Data Note

Net-zero 1.5 °C sectorial pathways for G20 countries: energy and emissions data to inform science-based decarbonization targets

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Abstract

This paper documents data for global, regional (EU-27), and country-specific (G20 member countries) energy and emission pathways required to achieve a defined carbon budget of between 400 $GtCO_2$ and 500 $GtCO_2$, developed to limit the mean global temperature rise to 1.5 °C, over 50% likelihood. The data were calculated with the 1.5 °C sectorial pathways of the One Earth Climate Model—an integrated energy assessment model devised at the University of Technology Sydney. The data consist of the following six zip-folder datasets (refer to Sect. 2 for an explanation of the data): (1) Appendix folder: Each file contains one worksheet, which summarizes the overall 1.5 °C scenario. (2) Sector folder (XLSX): Each file contains one worksheet, which summarizes the industry sectors analysed. (3) Sector folder (CSV): The data contained are the same as those described in point 2. (4) Sector emissions folder: Each file contains one worksheet, which summarizes the total annual emissions for each industry sector. (5) Scope emissions folder (XLSX): Each file contains one worksheet, which summarizes the total annual emissions for each industry sector—with the additional specificity of emission scope. (6) Scope emissions folder (CSV): The data contained are the same as those described in point 5.

Article Highlights

- Scope 1, 2 and 3 emission data for 16 industry sectors—data format was developed with the financialindustry specifically for Net-Zero target setting.
- Industry specific mission data for all G20 member countries, one region (EU27) and globally.
- Detailled country specific 1.5 °C decabonization pathways for all G20 member countries.

Keywords 1.5 °C sectorial pathway · G20 country 1.5 °C pathway · Scope 1, 2, 3 · Industry sector · Decarbonization · Energy intensity · Emissions intensity · Carbon budget · Global stocktake · Activity-based energy calculation

Abbreviations

CO_2	Carbon dioxide
°C	Degree celsius
DLR	German aerospace center (Deutsches Luft- und Raumfahrt Zentrum)
ECF	European climate foundation
ESM	Energy system model
EU-27	European Union (27)
G20	The group of twenty: Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Republic of Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey, United Kingdom, United States, and the European Union

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gCO_2	Gram CO_2
GDP	Gross domestic product
GHG	Greenhouse gas
GICS	Global industry classification system
Gt	Gigatons
IPCC	Intergovernmental panel on climate change
ISF	Institute for sustainable futures
m^2	Square meter
m^3	Cubic meter
MJ	Mega joule
OECM	One earth climate model
pkm	Passenger kilometres
PRI	Principles for responsible investment
tCO_2	Tons of carbon dioxide
UN	United nations
UNEP	United nations environment programme
US$	US dollar
USA	United States of America
UTS	University of Technology Sydney
WBCSD	World business council for sustainable development
WRI	World Resource Institute

1 Objective

This paper documents data for the global, regional (EU-27), and country-specific (G20 member countries) energy and emissions pathways required to achieve a defined carbon budget of between 400 $GtCO_2$ and 500 $GtCO_2$, developed to limit the global mean temperature rise to 1.5 °C, with over 50% likelihood. A total of 21 assessments were made: for the G20 countries, and an additional model of global emissions. The energy and emissions data were calculated with the 1.5 °C sectorial pathways of the One Earth Climate Model (OECM)—an integrated energy assessment tool from the University of Technology Sydney (UTS; Sydney, Australia). The pathways developed represent credible scenarios under which the increase in temperature is limited to 1.5 °C, so the OECM data support the use of investment benchmarks for the major industries classified in the Global Industry Classification System (GICS) to achieve the targets of the Paris Climate Agreement, and also allow the UN-convened Net Zero Asset Owners Alliance to set science-based investment targets. The energy scenarios were developed on the basis of statistical data from the International Energy Agency [1] and were calculated with the One Earth Climate Model 2.0 [2–5].

The OECM was developed by the Institute for Sustainable Futures (ISF) at UTS in close co-operation with institutional investors, based on the German Aerospace Center (DLR) Energy System Model, as an integrated energy assessment tool for industry-specific 1.5 °C pathways, with high technical resolution [2]. The assumed carbon budget between 2020 and 2050 of between 400 $GtCO_2$ and 500 $GtCO_2$, is based on the Intergovernmental Panel on Climate Change Sixth Assessment Report (IPCC AR6) [6]. Energy generation pathways that include all currently available renewable generation technologies are developed based on projections of industry-specific energy demands, with high technical resolution. The detailed methodology and energy model architecture of the OECM 2.0 release has been documented in various scientific article [3, 4]. In addition to industry-sector-specific energy demands and generation pathways, the OECM also calculates Scope 1, 2, and 3 emissions. Scope 1 and 3 emissions are calculated with a new methodology described in [5]. More details of the emission scopes are presented in Sect. 2.

Scope 1, 2, and 3 emissions: In addition to direct energy-related CO_2 emissions, companies progressively report those of other greenhouse gases (GHGs)—direct and indirect emissions that occur in supply chains upstream and downstream. The Greenhouse Gas Protocol, a global standard for accounting and reporting greenhouse gases for companies [7], distinguishes between three "scope areas":

- Scope 1 emissions—direct emissions from owned or controlled sources;
- Scope 2 emissions—indirect emissions from the generation of purchased energy;
- Scope 3 emissions—all indirect emissions not included in Scope 2 that occur in the reporting company's value chain, including both upstream and downstream emissions. The reported Scope 3 emissions are limited to the GICS sector specific emissions documented in various scientific article [4, 5].

2 Data description

The data consist of the following six zipped dataset folders, each containing 21 separate files for each of the areas assessed.

1. Appendix zip folder: contains 21 XLSX files. Each file contains one worksheet, which summarizes the overall 1.5 °C scenario. This tab is called the 'Appendix' and contains: electricity generation (TWh/a), transport—final energy (PJ/a), heat supply and air conditioning (PJ/a), installed capacity (GW), final energy demand (PJ/a), energy-related CO_2 emissions (million tons/a), and primary energy demand (PJ/a).
2. Sector zip folder (XLSX): contains 21 XLSX files. Each file contains one worksheet, which summarizes the industry sectors analysed. Key industry metrics are

provided, such as the energy and carbon intensities of the GICS sectors analysed. Due to industry specificity—and the choice of methodology—the units of data vary between the different sectors.

3. Sector zip folder (CSV): contains 21 CSV files. The data contained are the same as those described in point 2. However, the data have been organized in a database layout and saved in the CSV file format, significantly improving data parsing.
4. Sector emission zip folder: contains 21 XLSX files. Each file contains one worksheet, which summarizes the total annual emissions ($MtCO_2/a$) for each industry sector.
5. Scope emissions zip folder (XLSX): contains 21 XLSX files. Each file contains one worksheet, which summarizes the total annual emissions ($MtCO_2/a$) for each industry sector—and specifies the emission scopes. This tab also provides an additional breakdown of emissions into the categories of CO_2 and total GHG emissions. Two accounting methodologies are presented: (i) the OECM approach, which defines Scope 1 emissions as those related to heat and energy use; and (ii) the production-centric approach, which places the emission burden of other non-energy and Scope 3 emissions on the producer, because they are categorized as Scope 1 emissions.
6. Scope emissions zip folder (CSV): contains 21 CSV files. The data contained are the same as those described in point 5. However, the data have been organized in a database layout and saved in the CSV file format to improve data parsing.

The six datasets are summarized in Table 1, with further information on the data presented in the following sub-sections.

2.1 Description of data parameters

The datasets contain the following scenario input parameters:

1. *Market development*: current and assumed development of the demand by sector, such as cement produced, passenger kilometres travelled, or assumed market volume in $US\$_{2015}$ gross domestic product (GDP).
2. *Energy intensity—activity based*: energy use per unit of service and/or product; for example, in megajoules (MJ) per passenger kilometres travelled (MJ/pkm), MJ per ton of steel (MJ/ton steel), aluminium, or cement.
3. *Energy intensity—finance based*: energy use per unit of investment in MJ per US$ GDP (MJ/$GDP) contributed by, for example, the forestry or agricultural sector.

The dataset contains the following scenario output parameters:

4. *Carbon intensity*: current and future carbon intensities per unit of product or service; for example, in tons of CO_2 per ton of steel produced (tCO_2/ton steel) or grams of carbon dioxide per passenger kilometer (gCO_2/pkm).
5. *Scope 1, 2, and 3 emissions*: datasets for each of the industry sectors and countries analysed. In addition to the emissions data, the deviations of the emissions from those of the year 2019 are provided.
6. *Country scenarios*: complete country scenario datasets of historical data (2012, 2015–2020) and future projections (2025–2050 in 5-year increments). Energy demand and supply data by technology, fuel, and sector are provided, including the overall energy and carbon emissions balance of the country analysed.

Table 1 Overview of the data files/datasets

Label	Name of data file/dataset	File types	Data repository and identifier (DOI or accession number)
Dataset 1	Appendix	XLSX	Data Dyrad—doi: https://doi.org/10.5061/dryad.cz8w9gj82
Dataset 2	Sector_XLSX	XLSX	Data Dyrad—doi: https://doi.org/10.5061/dryad.cz8w9gj82
Dataset 3	Sector_CSV	CSV	Data Dyrad—doi: https://doi.org/10.5061/dryad.cz8w9gj82
Dataset 4	Sector_Emission	XLSX	Data Dyrad—doi: https://doi.org/10.5061/dryad.cz8w9gj82
Dataset 5	Scope_Emission_XLSX	XLSX	Data Dyrad—doi: https://doi.org/10.5061/dryad.cz8w9gj82
Dataset 6	Scope_Emission_CSV	CSV	Data Dyrad—doi: https://doi.org/10.5061/dryad.cz8w9gj82

2.2 Geographic resolution: country data provided

The dataset contains data for the following 21 countries and regions:

- Regions: global, EU-27
- Countries: G20 member countries—Canada, USA, Mexico, Brazil, Argentina, Germany, France, Italy, United Kingdom, Turkey, Russian Federation, Saudi Arabia, South Africa, Indonesia, India, China, Japan, South Korea, and Australia

2.3 Sectorial resolution: industry sector data provided

The dataset contains data for the following industry sectors:

Agriculture & food processing, forestry & wood products, chemical industry, aluminium industry, construction and buildings, water utilities, textile & leather industry, steel industry, cement industry, transport sector (aviation: freight & passenger transport; shipping: freight & passenger transport; and road transport: freight & passenger transport).

2.4 Time resolution

The scenario data are provided for the years 2017, 2018, 2019, 2020, 2025, 2030, 2035, 2040, 2045, and 2050.

3 Limitations

Industry-specific energy intensities and energy demands are not available for all industries. Therefore, GDP-based calculations were used when industry-specific production-based energy intensities were not available. Although energy intensities can be estimated based on the data available, the input parameters can be derived from various sources, and their estimation may not follow the same methodology. Energy intensities based on GDP, for example, can be calculated with either nominal GDP, real GDP, or purchasing power parity GDP. Moreover, energy intensities can be provided as the final energy or primary energy. In some cases, this information is not available at all. A database of industry-specific energy demands and energy intensities, calculated with a consistent methodology, would improve the accuracy of calculations in future research. The non-energy greenhouse gas emissions (GHG) for the agriculture and the forestry sector are based on statistics for Agriculture, Forestry and Other Land Use (AFOLU) of the Food and Agriculture Organization of the United Nations (FAO). The scenario system boundaries are based on the Global Industry Classification System (GICS) and calculated with statistics of the International Energy Agency (IEA), and the AFOLU emissions are based on FAO statistical data which can lead to statistical inaccuracies.

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Author contributions ST: project and scenario development lead, development of manuscript concept, and paper writing. JR: model improvement and review, modelling individual country scenarios, paper writing, and paper editing. SN: project management; collection of data on steel, aluminium, cement, and water utilities sectors; lead; paper writing. MF: technical lead for the development of the synthetic fuels and chemical industry sector; modelling individual country scenarios; model improvement; paper writing. SM: modelling individual country scenarios; designing computer programs for efficient file modification; reviewing and editing the paper. ST: country scenario research; data research and collection. SM: country scenario research; methodology development; and data collection for AFOLU sector.

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Data availability Availability of data material statement reading: The data described in this data note can be freely and openly accessed on *'datadryad.org'* under doi: https://doi.org/10.5061/dryad.cz8w9gj82. Please see Table 1 and references for details and links to the data.

Declarations

Conflict of interest The authors have no competing interests to declare.

Ethical approval The UN-convened Net Zero Asset Owner Alliance (the Alliance) is a Principles for Responsible Investment (PRI)- and UNEP FI-supported initiative, which commissioned the Institute for Sustainable Futures (ISF) at the University of Technology Sydney (UTS) to utilize their 1.5 °C One Earth Climate Model (OECM) (Teske et al. [8]) to derive decarbonization pathways.

Research involving human and animal rights This research involved no human participant or animal.

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