes, which significantly reduce non-energy-related CO_2 emissions, must become mainstream by 2035 to meet the targets of the 1.5°C pathway.

The *Scope 2* emissions for electricity will decline rapidly with increased shares of renewable electricity, either via PPAs from utilities or as direct investments of the steel industry in large-scale renewable power generation, such as offshore wind projects.

Table 17: Steel sector—Scope 1 and 2 emissions: Global, OECD North America, and OECD Europe

Steel Sector		2019	2020 Estimated reduced GDP	2020 Estimated GDP stable	2025	2030	2040	2050
Global: Scope 1	[$MtCO_2e$]	4,231	3,873	3,855	3,313	2,224	845	216
Global: Scope 2	[$MtCO_2e$]	619	541	523	389	228	53	0
Europe: Scope 1	[$MtCO_2e$]	447	450	425	406	346	95	26
Europe: Scope 2	[$MtCO_2e$]	48	48	40	45	31	9	0
North America: Scope 1	[$MtCO_2e$]	240	235	253	235	185	88	15
North America: Scope 2	[$MtCO_2e$]	28	24	31	16	6	1	0

[47] IPCC (2006). Guidelines for National Greenhouse Gas Inventories, p. 25 (global average factor). https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/3_Volume3/V3_4_Ch4_Metal_Industry.pdf

Figure 24: Global CO_2 emissions—Iron & Steel industry sector

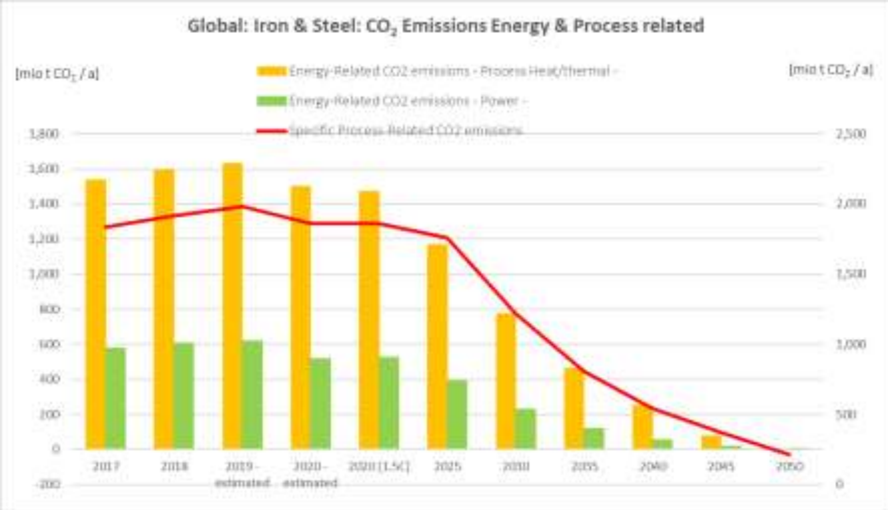


Figure 25: OECD Europe: CO_2 emissions—Iron & Steel industry sector

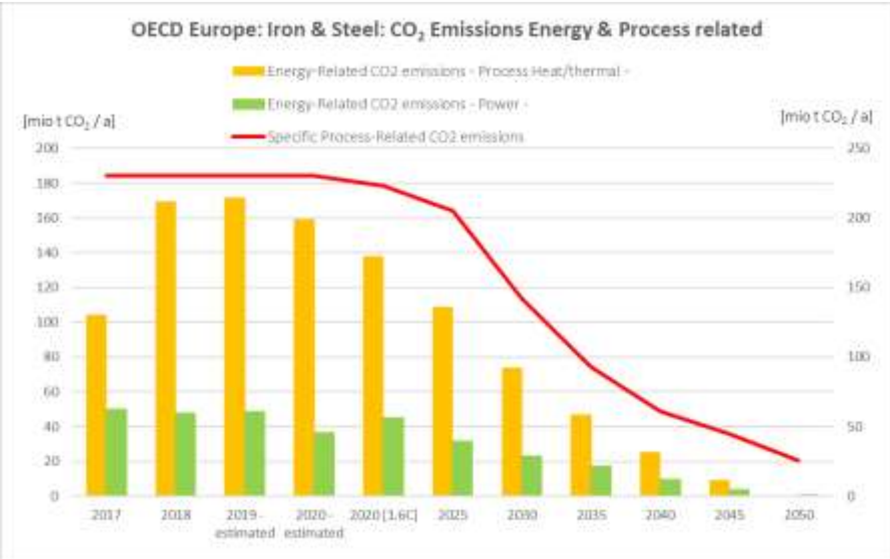
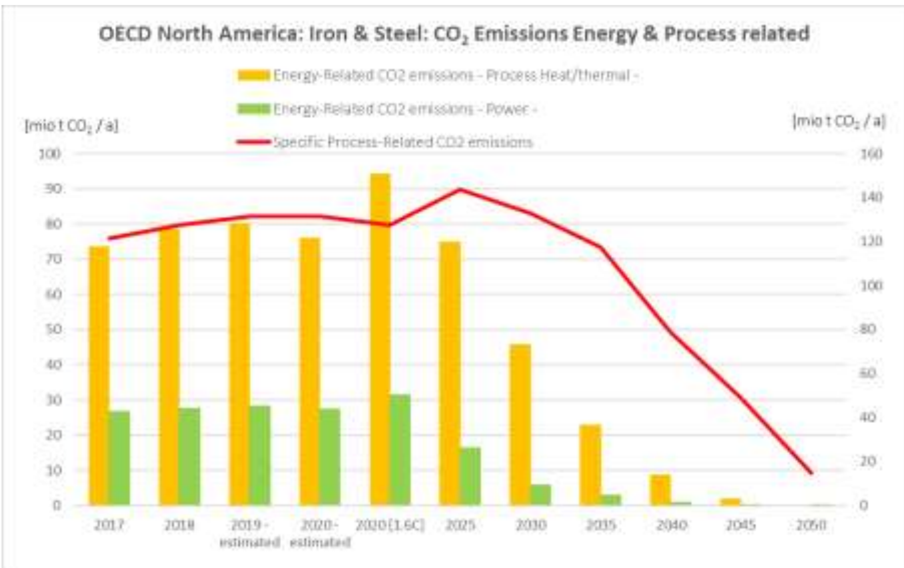


Figure 26: OECD North America: CO_2 emissions—Iron & Steel industry sector



Cement Sector—Key Results and Assumptions

The *Cement* sector covers all activities required to produce cement: from mining limestone and clay to the final cement product:

1. Mining limestone and clay (= marl)
2. Processing marl to clinker
3. Production of cement

It does not include the further processing of cement, e.g., in the construction industry.

Scope 1 emissions are all direct emissions from mining, processing marl to clinker, and the production of the cement itself. The emissions are related to the energy supply for process heat and electricity, as well as process-related emissions.

Scope 2 emissions are indirect emissions from the electricity purchased and used for all the processes required for cement production.

Development of cement demand

The figures for global cement production for 2017, 2018, and 2019 are taken from the IEA's (2018) low-variability reference technology scenario. The global market projections for cement until 2050 are based on the IEA Energy Technology Perspectives, *Beyond 2 Degrees Scenario* (IEA ETP 2017)[48]. According to this project, cement production will continue to increase from 4,100 million tons in 2018 to 4,550 million tons in 2025, and reach 5,100 million tons in 2050 (Figure 27).

Process-related assumptions and energy intensities

All the process-related assumptions and energy intensities of the 1.5°C pathway are based on IEA ETP (2017) and used for all the regions analysed. They are documented in the following section. The following key parameters define the future energy demand for the projected production of global cement and the resulting process emissions (Figure 27 and Figure 28). They do not influence the assumed energy supply.

1. Clinker-to-cement ratio: Clinker is the main constituent of most types of cement. It is assumed that the global clinker-to-cement ratio will decline from 65% in 2019 to 60% in 2050. This decline is attributed to the increased use of cement constituents and alternative binding materials.
2. Energy intensity of the average global cement production (GJ/t) will decreases from 2.9 GJ/t in 2019 to 2.01 GJ/t in 2050.
3. Thermal energy intensity of clinker production (GJ/t clinker) will decline from 3.5 GJ/t clinker in 2019 to 3.1 GJ/t clinker in 2050.
4. Electricity intensity of cement production (kWh/t) will fall from 116 kWh/t cement (2019) to 79 kWh/t in 2050. The electricity share of the total energy demand of cement production will remain at 13% until 2050. The increased electrification of the production process and the reduced specific electricity demand will maintain this balance.

The 1.5°C pathway for the energy supply scenario—compared with IEA ETP 2017—assumes a significantly accelerated transition to renewables-based heat- and power-generation technologies.

Emissions intensities

The process emissions resulting from cement production are assumed to decline evenly from 0.4 tCO_2/t clinker in 2017–2025 to 0.240 tCO_2/t clinker in 2050.

According to Andrew (2019)[49], the total global process emissions from cement production reached 1,500 million tons CO_2 ($MtCO_2$) in 2018, whereas we calculated them to be 1,139 $MtCO_2$. This discrepancy is due to the different estimates for the clinker-to-cement ratio: Andrew assumed 75%, whereas with our approach, we calculated it to be 64.5%. However, we followed the IEA ETP scenario definition for a better comparison.

The global market shares for the OECD North America and OECD European cement industries are assumed to remain at the 2019 levels.

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[48] IEA ETP 2017, Beyond 2 Degrees Scenario. Conversion Rates: Electricity share (of total energy demand) for cement production 12% (base year) increase to 17% (2050).
[49] Andrew, R. M., 2019. Global CO_2 emissions from cement production, 1928–2018, Earth Syst. Sci. Data, 11, 1675–1710, https://doi.org/10.5194/essd-11-1675-2019, 2019.

Figure 27: Global: Cement sector—production volumes and clinker-to-cement ratio

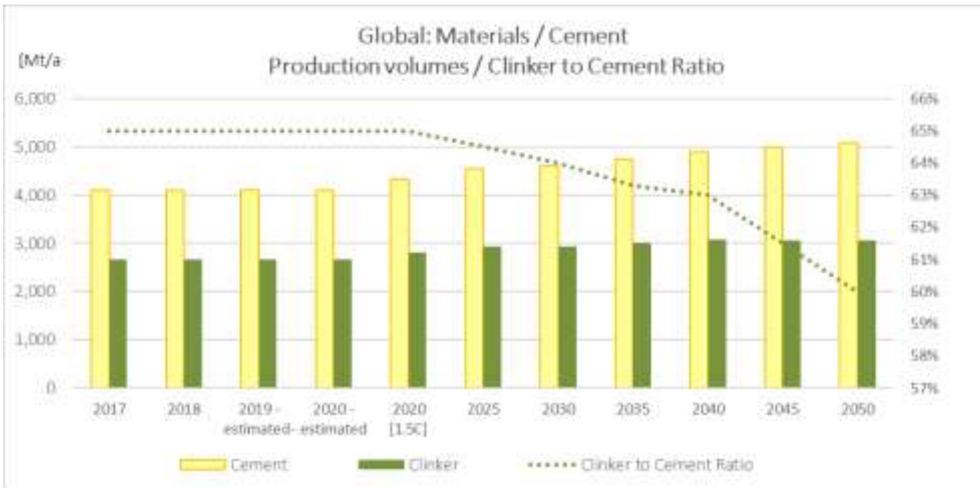


Figure 28: Global: Cement sector—energy and electricity intensities

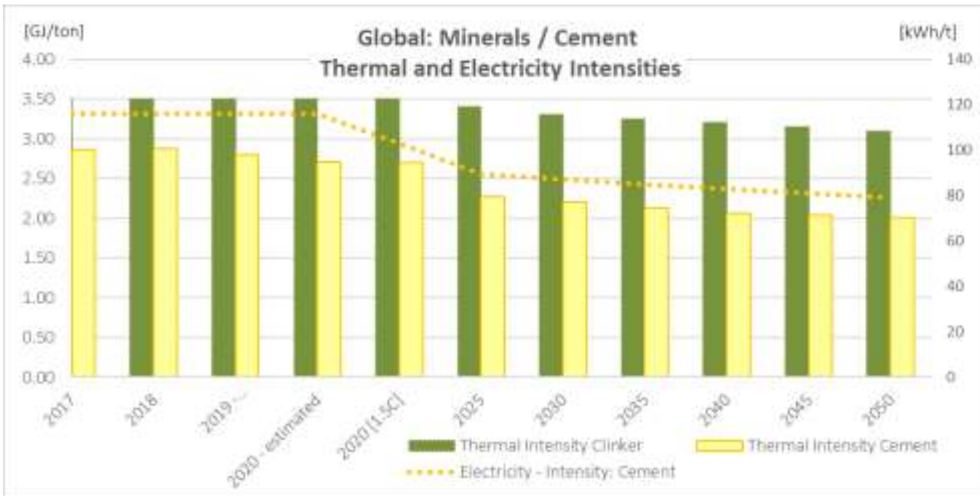


Table 18 shows the *Scope 1* and *Scope 2* emissions for the *Cement* sector for all the regions analysed. The *Scope 1* emissions must decrease by 13% within the next 5 years in order to reduce the global energy-related CO_2 emissions according to the Paris Climate Agreement goals. This reduction is based on the rapid phase-out of fossil fuels for process heat and electricity generation. Changing the energy supply is the most important measure for decarbonizing the cement industry over the next decade, towards 2030. Decreasing the clinker-to-cement ratios and the energy intensities, for both thermal and electrical energies, is vital. To reduce the process emissions for the calcination process, from 0.4 tCO_2 per ton of clinker currently to 0.24 tCO_2/t clinker is key, and further reduction will be required to reduce the overall global process emissions from 800 $MtCO_2$ to under 400 $MtCO_2$ in order to utilize natural carbon sinks and not rely on CCS.

The *Scope 2* emissions for electricity will decline rapidly with increased shares of renewable electricity, either via PPAs from utilities or as direct investments of the cement industry in large-scale renewable power generation, such as offshore wind projects.

Table 18: Cement sector—Scope 1 and 2 emissions: Global, OECD North America, and OECD Europe

Cement Sector		2019	2020 Estimated reduced GDP	2020 Estimated GDP stable	2025	2030	2040	2050
Global: Scope 1	[$MtCO_2e$]	1,946	1,847	1,862	1,701	1,407	1,082	807
Global: Scope 2	[$MtCO_2e$]	225	199	198	113	55	9	0
Europe: Scope 1	[$MtCO_2e$]	142	138	140	141	127	93	62
Europe: Scope 2	[$MtCO_2e$]	15	12	10	5	3	1	0
North America: Scope 1	[$MtCO_2e$]	71	69	63	60	50	34	25
North America: Scope 2	[$MtCO_2e$]	9	7	6	3	1	0	0

Figure 29: Global CO_2 emissions—Cement industry sector

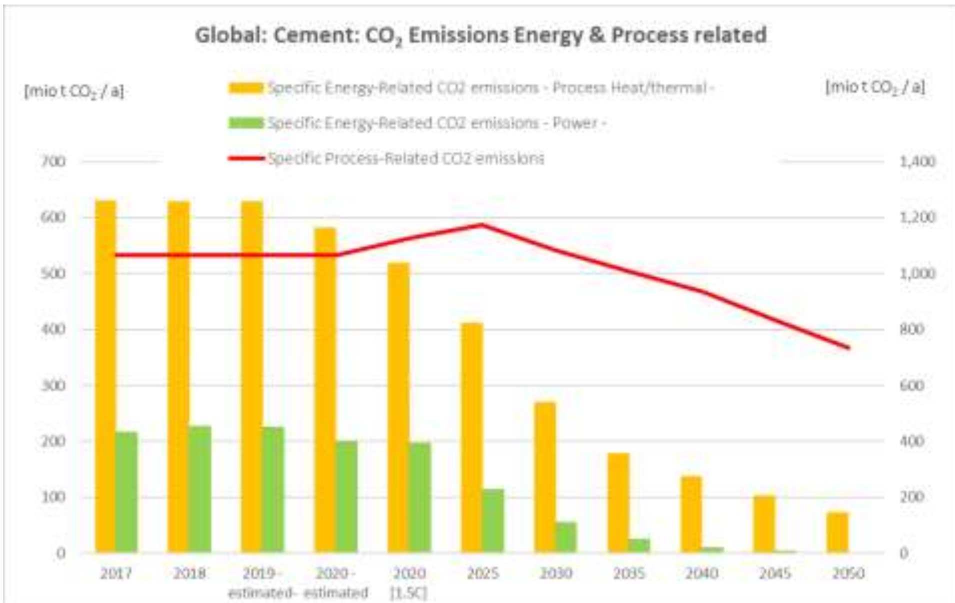


Figure 30: Global Scope 1 and Scope 2 emissions—Cement industry sector

Results: Investment Required in Energy Generation

Global and Regional Results

The estimated investments in new power-, combined heat and power (CHP)-, and heat-generation capacities and in biofuel and synthetic fuel production to achieve the Paris Climate Agreement are calculated to be US$60 trillion between 2021 and 2050 under the 1.5°C pathway—an average of US$2 trillion annually or around 1.5% of global GDP. This does not include investments in new energy infrastructure.

Under the 1.5°C pathway, 18% of those investments will go to solar photovoltaics and 28% to wind power (onshore and offshore). A significant share of solar and wind electricity will be used in this pathway to produce synthetic fuels and hydrogen for industrial processes, heat, and fuels for aviation and shipping. The total investment volume of US$60 trillion breaks down to US$47 trillion for power generation (including CHP) and US$13 trillion for heat-generation technologies (including heat pumps).

The investment required in generation capacity for power, heat, and synthetic fuel production for the 1.5°C pathway and for a reference case (IEA World Energy Outlook 2017—the Current Policy) were calculated with the assumptions documented in this report and in Teske et al. (2019)[34].

Power sector: Investments and fuel costs

Table 19 shows the investments and fuel costs for both cases (1.5°C pathway and the reference case) and compares them. The results are provided for 5-year intervals and average annual costs. The shift towards high electrification for transport and heating services will lead to significantly reduced fossil fuel costs but higher investment costs for renewable-power-generation capacities. Possible infrastructural investments, such as in additional electricity transmission lines, charging stations for electric vehicles, and distribution systems for hydrogen and synthetic fuels, are not calculated because they are beyond the scope of this project.

The 1.5°C pathway requires a total investment in power-generation plants—including CHP—of US$46.9 trillion between 2021 and 2050. The references case (IEA Current Policies 2017) requires a total investment of US$21 trillion, but generates 30% less electricity than the 1.5°C pathway in 2050. The additional electricity is used to replace fossil fuels in the *Heating* and *Transport* sectors.

The fuel cost savings (2021–2050) in the 1.5°C pathway compared with the reference case, shown in Table 19, were calculated to be US$14 trillion.

Heating sector: Investments and fuel costs

In addition to the investments and fuel cost (savings) in the power sector, Table 20 shows the investments required in renewable heating technologies under the 1.5°C and reference scenarios. Between 2021 and 2050, investments in renewable heating technologies under the 1.5°C pathway will be US$13.1 trillion, but will be just under US$3 trillion in the reference case. The overall fuel cost savings in the 1.5 ˚C pathway will add up to US$23 trillion, which will more than refinance the additional investment costs. However, part of the investment costs in the power sector must be factored in because although the increased use of heat pumps will reduce fuel use, it will increase electricity demand.

Transport sector: Investments and fuel costs

Table 22 shows the fuels cost for the *Transport* sector under the 1.5°C and reference scenarios; the calculated fuel costs savings are compared. Relative to the reference case, the 1.5°C pathway will result in an overall fuel cost saving of US$22.8 trillion, as shown in Table 21.

As in the *Heating* sector, the increased use of electricity in the *Transport* sector—either directly in electric vehicles and trains or indirectly for the production of hydrogen and synthetic fuels—will reduce the fuel demand but increase the electricity demand. This will lead to higher investments in electricity-generation capacities.

Table 19: Global: Power sector–required investment in generation capacity and fuels for 1.5°C and reference cases

Power & Combined Heat and Power (CHP)	Units	2021–2025	2026–2030	2031–2035	2036–2040	2041–2045	2046–2050	2021–2050
Investments - power generation (incl. CHP) - 1.5°C pathway	**billion $**	**5,853**	**8,669**	**8,829**	**8,073**	**7,901**	**7,606**	**46,931**
Investment cost - power generation (incl. CHP) - IEA WEO 2017 Current Policy Scenario	billion $	2,658	3,370	3,818	3,770	3,484	3,944	21,045
Additional Investment Costs - 1.5°C pathway	**billion $**	3,195	5,299	5,011	4,303	4,417	3,661	25,886
- fossil (power)	billion $	8	0	0	0	0	0	8
- fossil (CHP)	billion $	266	209	485	180	52	11	1,203
- public fossil (CHP)	billion $	202	195	435	0	50	10	892
- industry fossil (CHP)	billion $	59	10	49	172	0	0	289
- other sectors fossil (CHP)	billion $	5	4	2	9	2	1	22
- nuclear	billion $	0	0	0	0	0	0	0
- renewables (power)	billion $	5,293	7,946	7,938	7,570	7,323	6,996	43,065
- renewables (CHP)	billion $	287	514	406	323	526	598	2,654
- public renewables (CHP)	billion $	125	319	176	140	169	283	1,213
- industry renewables (CHP)	billion $	157	187	223	172	340	290	1,369
- other sectors renewables (CHP)	billion $	4	8	6	12	17	25	73
Power (fossil & renewables)	billion $	5,301	7,946	7,938	7,570	7,323	6,996	43,074
- solar photovoltaic		1,810	1,771	1,792	1,838	2,073	1,507	10,790
- onshore & offshore wind		2,084	3,165	2,997	2,485	3,063	3,205	16,999
- CHP (fossil + renewable)	billion $	552	723	891	503	578	610	3,857
Annual investment (incl. CHP)	**billion $/a**	**1,171**	**1,734**	**1,766**	**1,615**	**1,580**	**1,521**	**1,564**
FUEL costs								
Fossil fuel costs: power (incl. CHP) - 1.5°C pathway	billion $	3,483	2,975	2,339	1,632	698	123	11,251
Biofuel & synthetic fuel costs: Power (incl. CHP) - 1.5°C pathway	billion $	819	1,342	1,673	1,868	1,974	1,820	9,496
Fossil fuel costs: power (incl. CHP) - IEA WEO 2017 Current Policy Scenario	billion $	4,226	4,812	5,442	6,095	6,043	5,490	32,108
Biofuel and synthetic fuel costs: power (incl. CHP) - IEA WEO 2017 Current Policy Scenario	billion $	364	423	472	510	537	563	2,870
Fuel costs savings: Power - compared with IEA WEO 2017 Current Policy (5-year intervals)	**billion $**	**289**	**919**	**1,902**	**3,105**	**3,907**	**4,111**	**14,232**
Annual average Fuel cost savings	**billion $/a**	**58**	**184**	**380**	**621**	**781**	**822**	**474**

Table 20: Global: Heating Sector–required investment in generation capacity and fuels for the 1.5°C and reference cases

Heat (excl. CHP)	unit	2021–2025	2026–2030	2031–2035	2036–2040	2041–2045	2046–2050	2021–2050
Investments - renewable heat generation - 1.5°C pathway (5-year intervals)	**billion $**	**1,678**	**2,447**	**2,374**	**1,672**	**2,325**	**2,611**	**13,108**
Investment cost - renewable heat - IEA WEO 2017 Current Policy Scenario	billion $	351	407	615	434	505	583	2,894
Additional investment costs - 1.5°C pathway	**billion $**	1,327	2,040	1,759	1,239	1,820	2,028	10,213
- heat pump	billion $	608	979	915	654	1,187	1,371	5,713
- geothermal	billion $	99	101	113	133	106	145	697
- solar thermal	billion $	804	1,273	1,346	886	1,032	1,095	6,437
- biomass	billion $	166	95	0	0	0	0	260
Annual investment costs - renewable heat	**billion $/a**	**336**	**489**	**475**	**334**	**465**	**522**	**2,622**
Fuel costs								
Fossil fuel cost: heat (excl. CHP) - 1.5°C pathway	billion $	4,040	3,060	2,074	1,234	465	73	10,947
Biofuel & synthetic fuel costs: heat (excl. CHP) - 1.5 °C pathway	billion $	2,299	2,259	2,148	2,042	1,790	1,300	11,837
Fossil fuel costs: heat (excl. CHP) - IEA WEO 2017 Current Policy Scenario	billion $	4,885	5,381	5,881	6,365	6,045	5,201	33,758
Biofuel & synthetic fuel costs: heat (excl. CHP) - IEA WEO 2017 Current Policy Scenario	billion $	2,250	2,254	2,195	2,084	1,871	1,588	12,242
Fuel costs savings: Heat - compared with IEA WEO 2017 Current Policy Scenario (5-year intervals)	**billion $**	**797**	**2,315**	**3,854**	**5,173**	**5,661**	**5,416**	**23,217**
Annual average fuel cost savings	**billion $/a**	**159**	**463**	**771**	**1,035**	**1,132**	**1,083**	**774**

Table 21: Global: Transport sector–required investment in fossil fuels, biofuels, and synthetic fuels for the 1.5°C and reference cases

Transport		2021–2025	2026–2030	2031–2035	2036–2040	2041–2045	2046–2050	2021–2050
Fuel costs								
Fossil fuel cost transport - 1.5°C pathway	billion $	4,491	2,724	1,199	419	95	9	8,937
Fossil fuel costs transport - IEA WEO 2017 Current Policy Scenario	billion $	5,348	5,685	5,896	5,937	5,559	4,808	33,232
Biofuel cost transport - 1.5°C pathway	billion $	83	115	112	95	79	62	545
Biofuel costs transport - IEA WEO 2017 Current Policy Scenario	billion $	50	56	61	64	65	69	365
Synthetic/H_2 fuel cost transport - 1.5°C pathway	billion $	54	128	198	312	327	258	1,278
Synthetic/H_2 fuel costs transport - IEA WEO 2017 Current Policy Scenario	billion $	0	0	0	0	0	0	0
Fuel cost savings 1.5 °C versus Reference								
Fossil fuel cost savings - compared with IEA WEO 2017 Current Policy Scenario	billion $	−856	−2,961	−4,697	−5,518	−5,464	−4,799	−24,295
Biofuel & synthetic fuel cost saving - compared with IEA WEO 2017 Current Policy Scenario	billion $	87	188	249	343	340	251	1,458
Overall balance compared with IEA WEO 2017 Current Policy Scenario (negative value 1.5°C pathways indicates lower costs than IEA WEO Current Policy)	billion $	−769	−2,773	−4,448	−5,175	−5,124	−4,548	−22,837

Table 21 shows the calculated costs of fossil fuels, biofuels, and synthetic fuels under the 1.5°C pathway and the IEA WEO 2017 case with the assumed specific fuel costs (see Table 6). The differences in the total fuel costs for the two cases are defined as the fuel cost savings.

Table 22, Table 23, and Table 24 (below) summarize the investments and fuel costs by sector provided in the previous tables and break them down by geography: Global, OECD North America, and OECD Europe.

Global: Energy investments and fuel cost savings—1.5°C and reference cases

The total annual global fuel cost savings under the 1.5°C case—compared with the reference case—exceed the required additional investment in power and heat generation by 2035 and remain positive until 2050. Between 2021 and 2050, the 1.5°C pathway results in a net positive savings of around US$800 billion per year, although during the first decade, additional investments of US$533 (in 2021–2025) and US$266 billion (in 2026–2030) are required (Table 22).

The investment required in new energy infrastructure, such power grids, transport of synthetic fuels, etc., and potentially stranded fossil-fuel energy assets are not included because they were beyond the scope of this research.

Table 22: Global: Energy investments and fuel cost savings for the 1.5°C pathway and reference cases

Energy Investments & Fuel		2021–2025	2026–2030	2031–2035	2036–2040	2041–2045	2046–2050	2021–2050
Total energy investment: power & heat – 1.5°C pathway (5-year intervals)	**billion $**	**7,531**	**11,117**	**11,203**	**9,745**	**10,226**	**10,217**	**60,038**
Annual average investment	**billion $/a**	**1,506**	**2,223**	**2,241**	**1,949**	**2,045**	**2,043**	**2,001**
Total additional energy investment: - compared with IEA WEO 2017 Current Policy Scenario	billion $	4,522	7,339	6,770	5,541	6,237	5,690	36,099
Annual average additional investments	billion $/a	904	1,468	1,354	1,108	1,247	1,138	1,203
Total fossil fuel costs: power, heat & transport - 5-year intervals	billion $	12,014	8,759	5,613	3,286	1,259	205	31,135
Annual average fuel costs	billion $/a	2,403	1,752	1,123	657	252	41	1,038
Total biofuel and synthetic fuel costs: power, heat & transport - 5-year intervals	billion $	3,254	3,845	4,131	4,316	4,170	3,440	23,156
Annual average fuel costs	billion $/a	651	769	826	863	834	688	772
Total fuel costs: power, heat & transport - 5-year intervals	billion $	15,268	12,603	9,744	7,602	5,428	3,645	54,291
Annual average fuel costs	billion $/a	3,054	2,521	1,949	1,520	1,086	729	1,810
Total fuel cost savings - compared with IEA WEO 2017 Current Policy Scenario 5-year intervals	billion $	1,855	6,007	10,203	13,454	14,692	14,075	60,286
Annual average	billion $/a	371	1,201	2,041	2,691	2,938	2,815	2,010
Additional investment versus fuel cost savings - 1.5°C pathway	**billion $**	**−2,667**	**−1,332**	**3,433**	**7,912**	**8,456**	**8,385**	**24,187**
Annual average	**billion $/a**	**−533**	**−266**	**687**	**1,582**	**1,691**	**1,677**	**806**

OECD North America and OECD Europe: Energy investments and fuel cost savings—1.5°C and reference cases

Similar results were calculated for OECD North America (Table 23), where the average fuel cost savings for the whole period (2021–2050) will be around US$200 billion per year, although additional investment in generation capacity are within the same range is required for the first 10 years. The results for OECD Europe (Table 24) will already be positive by 2030.

Table 23: OECD North America: Summary Investments and fuel cost savings

Energy Investments & Fuel		2021–2025	2026–2030	2031–2035	2036–2040	2041–2045	2046–2050	2021–2050
Total energy investment: power & heat – 5-year intervals	billion $	2,051	2,877	1,522	1,250	2,129	2,341	12,170
Annual average	billion $/a	410	575	304	250	426	468	406
Total additional energy investment: - compared with IEA WEO 2017 Current Policy Scenario	billion $	1,599	2,336	904	589	1,493	1,637	8,557
Annual average	billion $/a	320	467	181	118	299	327	285
Total fossil fuel costs: power, heat & transport - 5-year intervals	billion $	2,987	1,632	724	332	90	4	5,768
Annual average	billion $/a	597	326	145	66	18	1	192
Total biofuel and synthetic fuel costs: power, heat & transport - 5-year intervals	billion $	336	460	514	547	509	410	2,776
Annual average	billion $/a	67	92	103	109	102	82	93
Total fuel costs: power, heat & transport – 5-year intervals	billion $	3,323	2,092	1,238	878	600	413	8,545
Annual average	billion $/a	665	418	248	176	120	83	285
Total fuel costs savings - compared with IEA WEO 2017 Current Policy Scenario (5-year intervals)	billion $	572	1,920	2,858	3,297	3,210	2,754	14,611
Annual average	billion $/a	114	384	572	659	642	551	487
Additional investment versus fuel cost savings - 1.5°C pathway	billion $	−1,027	−415	1,954	2,708	1,717	1,117	6,054
Annual average	billion $/a	−205	−83	391	542	343	223	202

Table 24: OECD Europe: Summary Investments and fuel cost savings

Energy Investments & Fuel		2021–2025	2026–2030	2031–2035	2036–2040	2041–2045	2046–2050	2021–2050
Total energy investment: power & heat – 5-year intervals	billion $	1,160	1,375	1,444	1,197	1,327	1,273	7,776
Annual average	billion $/a	232	275	289	239	265	255	259
Total additional energy investment: - compared to IEA WEO 2017 Current Policy Scenario	billion $	652	762	813	757	774	720	4,478
Annual average	billion $/a	130	152	163	151	155	144	149
Total fossil fuel costs: power, heat & transport - 5-year intervals	billion $	1,597	1,052	687	421	162	30	3,950
Annual average	billion $/a	319	210	137	84	32	6	132
Total biofuel and synthetic fuel costs: power, heat & transport - 5-year intervals	billion $	421	502	546	564	528	448	3,009
Annual average	billion $/a	84	100	109	113	106	90	100
Total fuel costs: power, heat & transport - 5-year interval	billion $	2,018	1,554	1,233	985	691	478	6,959
Annual average	billion $/a	404	311	247	197	138	96	232
Total fuel cost savings - compared with IEA WEO 2017 Current Policy Scenario (5-year intervals)	billion $	435	1,005	1,386	1,670	1,721	1,525	7,742
Annual average	billion $/a	87	201	277	334	344	305	258
Additional investment versus fuel costs savings - 1.5°C pathway	billion $	−217	243	573	913	947	805	3,264
Annual average	billion $/a	−43	49	115	183	189	161	109

Investment results by sector

For the sectoral pathways developed in this analysis, the investment requirements have been broken down by sector in line with the *Scope 1* and *Scope 2* emissions concept. The *Scope 1* investments cover all assets for renewable power and heat generation required to achieve the *Scope 1* emission pathway. Therefore, the investments for all five financial sectors analysed do not add up because they overlap, just like the *Scope 1* emissions. For that reason, the authors have developed the concept of 'weighted investments'.

Scope 2 investments—by analogy with *Scope 2* emissions—focus on the additional renewable power generation and electricity required for synthetic fuel production. Therefore, *Scope 2* investments for the *Transport* sector are significantly higher than the *Scope 1* investments because the entire electricity for synthetic fuel production—especially for the aviation and shipping sub-sectors—is included.

'***Weighted investments'*** for energy and power generation are calculated for each sector. The assumption for a '*weighted investment*' is that, for example, new power-generation capacities are added to supply the electricity for industrial, business, or private consumers. Therefore, the investment is distributed between the energy supplier and the energy consumer.

In this calculation-based approach, developed by UTS-ISF, a distinction is made between primary and secondary producers and consumers. Today's fossil fuel industries are primary producers and all industries are primary consumers. Secondary producers are utilities, and secondary consumers are service providers and private consumers.

The investments required to achieve the 1.5°C emission pathway are divided equally between suppliers, industry, and private consumers (including small businesses and services). This reduces the investment burden for everyone involved. In this analysis, the overall investments are distributed equally (33% each) between the supplier (*Energy* and *Utility* sectors), industry ('*primary consumer*'), and residential customers ('*secondary consumer*').

The *Steel* sector, for example, is only accountable for a third of the investments required to install renewable energy capacities to supply carbon-free energy and electricity.

The authors developed this approach in order to calculate the sectoral investment needs for the analysed finance sectors. The breakdown to 33% *Energy*, 33% *Utilities*, and 33% for the demand sector *Transport*, *Steel*, or *Cement* should be seen as a proposal for discussion, and other shares may also be possible. The concept of 'weighted investment for each financial sector' requires further discussion.

Table 25, Table 26, and Table 27 show the results for the '*weighted investments'* in the *Energy*, *Utilities*, *Transport*, *Cement*, and *Steel* sectors for the world, OECD North America, and OECD Europe.

Table 25: Global: Scope 1 and Scope 2 investment requirements by financial sector

Total Energy, Gas, Oil & Coal Sector -		2021–2025	2026–2030	2031–2035	2036–2040	2041–2045	2046–2050	2021–2050 [Average]
Energy Sector - Scope 1 investments	[billion $/a]	1,506	2,223	2,241	1,949	2,045	2,043	2,001
Scope 1: Energy sector - weighted investment (energy)	**[billion $/a]**	**497**	**734**	**739**	**643**	**675**	**674**	**660**
Energy Sector - Scope 2 investments	[billion $/a]	68	67	31	13	6	3	31
Scope 2: Energy sector - weighted investment (power)	**[billion $/a]**	**22**	**22**	**10**	**4**	**2**	**1**	**10**
Total Utilities Sector		2021–2025	2026–2030	2031–2035	2036–2040	2041–2045	2046–2050	2021–2050 [Average]
Utilities Sector - Scope 1 Investments	[billion $/a]	1,076	1,643	1,730	1,613	1,589	1,532	1,530
Scope 1: Utilities sector - weighted Investment (energy)	**[billion $/a]**	**355**	**542**	**571**	**532**	**524**	**506**	**505**
Utilities Sector - Scope 2 investments	[billion $/a]	22	24	12	4	2	0	324
Scope 2: Utilities sector - weighted investment (power)	**[billion $/a]**	**7**	**8**	**4**	**1**	**1**	**0**	**4**
Total Transport Sector		2021–2025	2026–2030	2031–2035	2036–2040	2041–2045	2046–2050	2021–2050 [Average]
Transport Sector - Scope 1 investments (biofuel & synthetic fuels)	[billion $/a]	27	49	62	81	81	64	61
Scope 1: Transport sector - weighted Investment (energy)	**[billion $/a]**	**9**	**16**	**20**	**27**	**27**	**21**	**20**
Transport Sector - Scope 2 investments (incl. electricity for synthetic fuel production)	[billion $/a]	8	40	125	194	216	203	131
Scope 2: Transport sector - weighted investment (power)	**[billion $/a]**	**3**	**13**	**41**	**64**	**71**	**67**	**43**
Total Materials–Steel		2021–2025	2026–2030	2031–2035	2036–2040	2041–2045	2046–2050	2021–2050 [Average]
Steel Sector - Scope 1 investments	[billion $/a]	403	644	699	673	774	853	674
Scope 1: Steel sector - weighted investment (energy)	**[billion $/a]**	**133**	**213**	**231**	**222**	**255**	**282**	**223**
Energy Sector - Scope 2 investments	[billion $/a]	52	81	80	70	66	65	69
Scope 2: Steel sector - weighted investment (power)	**[billion $/a]**	**17**	**27**	**26**	**23**	**22**	**22**	**23**
Total Materials–Cement		2021–2025	2026–2030	2031–2035	2036–2040	2041–2045	2046–2050	2021–2050 [Average]
Cement Sector - Scope 1 investments	[billion $/a]	145	221	225	209	233	241	212
Scope 1: Cement sector - weighted investment (energy)	**[billion $/a]**	**48**	**73**	**74**	**69**	**77**	**80**	**70**
Cement Sector - Scope 2 investments	[billion $/a]	20	24	19	14	12	10	16
Scope 2: Cement sector - weighted investment (power)	**[billion $/a]**	**7**	**8**	**6**	**5**	**4**	**3**	**5**

Table 26: OECD Europe: Scope 1 and Scope 2 investment requirements by financial sector

Total Energy, Gas, Oil & Coal Sector -		2021-–2025	2026–2030	2031–2035	2036-–2040	2041–2045	2046–2050	2021–2050 [Average]
Energy Sector - Scope 1 investments	[billion $/a]	232	275	289	239	265	255	259
Scope 1: Energy sector - weighted investment (energy)	**[billion $/a]**	**77**	**91**	**95**	**79**	**88**	**84**	**86**
Energy Sector - Scope 2 investments	[billion $/a]	5	4	1	1	0	0	2
Scope 2: Energy sector - weighted investment (power)	**[billion $/a]**	**2**	**1**	**0**	**0**	**0**	**0**	**1**
Total Utilities Sector		**2021–2025**	**2026–2030**	**2031–2035**	**2036–2040**	**2041–2045**	**2046–2050**	**2021–2050 [Average]**
Utilities Sector - Scope 1 investments	[billion $/a]	144	196	220	167	175	187	181
Scope 1: Utilities sector - weighted investment (energy)	**[billion $/a]**	**47**	**65**	**73**	**55**	**58**	**62**	**60**
Utilities Sector - Scope 2 investments	[billion $/a]	3	3	2	1	0	0	39
Scope 2: Utilities sector - weighted investment (power)	**[billion $/a]**	**1**	**1**	**1**	**0**	**0**	**0**	**0**
Total Transport Sector		**2021–2025**	**2026–2030**	**2031–2035**	**2036–2040**	**2041–2045**	**2046–2050**	**2021–2050 [Average]**
Transport Sector - Scope 1 investments (biofuels & synthetic fuels)	[billion $/a]	3	7	10	11	10	8	8
Scope 1: Transport sector - weighted investment (energy)	**[billion $/a]**	**1**	**2**	**3**	**4**	**3**	**2**	**3**
Transport Sector - Scope 2 investments (incl. electricity for synthetic fuels production)	[billion $/a]	0	7	22	20	24	33	18
Scope 2: Transport sector - weighted investment (power)	**[billion $/a]**	**0**	**2**	**7**	**7**	**8**	**11**	**6**
Total Materials–Steel		**2021–2025**	**2026–2030**	**2031–2035**	**2036–2040**	**2041–2045**	**2046–2050**	**2021–205 [Average]0**
Steel Sector - Scope 1 investments	[billion $/a]	74	96	117	102	118	119	104
Scope 1: Steel sector - weighted investment (energy)	**[billion $/a]**	**24**	**32**	**39**	**34**	**39**	**39**	**34**
Steel Sector - Scope 2 Investments	[billion $/a]	7	11	13	10	12	14	11
Scope 2: Steel sector - weighted investment (power)	**[billion $/a]**	**2**	**4**	**4**	**3**	**4**	**5**	**4**
Total Materials–Cement		**2021–2025**	**2026–2030**	**2031–2035**	**2036–2040**	**2041–2045**	**2046–2050**	**2021–2050 [Average]**
Cement Sector - Scope 1 investments	[billion $/a]	19	25	28	24	28	28	25
Scope 1: Cement sector - weighted investment (energy)	**[billion $/a]**	**6**	**8**	**9**	**8**	**9**	**9**	**8**
Cement Sector - Scope 2 investments	[billion $/a]	2	2	2	1	1	1	1
Scope 2: Cement sector - weighted investment (power)	**[billion $/a]**	**1**	**1**	**1**	**0**	**0**	**0**	**0**

Table 27: OECD North America: Scope 1 and Scope 2 investment requirements by financial sector

Total Energy, Gas, Oil & Coal Sector -		2021–2025	2026–2030	2031–2035	2036–2040	2041–2045	2046–2050	2021–2050 [Average]
Energy Sector - Scope 1 investments	[billion $/a]	410	575	304	250	426	468	406
Scope 1: Energy sector - weighted investment (energy)	**[billion $/a]**	**135**	**190**	**100**	**83**	**141**	**155**	**134**
Energy Sector - Scope 2 investments	[billion $/a]	17	15	2	1	1	1	6
Scope 2: Energy sector - weighted Investment (power)	**[billion $/a]**	**6**	**5**	**1**	**0**	**0**	**0**	**2**
Total Utilities Sector		2021–2025	2026–2030	2031–2035	2036–2040	2041–2045	2046–2050	2021–2050 [Average]
Utilities Sector - Scope 1 investments	[billion $/a]	272	410	206	204	294	334	287
Scope 1:Utilities sector - weighted investment (energy)	**[billion $/a]**	**90**	**135**	**68**	**67**	**97**	**110**	**95**
Utilities Sector - Scope 2 investments	[billion $/a]	7	7	1	0	0	0	75
Scope 2: Utilities sector - weighted investment (power)	**[billion $/a]**	**2**	**2**	**0**	**0**	**0**	**0**	**1**
Total Transport Sector		2021–2025	2026–2030	2031–2035	2036–2040	2041–2045	2046–2050	2021–2050 [Average]
Transport Sector - Scope 1 investments (bio & Synthetic fuels)	[billion $/a]	13	22	25	27	25	20	22
Scope 1: Transport sector - weighted investment (energy)	**[billion $/a]**	**4**	**7**	**8**	**9**	**8**	**7**	**7**
Transport Sector - Scope 2 investments (incl. electricity for synthetic fuels production)	[billion $/a]	1	17	24	35	48	54	30
Scope 2: Transport sector - weighted investment (power)	**[billion $/a]**	**0**	**6**	**8**	**11**	**16**	**18**	**10**
Total Materials–Steel		2021–2025	2026–2030	2031–2035	2036–2040	2041–2045	2046–2050	2021–2050 [Average]
Steel Sector - Scope 1 investments	[billion $/a]	63	100	67	63	109	122	87
Scope 1: Steel sector - weighted investment (energy)	**[billion $/a]**	**21**	**33**	**22**	**21**	**36**	**40**	**29**
Steel Sector - Scope 2 investments	[billion $/a]	4	7	4	4	6	7	5
Scope 2: Steel sector - weighted investment (power)	**[billion $/a]**	**1**	**2**	**1**	**1**	**2**	**2**	**2**
Total Materials–Cement		2021–2025	2026–2030	2031–2035	2036–2040	2041–2045	2046–2050	2021–2050 [Average]
Energy Cement - Scope 1 investments	[billion $/a]	11	18	11	10	16	17	14
Scope 1: Cement sector - weighted investment (energy)	**[billion $/a]**	**4**	**6**	**4**	**3**	**5**	**6**	**5**
Energy Cement - Scope 2 investments	[billion $/a]	1	1	1	0	0	0	1
Scope 2: Cement sector - weighted investment (power)	**[billion $/a]**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Results: Additions to Energy-generation Capacity Required

Table 28 shows the additions required in the global power- and heat-generation capacities under the 1.5°C pathway in 5-year intervals between 2021 and 2050. It is assumed that the *Energy* sector (as defined in Table 2) will be the primary actor in the development and implementation of new energy projects for power and heat generation. The current fossil resource industry—such as oil and gas companies—must transform into a large-scale project developer under the 1.5°C pathway. Therefore, the core business activity must move from fossil fuel exploration and exploitation with on- and offshore production machinery, such as oil rigs, towards the installation and operation of equipment for utility-scale renewable energy generation, such as on- and offshore wind farms, solar power stations, and synthetic fuel production facilities.

Table 28: Additional global capacity for power and heat generation

Energy Sector Project development for electricity/heat production = "Supply enabler"		Additional cumulative capacity over 5-year periods						
		2020–2025	2026–2030	2031–2035	2036–2040	2041–2045	2046–2050	Cumulative 2020-2050
Solar Photovoltaic (roof-top + utility-scale)	[$GW_{electric}$]	1,981	2,223	2,409	2,600	1,872	811	11,895
Solar Photovoltaic (utility-scale share 25% of total capacity)	[$GW_{electric}$]	495	556	602	650	468	203	2,974
Concentrated Solar Power	[$GW_{electric}$]	90	412	464	488	248	265	1,967
Solar Thermal and Solar District Heating Plant	[$GW_{thermal}$]	36	1,612	1,901	1,256	680	354	5,839
Onshore Wind	[$GW_{electric}$]	1,003	1,295	1,188	967	589	194	5,236
Offshore Wind	[$GW_{electric}$]	144	363	342	275	184	61	1,370
Hydro Power Plants	[$GW_{electric}$]	57	19	26	15	23	25	165
Ocean Energy	[$GW_{electric}$]	20	63	100	120	103	70	476
Bio Energy Power Plants	[$GW_{electric}$]	83	33	−15	15	−7	−14	95
Bio Energy Co-Gen Plants	[$GW_{electric}$]	91	112	75	55	59	45	438
Bio District Heating Plants	[$GW_{thermal}$]	6	−581	−504	−716	−657	−1,138	-3,590
Geo Energy Power Plants	[$GW_{electric}$]	24	63	70	82	61	56	357
Geo Energy Co-Gen Plants	[$GW_{electric}$]	9	29	29	26	29	20	142
Gas Power Plant to H_2 Conversion	[$GW_{electric}$]	10	39	62	117	154	11	392
Gas Power Co-Gen to H_2 Conversion	[$GW_{electric}$]	4	20	55	125	55	53	310
Fuel Cell & Synthetic Fuels Co-Gen Plants	[$GW_{electric}$]	3	5	6	16	91	−28	92
Nuclear Power Plants	[$GW_{electric}$]	−114	−109	−95	−91	−23	−2	-433
Industrial/District Heat Pumps	[$GW_{thermal}$]	80	574	552	471	473	471	2,620

Between 2021 and 2025, approximately 2,500 GW of solar photovoltaic, 1000 GW of onshore wind, and 150 GW of offshore wind power plants must be installed globally. Compared with the market volumes in 2019, solar photovoltaic must increase from 115 GW per year (GW/a) to 500 GW/a; onshore wind from 54 GW/a to 200 GW/a; and offshore wind from 6 GW/a to 30GW/a.

Table 29 shows the global quantities of power and heat generation and the renewable fuel production required under the 1.5°C pathway. The *Utilities* sector, as defined in Table 2, will remain the interface between the primary-energy-producing *Energy* sector and industrial and private customers. The operation and maintenance of renewable power plants and the distribution of electricity and renewably produced gas and (synthetic) fuels are the core business activities.

Table 29: Global power and heat generation

Utilities Sector	Units	2018	2019	2020	2020	2025	2030	2035	2040	2045	2050
Connects primary production with consumer = "Demand enabler"		Base year	Estimated	Estimated GDP reduced	Estimated GDP stable	Projected annual energy and electricity generation for the years provided, 2025–2050. These are annual values, not cumulative values.					
Generation - operation & maintenance											
Solar Photovoltaic (roof-top + utility-scale)	[$TWh_{electric}$/a]	583	642	763	946	3,936	7,530	11,396	15,650	18,497	19,710
Solar Photovoltaic (utility-scale - 25% of total generation)	[$TWh_{electric}$/a]	146	160	191	236	984	1,883	2,849	3,912	4,624	4,928
Concentrated Solar Power	[$TWh_{electric}$/a]	17	19	37	32	329	1,834	3,772	5,709	7,211	8,139
Solar District Heating Plants	[PJ/a]	90	91	92	91	1,350	1,468	1,564	1,771	1,606	1,435
Onshore Wind	[$TWh_{electric}$/a]	1,359	1,391	1,417	1,475	3,984	7,253	10,599	13,549	15,449	16,405
Offshore Wind	[$TWh_{electric}$/a]	0	0	80	69	552	1,811	3,070	4,125	4,872	5,160
Hydro Power Plants	[$TWh_{electric}$/a]	4,230	4,332	3,869	4,299	4,495	4,625	4,743	4,823	4,909	4,988
Ocean Energy	[$TWh_{electric}$/a]	1	1	2	2	41	168	414	705	991	1,178
Bio Energy Power Plants	[$TWh_{electric}$/a]	370	379	583	511	894	1,030	911	898	816	707
Bio Energy Co-Gen Plants	[$TWh_{electric}$/a]	253	259	312	312	790	1,377	1,759	2,035	2,340	2,574
Bio District Heating Plants	[PJ/a]	2,533	2,535	2,538	2,199	2,195	1,931	1,715	1,539	1,282	1,372
Geo Energy Power Plants	[$TWh_{electric}$/a]	85	87	138	104	247	644	1,107	1,630	2,015	2,355
Geo Energy Co-Gen Plants	[$TWh_{electric}$/a]	5	5	9	9	68	264	461	636	833	968
Gas Power Plant to H_2 Conversion	[$TWh_{electric}$/a]	0	0	0	0	33	167	387	807	1,381	1,431
Gas Power Co-Gen to H_2 Conversion	[$TWh_{electric}$/a]	0	0	0	0	13	93	293	871	1,107	1,335
Fuel Cell & Synthetic Fuel Co-Gen Plants	[$TWh_{electric}$/a]	0	0	3	4	19	39	65	132	522	400
Nuclear Power Plants	[$TWh_{electric}$/a]	2,511	2,571	2,599	2,921	2,250	1,515	810	182	12	0
Industrial/District Heat Pumps	[$TWh_{electric}$/a]	256	262	288	163	509	983	1,472	1,908	2,352	2,792
Bio Energy (fuels, gas and solids)	[PJ/a]	47,530	48,671	48,585	59,733	78,611	87,488	86,242	83,243	79,807	71,478
Hydrogen Fuel Production - electricity demand	[$TWh_{electric}$/a]	0	0	0	16	668	2,631	5,940	11,452	16,214	15,264
Hydrogen Fuel Production - see above in PJ/a	[PJ/a]	0	0	0	56	2,406	9,473	21,385	41,226	58,370	54,949
Synthetic Fuel Production - electricity demand	[$TWh_{electric}$/a]	0	0	0	1	4	283	1,483	3,106	3,807	4,119
Synthetic Fuel Production - see above in PJ/a	[PJ/a]	0	0	0	5	13	1,020	5,340	11,183	13,705	14,828
Synthetic Fuel Production - regional production	[PJ/a]	0	0	0	2	5	404	2,115	4,551	5,632	6,340
Electricity Transmission - power Grids	[$TWh_{electric}$/a]	26,551	27,188	25,149	26,628	30,043	36,818	45,265	54,722	62,081	65,352

Results: Emission Pathways by Region and Sector

The overall carbon budget for the 1.5°C pathway (66% probability) is 450 $GtCO_2$, accumulated between 2015 and 2050. The majority (71%) of those energy-related carbon emissions must to be phase-out by 2030. In the 1.5°C pathway, the cumulative CO_2 emissions between 2017 and 2030 will be 320 Gt, and the remaining approx. 80 Gt will be emitted between 2031 and 2050. This trajectory is mandatory to comply with the central aim of the Paris Agreement "*to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius*"[50].

Therefore, the emissions reduction pathways for all financial sectors are steep and require very ambitious action in the next 5 years towards 2025. This is a requirement for reaching the 1.5°C target and not a forecast.

Table 30 provides an overview of the cumulative energy-related CO_2 emissions by sector and region. This analysis does not cover all financial sectors. It is important to note that the *Scope 1* emissions for each financial sector count emissions twice. The embedded carbon emission of each barrel of oil is calculated for the *Energy* sector, the *Transport* sector, and every other sector that consumes oil. However, to provide an orientation for the amounts of emissions under the global and regional 1.5°C pathways calculated in Teske et al. (2019), the table shows the cumulative emissions by the energy sectors *industry*, *transport*, and *buildings/other* sectors with white background, whereas data with a coloured background show the calculated *Scope 1* emissions for the OECM-derived sectoral pathways for *Steel*, *Cement*, *Transport*, *Energy*, and *Utilities*.

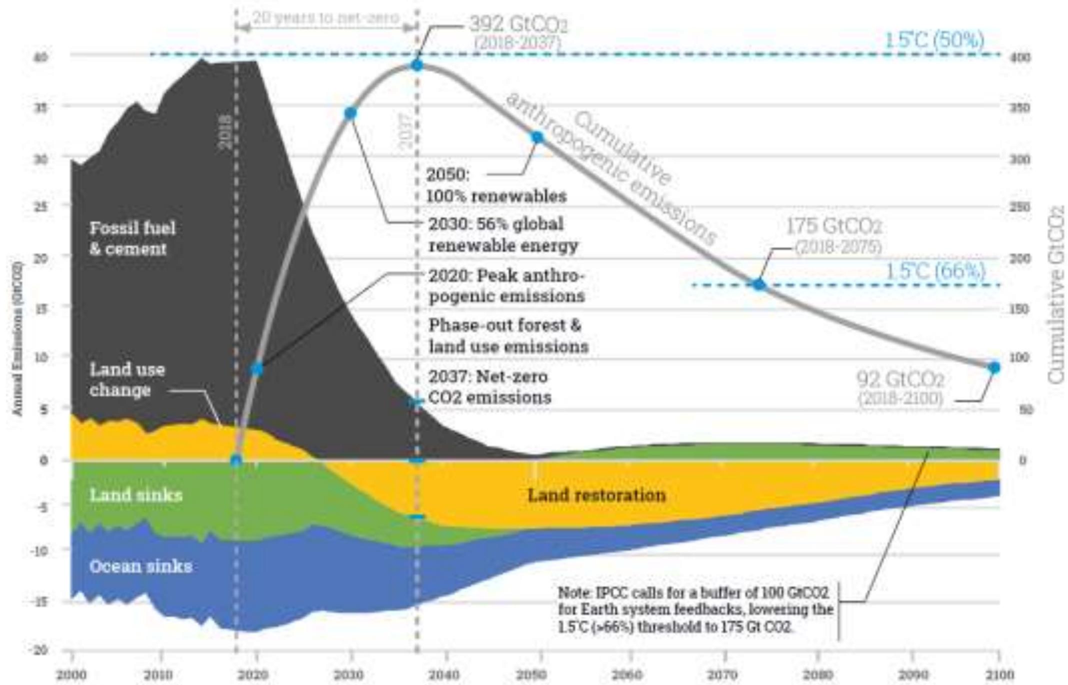
Table 30 Cumulative energy-related CO_2 emissions [$GtCO_2$]

Cumulative energy-related CO_2 emissions [$GtCO_2$]
Note (A): Energy statistics and sectoral financial breakdowns differ, so the emissions do not add up.

	Global			OECD North America			Share of global emissions	OECD Europe			Share of global emissions
			Sector			Sector				Sector	
	2017–2030	2017–2050	[%]	2017–2030	2017–2050	[%]	[%]	2017–2030	2017–2050	[%]	[%]
Industry	71.7	94.2	24%	6.7	8.0	13%	8%	5.5	7.5	19%	8%
- Cement	8.3	11.4	3%	0.3	0.4	1%	3%	0.6	0.9	2%	8%
- Steel	21.9	27.2	7%	1.2	1.5	2%	5%	1.6	2.1	5%	8%
Transport	78.0	90.7	23%	21.5	23.6	37%	26%	9.1	9.8	24%	11%
- Aviation	4.1	4.9	1%	1.9	2.2	3%	44%	0.3	0.3	1%	6%
- Navigation	2.0	2.6	1%	0.3	0.4	1%	14%	0.2	0.2	1%	8%
- Road	67.2	77.7.6	20%	17.8	19.3	31%	25%	7.9	8.5	21%	11%
Power	113.2	137.5	35%	17.5	18.7	30%	14%	9.2	11.6	29%	8%
- Utilities	192.7	261.4	66%	38.9	45.3	72%	17%	21.6	30.1	74%	12%
- Energy Sector	345.0	421.3	106%	60.8	68.1	108%	16%	34.0	41.1	102%	10%
Buildings/Other Sector	36.6	46.5	12%	7.0	7.7	12%	17%	6.9	8.5	21%	18%
Other conversions	20.3	27.2	7%	4.4	5.1	8%	19%	2.4	3.1	8%	11%
Total actual CO_2 emissions	**320.0**	**396.0**	**100%**	**57.0**	**63.1**	**100%**	See (A)	**33.1**	**40.5**	**100%**	See (A)

[50] UNFCCC, website viewed October 2020; https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

Figure 31: Overview: One Earth Climate Model—Energy-related emissions and carbon sinks



The One Earth Climate Model achieves net zero annual CO_2 emissions in approximately 20 years, from 2018 to 2037. The black area represents emissions from fossil fuels, which must decline, by more than half by 2030. The gold area represents emissions from land use, including deforestation, the emissions for which decline and it becomes a source of negative emissions in the late 2020s through forest restoration. The blue area represents natural ocean carbon sinks, which continue absorbing CO_2 throughout the century. The green areas represent natural land carbon sinks, which become a contributor of CO_2 emissions in the second half of the century due to biosphere feedback. The blue dotted lines show the carbon budgets (commencing January 1, 2018) required to stay below 1.5°C with 50% probability (top line) or with > 66% probability (lower line).

Carbon Sinks—Nature-based Solutions

The following section is based on modelling work conducted by Dr Malte Meinshausen and Dr Kate Dooley of the University of Melbourne, as part of the research work for the One Earth Climate Model, published in Teske et al. (2019), Chapters 4 and 12.

The One Earth Climate Model (OECM) combines energy decarbonization with large-scale natural restoration, calculating the carbon removal required to achieve the 1.5°C limit. Restoration of natural carbon sinks through forestry and land-use pathways can remove up to 513 $GtCO_2$ by the end of the century.

However, a significant portion of this will be required to offset ongoing agriculture, forestry, and other land use (AFLOU) emissions, estimated to be 124 $GtCO_2$ through to 2100 (UNFCCC—Shared Socio-Economic Pathway No 2 [SSP][51], which assumes a gradual phase-out of AFOLU emissions to 2080. Given political realities, realizing 100% of the identified restoration potential is unlikely).

Therefore, deforestation and other forms of land conversion must decline much more quickly. Moreover, reductions in methane and nitrogen must also be achieved in the agriculture sector. Without nature-based solutions, the 1.5°C limit is not possible, even with a rapid decline in fossil fuel emissions.

Four main natural sequestration pathways are utilized in the model, divided into temperate and tropical zones: reforestation, natural forest restoration, sustainable forest management, and cropland afforestation (trees in croplands):

1. Wildlands cover approximately 50% of the Earth's terrestrial area and are vital to the world's carbon cycle, sequestering as much as one quarter of anthropogenic carbon emissions and storing approximately 450 gigatonnes of solid carbon (Heinz 2017)[52]. Preserving these lands and forests intact is key to maintaining our global carbon sinks, making the 1.5°C limit possible.

[51] UNFCCC, The Shared Socio-Economic Pathways (SSPs), https://unfccc.int/sites/default/files/part1_iiasa_rogelj_ssp_poster.pdf
[52] Heinz 2017, Erb, Karl-Heinz et al. (2017). Unexpectedly large impact of forest management and grazing on global vegetation biomass, https://www.nature.com/articles/nature25138

2. End deforestation: Today, land use changes account for more than 10% of global CO_2 emissions, approximately 4 $GtCO_2$ per year, resulting largely from the clearing of forests for agriculture or other forms of development. Rapidly phasing out the practice of deforestation will greatly increase the chance of achieving the 1.5°C limit.
3. Large-scale reforestation: The most important sequestration measure identified is large-scale reforestation, particularly in the sub-tropics and tropics. Under the 1.5°C model, 300 megahectares (Mha) of land area will be reforested in the tropics and an additional 50 Mha will be reforested in temperate regions.
4. Natural restoration: The second most important pathway for carbon removal relies upon natural forest restoration or 'rewilding', increasing the carbon density within approximately 600 Mha of existing forests. Reduced logging and better forestry practices in managed forests will also contribute significantly to reducing the total carbon removal.

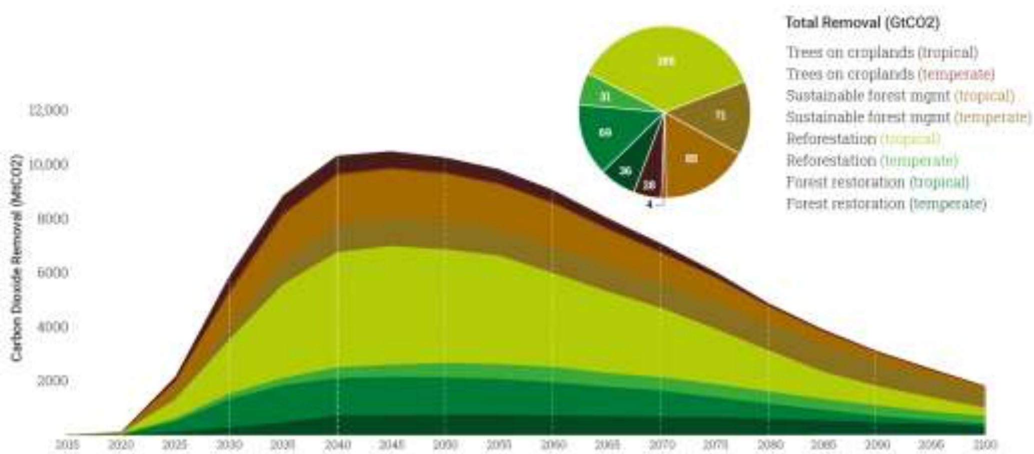
Planting trees on croplands

Tree cropping—a strategy that uses tree planting within croplands—can significantly increase carbon storage on agricultural lands. The model estimates that planting trees on 400 Mha of cropland will achieve approximately 30 $GtCO_2$ of carbon removal by 2100. The four sequestration pathways occur in all countries and regions, although we have excluded reforestation in the boreal forest zone because of the albedo effect.

All four sequestration pathways start in 2020, but have different phase-in and phase-out rates, which also differ between the boreal/temperate and tropical/sub-tropical biomes.

- Forest restoration: boreal/temperate—full potential by 2035, saturation by 2065 (decline to zero around 2100). Tropical/sub-tropical—full potential by 2030, saturation by 2045 (decline to zero around 2100).
- Reforestation: boreal/temperate—full potential by 2045, saturation by 2075 (decline to zero around 2150). Tropical/sub-tropical—full potential by 2040, saturation by 2065 (decline to zero around 2120).
- Sustainable use of forests: boreal/temperate—full potential by 2040, saturation by 2070 (decline to zero around 2150). Tropical/sub-tropical—full potential by 2035, saturation by 2055 (decline to zero around 2100).
- Agroforestry: boreal/temperate—full potential by 2040, saturation by 2060 (decline to zero around 2080). Tropical/sub-tropical—full potential by 2030, saturation by 2050 (decline to zero around 2080).

Figure 32: Carbon Removal Potential of Land Restoration Pathways 2020–2100



OECM presents a statistical analysis (Monte Carlo) of the time horizons and potential cumulative carbon uptakes for four major forest-restoration pathways, divided into temperate and tropical zones. The chart shows a total potential carbon removal of 513 $GtCO_2$ through these pathways, with rapid deployment beginning in the 2020s.

Policy Recommendations

To implement the 1.5°C pathway and meet the sector-based targets will require a significant shift in current policies. This section documents the policy measures that were assumed for the pathways presented, as well as the policy measures known to be successful. Legal frameworks and regulations differ significantly on national and community levels. Therefore, only the functions and aims of the suggested policy measures can be discussed, but not how they can be integrated into various different current jurisdictions. That said, it is assumed that the Paris Agreement will be the global political basis for all policies related to energy and climate measures, to implement the target stated below:

Paris Agreement - Article 2

1. This Agreement, in enhancing the implementation of the Convention, including its objective, aims to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty, including by:

(a) Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;

(b) Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production; and

(c) Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development.

2. This Agreement will be implemented to reflect equity and the principle of common but differentiated responsibilities and respective capabilities, in the light of different national circumstances.

The basic principles for the development of the 1.5°C pathway derive from the long-term experiences of the authorship team with scenario development and have led to a 'seven-step logic'.

This logic extends from the definition of the final state of the energy systems in the long-term future to the key drivers of the energy demand and the energy efficiency potentials, a technological analysis of supply and demand and the market development potential, and the specific policy measures required to implement a theoretical concept in the real market place.

The seven steps are:

1. Define the maximum carbon budget, milestones, and constraints to achieve the climate goal;
2. Define the renewable energy resource potentials for each sector;
3. Identify the economic and societal drivers of demand;
4. Define the efficiency potentials and energy intensities for each sector;
5. Establish time lines and narratives for technology implementation on the end-user and supply sides;
6. Estimate the infrastructure needs, generation costs, and other effects;
7. Identify the policies required and discuss the policy options.

Energy

The financial sector *Energy* covers the extraction of gas and oil, the mining of hard and brown coal, and the project development and installation of utility-scale renewable power projects, renewable heat generation, and the production of renewable fuels (bio energy, synthetic fuels, and hydrogen). Therefore, the energy sector is not a homogeneous sector but is highly diverse. Consequently, policy measures will follow different strategies and will address different aspects and different stakeholders.

For the energy sector to establish long-term planning security, long-term and reliable targets (for both emissions and certain fuels) must be prescribed at the regional level. To establish investment security for renewable energy projects large enough to replace the current fossil-fuel industry and deliver an equal amount of energy is the basic requirement to achieve the Paris Climate Agreement.

The 1.5°C pathway does not allow the *Energy* sector to invest in any new oil or gas extraction projects or new coal mining projects. Instead, the security of supply will rely on new renewable energy projects, such as offshore wind and solar power projects and renewable fuel production facilities. In this regard, the *Energy* sector must work closely with the *Utilities* sector, which covers the distribution and operation of renewable-energy-generating equipment. The following high-level policy measures will be required:

1. Binding CO_2 emission targets in 5-year steps towards a total phase-out of fossil fuels by 2050.
2. Legally binding renewable energy targets in 5-years steps for:
    a. Power;
    b. Heating;
    c. Fuels.
3. Gradual and reliable discontinuation of direct and indirect subsidies for fossil energy investments.
4. Streamlined processes dispensing construction permits for all renewable-energy-related projects (power, heat, and fuels).
5. Change of national taxation systems strictly towards renewable energy projects.
6. Internalization of external costs by carbon tax or surcharge.

Renewable energy targets are vital to accelerate the deployment of renewable energy. Experiences of the past two decades clearly show the effectiveness of renewable energy policy development. The Renewable Policy Network for the 21st Century (REN21) states in their annual market analysis, Renewables 2018, that "(t)argets remain one of the primary means for policy makers to express their commitment to renewable energy deployment. Targets are enacted for economy-wide energy development as well as for specific sectors" (REN21-GSR-2018)[53]. To achieve these goals, innovation processes must be initiated, markets developed, and investment stimulated. For the latter, auctions and feed-in tariffs have proven suitable. In this context, it is important to guarantee investment security and to enable long-term but appropriate revenues.

Climate change leads to several types of environmental damage. Carbon emissions cause climate change. Therefore, it is vital to put a price on carbon to internalize the external costs. Carbon-pricing schemes can be established as cap-and-trade schemes or taxes. Carbon pricing is not sufficient on its own to achieve the objective of the Paris Agreement, and many leading international agencies and institutions argue that a much more concerted and widespread global take-up of carbon pricing will be necessary (Carbon Tracker 2018)[54]. To make carbon pricing an efficient measure, the price of carbon must be sufficient to reflect the environmental damage it causes and must be reliable. Therefore, a minimum price should be implemented to provide planning security.

Subsidies for fossil fuels counteract any efforts to ensure that energy efficiency and renewable energy are competitive. According to the IEA, the total amount of global fossil fuel subsidies was estimated to be around US$260 billion in 2016 (IEA-DB 2018)[55]. The governments of the G20 and the Asia-Pacific Economic Cooperation (APEC) reached an agreement to "rationalize and phase out over the medium term inefficient fossil fuel subsidies that encourage wasteful consumption" (OECD-IEA 2018)[56].

Setting legally binding national targets for 100% renewable energy pathways will lead to an orderly phase-out of fossil fuels. This is vital in planning the socio-economic effects of the energy transition. Supporting measures to achieve the replacement of fossil fuels and inefficient technologies and energy sources will be necessary because targets and economic incentives may not be sufficient in all areas. Regulatory interventions for the decommissioning and replacement of facilities are a way to stop opposing business scenarios and to overcome the inertia of consumers and investors. Moreover, economic policy measures and the clearer definition and stringent enforcement of international standards will accelerate the implementation of the best available technologies in the industry. Both a minimum price on carbon and the immediate phase-out of fossil fuel subsidies must be implemented to support the global energy transition. Policy support for technological innovation is another important measure to create the basis for energy transition processes.

[53] REN21-GSR (2018), REN21, 2018, Renewables 2018, Global Status Report, Paris/France, http://www.ren21.net/status-of-renewables/global-status-report/ page 20
[54] Carbon Tracker (2018), Closing the Gap to a Paris-compliant EU-ETS, 25th April 2018, website, viewed October 2018, https://www.carbontracker.org/reports/carbon-clampdown/
[55] IEA-DB (2018), International Energy Agency Database 2018, Energy Subsidies, web-based database, viewed October 2018, https://www.iea.org/statistics/resources/energysubsidies/
[56] OECD-IEA (2018), OECD website, OECD-IEA analysis of fossil fuels and other support, viewed October 2018, http://www.oecd.org/site/tadffss/

Utilities

The *Energy* and *Utilities* sectors may be separate categories for the financial sector, but for the energy sector, they are two sides of the same coin. The 1.5°C pathway will lead to a 100% renewable electricity supply, with a significant share of variable power generation. The traditional electricity market framework has been developed for central suppliers operating dispatchable and limited dispatchable ('base load') thermal power plants. The electricity markets of the future will be dominated by variable generation, without marginal or fuel costs. The power system will also require the build-up and economic operation of a combination of dispatch generation, storage, and other system services, the operation of which will be conditioned by renewable electricity feed-ins. For both reasons, a significantly different market framework is urgently required, in which the technologies can be operated economically and refinanced. Renewable electricity should be guaranteed priority access to the grid. Access to the exchange capacity available at any given moment should be fully transparent and the transmission of renewable electricity must always have preference. Furthermore, the design of distribution and transmission networks, particularly for interconnections and transformer stations, should be guided by the objective of facilitating the integration of renewables and to achieve a 100% renewable electricity system.

To establish fair and equal market conditions, the ownership of electrical grids should be completely disengaged from the ownership of power-generation and supply companies. To encourage new businesses, relevant grid data must be made available by transmission and distribution system operators. This will require establishing communication standards and data protection guidelines for smart grids. Legislation to support and expand demand-side management is required to create new markets for integration services for renewable electricity. Public funding for research and development is required to further develop and implement technologies that allow variable power integration, such as the smart grid technology, virtual power stations, low-cost storage solutions, and responsive demand-side management. Finally, a policy framework that supports the electrification and sector coupling of the *Heating* and *Transport* sectors is urgently needed to ensure a successful and cost-efficient transition process.

Transport

Road transport must move to the resolute electrification of passenger and—with some limits—freight vehicles. Synthetic fuels and biofuels will complement the transition away from fossil fuels. The *Transport* sector is primarily responsible for the design, manufacture, and operation of new vehicles. However, the fuel and electricity supply, together with the required charging and energy supply infrastructure, is a joint task of the *Energy* and *Utilities* sectors and cannot be seen—or handled by policy markets—in isolation. However, the *Transport* sector transition is not simply a technical process. The aim should be to promote the use of less ecologically problematic transport modes, and public transport wherever possible. This can be done by, for example, the introduction of fiscal and regulatory measures that effectively reduce the subsidization of currently untaxed emissions and the internalisation of external costs.

In parallel, environmentally less-harmful transportation modes should be incentivized. Investments must also be channelled towards highly productive and energy-efficient passenger and freight railway systems and towards a dense network of battery-recharging and hydrogen-refuelling infrastructure for road vehicles. In the context of passenger cars and trucks, direct subsidies or tax incentives for electric vehicles will speed up the electrification of fleets. CO_2 taxation, road tolls, and congestion charges could be applied, in addition to parking-space management schemes to reduce road traffic—and thus internal combustion engines—in a transition to car-reduced cities. The assignment of parking lots and driving lanes exclusively to electric cars will speed the phase-out of internal combustion engines.

In aviation, measures could include the taxation of jet fuel and CO_2, and the application of an emissions-trading scheme on the direct and indirect climate effects of flight at high altitudes. Direct and indirect public subsidies for carriers and airports should be abolished (investment and operational grants should be reduced and funding should be allocated to a competitive and attractive rail system).

All measures curtailing the use of individual passenger transport should be accompanied by the promotion of ubiquitous, fast, comfortable, and price-competitive public transport systems, ride and car sharing, and on-demand services (especially for less densely populated semi-urban and rural areas). Last but not least, an attractive and safe infrastructure for bicycles and e-bikes will help to reduce emissions and the other unwanted side effects of transport. In this arena, Copenhagen and Amsterdam are at the cycling forefront and are inspiring more and more cities to follow their path. Cities must also curtail tendencies to urban sprawl and 'reinvent' the compact city ideal, which means becoming pedestrian-friendly cities, thus reducing the need for individual motorized mobility and freeing up space for recreation and green spaces.

Cities in developed countries should aim to transform their transport systems (often) from passenger-car-centred urban structures and redirect their policies towards pedestrian-, bike-, and mass-transport-friendly environments. The often densely populated megacities emerging in the upcoming economic powerhouses of Africa, Latin America, and Asia should invest, right from the start, in resilient public-transport-oriented urban structures instead of relying too strongly on individual passenger car traffic, as the OECD countries have done in the past.

Industry—general

Policies to achieve the implementation of new highly efficient technologies and to replace fossil fuel use in industry must be defined region-wide or even on the global level, and will require stringent and regulated implementation. Economic incentives, national initiatives, and voluntary agreements with industrial branches will probably not, by themselves, see the achievement of rapid technological change. Concrete standards and requirements must be defined at a very detailed level, covering as far as possible all technologies and their areas of application. The systematic implementation of already-identified best-available technologies could begin immediately.

Mandatory energy management systems should be introduced to identify efficiency potentials and to monitor efficiency progress. The sustainability features of process chains and material flows must also be taken into account when designing political measures. Particular attention must be paid to the material efficiency of both production processes and their products, because this can open up major energy efficiency potentials and reduce other environmental effects. Public procurement policies and guidelines will help to establish new markets and to demonstrate new more-efficient products and opportunities. The effectiveness of policy interventions must be assessed by independent experts, and the further development of efficiency programs and measures will require ongoing co-ordination by independent executive agencies. The public provision of low-interest loans, investment risk management, and tax exemptions for energy-efficient technologies and processes will significantly support technological changes and incentivize the huge investments required. Knowledge transfer between sectors and countries can be achieved through networks initiated and coordinated by governments. Public funding for research and development activities with regard to technological innovation, low-carbon solutions, and their process integration will be vital to push the technological limits further. Innovative approaches to the realization of material cycles and recycling options, the recovery of industrial waste heat, and low-carbon raw materials and process routes in industry must also be identified and implemented.

Steel

The policy recommendations for the *Steel* industry are twofold:

1. Support to decarbonize the thermal and electrical energy supply until 2030;
2. Support to expand new production processes to decarbonize steel manufacturing towards
    - EAF processes;
    - Hydrogen-based steel production.

Although policies to support the transition towards a renewable energy supply are identical to those described for the *Energy* and *Utility* sectors, support for mainstreaming steel production processes to reduce process emissions must be developed specifically for the regional steel industry.

Research and development (R&D) grants are required, as well as product certification schemes, to financially encourage change towards new production lines. Steel-processing industries, such as the automotive and construction sectors, require binding purchase quotas for CO_2-neutral steel. CO_2-intensive steel should gradually be made more expensive with a special 'steel tax' in order to further promote the production of 'green steel'.

Cement

Just as in the steel industry, the decarbonization of production energy for cement has the highest priority in order to achieve short-term emission reductions. The reduction of process emissions requires increased efficiency along all the steps of the production line. However, to date, no processes are available for the production of emissions-free cement. Therefore, measures for nature-based carbon sinks must be supported to compensate for the residual process emissions.

The Global Cement and Concrete Association (GCCA 2020)[57] published a 2050 road map that set a 'long-term vision for the industry'. A detailed roadmap and implementation strategy are planned for 2021, which will cover the following topics:

- emissions reduction in cement and concrete production;
- savings delivered by concrete during its lifetime;
- reduced demand by promoting design and different materials (e.g., wood);
- material and construction efficiencies and improved standards;
- re-use of whole-concrete structures;
- designs for the disassembly and re-use of elements;
- accounting for CO_2 savings at the end of life, including concrete recycling and enhanced re-carbonation.

[57] GCCA 2020, 2050 Roadmap; website viewed in September 2020; https://gccassociation.org/climate-ambition/

Conclusion

The decarbonization of the financial sectors analysed, *Energy*, *Utilities*, *Transport*, *Steel*, and *Cement*, to achieve the Paris Climate Agreements by 2050 is possible with current technologies. It is economically viable and cost competitive in the mid to long term but requires additional investments over the next decade.

Scope 1 and *Scope 2* emissions must decrease by around 28% (± 5%) between 2021 and 2025, with some differences between sectors. The rapid and consequent decarbonization of the power sector is vital to achieve the 1.5°C pathway. Renewables-based power generation is the backbone of decarbonization for all the financial sectors analysed as fossil fuels are replaced by increased electrification.

There is no alternative to a phase-out of coal-based power and heat generation in OECD Europe and OECD North America by 2030. A delayed coal phase-out will put the Paris Climate Agreement out of reach.

The *Energy* and *Utility* sectors play key roles in the implementation of the 1.5°C target by all other industries. Although the *Steel* and *Cement* sectors may be able to set up their own renewable energy and power supplies or PPA, the *Transport* sector is dependent on the *Energy* and *Utilities* sectors to provide sufficient amounts of renewable electricity, biofuels, and synthetic fuels to supply airlines, shipping lines, and road vehicles for passenger and freight transport.

The *Energy* and *Utility* sectors must be the first sectors to decarbonize energy for their customers, to allow them to fulfil their emission reduction targets.

The key responsibility of the *Transport* sector is to move to electric vehicles, biofuels, and renewably produced synthetic fuels. Manufacturers of road vehicles, planes, and ships must phase-out fossil-fuel-based combustion engines over the next two decades.

The market share of electric road vehicles, for both passenger and freight transport, must increase globally from around 2% currently to 30% by 2030. The increased electricity demand must be met by renewably generated electricity.

The rapid electrification of for road transport will have cross benefits for the *Energy* sector and especially for the *Utilities* sector because the increased numbers of electric vehicles will come with higher storage capacities for electricity and significant demand-side management possibilities to integrate high shares of variable solar and wind generation.

Fuel cost savings will more than compensate the increased investment required in renewables-based power and heat generation for all industries.

Whereas early action in the *Energy*, *Utilities*, and *Transport* sectors is required and the technologies are available, the *Steel* and *Cement* sectors will require more time to eliminate process-related emissions. In this analysis, we recommend that renewable energies are first supplied for the production processes in the *Steel* and *Cement* sectors. A reduction in process emissions is calculated for the period after 2030 and requires gradual changes in production processes.

The *Steel* industry must move to electricity-based steel-making processes, such as EAF and hydrogen-based steel production. The latter is currently still in its demonstration phase and must move into mainstream steel manufacture within the next 15 years.

Based on current technologies, the process emissions of the *Cement* industry cannot be reduced to zero. Therefore, nature-based carbon sinks—mainly forests—are factored in to compensate for the residual emissions in 2050. The authors of this analysis recommend that the *Cement* industry—among all other industries—support projects to expand nature-based solutions for negative emissions (= carbon sinks) on global and regional levels.

Annex I: Comparison with IEA NZE2050

Context

In this chapter, we compare the OECM with the *International Energy Agency's Net Zero 2050* (NZE2050) of World Energy Outlook 2020 (IEA WEO2020)[58], which was published in October 2020.

This is a high-level data comparison because the detailed datasets for the scenario was unavailable at the time of writing. The scenario was developed at the same time as the OECM Sectorial pathways—first half of 2020—and are not in any way related to each other.

Scenario Narrative: IEA Net Zero 2050

The IEA NZE2050 is based on IEA's Sustainable Development Scenario (SDS), which sets out an *energy future that simultaneously achieves the three main energy-related UN Sustainable Development Goals on access, air pollution, and climate change. Full access to electricity and clean cooking is achieved by 2030 and there is a substantial reduction in the three main air pollutants, leading to significant improvements in air quality and a reduction in premature deaths*[59]. The NZE2050 accelerates the ambitions of the SDS with regard to energy-related CO_2 emissions, predominantly via increased renewable energy supply and energy efficiency measures. The NZE2050 aims to limit the global surface temperature rise '*without a large level* of net negative emissions globally' to 1.5 °C, with 50% probability.

In comparison, the OECM aims to limit it to 1.5°C with 66% probability.

Selected key parameters: OECM and the IEA NZE2050

At the time of writing, no detailed data for the IEA NZE2050 were available. For example, in the case of the final energy demand results for the industry, transport, and buildings sectors, only a graph was published and the values had to be estimated. The IEA has not published specific data for industry sub-sectors, such as the steel or cement industries. Furthermore, no data are available for the period after 2030 until 2050, except for the actual target of achieving "net zero" emissions. The extent to which negative emissions are factored into this scenario is unknown.

The NZE2050 aims to limit the global surface temperature rise to 1.5°C with 50% probability, whereas the OECM aims for 66% probability.

Table 31 shows the available key parameters of the IEA NZE2050 and compares them with those of the OECM. In a nutshell, the OECM is approximately 5 years ahead of the IEA NZE2050 in terms of CO2 reduction. The NZE2050 leads to energy-related carbon emissions of 20.2 GtCO2 by 2030, whereas the OECM will achieve this in 2025, with a further reduction to 12 GtCO2 in 2030.

Remarkably, the levels of solar-photovoltaic-generated electricity in 2030 are similar in both scenarios. Wind electricity plays a larger role in the OECM, at roughly in the same order of magnitude as the different projections for nuclear electricity: the OECM projects 1,500 TWh/a less nuclear electricity in 2030 and about 2000 TWh/a more wind electricity.

The projected role of coal-generated electricity is similar in both scenarios: The IEA NZE2050 projects 6% of total global electricity (1,880 TWh/a coal electricity – total demand 31,300 TWh/a), while the OECM arrives at 4% (1,505 TWh/a – total demand 36,800 TWh/a). In regard to primary energy, coal will have a share of 12% under the NZE2050 by 2030, in comparison coal in the OECM will supply 8% of primary energy in the same year. The difference is due to increased use of coal in space and process heating in the NZE2050, while the OECM decreases coal across all sectors.

Furthermore, the significant difference in carbon emissions for the industry sector in 2030—6.5 GtCO2 in the NZE2050 versus 3.2 GtCO2 in the OECM—suggests that the use of coal in this sector is significantly different in the two scenarios.

The overall final energy demand in 2030 is 21% higher in the NZE2050 than in the OECM. The electrification process in the OECM is more ambitious across all sectors, leading to 117% more electricity demand than in the NZE2050 case.

[58] IEA WEO 2020, World Energy Outlook 2020, Chapter 4, International Energy Agency, Paris/France, October 2020
[59] IEA WEO 2020, Chapter 4.1, page 125

Table 31: Selected key parameters: OECM versus IEA NZE2050

Parameter	Units	2030 IEA NZE 2050	2030 OECM	IEA versus OECM Difference
Final Energy Demand	[Mtoe]	8,543	6,759	79%
Industry	[Mtoe]	2,700	2,652	98%
Transport	[Mtoe]	2,200	1,418	64%
Buildings	[Mtoe]	2,500	2,689	108%
Primary Energy Demand	[Mtoe]	12,245	10,449	85%
Oil (supply)	[Mtoe]	3,000	1,796	60%
Gas (supply)	[Mtoe]	3,000	2,265	75%
Coal (supply)	[Mtoe]	1,500	840	56%
Power Generation (total)	[TWh/a]	31,342	36,818	117%
Photovoltaic (generation)	[TWh/a]	8,000	7,530	94%
Wind (generation)	[TWh/a]	7,000	9,064	129%
Coal (generation)	[TWh/a]	1,881	1,505	80%
Nuclear (generation)	[TWh/a]	3,134	1,515	48%
CO_2 emissions				
Global	[GtCO_2/a]	20.2	12.24	61%
Industry	[GtCO_2/a]	6.5	3.20	49%
Transport	[GtCO_2/a]	6.4	2.60	41%
Power	[GtCO_2/a]	5.3	4.07	77%
Buildings	[GtCO_2/a]	2	1.40	70%

Annex II: Alignment with Other Financial Sector Initiatives

Context

Voluntary non-governmental ESG-related reporting has existed since 1997, when the first Global Reporting Initiative (GRI)[60] guidelines were published. Other standards, such as the Sustainable Accounting Standards Boards (SASB)[61] standards and the Climate Disclosure Standards Board[62] framework, have since followed, including a range of other sectoral frameworks, tools, and models. Despite these initiatives, the financial sector has identified a need for further clarity in both the definitions and the standardisation of what constitutes a green investment. Although governments and private-sector actors are increasingly channelling financial flows towards those projects that support environmental objectives, uncertainty remains about the legitimacy, impact, and final outcomes of different investments. Inspired by the European Union's initiative to produce a 'green taxonomy', there are now many new initiatives at state, country, and institutional levels that aim to develop definitions of the activities and investments required to meet national environmental and climate change objectives. Such objectives include reducing GHG emissions, reducing deforestation, and minimising pollution, among others.

There are now at least five jurisdictions in which sustainable finance definitions and taxonomies are actively being pursued: the EU, China, Japan, France, and the Netherlands. These taxonomies cover investment assets such as infrastructure and equities, as well as debt and credit markets, including green bonds and sustainability-linked loans.

According to the ICMA, a green taxonomy is a classification system for identifying activities or investments that allow specific targets related to priority environmental objectives to be met. Therefore, a green taxonomy aims to help financial actors, investors, and stakeholders determine the investments that are 'green' for the purposes of meeting specific environmental objectives. Support for making informed decisions on environmentally friendly investments can encourage new projects and activities to be undertaken to help scale-up environmentally sustainable economic development.

The strategic goal of a taxonomy is to ensure that future investments are environmentally sustainable. To achieve this a taxonomy, specific aims must be incorporated:

- Standardising the set of definitions of what constitutes a green investment to achieve sustainability goals;
- Limiting the potential for 'green washing' in the marketplace;
- Assurance of the quality and sustainability credentials of different assets;
- Support for the long-term growth of domestic and foreign green financial markets;
- Increasing the attractiveness of assets to responsible investors;
- Facilitating the tracking and reporting of public and private expenditure, for transparency and international alignment;
- Signalling to investors and broader financial markets that progress is being made towards priority environmental goals;
- Identifying opportunities and areas of underinvestment;
- Direct financial capital flows away from dirty unsustainable investments to green investments.

Investors can benefit from Green Taxonomy in several ways:

- Identifying opportunities that comply with the sustainability criteria for high-impact investments;
- Disclosure exposure to sustainable and non-sustainable investments so that financial markets can include this information in financial decision-making;
- Facilitating the design of new portfolios and financial products that are aligned with 'green taxonomy' principles for clients and beneficiaries;
- Supporting investor engagement with investees in terms of business models and low-carbon transition plans.

Users of taxonomies are not necessarily interested in understanding why a given metric or threshold must be used for a particular asset or activity. Instead, these taxonomies will be used to screen activities to determine their eligibility under the taxonomy. For policymakers, the taxonomy offers a mechanism for driving action across specific environmental and sustainability policy objectives. Setting out pre-defined criteria to identify investment activities that genuinely contribute to the achievement of environmental objectives

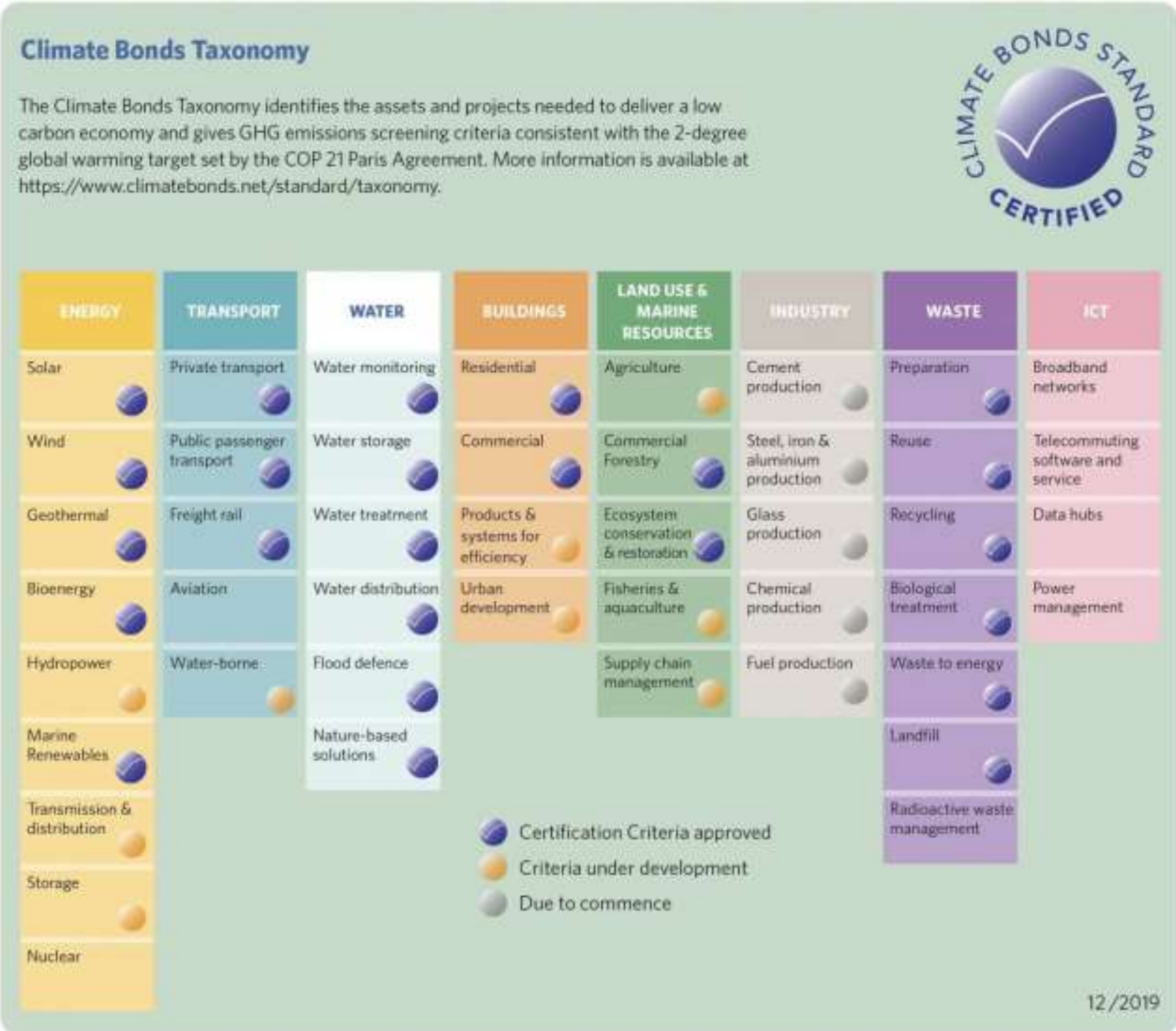
[60] https://www.globalreporting.org/Pages/default.aspx
[61] https://www.sasb.org/
[62] https://www.cdsb.net/

provides both a signal and certainty to the market compared with the situation in which no official definition exists. Providing sustainable finance definitions is an opportunity for asset owners, asset managers, and banks to signal the alignment of their existing and future portfolios. Therefore, it represents both a commercial and a reputational opportunity.

Climate Bonds Taxonomy

The Climate Bonds Taxonomy developed by the Climate Bonds Initiative[63] was the first official sustainable finance taxonomy to be developed. The purpose of the Climate Bonds Taxonomy is to provide a guide for bond issuers, investors, governments, and municipalities to understand what investments are aligned to a low-carbon economy. It is grounded in the latest climate science and has been through an extensive multi-stakeholder approach, leveraging the work of technical and industry working groups. The taxonomy aims to be an important resource for defining green investments across global markets while meeting the objectives of a low-carbon economy. The Climate Bonds Initiative has been a major contributor to the development of the EU Sustainable Finance Taxonomy.

Figure 33: Climate Bonds Taxonomy



The Climate Bonds Taxonomy cuts across seven sectors of the economy: energy, transport, water, buildings, land use and marine resources, industry, waste, and ICT. In each of these seven broad categories, there are specific definitions for a further 45 sub-categories. Figure 33 is a graphical representation of the Climate

[63] https://www.climatebonds.net/

Bonds Taxonomy, showing the different sectors included and the progress in the development of different criteria. Table 32 gives the specific thresholds required to meet the Climate Bond eligibility criteria.

Table 32: Climate Bond Initiative CO_2e Thresholds

Sector	NACE	Green Bond Threshold
Energy	Geothermal energy	Direct emissions less than 100 gCO_2/kWh
	Marine/hydro renewable energy	Power density > 5 w/m^2 & emissions < 100 gCO_2/kWh
	Solar energy	No more than 15% of electricity generated from non-renewable sources
	Wind energy	No more than 15% of electricity generated from non-renewable sources
	Bioenergy	80% GHG emissions reduction compared with fuel baseline + biofuel must be sourced from sustainable feedstock
	Pumped storage	Contributing to a grid with at least 20% renewables
	Nuclear energy	All nuclear energy is eligible
	Transmission and distribution	If infrastructure supports the integration of renewables
Low-carbon transport	Private transport	Electric vehicles and hydrogen vehicles
	Public passenger transport	Trains are eligible and buses with no direct emissions are eligible.
	Freight rail	Trains with no direct emissions are eligible
	Aviation	Use of low-GHG fuel, delivering substantial reduction in gCO_2/passenger
	Shipping - Freight & passenger	Use of low-GHG fuel (hydrogen, ammonia, electric, high % of biofuel)
Ecosystems	Commercial forestry	No conversion from natural landscapes; health of forests is well managed.
	Agricultural production	Demonstration of significant reduction in carbon sequestration and emissions.
	Ecosystem conservation and restoration	Land remediation and clean up, so habitat is appropriate for location.

The EU Taxonomy

The EU Taxonomy is the cornerstone of Europe's sustainable finance policy stream and will have profound implications for the flow of capital towards climate-aligned solutions. An important feature of the EU taxonomy is that it is aligned with the Paris Agreement and can therefore be used as the foundation for the harmonisation of regional green finance classification systems. It defines what is green, or green enough, to be sufficiently aligned with less than 2 °C warming.

The Taxonomy can be used to indicate the proportion of an investment portfolio that is already net zero aligned. It also provides a clear benchmark for emissions performance, against which transition investment strategies can be assessed.

The Taxonomy criteria are aligned with a goal of net zero emissions by 2050 and can be used in any jurisdiction that has a stated emissions target of net zero emissions by 2050. By law, the financial product of every investment fund issued in Europe from 2021 will be required to either refer to the Taxonomy, by disclosing the proportion of Taxonomy alignment within the financial product, or state that the financial product does not contribute to environmental objectives. Furthermore, over 7,000 share-market-listed companies must disclose the proportion of their turnover and capital expenditure that is aligned with the Taxonomy.

The EU Taxonomy has three stated objectives:

- Re-orientation of capital flows towards sustainable investment, in order to achieve sustainable and inclusive growth.
- Management of financial risks stemming from climate change, environmental degradation, and social issues.
- Fostering transparency and long-term perspectives in financial and economic activities.

The Taxonomy includes six environmental objectives. For an activity to be considered 'Taxonomy compliant', it must contribute substantially to one or more of the environmental objectives, comply with minimum social safeguards, and meet the 'do no significant harm' criterion. The 'do no harm' criterion simply means that progress towards any of the six environmental objectives cannot be made at the expense of one of the other objectives.

The six environmental objectives are:

1. Climate change mitigation;
2. Climate change adaptation;
3. Sustainable use and protection of water and marine resources;
4. Transition to a circular economy, waste prevention, and recycling;
5. Pollution prevention and control;
6. Protection of healthy ecosystems.

The Technical Expert Group on Sustainable Finance has developed principles, metrics, and thresholds for climate mitigation and adaptation for 70 economic activities. For example, for power generation, there is a threshold of 100 gCO_2e/kWh, which must be applied consistently and without discrimination amongst technologies.

Areas of alignment and differences with the EU Taxonomy

An important feature of the EU Taxonomy is that it does not consider the overall impact of an activity, simply whether the activity meets a specific threshold. An impact measurement approach would, in principle, steer investment towards projects with the greatest environmental impact. However, an impact approach would involve higher costs than the EC approach, which involves assessment against a threshold rather than measurement. The data and outputs from this project are sufficiently detailed for the potential development of an impact measurement score, although this step has not been undertaken and remains to be developed.

The emerging EU Taxonomy includes not only low-carbon economic activities but also 'transition' and 'enabling' activities. Although these categories are important for transitioning to a net zero-emissions economy by 2050, transition and enabling activities have not been defined separately in the present research. This is because this research is based on the premise that all sectors must transition to net zero emissions by 2050 and estimates the allowable emissions paths to achieve that trajectory.

Although the EU Taxonomy includes six environmental objectives, one of which is the mitigation of climate change, our research only considers climate-change mitigation and adaptation at this stage. Consistent with the EU Taxonomy, the Alliance Net Zero Taxonomy does not include nuclear power. However, the EU Taxonomy does include carbon capture and utilization (CCU) and carbon capture and storage (CCS).

The EU Taxonomy includes eight macro-sectors and 70 economic activities, each of which belongs to a macro-sector. Each economic activity aligns with the European NACE sectoral classification system. Our research largely matches those sectors that are covered by the EU Taxonomy for mitigation. The major similarities and differences shown in Table 33 below are ranked by total emissions (*Scope 1*).

Table 33: NACE sector comparisons between EU Taxonomy and the Alliance Net Zero Taxonomy

NACE Macro-sector	EU Taxonomy (mitigation)	NZAOA Net Zero Taxonomy	Total Emissions tCO_2e (2018) (Scope 1) (Europe)
D – Electricity, gas, steam, and air-conditioning supply	Fully considered	Fully considered	1,021,327
C – Manufacturing	Partially considered	Partially considered	836,131
H – Transport and storage	Partially considered	Partially considered	543,991
A – Agriculture, forestry, fishing	Fully considered	Partially considered	526,387
E – Water supply, sewerage, waste management, and remediation	Fully considered	Not considered	161,962
B – Mining and quarrying	Partially considered	Partially considered	81,201
G – Wholesale and retail trade; repair of motor vehicles	Not considered	Not considered	79,399
F – Construction	Partially considered	Partially considered	64,791
Q – Human health and social work activities	Not considered	Not considered	32,512
O – Public administration and defence; compulsory social security	Not considered	Not considered	29,297
N – Administration and support service activities	Not considered	Not considered	21,424
I – Accommodation and food service activities	Not considered	Not considered	17,333
P – Education	Not considered	Not considered	17,273
M – Professional, scientific, and technical activities	Selected based on enabling activity, partially considered	Not considered	17,056
K – Financial insurance activities	Not considered	Not considered	10,837
S – Other service activities	Not considered	Not considered	9,816
J – information and communication	Selected based on enabling activity, fully considered	Not considered	8,781
R – Arts, entertainment, and recreation	Not considered	Not considered	8,299
L – Real-estate activities	Partially considered	Not considered	5,726
T – Activities of households as employers; undifferentiated goods-and-service-producing activities	Not considered	Not considered	235
U – Activities of extraterritorial organisations and bodies	Not considered	Not considered	27

The following tables map the thresholds provided in the EU Taxonomy and the Climate Bonds Initiative to the NACE sectors used in the Alliance Net Zero Taxonomy.

Table 34: EU Taxonomy CO_2e Thresholds for Alliance Net Zero Sectors—part 1

Sector	Relevant NACE Sector	EU Taxonomy Threshold Value	Further details
Energy/Oil & Gas	B - Mining and quarrying	Not eligible	
	B5 - Mining of coal and lignite	Not eligible	
	B6 - Extraction of crude petroleum and natural gas	Not eligible	
Electricity generation	Solar Photovoltaic	100 gCO^2/kWh	Appendix
	Concentrated Solar Power	100 gCO_2/kWh	Appendix
	Wind Power	100 gCO^2/kWh	Appendix
	Ocean Energy	100 gCO_2/kWh	Appendix
	Hydropower	100 gCO_2/kWh	Appendix
	Geothermal Power	100 gCO_2/kWh	Appendix
	Gas (not limited to natural gas)	100 gCO_2/kWh	Appendix
	Bioenergy (biomass, biogas, and biofuels)	80% GHG emissions reduction relative to the relative fossil fuel comparator (RED II)	Appendix
Utilities	D - Electricity, gas, steam, and air-conditioning supply	100 gCO_2/kWh	Appendix
	Storage of electricity	All electricity storage is eligible	Appendix
	Retro-fitting gas transmission and distribution networks	Any gas network that can integrate low-carbon fuels (e.g., hydrogen)	Appendix
	D35.1 - Electric power generation, transmission, and distribution	67% of grid connections must be below 100 gCO_2/kWh for electric power grids to be eligible.	Appendix

Table 35: EU Taxonomy CO_2e Thresholds for the Alliance Net Zero Sectors—part 2

Sector	Relevant NACE Sector	EU Taxonomy Threshold Value	Further details
Materials–Cement	C23.5.1 - Manufacture of cement	0.766 tCO_2e/t of clinker	Appendix
Steel	C24.1 - Manufacture of basic iron, steel, and of ferro-alloys C24.2 - Manufacture of tubes, pipes, hollow profiles, and related fittings, from steel C24.3 - Manufacture of other products from the first processing of steel	• Hot metal = 1.328 tCO_2e/t product • Sintered ore = 0.171 tCO_2e/t product • Iron casting = 0.325 tCO_2e/t product • Electric arc furnace (EAF) high alloy steel = 0.352 tCO_2e/t product • Electric arc furnace (EAF) carbon steel = 0.283 tCO_{2e}/t product • Coke (excluding lignite coke) = 0.286 tCO_2e/t product	Appendix
Transport	H50 - Water transport—Freight	50% lower than the average reference value	Appendix
	H50 - Water transport—Passenger	50 gCO_2e emissions per passenger kilometre (gCO_2e/pkm)	Appendix
	H51 - Air transport	No viable alternative available	Appendix
	Passenger cars and commercial vehicles	50 gCO_2/km	Appendix
Manufacturing	C - Manufacturing	No details	Appendix
	C29.1 - Manufacture of motor vehicles	No details	Appendix
	C30.1 - Building of ships and boats	No details	Appendix
	C30.3 - Manufacture of air- and spacecraft and related machinery	No details	Appendix
	Manufacture of low-carbon technologies	Very detailed (see Appendix)	Appendix
Afforestation	A - Agriculture, forestry, and fishing	1 tonne biomass = 0.5 tonne carbon = 0.5 × 3.67 tonne CO_2	Appendix

Annex III: Results

Overview: Global—Scope 1 and 2 emissions for five financial sectors

r	Units	2018	2019	2020	2020	2025	2030	2035	2040	2045	2050
Global		Base year	[estimated]	[estimated]	[1.5 °C]	Projection					
Total Energy, Gas, Oil & Coal Sector -											
Total CO_2 Emissions	[$MtCO_2$/a]	32,635	33,410	30,232	31,076	23,311	12,474	6,393	2,997	854	48
Variation compared with 2019	[%]				−7%	−30%	−63%	−81%	−91%	−97%	−100%
Energy Sector - Scope 1: Total CO_2 equivalents (CO_2e)	[Mt**CO_2e**]	34,422	35,240	31,861	32,818	24,660	13,200	6,790	3,232	997	157
Change to 2019	[%]				−7%	−30%	−63%	−81%	−91%	−97%	-100%
Energy Sector - Scope 2: Total CO_2 equivalents	[Mt**CO_2e**]	475	487	450	449	328	171	91	51	30	22
Change to 2019	[%]				−8%	−33%	−65%	−81%	−89%	−94%	−96%
Total Energy Production	[PJ/a]	552,496	565,655	524,822	549,519	501,175	437,483	415,300	418,325	421,520	422,668
Variation compared with 2019	[%]				−3%	−11%	−23%	−27%	−26%	−25%	−25%
Intensities											
Sector CO_2 Intensity	[$MtCO_2$/PJ]	0.06	0.06	0.06	0.06	0.05	0.03	0.02	0.01	0.00	0.00
Variation compared with 2019	[%]				−4%	−21%	−52%	−74%	−88%	−97%	−100%
Sector **CO_2 equivalent** Intensity (CO_2 + CH_4)	[$MtCO_2$/PJ]	0.06	0.06	0.06	0.06	0.05	0.03	0.02	0.01	0.00	0.00
Variation compared with 2019	[%]				96%	79%	48%	26%	12%	4%	1%
Regional Energy Intensity	[PJ/$GDP]	7.2	7.2	6.4	6.7	4.9	3.6	2.8	2.3	2.0	1.7
Variation compared with 2019	[%]				−6%	−31%	−50%	−62%	−67%	−73%	−76%
Total Utilities Sector											
Total CO_2 Emissions	[$MtCO_2$/a]	18,961	19,416	17,614	15,933	12,164	9,144	5,879	3,143	1,060	0
Variation compared with 2019	[%]				−18%	−37%	−53%	−70%	−84%	−95%	−100%
Utilities - Scope 1: Total CO_2 equivalents	[Mt**CO_2e**]	19,854	20,331	18,511	16,630	12,772	9,886	6,577	3,737	1,457	265
Change to 2019	[%]				−18%	−37%	−51%	−68%	−82%	−93%	−99%
Utilities - Scope 2: Total CO_2 equivalents	[Mt**CO_2e**]	249	255	247	228	193	160	107	61	22	5
Change to 2019	[%]				−11%	−24%	−37%	−58%	−76%	−91%	−98%
Total Energy Production	[PJ/a]	201,394	206,228	197,269	193,272	200,681	235,183	262,759	295,640	314,329	313,275
Variation compared with 2019	[%]				−6%	−3%	14%	27%	43%	52%	52%
Intensities											
Sector CO_2 Intensity	[$MtCO_2$/PJ]	0.09	0.09	0.09	0.08	0.06	0.04	0.02	0.01	0.00	0.00
Variation compared with 2019	[%]				−12%	−36%	−59%	−76%	−89%	−96%	−100%
Sector **CO_2 equivalent** Intensity (CO_2 + CH_4)	[Mt**CO_2e/**PJ]	0.10	0.10	0.09	0.09	0.06	0.04	0.03	0.01	0.00	0.00
Variation compared with 2019	[%]				87%	65%	43%	25%	13%	5%	1%
Regional Energy Intensity	[PJ/$GDP]	2.64	2.61	2.42	2.37	1.97	1.91	1.74	1.65	1.47	1.26
Variation compared with 2019	[%]				−9%	−25%	−27%	−33%	−37%	−44%	−52%
Total Transport Sector		2018	2019	2020	2020	2025	2030	2035	2040	2045	2050
Transport - Scope 1: Total CO_2 equivalents	[Mt**CO_2e**]	7,015	7,204	6,494	6,631	5,052	2,404	997	305	42	0
Change to 2019	[%]	0	0	0	-5%	-28%	-66%	-86%	-96%	-99%	-100%
Transport - Scope 2: Total CO_2 equivalents	[Mt**CO_2e**]	44.7	63.9	70.6	82.4	333.3	494.8	354.9	165.6	49.6	0.0
Change to 2019	[%]										
Total Sector Energy Demand	[PJ/a]	102,023	104,894	95,110	97,517	87,025	65,751	57,115	51,886	46,493	42,005
Variation compared with 2019	[%]				-4%	-15%	-36%	-44%	-49%	-54%	-59%
Intensities											
Air Passenger Transport											
Emission Intensity	[gCO_2/pkm]	125.57	117.20	117.20	117.20	97.00	73.59	63.03	46.74	13.81	0.00
Emission Intensity reduction compared with 2019	[%]				0%	-17%	-37%	-46%	-60%	-88%	-100%
Energy Intensity	[MJ/pkm]	1.7	1.6	1.6	1.6	1.5	1.4	1.3	1.3	1.3	1.2
Emission intensity reduction compared with 2019	[%]				0%	-6%	-14%	-17%	-20%	-21%	-23%
Air Freight Transport											
Emission Intensity	[gCO_2/tkm]	2360.26	2237.12	2237.12	2237.12	1878.36	1458.28	1260.69	944.10	280.15	0.00
Emission intensity reduction compared with 2019	[%]				0%	-16%	-35%	-44%	-58%	-87%	-100%
Energy Intensity	[MJ/tkm]	32.2	30.52	30.52	30.52	29.12	27.16	26.46	25.76	25.48	25.2
Emission intensity reduction compared with 2019	[%]				0%	-5%	-11%	-13%	-16%	-17%	-17%
Navigation: Passenger Transport											
Emission Intensity	[gCO_2/pkm]	4.55	4.55	4.55	4.51	3.93	2.96	1.75	0.00	0.00	0.00
Emission intensity reduction compared with 2019	[%]				−1%	−14%	−35%	−62%	−100%	−100%	−100%
Energy Intensity	[MJ/pkm]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Emission intensity reduction compared with 2019	[%]				−1%	−2%	−3%	−4%	−5%	−6%	−7%
Navigation: Freight Transport											
Emission Intensity	[gCO_2/tkm]	15.35	15.35	15.35	15.35	13.28	9.94	5.83	0.00	0.00	0.00
Emission intensity reduction (base 2019)	[%]				0%	−13%	−35%	−62%	−100%	−100%	−100%
Energy Intensity	[MJ/tkm]	0.19	0.19	0.19	0.19	0.19	0.18	0.18	0.18	0.17	0.17
Emission intensity reduction (base 2019)	[%]				0%	−2%	−3%	−5%	−7%	−8%	−9%
Road: Light-Duty Vehicles/Passenger Transport											
Emission Intensity	[gCO_2/pkm]	718.91	738.66	752.82	753.40	620.34	288.45	111.08	34.16	4.72	0.00
Emission intensity reduction (base 2019)	[%]				−2%	−15%	−43%	−68%	−79%	−83%	−85%
Energy Intensity	[MJ/pkm]	1.5	1.3	1.3	1.3	1.2	0.9	0.7	0.6	0.5	0.5
Emission intensity reduction (base 2019)	[%]				−2%	−12%	−30%	−44%	−53%	−59%	−61%
Road: Trucks/Freight Transport											
Emission Intensity	[gCO_2/tkm]	874	940	954	884	767	426	200	63	9	0
Emission intensity reduction (base 2019)	[%]				−1%	−19%	−56%	−87%	−97%	−100%	−100%
Energy Intensity	[MJ/tkm]	1.3	1.3	1.3	1.3	1.2	0.9	0.8	0.6	0.6	0.5
Emission intensity reduction (base 2019)	[%]				0%	−9%	−26%	−41%	-49%	−55%	−57%

Global	Units	2018	2019	2020	2020	2025	2030	2035	2040	2045	2050
Sub-sector		Base year	[estimated]	[estimated]	[1.5 °C]	Projection					
Total Materials–Steel											
Scope 1: Total direct emissions in CO_2 equivalents (CO_2e)	[$MtCO_2e$/a]	4,113	4,231	3,873	3,855	3,313	2,224	1,386	845	470	216
Change to 2019	[%]				−9%	−22%	−47%	−67%	−80%	−89%	−95%
Scope 2: Electricity generation for steel production	[tCO_2/ton steel]	604	619	541	523	389	228	117	53	18	0
Change to 2019	[%]				−16%	−37%	−63%	−81%	−91%	−97%	−100%
Specific energy-related CO_2 emissions per ton of steel	[tCO_2/ton steel]	2.27	2.26	2.14	2.13	1.74	1.10	0.64	0.37	0.19	0.08
Deviation compared with 2019	[%]				−6%	−23%	−51%	−72%	−84%	−92%	−96%
Specific process-related CO_2 emissions per ton of steel	[tCO_2/ton steel]	1.06	1.06	1.02	1.02	0.92	0.60	0.37	0.23	0.15	0.08
Deviation compared with 2019	[%]				−55%	−59%	−73%	−84%	−90%	−93%	−96%
Total Final Energy Demand	[PJ/a]	30,398	31,128	28,861	32,235	33,399	34,638	36,059	37,510	39,351	41,247
Deviation in energy demand compared with 2019	[%]				4%	7%	11%	16%	21%	26%	33%
Product Energy Intensity	[GJ/ton steel]	18.6	18.6	18.6	18.0	17.5	17.2	16.7	16.2	15.8	15.3
Deviation compared with 2019	[%]				−3%	−6%	−8%	−10%	−13%	−15%	−18%
Total Materials–Cement											
Scope 1: Total direct emissions in CO_2 equivalents	[$MtCO_2e$/a]	1,920	1,946	1,847	1,862	1,701	1,407	1,209	1,082	940	807
Change to 2019	[%]				−4%	−13%	−28%	−38%	−44%	−52%	−59%
Scope 2: Emissions - Electricity generation for cement production	[$MtCO_2e$/a]	225	225	199	198	113	55	24	9	3	0
Change to 2019	[%]				−12%	−50%	−76%	−89%	−96%	−99%	−100%
Total CO_2 Emissions	[mio. tCO_2/a]	854.2	853.6	780.9	723.5	525.2	324.7	201.4	146.3	105.3	73.0
CO_2 emission reduction compared with 2019	[%]				−15%	−38%	−62%	−76%	−83%	−88%	−91%
Specific energy-related CO_2 emissions per ton of clinker	[tCO_2/ton clinker]	0.236	0.230	0.218	0.185	0.140	0.092	0.059	0.045	0.033	0.024
Deviation compared with 2019	[%]				−20%	−39%	−60%	−74%	−81%	−85%	−90%
Specific energy-related CO_2 emissions per ton of cement	[tCO_2/ton cement]	0.291	0.284	0.267	0.230	0.165	0.104	0.064	0.046	0.034	0.024
Deviation compared with 2019	[%]				−19%	−42%	−63%	−77%	−84%	−88%	−92%
Total Energy Demand	[PJ/a]	11,801	11,762	11,107	11,585	11,469	11,144	11,199	11,303	11,119	10,924
Deviation in energy demand compared with 2019	[%]				−2%	−2%	−5%	−5%	−4%	−5%	−7%
Product energy intensity (thermal + electricity)	[GJ/ton cement]	2.9	2.8	2.7	2.6	2.5	2.4	2.4	2.3	2.2	2.1
Deviation compared with 2019	[%]				−6%	−10%	−13%	−16%	−17%	−20%	−23%

Overview: OECD Europe—Scope 1 and 2 emissions for five financial sectors

OECD Europe		2018	2019	2020	2020	2025	2030	2035	2040	2045	2050
Sub-sector	Units	Base year	[estimated]	[estimated]	[1.5 °C]	Projection					
Total Energy, Gas, Oil & Coal Sector -											
Total CO_2 Emissions	[$MtCO_2$/a]	3,712	3,767	3,371	3,218	2,040	971	631	297	106	3
Variation compared with 2019	[%]				−15%	−46%	−74%	−83%	−92%	−97%	−100%
Energy Sector - Scope 1: Total CO_2 equivalents (CO_2e)	[Mt**CO_2e**]	3,950	4,008	3,586	3,433	2,189	1,054	691	333	129	17
Change to 2019	[%]				−14%	−45%	−74%	−83%	−92%	−97%	−100%
Energy Sector - Scope 2: Total CO_2 equivalents	[Mt**CO_2e**]	37	38	35	32	18	7	4	3	2	2
Change to 2019	[%]				−15%	−52%	−82%	−89%	−93%	−95%	−96%
Total Energy Production	[PJ/a]	73,686	74,778	69,319	69,309	56,512	45,249	42,974	39,648	37,928	37,336
Variation compared with 2019	[%]				93%	76%	61%	57%	53%	51%	50%
Intensities											
Sector CO_2 Intensity	[$MtCO_2$/PJ]	0.05	0.05	0.05	0.05	0.04	0.02	0.01	0.01	0.00	0.00
Variation compared with 2019	[%]				−8%	−28%	−57%	−71%	−85%	−94%	−100%
Sector **CO_2 equivalent** Intensity (CO_2 + CH_4)	[mio. tCO_2/PJ]	0.05	0.05	0.05	0.05	0.04	0.02	0.02	0.01	0.00	0.00
Variation compared with 2019	[%]				−8%	−28%	−57%	−70%	−84%	−94%	−99%
Regional Energy Intensity	[PJ/$GDP]	3.2	3.2	2.9	2.9	2.2	1.6	1.4	1.2	1.1	1.0
Variation compared with 2019	[%]				91%	68%	50%	44%	38%	34%	32%
Total Utilities Sector											
Total CO_2 Emissions	[$MtCO_2$/a]	2,072	2,104	1,863	1,790	1,357	1,035	765	380	136	0
Variation compared with 2019	[%]				−15%	−35%	−51%	−64%	−82%	−94%	−100%
Utilities - Scope 1: Total CO_2 equivalents	[Mt**CO_2e**]	2,125	2,157	1,916	1,837	1,408	1,112	867	461	185	33
Change to 2019	[%]				−15%	−35%	−48%	−60%	−79%	−91%	−98%
Utilities - Scope 2: Total CO_2 equivalents	[Mt**CO_2e**]	33	33	32	31	27	22	15	7	3	1
Change to 2019	[%]				−6%	−17%	−33%	−55%	−78%	−91%	−98%
Total Energy Production	[PJ/a]	29,666	30,111	28,810	28,587	28,548	30,116	32,416	31,230	30,594	30,327
Variation compared with 2019	[%]				−5%	−5%	0%	8%	4%	2%	1%
Intensities											
Sector CO_2 Intensity	[$MtCO_2$/PJ]	0.07	0.07	0.06	0.06	0.05	0.03	0.02	0.01	0.00	0.00
Variation compared with 2019	[%]				−10%	−32%	−51%	−66%	−83%	−94%	−100%
Sector **CO_2 equivalent** Intensity (CO_2 + CH_4)	[mio. **tCO_2e**/PJ]	0.07	0.07	0.07	0.06	0.05	0.04	0.03	0.01	0.01	0.00
Variation compared with 2019	[%]				90%	69%	52%	37%	21%	8%	2%
Regional Energy Intensity	[PJ/$GDP]	1.29	1.28	1.21	1.20	1.09	1.07	1.06	0.95	0.88	0.82
Variation compared with 2019	[%]				−7%	−15%	−17%	−17%	−26%	−32%	−36%
Total Transport Sector											
Transport - Scope 1: Total CO_2 equivalents	[Mt**CO_2e**]	903	901	891	891	524	135	57	8	0	0
Change to 2019	[%]	0	0	0	-1%	−42%	−85%	−94%	−99%	−100%	−100%
Transport - Scope 2: Total CO_2 equivalents	[Mt**CO_2e**]	1.3	1.8	2.2	1.9	27.5	57.3	48.5	22.5	7.2	0.0
Change to 2019	[%]										
Total Sector Energy Demand	[PJ/a]	12,919	12,894	12,804	13,172	8,985	6,113	6,044	5,151	4,558	4,131
Variation compared with 2019	[%]				2%	-30%	-53%	-53%	-60%	-65%	-68%
Intensities											
Air Passenger Transport											
Emission Intensity	[gCO_2/pkm]	125.57	117.20	117.20	117.20	97.00	75.34	45.58	0.00	0.00	0.00
Emission intensity reduction compared with 2019	[%]				0%	-17%	-36%	-61%	-100%	-100%	-100%
Energy Intensity	[MJ/pkm]	1.7	1.6	1.6	1.6	1.5	1.4	1.3	1.3	1.3	1.2
Emission intensity reduction compared with 2019	[%]				0%	-6%	-14%	-17%	-20%	-21%	-23%
Air Freight Transport											
Emission Intensity	[gCO_2/tkm]	2360.26	2237.12	2237.12	2237.12	1878.36	1493.12	911.57	0.00	0.00	0.00
Emission intensity reduction compared with 2019	[%]				0%	-16%	-33%	-59%	-100%	-100%	-100%
Energy Intensity	[MJ/tkm]	32.2	30.52	30.52	30.52	29.12	27.16	26.46	25.76	25.48	25.2
Emission intensity reduction compared with 2019	[%]				0%	-5%	-11%	-13%	-16%	-17%	-17%
Navigation: Passenger Transport											
Emission Intensity	[gCO_2/pkm]	4.55	4.55	4.55	4.51	3.93	2.96	1.75	0.00	0.00	0.00
Emission intensity reduction compared with 2019	[%]				−1%	−14%	−35%	−62%	−100%	−100%	−100%
Energy Intensity	[MJ/pkm]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Emission intensity reduction compared with 2019	[%]				−1%	−2%	−3%	−4%	−5%	−6%	−7%
Navigation: Freight Transport											
Emission Intensity	[gCO_2/tkm]	15.35	15.35	15.35	15.35	13.28	9.94	5.83	0.00	0.00	0.00
Emission intensity reduction compared with 2019	[%]				0%	−13%	−35%	−62%	−100%	−100%	−100%
Energy Intensity	[MJ/tkm]	0.19	0.19	0.19	0.19	0.19	0.18	0.18	0.18	0.17	0.17
Emission intensity reduction compared with 2019	[%]				0%	−2%	−3%	−5%	−7%	−8%	−9%
Road: Light-Duty Vehicles/Passenger Transport											
Emission Intensity	[gCO_2/pkm]	98.17	100.11	111.53	105.64	66.40	17.05	6.90	0.94	0.00	0.00
Emission intensity reduction compared with 2019	[%]				−12%	−26%	−62%	−85%	−93%	−95%	−95%
Energy Intensity	[MJ/pkm]	1.5	1.5	1.5	1.3	1.2	0.9	0.7	0.6	0.5	0.5
Emission intensity reduction compared with 2019	[%]				−12%	−22%	−38%	−50%	−58%	−63%	−65%
Road: Trucks/Freight Transport											
Emission Intensity	[gCO_2/tkm]	112	112	112	120	80	23	11	2	0	0
Emission intensity reduction compared with 2019	[%]				−6%	−22%	−73%	−97%	−100%	−100%	−100%
Energy Intensity	[MJ/tkm]	1.3	1.3	1.3	1.3	1.2	0.9	0.8	0.6	0.6	0.5
Emission intensity reduction compared with 2019	[%]				0%	−9%	−26%	−41%	−49%	−55%	−57%

OECD Europe		2018	2019	2020	2020	2025	2030	2035	2040	2045	2050
Sub-sector	Units	Base year	[estimated]	[estimated]	[1.5°C]	Projection					
Total Materials–Steel											
Scope 1: Total direct emissions in CO_2 equivalents (CO_2e)	[$MtCO_2e/a$]	447	450	425	406	346	238	157	95	57	26
Change to 2019	[%]				−10%	−23%	−47%	−65%	−79%	−87%	−94%
Scope 2: Electricity generation for steel production	[tCO_2/ton steel]	48	48	40	45	31	23	17	9	4	0
Change to 2019	[%]				−7%	−35%	−53%	−64%	−81%	−92%	−100%
Specific energy-related CO_2 emissions per ton of steel	[tCO_2/ton steel]	2.06	2.07	1.96	1.93	1.55	0.97	0.60	0.34	0.19	0.08
Deviation compared with 2019	[%]				−7%	−25%	−53%	−71%	−83%	−91%	−96%
Specific process-related CO_2 emissions per ton of steel	[tCO_2/ton steel]	1.06	1.06	1.06	1.06	0.92	0.58	0.36	0.22	0.15	0.08
Deviation compared with 2019	[%]				−49%	−55%	−72%	−83%	−89%	−93%	−96%
Total Final Energy Demand	[PJ/a]	3,764	3,821	3,560	3,696	3,693	3,889	3,933	3,965	4,017	4,055
Deviation in energy demand compared with 2019	[%]				−3%	−3%	2%	3%	4%	5%	6%
Product Energy Intensity	[GJ/ton steel]	18.6	18.6	18.6	17.6	16.6	15.9	15.1	14.3	13.4	12.6
Deviation compared with 2019	[%]				−6%	−11%	−15%	−19%	−23%	−28%	−32%
Total Materials–Cement											
Scope 1: Total direct emissions in CO_2e	[$MtCO_2e/a$]	148	142	138	140	141	127	109	93	76	62
Change to 2019	[%]				−2%	−1%	−11%	−23%	−35%	−47%	−57%
Scope 2: Emissions - Electricity generation for cement production	[$MtCO_2e/a$]	14	15	12	10	5	3	2	1	0	0
Change to 2019	[%]				−31%	−63%	−80%	−87%	−94%	−98%	−100%
Total CO_2 Emissions	[$MtCO_2/a$]	58.2	52.8	48.1	45.5	42.0	36.0	24.5	14.1	5.3	0.0
CO_2 emission reduction compared with 2019	[%]				−14%	−20%	−32%	−54%	−73%	−90%	−100%
Specific energy-related CO_2 emissions per ton of clinker	[tCO_2/ton clinker]	0.195	0.170	0.162	0.150	0.148	0.133	0.090	0.051	0.019	0.000
Deviation compared with 2019	[%]				−12%	−13%	−22%	−47%	−70%	−89%	−100%
Specific energy-related CO_2 emissions per ton of cement	[tCO_2/ton cement]	0.237	0.213	0.196	0.177	0.162	0.141	0.094	0.053	0.020	0.000
Deviation compared with 2019	[%]				−17%	−24%	−34%	−56%	−75%	−91%	−100%
Total Energy Demand	[PJ/a]	965	979	921	963	963	938	943	951	936	919
Deviation in energy demand compared with 2019	[%]				−2%	−2%	−4%	−4%	−3%	−4%	−6%
Product energy intensity (thermal + electricity)	[GJ/ton cement]	2.8	2.8	2.7	2.6	2.5	2.4	2.4	2.3	2.2	2.1
Deviation compared with 2019	[%]				−7%	−11%	−15%	−17%	−18%	−21%	−24%

Overview: OECD North America—Scope 1 and 2 emissions for five financial sectors

OECD North America		2018	2019	2020	2020	2025	2030	2035	2040	2045	2050
Sub-sector	Units	Base year	[estimated]	[estimated]	[1.5 °C]	Projection					
Total Energy, Gas, Oil & Coal Sector -											
Total CO_2 Emissions	[$MtCO_2$/a]	6,266	6,389	5,742	6,408	3,513	1,326	562	247	22	7
Variation compared to 2019	[%]				0%	−45%	−79%	−91%	−96%	−100%	−100%
Energy Sector - Scope 1: Total CO_2 equivalents (CO_2e)	[Mt**CO_2e**]	6,505	6,633	5,947	6,652	3,648	1,373	588	266	40	24
Change to 2019	[%]				0%	−45%	−79%	−91%	−96%	−99%	−100%
Energy Sector - Scope 2: Total CO_2 equivalents	[Mt**CO_2e**]	86	88	81	90	51	18	10	6	4	4
Change to 2019	[%]				2%	−42%	−80%	−89%	−93%	−95%	−96%
Total Energy Production	[PJ/a]	111,913	114,131	105,226	113,386	90,304	70,234	60,336	59,004	56,387	55,513
Variation compared with 2019	[%]				99%	79%	62%	53%	52%	49%	49%
Intensities											
Sector CO_2 Intensity	[$MtCO_2$/PJ]	0.06	0.06	0.05	0.06	0.04	0.02	0.01	0.00	0.00	0.00
Variation compared with 2019	[%]				1%	−31%	−66%	−83%	−93%	−99%	−100%
Sector **CO_2 equivalent** Intensity (CO_2 + CH_4)	[$MtCO_2$/PJ]	0.06	0.06	0.06	0.06	0.04	0.02	0.01	0.00	0.00	0.00
Variation compared with 2019	[%]				101%	69%	34%	17%	8%	1%	1%
Regional Energy Intensity	[PJ/$GDP]	4.7	4.7	4.2	4.6	3.3	2.3	1.8	1.6	1.4	1.2
Variation compared with 2019	[%]				97%	69%	49%	38%	33%	29%	26%
Total Utilities Sector											
Total CO_2 Emissions	[$MtCO_2$/a]	3,778	3,854	3,512	3,866	2,352	1,059	511	236	15	0
Variation compared with 2019	[%]				0%	−39%	−73%	−87%	−94%	−100%	−100%
Utilities - Scope 1: Total CO_2 equivalents	[Mt**CO_2e**]	3,963	4,043	3,697	4,032	2,535	1,271	705	408	62	48
Change to 2019	[%]				0%	−37%	−69%	−83%	−90%	−98%	−99%
Utilities - Scope 2: Total CO_2 equivalents	[Mt**CO_2e**]	67	68	66	65	49	23	10	5	1	1
Change to 2019	[%]				−4%	−28%	−67%	−85%	−92%	−98%	−99%
Total Energy Production	[PJ/a]	52,358	53,405	51,253	51,771	47,271	42,186	40,514	45,686	45,953	45,998
Variation compared with 2019	[%]				−3%	−11%	−21%	−24%	−14%	−14%	−14%
Intensities											
Sector CO_2 Intensity	[$MtCO_2$/PJ]	0.07	0.07	0.07	0.07	0.05	0.03	0.01	0.01	0.00	0.00
Variation compared with 2019	[%]				3%	−31%	−65%	−83%	−93%	−100%	−100%
Sector **CO_2 equivalent** Intensity (CO_2 + CH_4)	[Mt**CO_2e**/PJ]	0.08	0.08	0.07	0.08	0.05	0.03	0.02	0.01	0.00	0.00
Variation compared with 2019	[%]				103%	71%	40%	23%	12%	2%	1%
Regional Energy Intensity	[PJ/$GDP]	7.92	7.78	7.20	7.27	5.11	3.71	2.81	2.61	2.09	1.74
Variation compared with 2019	[%]				−7%	−34%	−52%	−64%	−66%	−73%	−78%
Total Transport Sector											
Transport - Scope 1: Total CO_2 equivalents	[Mt**CO_2e**]	2,138	2,142	2,077	2,192	1,175	396	135	58	1	0
Change to 2019	[%]	0	0	0	3%	−45%	−81%	−94%	−97%	−100%	−100%
Transport - Scope 2: Total CO_2 equivalents	[Mt**CO_2e**]	1.8	3.1	4.7	6.1	65.5	57.1	30.6	7.8	0.2	0.0
Change to 2019	[%]										
Total Sector Energy Demand	[PJ/a]	32,214	32,351	31,672	32,304	26,727	19,336	15,068	12,035	10,425	9,532
Variation compared with 2019	[%]				0%	-17%	-40%	-53%	-63%	-68%	-70%
Intensities											
Air Passenger Transport											
Emission Intensity	[gCO_2/pkm]	125.57	117.20	117.20	117.20	92.87	59.27	28.61	0.00	0.00	0.00
Emission intensity reduction (base 2019)	[%]				0%	-21%	-49%	-76%	-100%	-100%	-100%
Energy Intensity	[MJ/pkm]	1.7	1.6	1.6	1.6	1.5	1.4	1.3	1.3	1.3	1.2
Emission intensity reduction (base 2019)	[%]				0%	-6%	-14%	-17%	-20%	-21%	-23%
Air Freight Transport											
Emission Intensity	[gCO_2/tkm]	2360.26	2237.12	2237.12	2237.12	1798.31	1174.59	572.16	0.00	0.00	0.00
Emission intensity reduction (base 2019)	[%]				0%	-20%	-47%	-74%	-100%	-100%	-100%
Energy Intensity	[MJ/tkm]	32.2	30.52	30.52	30.52	29.12	27.16	26.46	25.76	25.48	25.2
Emission intensity reduction (base 2019)	[%]				0%	-5%	-11%	-13%	-16%	-17%	-17%
Navigation: Passenger Transport											
Emission Intensity	[gCO_2/pkm]	4.55	4.55	4.55	4.51	3.97	3.25	2.62	0.00	0.00	0.00
Emission intensity reduction (base 2019)	[%]				−1%	−13%	−29%	−42%	−100%	−100%	−100%
Energy Intensity	[MJ/pkm]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Emission intensity reduction (base 2019)	[%]				−1%	−2%	−3%	−4%	−5%	−6%	−7%
Navigation: Freight Transport											
Emission Intensity	[gCO_2/tkm]	15.35	15.35	15.35	15.35	13.43	10.90	8.74	0.00	0.00	0.00
Emission intensity reduction (base 2019)	[%]				0%	−13%	−29%	−43%	−100%	−100%	−100%
Energy Intensity	[MJ/tkm]	0.19	0.19	0.19	0.19	0.19	0.18	0.18	0.18	0.17	0.17
Emission intensity reduction (base 2019)	[%]				0%	−2%	−3%	−5%	−7%	−8%	−9%
Road: Light-Duty Vehicles/Passenger Transport											
Emission Intensity	[gCO_2/pkm]	227.01	231.98	258.10	252.96	146.74	48.85	15.92	6.68	0.08	0.01
Emission intensity (base 2019)	[%]				−2%	−9%	−43%	−66%	−78%	−83%	−84%
Energy Intensity	[MJ/pkm]	1.5	1.5	1.5	1.4	1.4	1.0	0.8	0.6	0.5	0.5
Emission intensity reduction (base 2019)	[%]				−2%	−6%	−30%	−46%	−58%	−63%	−65%
Road: Trucks/Freight Transport											
Emission Intensity	[gCO_2/tkm]	231	232	231	261	157	60	23	10	0	0
Emission intensity reduction (base 2019)	[%]				5%	−40%	−86%	−109%	−102%	−102%	−99%
Energy Intensity	[MJ/tkm]	1.3	1.3	1.3	1.3	1.2	0.9	0.8	0.6	0.6	0.5
Emission intensity reduction (base 2019)	[%]				0%	−9%	−26%	−41%	−49%	−55%	−57%

OECD North America		2018	2019	2020	2020	2025	2030	2035	2040	2045	2050
Sub-sector	Units	Base year	[estimated]	[estimated]	[1.5°C]	Projection					
Total Materials–Steel											
Scope 1: Total direct emissions in CO_2 equivalents (CO_2e)	[$MtCO_2e$/a]	233	240	235	253	235	185	143	88	51	15
Change to 2019	[%]				6%	−2%	−23%	−40%	−63%	−79%	−94%
Scope 2: Emissions - Electricity generation for steel production	[tCO_2/ton steel]	28	28	24	31	16	6	3	1	0	0
Change to 2019	[%]				11%	−42%	−79%	−90%	−97%	−100%	−100%
Specific energy-related CO_2 emissions per ton of steel	[tCO_2/ton steel]	1.94	1.93	1.89	2.10	1.84	1.32	0.96	0.55	0.30	0.08
Deviation compared with 2019	[%]				9%	−4%	−32%	−50%	−71%	−85%	−96%
Specific process-related CO_2 emissions per ton of steel	[tCO_2/ton steel]	1.06	1.06	1.06	1.06	1.13	0.95	0.79	0.49	0.29	0.08
Deviation compared with 2019	[%]				−45%	−41%	−51%	−59%	−74%	−85%	−96%
Total Final Energy Demand	[PJ/a]	1,801	1,837	1,752	2,168	2,222	2,383	2,458	2,532	2,626	2,720
Deviation in energy demand compared with 2019	[%]				18%	21%	30%	34%	38%	43%	48%
Product energy intensity	[GJ/ton steel]	18.6	18.6	18.6	18.0	17.5	17.0	16.5	15.9	15.4	14.8
Deviation compared with 2019	[%]				−3%	−6%	−9%	−12%	−14%	−17%	−20%
Total Materials–Cement											
Scope 1: Total direct emissions in CO_2e	[$MtCO_2e$/a]	72	71	69	63	60	50	41	34	29	25
Change to 2019	[%]				−11%	−15%	−30%	−43%	−52%	−60%	−65%
Scope 2: Emissions - Electricity generation for cement production	[$MtCO_2e$ a]	9	9	7	6	3	1	0	0	0	0
Change to 2019	[%]				−27%	−69%	−91%	−97%	−−99%	−100%	−100%
Total CO_2 Emissions	[$MtCO_2$/a]	36.5	35.1	32.4	25.0	20.5	13.3	6.7	2.5	0.5	0.0
CO_2 emissions reduction compared with 2019	[%]				−29%	−42%	−62%	−81%	−93%	−98%	−100%
Specific energy-related CO_2 emissions per ton of clinker	[tCO_2/ton clinker]	0.311	0.293	0.276	0.197	0.180	0.127	0.063	0.024	0.005	0.000
Deviation compared with 2019	[%]				−33%	−39%	−57%	−78%	−92%	−98%	−100%
Specific energy-related CO_2 emissions per ton of cement	[tCO_2/ton cement]	0.373	0.357	0.330	0.241	0.198	0.132	0.065	0.024	0.005	0.000
Deviation compared with 2019	[%]				−32%	−45%	−63%	−82%	−93%	−99%	−100%
Total Energy Demand	[PJ/a]	507	517	490	389	393	384	382	380	374	368
Deviation in energy demand compared with 2019	[%]				−25%	−24%	−26%	−26%	−26%	−28%	−29%
Product energy intensity (thermal + electricity)	[GJ/ton cement]	3.7	3.7	3.5	2.7	2.6	2.5	2.4	2.3	2.2	2.1
Deviation compared with 2019	[%]				−29%	−31%	−34%	−36%	−38%	−41%	−43%

Annex IV: EU Taxonomy Details

1. Energy/Oil and Gas

Not eligible.

2. Electricity Generation

Any electricity-generation technology can be included in the Taxonomy if it can be demonstrated, using an ISO 14067 or GHG Protocol Product Lifecycle Standard-compliant Product Carbon Footprint (PCF) assessment, that the life cycle impacts for producing 1 kWh of electricity are below the declining threshold.

2.1. Production of electricity from Solar Photovoltaic

Declining thresholds:

- Facilities operating at life-cycle emissions lower than 100 gCO_2e/kWh, declining to net 0 gCO_2e/kWh by 2050, are eligible.
- This threshold will be reduced every 5 years in line with the trajectory towards net zero CO_2e in 2050.
- Assets and activities must meet the threshold at the point in time at which Taxonomy approval is sought.
- For activities that operate beyond 2050, it must be technically feasible to reach net zero emissions using *Scope 1* emissions.

Caveats:

- Solar photovoltaic is currently derogated from performing a PCF or GHG life-cycle assessment, subject to regular review in accordance with the declining threshold.
- Solar photovoltaic is currently deemed to be Taxonomy eligible, which is subject to regular review.

2.2. Electricity generation from concentrated Solar Power

Declining thresholds:

- Facilities operating at life-cycle emissions lower than 100 gCO_2e/kWh, declining to 0 gCO_2e/kWh by 2050, are eligible.
- This threshold will be reduced every 5 years in line with the trajectory towards net zero CO_2e in 2050.
- Assets and activities must meet the threshold at the point in time at which Taxonomy approval is sought.
- For activities that go beyond 2050, it must be technically feasible to reach net zero emissions.

Caveats

- Concentrated solar power (CSP) is currently derogated from performing a PCF or GHG life-cycle assessment, subject to regular review in accordance with the declining threshold.
- CSP is currently deemed to be Taxonomy eligible, which is subject to regular review.
- Co-generation of heat and power is covered under *construction* and the operation of a facility used for the co-generation of heating or cooling and the *power* threshold.
- Generation of heating and cooling is covered under the generation of heating and cooling threshold.

2.3. Production of electricity from Wind Power

Declining threshold

- Facilities operating at life-cycle emissions lower than 100 gCO_2e/kWh, declining to 0 gCO_2e/kWh by 2050, are eligible.
- This threshold will be reduced every 5 years in line with the trajectory towards net zero CO_2e in 2050.
- Assets and activities must meet the threshold at the point in time at which Taxonomy approval is sought.
- For activities that go beyond 2050, it must be technically feasible to reach net zero emissions.

Caveats

- Wind power is currently derogated from performing a PCF or GHG life-cycle assessment, subject to regular review in accordance with the declining threshold.
- Wind power is currently deemed to be Taxonomy eligible, which is subject to regular review.

2.4. Production of electricity from Ocean Energy

Declining threshold

- Facilities operating at life-cycle emissions lower than 100 gCO_2e/kWh, declining to 0 gCO_2e/kWh by 2050, are eligible.
- This threshold will be reduced every 5 years in line with the trajectory towards net zero CO_2e in 2050.
- Assets and activities must meet the threshold at the point in time at which Taxonomy approval is sought.
- For activities that go beyond 2050, it must be technically feasible to reach net zero emissions.

Caveats

- Ocean energy is currently derogated from performing a PCF or GHG life-cycle assessment, subject to regular review in accordance with the declining threshold.
- Ocean energy is currently deemed to be Taxonomy eligible, which is subject to regular review.

2.5. Production of electricity from Hydropower

- Hydropower facilities with a power density above 5 W/m^2 are currently derogated from conducting a PCF or GHG life-cycle assessment (subject to regular review in accordance with the declining threshold).
- As part of ISO 14067, the G-res tool and the IEA Hydro Framework are acceptable methodologies.
- Allocated emissions should be calculated according to the operating regime, according to the allocation methodology developed by UNESCO/IHA and embedded in the G-res tool and the IEA Hydro Framework.
- These criteria also apply to pumped-storage facilities.
- The full PCF assessment shall be subject to review.

Declining threshold

- Facilities operating at life-cycle emissions lower than 100 gCO_2e/kWh, declining to 0 gCO_2e/kWh by 2050, are eligible.
- This threshold will be reduced every 5 years in line with a trajectory towards net zero CO_2e in 2050.
- Assets and activities must meet the threshold at the point in time at which Taxonomy approval is sought.
- For activities that go beyond 2050, it must be technically feasible to reach net zero emissions.

2.6. Production of electricity from Geothermal Energy

Declining threshold

- Facilities operating at life-cycle emissions lower than 100 gCO_2e/kWh, declining to 0 gCO_2e/kWh by 2050, are eligible.
- This threshold will be reduced every 5 years in line with the trajectory towards net zero CO_2e in 2050.
- Assets and activities must meet the threshold at the point in time at which Taxonomy approval is sought.
- For activities that go beyond 2050, it must be technically feasible to reach net zero emissions.
- A full PCF or GHG life-cycle assessment will be applied, using project-specific data where relevant, and will be subject to review.
- Combined heat and power is covered under *construction* and the operation of a facility used for co-generation of heating and cooling and the *power* threshold.

2.7. Production of electricity from Gas (not limited to natural gas)

This assessment should include actual physical measurements (e.g., methane leakage measurements) across gas extraction, transport, and storage systems.

Declining threshold

- Facilities operating at life-cycle emissions lower than 100 gCO_2e/kWh, declining to 0 gCO_2e/kWh by 2050, are eligible.
- This threshold will be reduced every 5 years in line with the trajectory towards net zero CO_2e in 2050.
- Assets and activities must meet the threshold at the point in time at which Taxonomy approval is sought.
- For activities that go beyond 2050, it must be technically feasible to reach net zero emissions.
- A full PCF will be applied, using project-specific data where relevant, and will be subject to review.

Caveats

- Facilities that incorporate any form of abatement (e.g., carbon capture and storage, co-firing) must show that the abatement activity is eligible under the Taxonomy.
- Electricity generation from other fossil-fuel-based gases will be eligible under the taxonomy, subject to meeting the declining emissions threshold.
- Combined heat and power is covered under *construction* and the operation of a facility used for co-generation of heat/cooling and *power* threshold.

2.8. Production of electricity from Bioenergy (biomass, biogas, and biofuels)

- Production of electricity from biofuels will be assessed relative to the 'relative fossil fuel comparator' set out in RED II.
- Facilities operating above 80% GHG emissions reductions in relation to the 'relative fossil fuel comparator' set out in RED II, increasing to 100% by 2050, will be eligible.
- Facilities must use feedstocks that meet the criteria for the manufacture of biomass, biogas, and biofuels.

Declining thresholds

- This threshold will be reduced every 5 years in line with the trajectory towards net zero CO_2e in 2050.
- Assets and activities must meet the threshold at the point in time at which Taxonomy approval is sought.

- For activities that go beyond 2050, it must be technically feasible to reach net zero emissions.
- For the anaerobic digestion of biowaste and sewage sludge, refer to activities 5.5 and 5.3, respectively.
- Any other anaerobic digestion of organic material (not covered under section 5.3 or 5.5) is eligible provided that:
  - methane leakage from the relevant facility (e.g., for biogas production and storage, energy generation, digestate storage) is controlled by a monitoring plan;
  - the digestate produced is used as fertiliser or soil improver—directly or after composting or any other treatment.

3. Energy Utilities

3.1. Electricity, gas, steam, and air-conditioning supply

Currently, the installation and operation of electric heat pumps is eligible, if:

- Refrigerant threshold is a global warming potential ⩽ 675; and
- They meet the energy efficiency requirements stipulated in the implementation of regulations under the Ecodesign Framework Directive.
- The criterion is subject to regular review.

3.2. Storage of electricity

- Currently, all electricity storage activities are eligible under the Taxonomy, subject to regular review.
- Eligibility criteria for demand-side management activities (load shedding and load shifting) are available under the transmission and distribution of electricity criteria.

Caveats

Hydropower pumped storage must comply with the criteria for the Production of Electricity from Hydropower (section 2.5).

3.3. Retrofitting gas transmission and distribution networks

- Retrofitting gas transmission and distribution networks whose main purpose is the integration of hydrogen and other low-carbon gases is eligible.
- Any gas transmission or distribution network activity that allows the network to increase the blend of hydrogen and/or other low-carbon gasses in the gas system is eligible.
- The repair of existing gas pipelines to reduce methane leakage is eligible if the pipelines are hydrogen-ready and/or ready for other low-carbon gasses.
- Retrofitting gas networks whose main purpose is the integration of captured CO_2 is eligible if the operation of the pipeline meets the criteria outlined for the transportation of captured CO_2.
- Gas network expansion is not eligible.

3.4. Electric power generation, transmission, and distribution

All electricity transmission and distribution infrastructure or equipment in *Systems* that are on a trajectory to full decarbonization are eligible, except for infrastructure that:

- Is dedicated to creating a direct connection, or expanding an existing direct connection between a power production plant that is more CO_2 intensive than 100 gCO2e/kWh (measured on an LCE basis) and a substation or network.
- A system is deemed to be on a trajectory to full decarbonization if either:
-
  1. more than 67% of newly connected generation capacity in the system is below the generation threshold value of 100 gCO_2e/kWh, measured on a PCF basis over a rolling 5-year period; or

2. the average system grid emissions factor is below the threshold value of 100 gCO_2e/kWh, measured on a PCF basis over a rolling 5-year average period.

- These criteria will be subject to regular review, in line with reviews of generation threshold values and the progress to decarbonization.
- Based on the results of an assessment carried out in 2019 by the EU JRC, the interconnected European System meets the above criteria, which define a system that is on a trajectory to full decarbonization. It, and its subordinated systems, meet the eligibility criteria for this activity and are derogated from carrying out a quantitative assessment.
- This derogation will also be subject to regular review, in line with the review of the criteria listed above, or should there be major policy changes that would negatively affect commitments to decarbonization.
- The following T&D-grid-related activities are eligible, irrespective of whether the system is on a pathway to full decarbonization:
    1. Direct connection or expansion of existing direct connection of low-carbon electricity generation below the threshold of 100 gCO_2e/kWh, declining to 0 gCO_2e/kWh in 2050, measured on a PCF basis, to a substation or network.
    2. Electric vehicle charging stations and supporting electrical infrastructure for the electrification of transport, subject to Taxonomy eligibility under the Transport section (section 5).
    3. Installation of T&D transformers that comply with the Tier 2 (2021) requirements of Regulation 548/2014 on the ecodesign of small, medium, and large power transformers, and of medium-power transformers with the highest voltage for equipment not exceeding 36 kV, and meeting the AAA0 level requirements on no-load losses set out in standard EN 50588-1.
    4. Equipment and infrastructure for which the main objective is to increase the generation or use of renewable electricity generation.
    5. Equipment to increase the controllability or observability of the electricity system to enable the development and integration of renewable energy sources, including:
        - sensors and measurement tools (including meteorological sensors for forecasting renewable production);
        - communication and control (including advanced software and control rooms, automation of substations or feeders, and voltage-control capabilities to adapt to more decentralised renewable in-feed);
        - equipment to carry information to users for remotely acting on consumption;
        - equipment to allow the exchange of renewable electricity between users;
        - interconnectors between transmission systems are eligible, provided that one of the systems is eligible.

Definitions and Notes:

- A ‘System’ is defined as the transmission or distribution network control area of a network or system operator(s) at which the activity takes place.
- The ‘European System’ is defined as the interconnected electricity system covering the interconnected control areas of EU member states, Norway, Switzerland, and the United Kingdom.
- The annual average System grid emissions factor is calculated as the total annual emissions from power generation divided by the total annual net electricity production in that System.
- The rolling 5-year (average) period used in determining compliance with the thresholds is based on historical data, and includes the year for which the most recent data are available.
- Transmission Systems may include the generation capacity connected to subordinated Distribution Systems.
- Distribution Systems subordinated to a Transmission System that is deemed to be on a trajectory to full decarbonization are also deemed to be on a trajectory to full decarbonization.
- To determine eligibility, it is possible to consider a System as covering multiple control areas that are interconnected, with significant energy exchanges between them. In such a case, the weighted average emissions factor across all control areas included is used to determine eligibility, and individual subordinated transmission or distribution systems within this System will not be required to demonstrate compliance separately.
- It is possible for a System to become ineligible after having previously been eligible. In Systems that become ineligible, no new T&D activities are eligible from that moment onward, until the System is again compliant with the threshold (except for those activities that are always eligible, see above).

Activities in subordinated Systems may still be eligible, if these subordinated Systems meet the criteria of this Taxonomy.

- The direct connection or expansion of an existing direct connection to a production plant includes the infrastructure that is essential to carrying the associated electricity from the power-generating facility to a substation or network.

4. Manufacture of Cement and Steel

4.1. Manufacture of cement

- Thresholds for cement clinker (A) are applicable to plants that produce clinker only, and do not produce finished cement. All other plants must meet the thresholds for cement or an alternative binder.
  (A) Cement clinker:
    - Specific emissions (calculated according to the methodology used for EU-ETS benchmarks) associated with clinker production processes are lower than the value of the related EU-ETS benchmark.
    - As of February 2020, the EU-ETS benchmark value for cement clinker manufacture is 0.766 tCO_2e/t of clinker.

  (B) Cement:
    - Specific emissions associated with clinker and cement production processes are lower than 0.498 tCO_2e/t of cement or alternative binder.

4.2. Manufacture of steel

- Manufacture of iron and steel is eligible if the GHG emissions (calculated according to the methodology used for EU-ETS benchmarks) associated with the production processes are lower than the values of the corresponding EU-ETS benchmarks.
- As of February 2020, the EU-ETS benchmark values for iron and steel manufacture are:
    - Hot metal = 1.328 tCO_2e/t product
    - Sintered ore = 0.171 tCO_2e/t product
    - Iron casting = 0.325 $tCO2_e$/t product
    - Electric arc furnace (EAF) high-alloy steel = 0.352 tCO_2e/t product
    - Electric arc furnace (EAF) carbon steel = 0.283 tCO_2e/t product
    - Coke (excluding lignite coke) = 0.286 tCO_2e/t product

- All new green steel production, or a combination of new and recycled steel production, is eligible if the emissions fall below the thresholds given above.
- All production of steel with EAF, when at least 90% of the iron content in the final products is sourced from scrap steel, is considered eligible. In this case, no other thresholds are applicable.

5. Transport

5.1. Water transport (freight)

- Inland waterways vessels with zero direct emissions are eligible.
- Dedicated vessels using only advanced biofuels or renewable liquid or gaseous transport fuels of non-biological origin, as defined in Article 2 (34) and Article 2 (36) in line with Directive (EU) 2018/2001), guaranteed either by technological design or ongoing third-party monitoring and verification, are eligible.
- For investment in new vessels, only vessels with efficiency corresponding to direct CO_2 emissions (gCO_2/tkm) (including biogenic CO_2) below the average reference value defined for heavy-duty vehicles (HDVs; Heavy-Duty CO_2 Regulation) are eligible. Eligibility should be reviewed in 2025, or when Directive (EU) 2018/2001 is reviewed.
- Other inland waterway vessels are eligible if their direct emissions per tonne kilometre (gCO_2e/tkm) or per tonne nautical mile (gCO_2e/tnm) are 50% lower than the average reference value defined for HDVs (Heavy Duty CO_2 Regulation). Eligibility should be reviewed in 2025.

- Vessels that are dedicated to the transport of fossil fuels or any blended fossil fuels are ineligible, even if they meet the criteria defined above.

Brief rationale:

- Inland waterway transport with zero direct emissions (e.g., electric, hydrogen) are eligible because:
  - With the present energy mix, the overall emissions associated with zero direct emissions from rail transport (i.e., electric or hydrogen) are among the lowest of all transport modes;
  - The generation of the energy carriers used by transport that has zero direct emissions is assumed to become low- or zero-carbon in the near future.
  - The threshold of 50% lower than the average reference CO_2 emissions for HDVs ensures that the carbon intensity remains similar to the criterion for eligible road freight vehicles, with a review in 2025 to assess the technological developments in the freight transport sector.
  - The Heavy Duty CO_2 Regulation uses a gCO_2/km metric. To convert this to a gCO_2/tkm metric, the average payload for road freight vehicles should be applied. Once reference value data are available, it is expected that the Taxonomy will specify CO_2e/tkm threshold values.
  - The substantial contribution to climate mitigation by fuel substitution is in line with the agreed Taxonomy regulation.

5.2. Water transport (passenger)

- Inland waterway vessels with zero direct emissions are eligible.
- Vessels operated solely with advanced biofuels or renewable liquid or gaseous transport fuels of non-biological origin, as defined in Article 2 (34) and Article 2 (36) in line with Directive (EU) 2018/2001, guaranteed by either technological design or ongoing monitoring and third-party verification, are eligible.
- In addition, for investment in new vessels, only vessels with efficiency corresponding to direct emissions of < 95 gCO_2e/pkm (including biogenic CO_2) are eligible.
- Eligibility should be reviewed at the latest by 2025, or when Directive (EU) 2018/2001 is reviewed.
- Other vessels for inland waterways are eligible if their direct emissions are < 50 gCO_2e per passenger kilometre (gCO_2e/pkm) or 92.6 g per passenger nautical mile (gCO_2e/pnm). Eligibility should be reviewed in 2025.

Brief Rationale

- Inland waterway transport with zero direct emissions (e.g., electric, hydrogen) is eligible because:
  - With the present energy mix, the overall emissions associated with rail transport with zero direct emissions (i.e., electric or hydrogen) are among the lowest of all other transport modes;
  - The generation of the energy carriers used by zero-direct-emissions transport is assumed to become low- or zero-carbon in the near future;
  - The threshold of 50 gCO_2e/pkm until 2025 (when it will be reviewed) will ensure that the carbon intensity remains similar to the criterion for eligible road vehicles with low occupation factor (50 gCO_2/vkm) and significantly lower than the emissions for an average car in the current vehicle stock.

- The substantial contribution to climate mitigation of fuel substitution is in line with the agreed Taxonomy regulation.

5.3. Air transport

Not presently eligible.

5.4. Passenger cars and commercial vehicles

- Vehicles with zero tail-pipe emissions (including hydrogen, fuel cells, electric) are automatically eligible.
- Vehicles with maximum tail-pipe emission intensities of 50 gCO_2/km (WLTP) are eligible until 2025.
- From 2026 onwards, only vehicles with an emission intensity of 0 gCO_2/km (WLTP) are eligible.

Brief rationale:

- Vehicles with zero direct emissions (e.g., electric, hydrogen) are eligible because the generation of the energy carriers used by zero-tail-pipe-emissions vehicles is assumed to become low- or zero-carbon in the near future.
- Vehicles with maximum tail-pipe emission intensities of 50 gCO_2/km (WLTP) are eligible until 2025 because the post-2020 CO_2 regulations for cars and vans sets this threshold as an ambitious mid-term target that is significantly below the expected average emissions of new cars and vans.
- The 50 gCO_2/km threshold will not apply to L vehicles (e.g., motorcycles) because their weight is low and their electrification potential high.

6. Manufacture of low-carbon materials

- Manufacture of products, key components, and machinery that are essential for eligible renewable energy technologies (geothermal power, hydropower, concentrated solar power, solar photovoltaic, solar thermal energy for district heat production, wind energy, ocean energy, and bio-energy technologies) that meet the conversion efficiency requirements set in the Renewable Energy Directive (EU) 2018/2001 and the installation of green hydrogen and hydrogen electrolysis is eligible.
- Manufacture of low-carbon transport vehicles and their respective key components, fleets, and vessels meeting the following criteria are eligible:

  1. Passenger cars, light commercial vehicles (CO_2 regulation for cars and vans [EU: 2019/631]):
  - Until 2025, vehicles with maximum tail-pipe emission intensities of 50 gCO_2/km (WLTP). This also includes vehicles with zero tail-pipe emissions (e.g., electric, hydrogen).
  - From 2026 onwards, only vehicles with emission intensities of 0 gCO_2/km (WLTP).
  - Category L vehicles and all vehicles with zero tail-pipe emissions (including hydrogen, fuel cells, electric) are eligible.

  2. Heavy-duty vehicles:
  - N2 and N3 vehicles, as defined by the Heavy Duty CO_2 Regulation (EU: 2019/1242).
  - Only heavy-duty vehicles with zero direct emissions are eligible and those that emit < 1 gCO_2/kWh (or 1 gCO_2/km for certain N2 vehicles).
  -Low-emission heavy-duty vehicles with specific direct CO_2 emissions of < 50% of the reference CO_2 emissions of all vehicles in the same sub-group are eligible.

  3. Rail fleets:
  - Trains, and urban, suburban, and interurban passenger land transport fleets with zero direct emissions are eligible.
  - Land transport fleets with zero direct emissions (e.g., light rail transit, metro, tram, trolleybus, bus, and rail) are eligible.

  4. Water transport: waterborne vessels with zero direct emissions are eligible.

- Manufacture of the following products (with thresholds where appropriate) as energy-efficient equipment for buildings and their key components is eligible:
  - Installation of building management systems;
  - High-efficiency windows (U-value better than 0.7 W/m^2K);
  - High-efficiency doors (U-value better than 1.2 W/m^2K);
  - Insulation products with low thermal conductivity (lambda $\leqslant$ 0.045 W/mK), external cladding with U-value < 0.5 W/m^2K, and roofing systems with U-values < 0.3 W/m^2K);
  - Hot water fittings (e.g., taps, showers) that are rated in the top class (dark green) of the European Water Label Scheme (http://www.europeanwaterlabel.eu/);
  - Household appliances (e.g., washing machines, dishwashers) rated in the top available class according to the EU Energy Label for each type of appliance;

- High-efficiency lighting appliances rated in the highest energy efficiency class that is significantly populated in the energy efficiency label (or higher classes) according to EU energy labelling regulations;
- Daylight controls for lighting systems;
- Highly efficient space heating and domestic hot water systems rated in the highest energy efficiency class significantly populated in the energy efficiency label (or higher class) according to EU energy labelling regulations;
- Highly efficient cooling and ventilation systems rated in the highest energy efficiency class significantly populated in the energy efficiency label (or higher class) according to EU energy labelling regulations;
- Heat pumps compliant with the criteria for heat pumps given in the energy section of the taxonomy;
- Façade and roofing elements with a solar shading or solar control function, including those that support the growing of vegetation;
- Energy-efficient building automation and control systems for commercial buildings, as defined according to the EN 15232 standard;
- Zoned thermostats and devices for the smart monitoring of the main electricity loads for residential buildings and sensing equipment, e.g., motion control;
- Products for heat metering and thermostatic controls for individual homes connected to district heating systems and for individual flats connected to central heating systems serving whole buildings;
- The manufacture of low-carbon technologies and their key components that result in substantial reductions in GHG emissions in other sectors of the economy (including private households) is eligible if it demonstrates substantially greater reductions in net GHG emissions than the best-performing alternative technology, product, or solution available on the market on the basis of a recognised or standardised cradle-to-cradle carbon footprint assessment (e.g., ISO 14067, 14040, EPD, or PEF) validated by a third party.

7. Afforestation

- Continued compliance with the Sustainable Forest Management requirements is demonstrated and disclosed at 10-year intervals through a forest management plan (or equivalent) that will be reviewed by an independent third-party certifier and/or competent authority (as described in Criterion 3, below).
- Verified baseline GHG balance is calculated for above-ground carbon pools, based on growth–yield curves for species per m^3/year/ha, carbon convertible. Calculating the baseline GHG balance requires knowledge of the area, the species, and the number of trees (in situations of afforestation and reforestation).
- Using growth–yield curves, information will be given on the annual increment in m^3/year/ha, which can be used as the basis of the GHG balance. The methodology is consistent with the approach in the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC Guidelines), which recommends the recalculation of the amount of carbon sequestered, with 1 ton of biomass representing approximately 0.5 ton of carbon. One ton of carbon equals 44/12 = 3.67 tons of CO_2.
- Above-ground carbon stocks will increase above the carbon baseline over a period of 20 years.
- Changes in carbon stocks should be disclosed based on growth–yield curves at 10-year intervals through a forest management plan (or equivalent instrument), which will be reviewed by an independent third-party certifier and/or competent authority (as described in Criterion 3, above).

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