wbcsd

Technical Documentation: Energy Climate Scenario Catalogue

February 2023

Acknowledgements

The Climate Scenario Catalogue was developed with supporting analysis from Vivid Economics. Specifically,

- The process of scenario Cataloguing, the design of the Catalogue interface, and the estimation of any non-public content contained throughout the Catalogue was delivered with support from a Vivid Economics team including: Alex Kazaglis (Project Director), Aditi Sahni (Project Manager), Fabian Knoedler-Thoma (Senior Project Economist), James Bragg (Project Economist) and Will Glevey (Project Economist);
- The 2023 update of the Catalogue was delivered with support from a Vivid Economics team including: Aditi Sahni (Project Director), Suzanne Angliviel (Project Manager), Algirdas Brochard (Project Analyst), Panchimma Cheriyan (Project Economist) and Fizza Rahman (Project Analyst).

Disclaimer

Contents

Table of Contents

List of figures

List of Boxes

1 Introduction

1.1 Purpose

The Climate Scenario Catalogue (the Catalogue) is designed to be used in association with and to support the Climate Scenario Reference Approach (the Approach) developed by the Energy Forum to enhance climate risk analysis and disclosure. The Approach was developed by the Energy Forum with the WBCSD Project Team to advance the project objectives and intended outcomes, including increasing the quantity and quality of strategic assessment and disclosure based on climate scenario analysis. It provides a yardstick for businesses to enhance transparency, consistency, and comparability of scenario analysis in response to the Task Force on Climate-Related Financial Disclosures' (TCFD) recommendations.[1]

The Catalogue helps companies address key challenges when conducting scenario analysis. The Catalogue supports scenario choices – how to choose, interpret and navigate climate scenarios. It also helps with the scenario process – how to apply scenarios under which conditions, and how to manage sensitivity analysis, data availability and reliability.

The Approach and the Catalogue follow six guiding principles developed by the Energy Forum:

- **Simplicity**: forum members agreed that they did not want to add to complexity by adding new scenarios to the existing "scenario universe." Instead, the Project focuses on "reference scenario families", certain existing scenarios and variables, compiled in a "Catalogue" and their application.
- **Business relevance**: by collating information from different sources and perspectives and providing key transition metrics and variables relevant to business, the Catalogue builds a bridge from scenario conditions to business drivers.
- **Comprehensiveness**: offer an approach to scenario analysis that encourages resilience assessment across a range of possible outcomes and diverse pathways as decarbonisation plans are progressed.
- **Neutrality**: considers a range of possible future industry and market developments, options and solutions drawn from public scenarios.
- Support a **common starting point and transparent approach** to scenario analysis.
- **Ease of interpretation**: the reference scenario approach is intended to provide a structured, transparent perspective to scenario analysis for a wide range of stakeholders, the process and results of which can be more easily interpreted and compared by investors.

1.2 Catalogue overview and features

The Catalogue is a live online repository within which certain public climate scenarios are referred to as "catalogued scenarios". New scenarios and additional variables will be added to the

[1] TCFD (2021). Proposed Guidance on Climate-related Metrics, Targets,and Transition Plans. https://assets.bbhub.io/company/sites/60/2021/05/2021-TCFD-Metrics_Targets_Guidance.pdf

Catalogue based on user requests. Additionally, existing catalogued scenarios will be updated as new information is released to ensure that users have access to the most accurate representation of each climate scenario.

Publicly available scenarios from leading institutions were filtered, categorised and augmented for use in the Catalogue. The project uses publicly available scenarios as a starting point, selecting only scenarios that have passed plausibility constraints defined by leading institutions. It categorises them into scenario families (described below). Finally, the project increases variable availability to close the gap between granularity of existing public scenarios and the requirements for business relevance set out by Forum members.

As of March 2022, the Catalogue is almost exclusively composed of scenarios taken from leading public institutions on climate transition modelling with small additions for alternative economic growth.

- The Catalogue includes scenarios from the following leading public institutions:
  - the International Energy Agency (IEA);
  - the Network for Greening the Financial System (NGFS);
  - the Inevitable Policy Response (IPR);
  - the International Renewable Energy Agency (IRENA);
  - Bloomberg New Energy Finance (BNEF).
- The catalogue includes two scenarios which explore the possible impacts of economic growth sensitivities. Both scenarios are aligned with 1.5C temperature increase, but they follow different Socioeconomic Pathways (SSPs). The “high growth” scenario follows SSP5, and the “low growth” scenario follows SSP3 - other scenarios included in the database follow the “middle of the road” SSP2 pathway. The former is characterized by fossil-fuel led economic growth. It assumes that a push for economic and social development is coupled with the exploitation of abundant fossil fuel resources, leading to rapid growth of the global economy. The latter is characterized by regional rivalry. The scenario builds on the narrative that nationalism, concerns about competitiveness and security, leads to low international priority for addressing environmental concerns causing environmental degradation low economic growth. Both scenarios illustrate how decarbonization pathways could be affected if the world diverges from assumed socioeconomic pathways. The scenarios were analysed in Riahi et al (2017), “The Shared SocioEconomics Pathways and their energy, land use, and greenhouse gas emissions implications: An overview”, *Global Environmental Change*, 42:153-168.
- In one part of the Catalogue – the Scenario Explorer – additional scenarios from the AR6 Scenario Explorer and Database, hosted by IIASA, provide more context to the comparison of scenarios, but they are not available for deeper analysis and download

The Catalogue is a live tool designed to be updated as new and improved climate scenarios are released over time.

The catalogued scenarios have been grouped into climate reference scenario families (families). The families have been identified and agreed with Forum members to ensure that users compare scenarios of similar climate ambition when conducting their analyses. These are:

- **Paris Ambitious 1.5°C**: Scenarios with outcomes designed to keep temperature rise within 1.5°C above pre-industrial levels with limited/no overshoot[2]
- **Paris Aligned Well-Below 2°C**: Scenarios with outcomes designed to keep temperature rise within 2°C above pre-industrial levels with limited/no overshoot
- **Current Policies/Business as Usual (BAU)**: Scenarios that reflect the range of current climate policies and Nationally Determined Contributions (NDCs) or other national pledges, resulting in a temperature rise between 2.5 and 3.5°C by 2100.

The scenarios included in the Catalogue are listed by provider in Figure 1 to Figure 5.

[2] Overshoot means that temperatures rise above a certain global warming target before falling below it.

Figure 1 Catalogued IEA scenarios and characteristics

	Net Zero Energy 2050	Stated Policies Scenario	Announced Pledges Scenario
Scenario family	Paris Ambitious 1.5°C	Current Policies/BAU	Current Policies/BAU
Temperature target in 2100	1.5°C	Not target-based, achieves ~2.65°C	Not target-based, achieves ~ 2.1°C
Scenario type	Orderly		
Geography	World	World	World
Sectors covered	Energy, power, transport, buildings, industry, mining		
Time steps	2020 – 2050; 5-year intervals		
Download	Available for download in the Catalogue.	Available for download in the Catalogue.	Available for download in the Catalogue.
Source details	IEA WEO (license required) Latest release: 2022; Release schedule: Annual Available from: IEA website	IEA WEO (license required) Latest release: 2022; Release schedule: Annual Available from: IEA website	IEA WEO (license required) Latest release: 2022; Release schedule: Annual Available from: IEA website

Note: The characteristics correspond to the information from IEA that is included in the Catalogue – some regional data is available directly from the IEA.
Source: Vivid Economics

Figure 2 Catalogued NGFS scenarios and characteristics

	Net Zero 2050		Divergent Net Zero		Below 2°C		Delayed Transition		NDCs		Current Policies	
Model	RM	GCAM	RM	GCAM	RM	GCAM	RM	GCAM	RM	GCAM	RM	GCAM
Scenario family	Paris Ambitious 1.5°C				Paris Aligned Well-Below 2°C				Current Policies/BAU			
Temperature target in 2100	1.5°C		1.5°C		1.7°C		1.8°C		2.5°C		3.0°C	
Scenario type	Orderly		Disorderly		Orderly		Disorderly		Current Policies/BAU			
Geography	Canada, Australia and New Zealand (CAZ), China (CHA), European Union and United Kingdon (EU27 + UK), India (IND), Japan (JPN), Latin America (LAM), Middle East, North Africa and Central Asia (MEA), Non-EU Europe (NEU), Other Asian States (OAS), Reforming Economies (REF), Sub-Saharan Africa (SSA), United States (USA), World											
Sectors covered	Energy, power, transport, buildings, industry, mining and AFOLU											
Time steps	2020 – 2050; 5-year intervals											
Download	Derived data available for download in the Catalogue.											
Source details	NGFS Latest release: v3.4 October 2022 ; Release schedule: next update Q2-Q32023 Available from: IXMP Scenario Explorer developed by IIASA											

Note: The characteristics correspond to the information from NGFS that is included in the Catalogue. RM = REMIND-MAgPIE model. Regional data is available from: IXMP Scenario Explorer developed by IIASA. Country-level results can also be downloaded for select variables from the IIASA website.
Source: Vivid Economics

Figure 3 Catalogued UN PRI (IPR) scenarios and characteristics

	Required Policy Scenario	Forecasted Policy Scenario
Scenario family	Paris Ambitious 1.5°C	Paris Aligned Well-Below 2°C
Temperature target in 2100	1.5°C	1.8°C
Scenario type	Disorderly	Disorderly
Geography	CAZ, CHA, EU27 + UK, IND, JPN, LAM, MEA, NEU, OAS, REF, SSA, USA, World	
Sectors covered	Energy, power, transport, buildings, industry, mining	
Time steps	2020 – 2050; 5-year intervals	
Download	Available for download in the Catalogue.	
Source details	UN PRI. The Inevitable Policy Response Available from: UNPRI website	UN PRI. The Inevitable Policy Response Available from: UNPRI website

Note: Available from: UNPRI website
Source: Vivid Economics

Figure 4 Catalogued IRENA scenarios and characteristics

	1.5°C Scenario	Transforming Energy Scenario
Scenario family	Paris Ambitious 1.5°C	Paris Aligned Well-Below 2°C
Temperature target in 2100	1.5°C	Unknown
Scenario type	Unknown	Unknown
Geography	World	
Sectors covered	Energy, power, transport, buildings	
Time steps	2050; no time series available.	
Download	Available for download in the Catalogue	
Source details	IRENA Global Renewables Outlook: Energy transformation 2050. Latest release: 2020; Available from: IRENA website	IRENA World Energy Transitions Outlook Latest release: 2021 Available from: IRENA website

Note: The characteristics correspond to the information from IRENA that is included in the Catalogue.
Source: Vivid Economics

Figure 5 Catalogued BNEF scenarios and characteristics

	Economic Transition Scenario	Net Zero Scenario
Scenario family	Current Policies/BAU	Paris Ambitious 1.5°C
Temperature target in 2100	2.6C	1.77C
Scenario type	Current Policies/BAU	Unknown
Geography	World	
Sectors covered	Energy, power, transport, buildings, industry	
Time steps	2020 – 2050; 5-year intervals	
Download	Not available for download in the Catalogue	
Source details	Get the NEO 2022 executive summary at: https://about.bnef.com/new-energy-outlook/	Get the NEO 2022 executive summary at: https://about.bnef.com/new-energy-outlook/

Note: The characteristics correspond to the information from BloombergNEF that is included in the Catalogue.
Source: Vivid Economics

The Catalogue includes 6,335, unique variables for climate risk testing and disclosure, which are either extracted directly from the selected scenarios, or, disaggregated and/or expanded with support and analysis by Vivid Economics. Disaggregated variables are a more granular version of existing variables which has been extracted directly from the scenario provider. Expanded variables are new variables which use extracted outputs from the scenario provider as inputs for calculation. Section 3 Catalogue contents of this document details the methodology for the additional variables. The final list of Catalogue variables has been agreed with Forum members as being necessary for business-relevant climate scenario analysis.

The Catalogue classifies the variables based on their place in the energy system:

- **Primary energy** refers to naturally occurring energy forms that have not been subjected to any human engineered conversion process, encompassing both fuels such as oil and gas as well as renewable energy such as wind and geothermal energy.
- **Secondary energy** describes the fuels converted into electricity, hydrogen, or other secondary fuels.

- **Final energy** includes primary and secondary energy used in end-use sectors of the economy including industry, transport, and buildings.

- **In addition to energy variables, the Catalogue includes other classes of variables that have been named by Forum members as having business-relevancy.** This includes:
  - **Emissions** which corresponds to Scope 1 CO_2energy emissions from fuel combustion and/or industrial process i.e. the direct CO_2 at the point of combustion or process. Other major GHG are also reported for the macroeconomy.
  - **Carbon capture and sequestration** which refers explicitly to either the capture and permanent storage of carbon from any technology (including direct air carbon capture and storage i.e. DACCS) or sequestration from natural sources such as afforestation.
  - **Demand and Production** refers to the quantity of a material or commodity, such as steel, cement, or lithium, at the point of consumption or production.
  - **Investment** includes total capital expenditures, typically including low-carbon and non-low-carbon in nature, for different activities within various sectors of the economy.
  - **Cost and price** refer to the total cost of producing some good or the price faced by consumers at a particular stage in the value change, respectively. Costs are levelized when appropriate, such as for power-sector generation or storage technologies.
  - **Macroeconomic indicators and policy** variables includes variables with macro-economy relevancy such as GDP and productivity, in addition to carbon prices (explicit levies or shadow prices) and economy-wide climate damages and mitigation costs.
- The Appendix provides a detailed list of the variables included in the catalogue.

The Catalogue has three main features:

1. **Scenario Explorer:** shows how selected scenarios compare across key variables in 2050 to present the distribution of scenarios within their family to illustrate the range of uncertainty across those scenarios.
2. **Variable Explorer:** presents all variables in the Catalogue in their full sectoral and regional disaggregation.
3. **Data Download:** offers extraction of variables from the Catalogue for further analysis and disclosure.

The Energy Forum's report and accompanying user guidance provides a more detailed overview of the Catalogue, its features and utility for companies conducting scenario analysis. This Technical Document focuses on the design and development of the Catalogue and its content, how it is structured, and how variables have been expanded and developed:

- *Section 2 Approach to catalogue creation* summarises the approach for creating the Catalogue.

- *Section 3 Catalogue contents* details the Catalogue variables, methods for estimation where applicable, and also describes the models and scenarios included in the Catalogue.

2 Approach to catalogue creation

This section covers the general approach taken to categorise and estimate variables within the Catalogue (*Section 2.1 General approach*) including processes to ensure scenario consistency and quality assurance (*Section* 2.2 Scenario alignment and quality assurance).

2.1 General approach

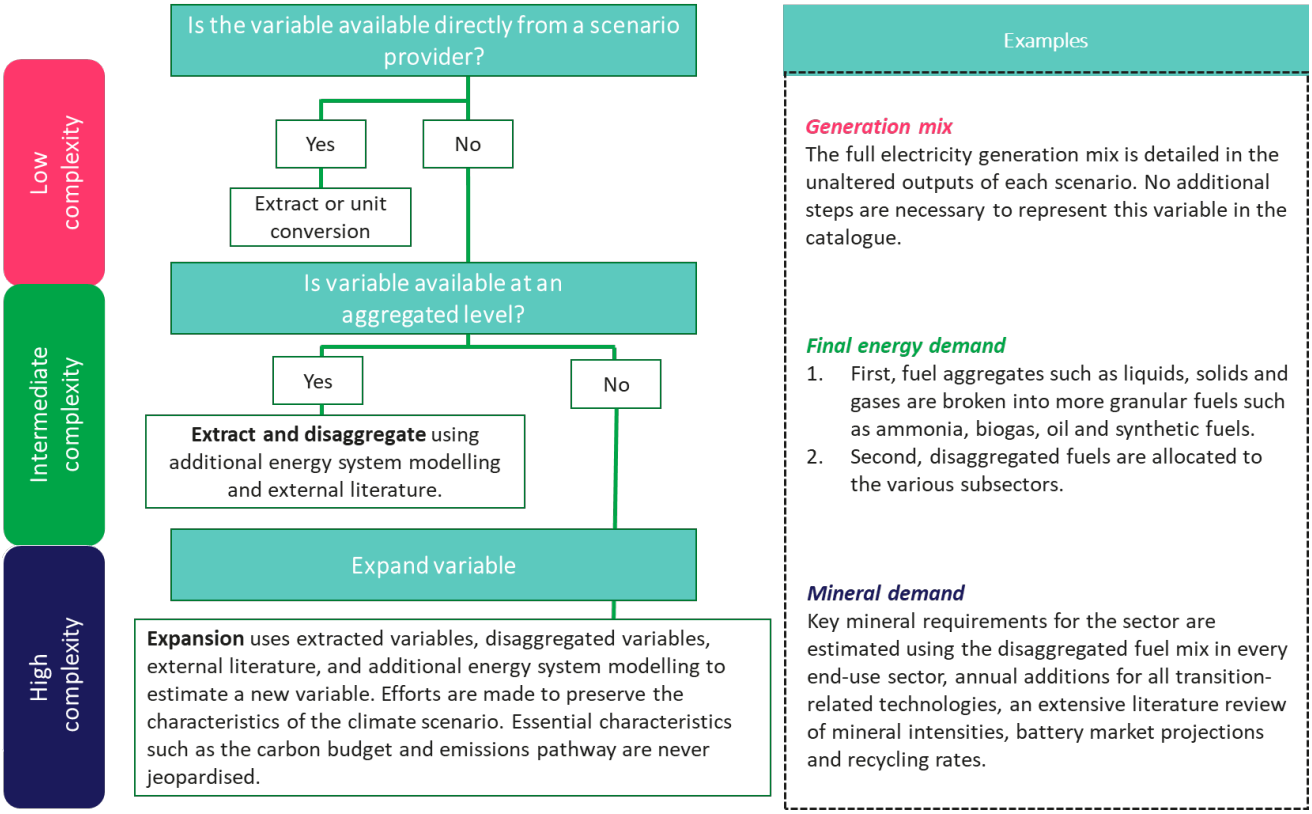
The Catalogue consists of:

- **Public scenarios listed in Section 1.2** Catalogue overview and features, **including extracted outputs and variables from those scenarios.** The public scenarios and associated variables are modelled using a wide range of models and methods. Except as otherwise stated, the Catalogue does not disturb or alter the public scenario outputs and variables.
- **New and bespoke variables developed with support and analysis by Vivid Economics**, which were estimated in response to Forum member advice on variables of most business-relevance for scenario analysis at the sector or sub-sector level.

Variables in the Catalogue are assigned a typology which is visible to users while exploring the data. The typology is designed to clearly signify which variables are extracted outputs from a scenario provider, and which variables are derived data i.e., new variables estimated at the request of Forum members. The typology is also used to communicate the number of intermediate steps that were required for estimation and the degree of alignment with the characteristics of a scenario.

Each variable in the Catalogue is either extracted, disaggregated or (partially) expanded. Assigning a variable to a typology is conducted through the application of a standardised decision tree which is outlined in Figure 6.

Figure 6 Standardised approach for variable categorisation and estimation



Source: Vivid Economics

The definitions for each type of variable are provided below.

1. ***Extracted* – variables in this category are taken directly from the public scenarios from which they originate and are unaltered.** In some cases, the variables are expressed to increase accessibility for users. For example, primary energy demand for natural gas can be transformed from Exajoules per year (EJ/year) into British thermal units (Btu/year) per year using a simple energy conversion factor. The variable itself remains unaltered.

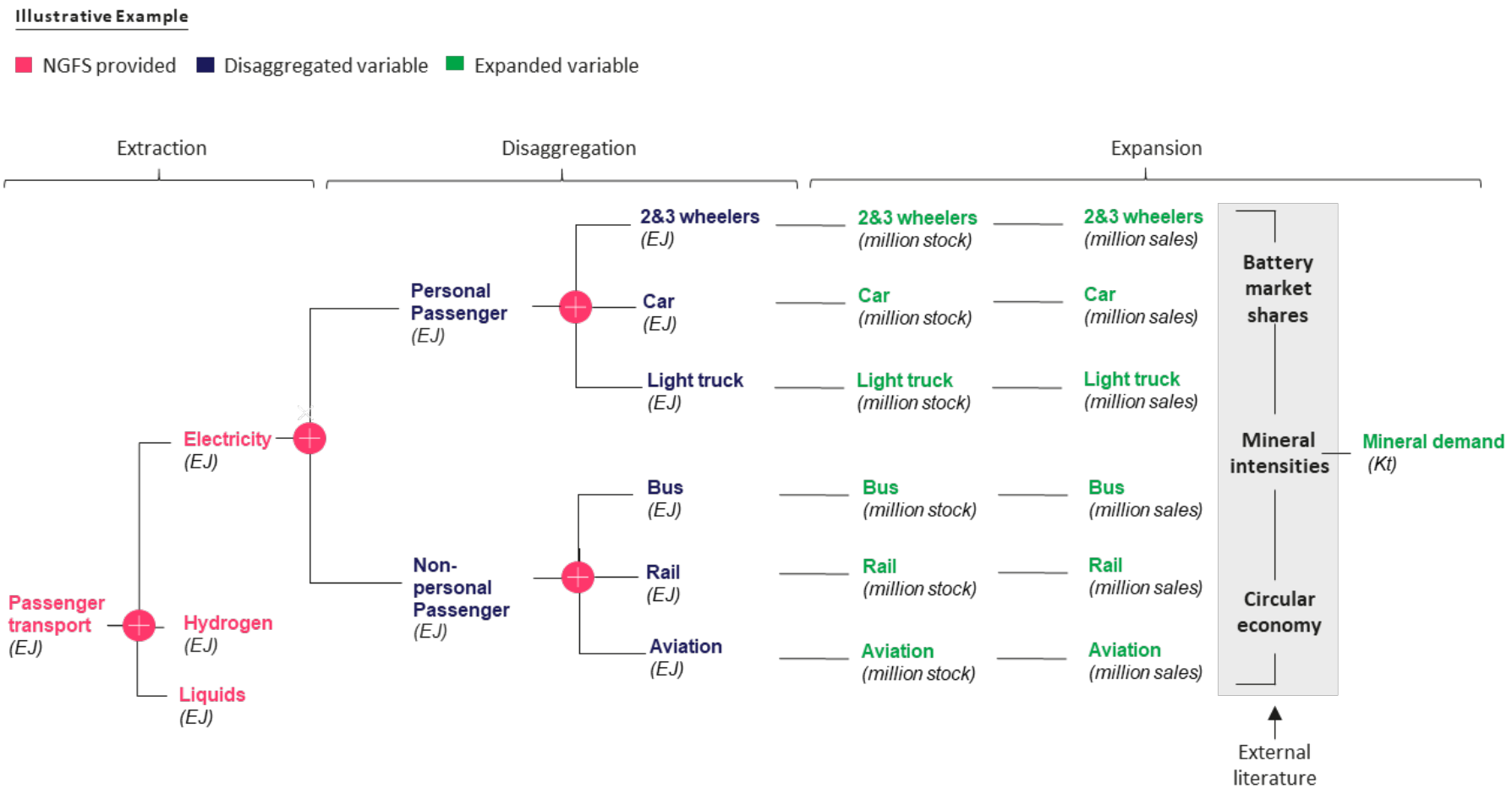
2. ***Disaggregated* – refers to the process of disaggregating extracted outputs into more detailed parts.** Scenario providers often provide a detailed but incomplete picture of the energy system. The most common omissions are full subsector and fuel granularity. A disaggregated variable breaks down a value into constituent parts without changing the overall aggregated value. For example, the final energy mix for road transport, aviation, shipping and rail are disaggregated using the final energy mix for passenger transport. The margin for error is therefore small on aggregate: the sum of the disaggregated components will always reconcile with the higher-level value of the aggregated scenario output. Some variables, specifically for IEA scenarios, are listed as "Disaggregated – 2021", which means the source of the variable remains a 2021 IEA publication, because the same data was not available from 2022 sources.

3. ***Expanded* – refers to the process of creating entirely new variables.** Variables created through expansion will use extracted and disaggregated variables as inputs to calculations. External literature and additional energy system modelling are also typically required. For

example, vehicle sales are estimated using disaggregated final energy mix, extracted energy service demand for passenger transport, and additional energy system modelling using the Vivid Energy System Model. In contrast to disaggregated variables, the alignment of an expanded variable with a climate scenario is typically indirect. The level of consistency therefore depends on the number of indirect channels for alignment. The margin for error is therefore larger relative to disaggregated variables as differences in model assumptions and inputs are likely. However, the defining characteristics of the scenario – including the observed energy mix, emissions, and, most notably, the carbon budget – are preserved. A step-by-step example of an expanded variable is provided in Box 1. Figure 7 also provides a visual representation of subsector disaggregation for the transport sector, which is then used to create several new expanded variables such as vehicle sales and the mineral requirements of vehicle sales.

4. ***Partially expanded*** **– refers to variables which have been altered or transformed without additional modelling.** A partial expansion involves substantive change to a variable but does not require complex calculations or additional modelling. Partially expanded variables are typically variables which have been transformed into a new unit or normalised for better comparisons across scenarios. Despite the simplicity in approach, a partially expanded variable is distinguished from an extracted variable to avoid misrepresenting outputs from the various scenario providers. However, the level of uncertainty for these variables is typically low relative to fully expanded variables. A prime example of a partially expanded variable is oil demand, which is converted from units of energy (EJ/year) into a unit of volume (Million barrels/year). This only requires an energy-to-volume conversion factor based on the average energy content per barrel of oil; however, the conversion factor introduces some uncertainty as the underlying average energy content assumed by the scenario or model is unknown. As such, the variable is no longer *extracted* directly from source.

Figure 7 Example approach for variable disaggregation (transport subsector final energy consumption) and variable expansion (vehicle sales and mineral requirements)



Source: Vivid Economics

Box 1 Illustrative example of variable expansion: mineral demand

Mineral demand is an example of an expanded variable. The methodology highlights the techniques and approaches used to create a new variable. For visual aid, the process of expansion, which includes data extraction and disaggregation using the NGFS as an example, is shown in Figure 7 for electric vehicles. The high-level steps taken to expand this variable are:

1. **Disaggregate the fuel mix in all end-consumption sectors.** Consumption of every fuel at the sector-level is broken down to the subsector-level. To ensure a realistic allocation of fuels between subsectors, several IAMs are used.
2. **Estimate technology stock associated with the disaggregated subsector fuel mix.** The disaggregated fuel mix in end-consumption is used to estimate the technology mix in every sector of the economy.
3. **Calculate technology additions.** The technology stock is converted into sales using a stock-flow optimization model and technology lifetimes.
4. **Apply mineral intensities.** A mineral intensity database allows us to calculate the total mineral requirements of each technology each year. Intensities originate from external literature and are calibrated to remain consistent with material production provided by unaltered scenario outputs. Additional factors such as circular economy, material efficiency changes and the market composition for batteries are also considered.

2.2 Scenario alignment and quality assurance

When a variable is requested to be included in the Catalogue, the first step taken is to check all available data or reports that have been published directly from the scenario provider. In many cases the variable request can be fulfilled without any additional analysis. The data is then processed into a standardised format so that the user can easily view and compare it across scenario providers. In general, disaggregation and expansion are never undertaken if the variable can be extracted directly from source. Disaggregation and expansion are only undertaken for variables where extracted scenario outputs do not sufficiently fulfil the request of a Forum member for a particular variable.

3 Catalogue contents

This section presents details of the Catalogue content and is structured as follows:

- a high-level summary of the variables included in the Catalogue (Section 3.1 Variable summary)
- a description of approach for every variable, by sector (Sections 3.2 Variables by sector
- 3.2.1 Energy variables to 3.2.7 Macro-economy variables)
- descriptions of scenarios included in the Catalogue (Section 3.3 Scenario descriptions)
- descriptions of models included in the Catalogue (Section 3.4 Model descriptions)

3.1 Variable summary

The Catalogue contains 6,754 distinct variables.[3] Table 1 summarizes the classification of the Catalogue variables according to whether they have been extracted directly from source or otherwise developed with the support of Vivid Economics**.** Most variables are extracted directly from source, though significant time has been invested to process and make these variables more accessible for business. The remaining 51.48% of unique variables in the Catalogue are either disaggregated or expanded (see *Section 2.1 General approach* for definitions) with support and additional analysis from Vivid Economics and are therefore not directly available from selected public climate scenarios. The Forum has not validated or reviewed in detail the expansion calculations or methodologies. As shown in Table 2, there are variables available for businesses operating in many sectors of the economy. A visualisation of the Catalogue variables, distinguished by sector, is also shown in Figure 8.

Table 1 Catalogue variables by classification

Variable type	Number of variables (percentage)
Expanded	2,706 (40.1%)
Disaggregated	658 (9.7%)
Extracted variables	3,390 (50.2%)

Source: Vivid Economics

Table 2 Catalogue variables by sector

Sector	Number of variables (percentage)
Buildings	990 (14.6%)
Energy (cross-sectoral)[4]	896 (13.3%)

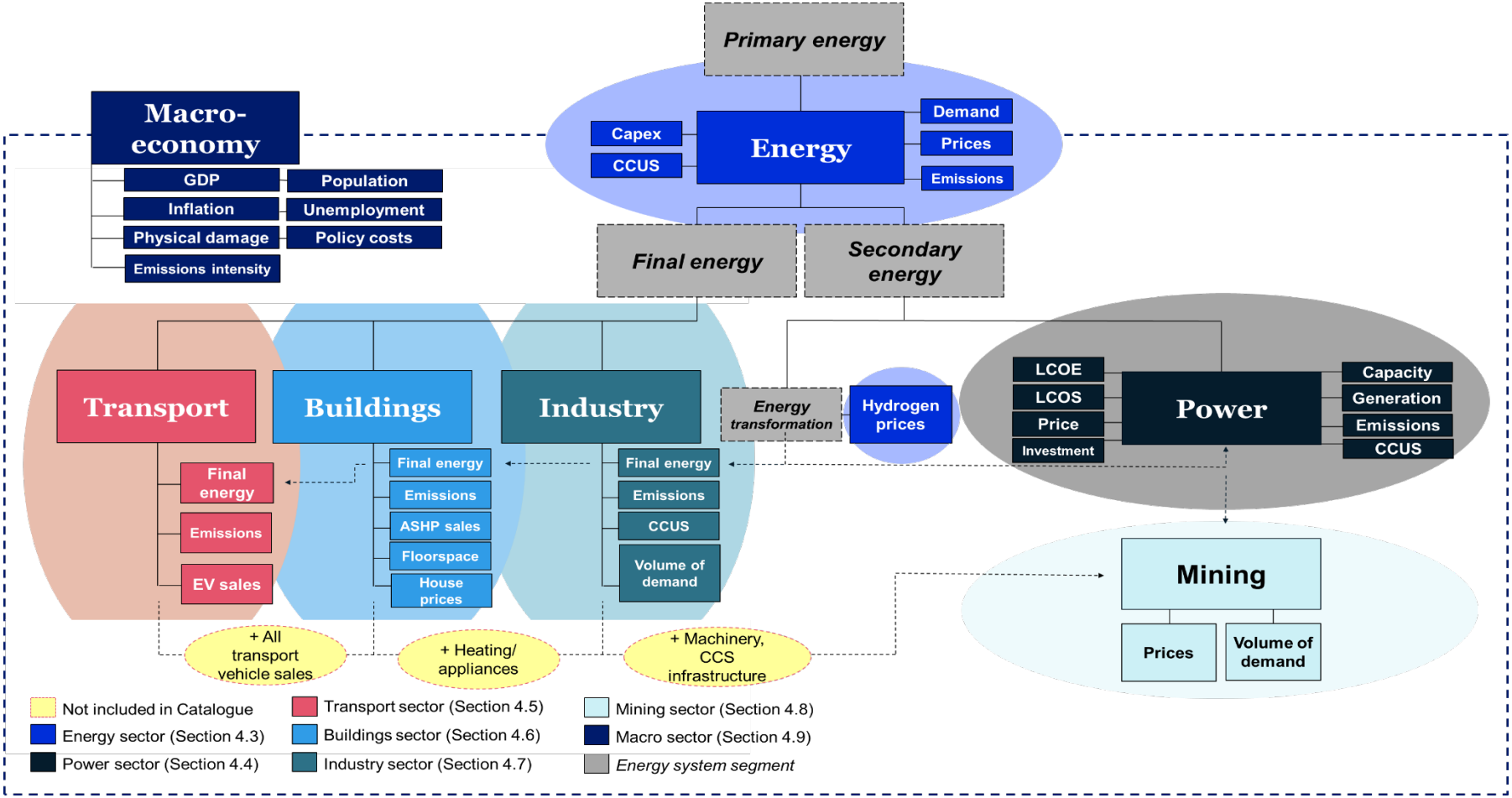
[3]Defined as any unique combination of model, scenario and data point – not including regions. Summary statistics as of February 2023 and may change with subsequent scenario and variable additions to the Catalogue.

[4]Energy refers to all sectors within the energy system and therefore can include power, transport, buildings and industry.

Sector	Number of variables (percentage)
Industry	2,381 (35.2%)
Macroeconomy/other	127 (1.88%)
Mining	130 (1.9%)
Power	1,366 (20.2%)
Transport	862 (12.8%)

Source: Vivid Economics

Figure 8 Catalogue variable tree and interactions



Notes: ASHP = Air to surface heat pump for heating.
Source: Vivid Economics

3.2 Variables by sector

3.2.1 Energy variables

3.2.1.1 Overview of sector

Energy variables are applicable across all sectors of the energy system (including power, transport, buildings and industry) and are represented in the Catalogue by the following:

1. **Primary energy demand:** total energy consumption of unconverted fuels.
2. **Primary energy prices:** the price before transport, taxation or processing.
3. **Primary energy emissions:** direct CO_2 emissions from the combustion of unconverted fuels. It does not include process emissions or emissions from other greenhouse gases.
4. **Primary energy investment:** total capital expenditure for the extraction and conversion of primary fuels, including coal, oil, gas and bioenergy.
5. **Final energy:** total final consumption of energy in transport, buildings, industry, mining and all other end-use sectors.
6. **Low-carbon energy shares:** the share of electricity, hydrogen or bioenergy in total final consumption across all end-use sectors.
7. **Hydrogen costs:** the average cost of producing hydrogen from all sources. It includes the additional costs from carbon pricing.
8. **Total CCS:** carbon captured and stored from CO_2 combustion in all sectors of the energy system including industrial processes.
9. **CCS investment:** all investment in equipment and infrastructure for the capture, transportation and storage of CO_2.
10. **Electrolyser capacity:** total productive capacity for green hydrogen in Gigawatts including merchant production and production for own-use in industry or refining.

The granularity of energy variables available in the Catalogue is provided in Figure 9.

Figure 9 Energy variable granularity

Variable	Regions	Sector	Subsectors	Technologies and fuels
Primary energy demand	NGFS & UN PRI (IPR): 12 regions IEA & BNEF: World	Energy	Not applicable	All fuels and technologies, Coal, oil, gas, biomass, nuclear, non-biomass renewables
Primary energy prices	NGFS & UN PRI (IPR): 12 regions IEA: World	Energy	Not applicable	Oil, gas, biomass, coal
Primary energy emissions	NGFS & UN PRI (IPR): 12 regions IEA & BNEF: World	Energy	Not applicable	NGFS, IEA & BNEF: All fuels and technologies Coal, oil, gas UN PRI (IPR): All fuels and technologies
Primary energy investment	NGFS: 12 regions	Energy	Extraction	Coal, oil, gas, bioenergy, total fossil
Final energy	NGFS & UN PRI (IPR): 12 regions IEA, BNEF & IRENA: World	Energy	Not applicable	Electricity, hydrogen, gases (biogas, natural gas, gas from coal), liquids (oil, biofuels, liquids from coal and natural gas, ammonia, synth fuels) and solids (coal, biomass)
Low-carbon energy shares	NGFS & UN PRI (IPR): 12 regions IEA, BNEF & IRENA: World	Energy	Not applicable	Bioenergy, electricity, hydrogen
Hydrogen costs	NGFS : 12 regions IEA : World	Energy	Not applicable	Not applicable

CCS	NGFS & UN PRI (IPR): 12 regions IEA: World	Energy	Not applicable	All fuels and technologies w CCS, Bioenergy with CCS (BECCS)
CCS Investment	NGFS: 12 regions	Energy	Not applicable	Total CCS investment
Capacity	NGFS: 12 regions IEA: World	Energy	Not applicable	Electrolyser

Source: Vivid Economics

3.2.1.3 Approach to variable disaggregation and expansion

Primary energy demand

Variable type: partial expansion

Primary energy demand is extracted directly from source and translated into native or volumetric units where appropriate. Primary energy demand is typically expressed in units of energy such as EJ/year. Some fossil fuels are converted into native[5] or volumetric units using either direct conversion factors or by estimating average energy content per volume from output tables. For example, oil is expressed in barrels and gas in British thermal units. Unit conversion is done purely for accessibility.

Primary energy prices

Variable type: partial expansion

Primary energy prices are extracted directly from NGFS and, as for primary energy demand, translated into native or volumetric units where appropriate. Prices for the IEA scenarios are extracted directly from source.

Primary energy emissions

Variable type: disaggregation

The following steps are taken to estimate NGFS and IRENA[6] primary energy emissions:

[5] Refers to conventional units used for trading in energy commodity markets. For oil, demand and price is reported in barrels (bbl) of crude.

[6] IRENA data availability limited to the year 2050.

1. **Extract primary energy demand for fossil fuels.** Scenarios provide primary energy demand for fossils both with and without CCS.
2. **Convert energy to emissions while accounting for CCS.** Fuel-specific emissions factors and CO_2 capture rates are used to convert EJ/year to $MtCO_2$/year.
3. **Calibrate emissions to reconcile with extracted NGFS outputs**. Emissions by fuel source are constructed so that the sum of emissions from all fossil fuels is exactly equal to total primary energy emissions in each scenario.

Emissions for the IEA and BNEF scenarios are taken directly from the source.

Primary energy investment

Variable type: extraction

Primary energy investment is taken directly from source for all scenarios. It measures all capital expenditures on the extraction and conversion of primary fuels.

Final energy

Variable type: extraction

Final energy is taken directly from source for all scenarios. It covers all fuels and consumption in every end-use sectors (excluding power sector inputs for electricity generation).

Hydrogen costs

Variable type: expansion

The average production cost of hydrogen is either partially expanded by unit conversion (NGFS). The cost per GJ of energy from hydrogen is provided by the NGFS. This is converted to $ per kilogram by estimating average energy content per volume from output tables. Hydrogen costs for BNEF scenarios were taken directly from source.

CCS

Variable type: extraction

CCS is taken directly from source for all scenarios. This variable strictly measures carbon captured that is permanently stored. Carbon captured for re-utilisation is not included. It includes CCS in every sector of the energy system, including power, industry, fuel processing and production, and atmospheric removals from innovative technologies such as direct air carbon capture and stoage (DACCS).

CCS investment

Variable type: extraction

CCS investment is taken directly from source for all scenarios. CCS investment segmented into the capture unit (CCS) and CO2 transport and storage capacity (CO2 transport and storage). Estimates

for the IEA scenarios do not distinguish between carbon capture and utilised and carbon captured and stored.

Electrolyser capacity

Variable type: expansion/extraction

For NGFS, electrolyser capacity is estimated as the required productive capacity for the volumetric production of green hydrogen in each scenario. The energy content of hydrogen from electricity is extracted directly from the NGFS and is assumed to come from dedicated renewables due to cost considerations. The energy content of hydrogen is converted into an annual volume and a required capacity factor per Mt is applied. Electrolyser capacity for IEA scenarios is extracted directly from source material.

3.2.2 Power variables

3.2.2.1 Overview of sector

The **power sector** is represented in the Catalogue by the following variables:

1. **Electricity generation and capacity:** energy output and maximum capable energy output of installed electricity generation sources. Annual capacity additions are also reported separately.
2. **The LCOE and LCOS:** the discounted cost of building and operating a generation or generation storage asset expressed per unit of electricity outputted or stored over the lifetime of the asset.
3. **Electricity generation emissions:** direct CO_2 emissions from the combustion of fuels for electricity generation.
4. **Carbon intensity of electricity:** the average carbon content of all electricity generation output.
5. **Electricity generation CCS:** the capture of CO_2in electricity generation for reutilisation and/or storage in geological deposits.
6. **Grid investment:** all investment in electricity transmission, distribution and storage.
7. **Electricity price indices:** tracks changes in the price electricity from 2020 (where 2020 = 1.00) for large-scale consumers. The index will include carbon price.
8. **Renewables share of generation**: the percentage share of electricity generation from renewables, including biomass. Nuclear is not included.

The granularity of power sector variables available in the Catalogue is provided in Figure 10.

Figure 10 Power sector variable granularity

Variable	Regions	Sector	Subsectors	Technologies and fuels
Electricity generation & capacity	NGFS & UN PRI (IPR): 12 regions IEA & BNEF: World	Power	Not applicable	All generation sources
LCOE/LCOS	NGFS: 12 regions IEA: CHA, EU, IND, USA	Power	Not applicable	Gas, solar PV, offshore wind, onshore wind, battery storage, All fuels and technologies (weighted average)
Electricity generation emissions	NGFS & UN PRI (IPR): 12 regions IEA & BNEF: World	Power	Not applicable	NGFS, IEA & BNEF: All fuels and technologies, coal, oil, gas UN PRI (IPR): Total
Carbon intensity of electricity	NGFS: 12 regions BNEF: World	Power	Not applicable	Not applicable
Electricity generation CCS	NGFS & UN PRI (IPR): 12 regions IEA: World	Power	Not applicable	Coal, gas, oil, biomass
Grid investment	NGFS: 12 regions	Power	Not applicable	Electricity storage, electricity transmission and distribution
Electricity prices	NGFS: 12 regions	Power	Not applicable	Not applicable
Renewable share of generation	NGFS& UN PRI: 12 regions IEA, BNEF & IRENA: World	Power	Not applicable	All renewables

Source: Vivid Economics

3.2.2.3 Approach to variable disaggregation and expansion

Electricity generation and capacity

Variable type: extraction

Electricity generation and capacity is taken directly from source for all scenarios apart from some disaggregation for some fuel types, e.g. summing together offshore and onshore wind to compute total wind.

Electricity generation emissions

Variable type: disaggregation

The following steps are taken to estimate NGFS and IRENA[7] electricity generationemissions:

1. **Extract secondary energy demand for all fossil fuel generation sources.**
2. **Convert generation to emissions while accounting for CCS.**
3. **Calibrate emissions to reconcile with extracted NGFS outputs**. The sum of emissions by generation source reconciles with total electricity emissions in each scenario, accounting for negative emissions from bioenergy with CCS (BECCS).

Power sector emissions from all other scenarios are extracted from source materials.

LCOE/LCOS

Variable type: expansion

The levelised costs of electricity and storage are estimates using cumulative deployment by generation or storage asset and technology-specific learning rates. Technology-specific learning rates are used to calculate costs as a function of experience. Experience for LCOE and LCOS are measured using the cumulative deployment of different technologies in each scenario. Current costs are taken from the IEA[8,9] and Lazard.[10] Where relevant, the LCOE also accounts for carbon costs, fossil fuel prices and CCS deployment which vary by scenario and region. For the sector-average, the

[7]IRENA data availability limited to the year 2050.
[8] IEA. (2022). Global Climate and Energy Model 2022. Retrievable from: https://www.iea.org/data-and-statistics/data-product/global-energy-and-climate-model-2022-key-input-data
[9] IEA. (2021). Net Zero by 2050 A Roadmap for the Global Energy Sector. Retrievable from: https://iea.blob.core.windows.net/assets/beceb956-0dcf-4d73-89fe-1310e3046d68/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf
[10]Lazard. (2019). Lazard's Levelized Cost of Storage Analysis – Version 5.0. Retrievable from: https://www.lazard.com/media/451087/lazards-levelized-cost-of-storage-version-50-vf.pdf

average technology-specific levelized cost weighted by its share of the total generation mix is used. LCOE for IEA scenarios are extracted directly from source.

Carbon intensity of electricity

Variable type: partial expansion

The carbon intensity of electricity is estimated as aggregate electricity generation emissions over annual electricity output. The measure includes all generation sources including negative emissions technologies such as BECCS. Both total generation emissions and total electricity output are extracted from source.

Electricity generation CCS

Variable type: disaggregation

Electricity generation CCS is estimated using technology-specific emissions factors and CO_2 capture rates. Emissions factors and capture rates are the same as those used to estimate electricity generation emissions. CCS by generation source are constructed so that the sum of CCS from all sources reconciles with total CCS in the supply of electricity for each scenario.

Grid investment

Variable type: extraction

Grid investment is taken directly from source for all scenarios. Investment figures for IEA scenarios are reported as an annual average over a multi-decade period due to data limitations.

Electricity price indices

Variable type: extraction

Electricity price indices are extracted directly from source. Price indices are only available for the NGFS scenarios. Please note that electricity prices are often set according to unique country- or regional-level policies and regulations. The index should be used as a general gauge for the underlying technology costs of electricity generation as well as a proxy for the effects of carbon pricing. Use of the index may benefit from additional consideration of regulatory conditions and additional non-market factors within a specific geography.

Renewables share of generation

Variable type: expansion

The share of electricity generation from renewable sources is calculated using the full generation mix extracted from source. The sum of electricity generated from wind, solar, biomass, hydro, marine and geothermal sources is divided by total electricity generation in that region.

3.2.3 Transport variables

The **transport sector** is represented in the Catalogue by the following variables:

1. **Transport final energy demand**: end-use consumption of energy for transport.

2. **Transport emissions:** direct CO_2 emissions from energy use in transport.
3. **Car sales**: annual sales of electric personal passenger vehicles (EV) and internal combustion engine (ICE) personal passenger vehicles.
4. **Transport infrastructure investment**: investment in all public and private transport infrastructure, including low carbon and non-low carbon investment.

The granularity of transport sector variables available in the Catalogue is provided in Figure 11.

Figure 11 Transport sector variable granularity

Variable	Regions	Sector	Subsectors	Technologies and fuels
Final energy demand	NGFS & UN PRI (IPR): 12 regions IEA & BNEF: World	Transport	NGFS & IEA: Road, Aviation, Shipping	All fuels and technologies, Electricity, hydrogen, gases (biogas, natural gas, gas from coal, ammonia), liquids (oil, biofuels, liquids from coal and natural gas, synth fuels) and solids (coal, biomass)
Emissions	NGFS & UN PRI (IPR): 12 regions IEA & BNEF: World	Transport	NGFS & IEA: Road, Aviation, Shipping	Not applicable
Car sales	NGFS & UN PRI (IPR): 12 regions IEA & BNEF: World	Transport	Road	NFGS: EV, FCEV and ICE IEA and UN PRI: EV and ICE BNEF: EV
Infrastructure investment	NGFS: 12 regions	Transport	Not applicable	Not applicable

Source: Vivid Economics
Source: Vivid Economics

3.2.3.3 Approach to variable disaggregation and expansion

Transport final energy demand

Variable type: disaggregation

Total transport final energy demand and total final energy demand by subsector (road, shipping and aviation) by fuel is taken directly from source for all scenarios. The breakdown of each subsector into fuels is performed using freely available data from IEA *WEO 2022*, IEA *Net Zero by 2050* (2021) and IEA *Energy Technology Perspectives* 2020 on the fuel mix by subsector. This fuel mix data is reconciled with the subsector and fuel totals provided by NGFS and IEA scenarios.

Final energy demand for IRENA, UN PRI, and BNEF scenarios are extracted from source.

Transport emissions

Variable type: disaggregation

Transport emissions are disaggregated using the full final energy mix and emissions factors in datasets where direct extracts are not available. Emissions factors are applied to the final consumption of fossil fuels within each subsector. Estimates are constructed to ensure that the sum of CO_2 emissions across all transport subsectors is equal to total transport sector emissions for that scenario. Emissions in the Catalogue cover scope 1 CO_2 emissions.

Energy Service Demand

Variable type: extraction

The Energy Service demand by transport mode is taken directly from source for NGFS scenarios. Different categories are available for the GCAM and REMIND-MAgPIE models, which are provided raw with no modifications.

Car sales

Variable type: expansion

The following steps are taken to expand car sales of all powertrains.

1. **Convert fuel consumption and energy service demand into vehicle stock.** NGFS scenarios now provide energy service demand by transport mode. The trend of energy service demand is used to project forward the current stock of cars. The stock is then split into vehicle types (Electric, Hydrogen Fuel Cells and ICE) using the passenger road transport final energy mix computed previously.

2. **Convert vehicle stock into annual sales using a stock-flow optimization model.** The model estimates the 'optimal' or 'best fit' sales profile for a given stock projection. The lifetime distribution of each vehicle type and technology, often referred to as a 'scrappage rate', is applied to ensure a realistic distribution of vehicle retirements over time.

Car sales for the IEA scenarios by fuel type are extracted from IEA reports and BNEF and UN PRI scenarios are extracted directly from source material.

Transport infrastructure investment

Variable type: expansion

Infrastructure investment refers to both public and private investments and covers the following:

1. **Non-low carbon infrastructure.** Infrastructure requirements are split by transport subsector and projected forward using the estimated evolution of vehicle, locomotive, aircraft, and shipping vessel stocks.

2. **EV charging stations.** The total charging infrastructure is estimated using electricity consumption in road transport and the charging capacity required to support EV vehicle stocks. Costs are differentiated between assumed splits in private and public chargers, as well as fast and slow chargers.

3. **Hydrogen refuelling infrastructure.** Hydrogen refuelling infrastructure is calculated using a projected capital requirement per vehicle from the McKinsey Centre for Future Mobility.[11]

Infrastructure requirements for non-NGFS scenarios are not included in this version of the Catalogue.[12]

3.2.4 Buildings variables

3.2.4.1 Overview of sector

The **buildings sector** is represented in the Catalogue by the following variables:

1. **Buildings final energy demand**: end-use consumption of energy in residential and commercial buildings.

2. **Buildings emissions**: direct CO_2 emissions from energy use in residential and commercial buildings.

3. **Heat pump sales**: annual installations of heat pumps in residential and commercial buildings.

4. **Floor space**: total floor space and annual floor space additions.

5. **Low carbon floor space:** total low carbon floor space split by new builds and retrofits of existing buildings. Annual low carbon additions are also reported separately.

6. **Buildings infrastructure investment**: total low-carbon and non-low-carbon investment in public or private buildings, including new builds, retrofits, and heating.

The granularity of buildings sector variables available in the Catalogue is provided in Figure 12.

[11] https://www.mckinsey.com/features/mckinsey-center-for-future-mobility/overview
[12] As of March 2022.

Variable	Regions	Sector	Subsectors	Technologies and fuels
Final energy demand	NGFS & UN PRI (IPR): 12 regions IEA & BNEF: World	Buildings	NGFS & IEA: Commercial Residential	All fuels and technologies, Electricity, Gases, Heat, Liquids, Solids, Solids biomass, Solids coal, Traditional use of Biomass, Hydrogen, Liquids biofuels Liquids natural gas, Liquids oil, Gases biomethane, Gases coal, Gases natural gas, Bioenergy
Emissions	NGFS & UN PRI (IPR): 12 regions IEA & BNEF: World	Buildings	NGFS & IEA: Commercial Residential	N/A
Heat pump sales	NGFS & UN PRI (IPR): 12 regions IEA & BNEF: World	Buildings	NGFS & IEA: Commercial Residential	Heat pumps
Floor space	NGFS: 12 regions IEA & BNEF: World	Buildings	Commercial Residential	Floor space, Floor space - annual additions
Low carbon floor space	NGFS: 12 regions IEA & BNEF: World	Buildings	Commercial Residential	Floor space - low carbon, Floor space - annual low carbon, Floor space - annual low carbon retrofits, Floor space - low carbon retrofits, Floor space - annual low carbon new builds, Floor space - low carbon new builds
Investment	NGFS: 12 regions	Buildings	Not applicable	N/A

Source: Vivid Economics

3.2.4.3 Approach to variable disaggregation and expansion

Buildings final energy demand

Variable type: Extraction/disaggregation

For NGFS, buildings final energy is extracted for GCAM and disaggregated to the commercial and residential subsectors for REMIND. Additional modelling is conducted to disaggregate models or scenarios which do not provide the fuel mix for residential and commercial subsectors. Fuel aggregates are further disaggregated using linking equations. The allocation of fuels between residential and commercial buildings is constructed to reconcile with extracted scenario outputs.

For IEA, building final energy by fuel and commercial and residential total final energy are extracted directly from source. Data from 2021 publications is used to split up commercial and residential final energy into relevant fuel types.

Buildings emissions

Variable type: disaggregation

Buildings emissions are disaggregated using the full final energy mix and emissions factors. Emissions factors are applied to the final consumption of fossil fuels within commercial and residential buildings. Estimates are constructed to ensure that the sum of CO_2 emissions across commercial and residential buildings is equal to total buildings sector emissions for that scenario. Emissions in the Catalogue cover scope 1 CO_2 emissions.

Heat pump sales

Variable type: expansion

Heat pump sales for NGFS are estimated in 3 steps, specifically:

1. Estimate the amount of electricity consumed for the heating of residential and commercial buildings.
2. Use the electricity consumption trend to project forward the stock of heat.
3. Convert stock into annual sales using an average technology lifetime and historical sales data.

IEA heat pump sales are extracted.

Floor space - NGFS

Variable type: extraction/disaggregation

For NGFS scenarios, floor space is taken directly from source and used to calculate annual floor space additions.

For IEA, floor space is estimated based on 2021 values, projected forward using 2022 final energy pathways.

Low carbon floor space

Variable type: expansion

Low carbon floor space is estimated using zero-carbon standards for new buildings and annual retrofit rates. The percentage of new buildings that meet zero-carbon or near zero-carbon building standards is applied to annual floor space additions to measure total floor space from new, low carbon buildings. Total floor space with low carbon retrofits – including insulation, sealing, window replacements and systems for energy management[13] – are calculated using annual retrofit rates and the existing buildings stock, including new buildings added that do not meet zero-carbon or near-zero-carbon building standards. Low carbon floor space from new buildings and retrofits are both only available for IEA scenarios.

Heat pump investment

Variable type: expansion

Heat pump investment are estimated based on costs, taken from recent literature, adjusted by location/building type and assuming learning over time.

Infrastructure requirements for non-NGFS scenarios are not included in this version of the Catalogue.[14]

3.2.5 Industry variables

3.2.5.1 Overview of sector

The **industry sector** is represented in the Catalogue by the following variables:

1. **Industry final energy demand:** end-use consumption of energy for industry.
2. **Industry emissions:** emissions from both energy use and industrial processes in industry.
3. **Industrial CCS:** carbon captured and stored from CO_2 combustion and industrial processes.
4. **Volume of demand:** total demand for key industrial goods in total volume (mega tonnes).

The granularity of industry sector variables available in the Catalogue is provided in Figure 13.

[13] Definition adopted from IEA. (2020). World Energy Outlook 2020. Retrievable from: https://www.iea.org/reports/world-energy-outlook-2020

[14] As of March 2022.

Variable	Regions	Sector	Subsectors	Technologies and fuels
Final energy demand	NGFS & UN PRI (IPR): 12 regions IEA & BNEF: World	Industry	Cement, Steel, Aluminium, Paper, pulp and printing, Other industry, Chemicals (Chemicals HVCs, Chemicals Methanol, Chemicals Plastics)	All fuels w CCS, All fuels and technologies, Electricity, Gases, Heat, Hydrogen, Liquids, Solids biomass, Solids coal, Gases biomethane, Gases natural gas w CCS, Gases natural gas w o CCS, Liquids oil, Other renewables, Solids, Solids coal w CCS, Solids coal w o CCS, Gases coal, Gases natural gas, Liquids biofuels, Liquids coal, Liquids natural gas, Gases synthetic methane, Bioenergy, Coal w CCS, Gas w CCS, Coal, Gas, Solids bioenergy
Emissions	NGFS & UN PRI (IPR): 12 regions IEA & BNEF: World	Industry	Cement, Steel, Chemicals, Aluminium, Paper, pulp and printing, Other industry	IEA and NGFS: Total energy and industrial process emissions, Energy Demand Emissions, Industrial Process Emissions UN PRI (IPR): Total energy and industrial process emissions BNEF: Total energy emissions
CCS	NGFS & UN PRI (IPR): 12 regions IEA: World	Industry	Cement, Steel Chemicals	NGFS and IEA: All fuels with CCS

Volume of demand	NGFS: 12 regions IEA, BNEF& UN PRI (IPR): World	Industry	Cement, Iron and steel, Chemicals (Ammonia, Methanol, HVCs, Plastics), Aluminium, Paper, pulp and printing	Not applicable
End-use of Materials	NGFS & IEA (World)	Industry	Steel & Cement	Steel: Construction, Vehicles, Transport & Other Infrastructure, Renewable Power Infrastructure, General Power Infrastructure, Losses, Electrical Equipment Cement: Buildings – Residential, Buildings – Commercial, General Power Infrastructrure, Transport & Other Infrastructure, Losses

Figure 12 Industry sector variable granularity

Source Vivid Economics

3.2.5.3 Approach to variable disaggregation and expansion

Industry final energy demand

Variable type: disaggregation or expansion

Industry final energy is disaggregated to industrial subsectors using current and projected energy balances and secondary energy production. Fuel use in 2022 is allocated to subsectors using the IEA's World Energy Balances. Additional modelling is done to project low-carbon fuel shares for all scenarios. Fuel aggregates are further disaggregated using linking equations. The allocation of fuels between industrial subsectors is constructed to reconcile with extracted scenario outputs.

Industry emissions

Variable type: disaggregation or expansion

Industrial emissions are disaggregated using the final energy pathways of the subsectors under different scenarios. Emissions estimates are then disaggregated into emissions from energy demand and emissions from industrial processes, while ensuring that the sum of CO_2 for all industrial subsectors reconciles with total industrial emissions extracted from source for that

particular scenario. Emissions in the Catalogue cover scope 1 CO_2 emissions. For BNEF, industrial emissions do not include process emissions.

Industry CCS

Variable type: disaggregation or extraction

Industrial CCS is disaggregated using subsector-specific CCS potential. Additional modelling is undertaken to estimate future CCS potential in each subsector using the same approach taken to final energy. Estimates are constructed to ensure that the sum of energy and process CCS in all industrial subsectors reconciles with total industrial CCS for that scenario.

Volume of commodity demand

Variable type: expansion

Industrial commodity demand is estimated using final energy demand and projected material and energy efficiency improvements. For subsectors that cannot be directly extracted from extracted outputs, commodity demand grows with energy and material efficiency-adjusted final energy demand. Production estimates are normalised to ensure consistency with actuals. Volume of demand for plastics measures industrial production from non-recycled content. Plastics production is estimated using changes in demand for primary chemicals, notably of high-value chemicals like ethylene that are used in plastic production. Aluminium volumes also do not include production from recycled content.

End-use of Materials

Variable type: expansion

Industrial material demand is split into end-use sectors, while accounting for the sector demand increase and the material efficiency gains across scenarios. Current and 2050 end-use splits are extracted from the IEA's Energy Technology Perspective 2020, and applied to the overall demand pathway for steel and cement. The pathways thus reflect demand changes driven by variations in sector size by scenario, as well as changes in material efficiency across end-use sectors.

3.2.6 Mining variables

3.2.6.1 Overview of sector

The **mining sector** is represented in the Catalogue by the following variables:

1. **Volume of material demand:** total transition and non-transition related mineral demand from mined and recycled sources.
2. **Material prices:** market prices for minerals.

The granularity of mining sector variables available in the Catalogue is provided in Figure 14.

Figure 13 Mining sector variable granularity

Variable	Regions	Sector	Subsectors	Technologies and fuels
Material demand	NGFS: 12 regions IEA: World	Mining	Copper, cobalt, lithium, nickel, silver	Not applicable
Material prices	NGFS &IEA: World	Mining	Copper, cobalt, lithium, nickel, silver	Not applicable

Source: Vivid Economics

3.2.6.3 Approach to variable disaggregation and expansion

Material demand

Variable type: expansion

The following steps are taken to estimate mineral demand.

1. **Estimate all transition-related drivers across all sectors.** Annual additions for every transition-related technology in energy production, power, transport, buildings and industry are estimated.
2. **Convert annual technology additions into mineral demand.** Technology-specific mineral intensities and market share projections for key technologies are combined to estimate minerals required to fulfil demand for each transition technology.
3. **Estimate non-transition related demand and combine with demand from transition-related sectors estimated in Step 2.**

Mineral prices

Variable type: expansion

Material prices for IEA are estimated using sector revenue and demand for IEA scenarios. Prices are consistent with the IEA's reporting on mineral prices which assume

"…cost increases (around a 10% - 20% increase from current levels to 2050)".[15] The same assumption is used for all scenarios.

Material prices for NGFS and IPR use the mineral demand estimates and empirical price elasticities in the mineral sector. An in-house model combines price elasticities from the academic literature on mineral transition and combines them with the estimates on mineral demand. The approach captures deviations from long-run mineral prices caused by steep increases in demand due to the climate transition. The prices are indexed, with 2020 the base value.

3.2.7 Macro-economy variables

3.2.7.1 Overview of sector

Variables covering the **macro-economy** in the Catalogue include:

1. **Gross domestic product (GDP):** the total value of goods and services produced in an economy.
2. **Population:** total persons.
3. **Inflation:** the annual inflation rate of the economy.
4. **Unemployment:** the annual percentage of the workforce that is unemployed.
5. **Productivity:** average output per hour of labour.
6. **Climate damages and climate policy costs:** the combined impact of physical damages from climate change and all climate policy on GDP. Damages are expressed in annual and cumulative terms in current dollars.
7. **Carbon prices:** carbon prices for the IEA and NGFS scenarios are defined and reported separately. Carbon prices in IEA scenarios represent an explicit price levied on each tonne of CO_2. Carbon prices in NGFS scenarios represent the shadow price of carbon, which is the price per tonne of CO_2, from all implicit or explicit mitigation policies, required to mitigate the last tonne of CO_2 in that year. The two measures are not comparable.
8. **House prices:** the level of housing prices in an economy
9. **Energy intensity:** energy requirements per unit of GDP, measured in terms of primary energy supply per US$2021 and final energy consumption per US$2021.
10. **Non-CO_2 emissions:** emissions from three largest sources of non-CO_2 greenhouse gases including methane (CH_4) nitrous oxide (NO_x) and fugitive gases (F-Gases).

The granularity of macro-economy variables available in the Catalogue is provided in Figure 15.

[15] From Figure 4.8 in IEA, 2021, "Net Zeroby 2050: A Roadmap for the Global EnergySector"; and Page 10 of IEA, 2021, "The Role of Critical World Energy Outlook Special Report Minerals in Clean Energy Transitions."

Figure 14 Macro-economic variable granularity

Variable	Regions	Sector	Subsectors	Technologies and fuels
GDP	NGFS: 12 regions NiGEM: 6 regions IEA & BNEF: World	Not applicable	Not applicable	Not applicable
Population	NGFS: 12 regions	Not applicable	Not applicable	Not applicable
Inflation	NiGEM: 5 regions and 47 countries	Not applicable	Not applicable	Not applicable
Unemployment	NiGEM: 5 regions and 47 countries	Not applicable	Not applicable	Not applicable
Productivity	NiGEM: 5 regions and 47 countries	Not applicable	Not applicable	Not applicable
Climate damages and policy costs	NiGEM: 5 regions and 47 countries	Not applicable	Not applicable	Not applicable
Carbon prices	12 regions	Not applicable	Not applicable	Not applicable
House Prices	NiGEM: 17 countries	Not applicable	Not applicable	Not applicable
Energy intensity	NGFS: 12 regions IEA & BNEF: World	Not applicable	Not applicable	Not applicable
Non-CO_2 Emissions	NGFS: 12 regions	Not applicable	Not applicable	Methane (CH4), Nitrous Oxide (NOx), F-Gases

Source: Vivid Economics

3.2.7.3 Approach to variable disaggregation and expansion

GDP

Variable type: extraction

GDP is taken directly from source for all scenarios and converted to US$2021 PPP for comparability. GDP for the NiGEM model has been converted into monetary units to increase accessibility.

Population

Variable type: extraction

Population is taken directly from source for all scenarios.

Inflation

Variable type: extraction

Inflation is taken directly from NiGEM model outputs. Units have been converted to express inflation as a percentage rather than a percentage point change relative to the baseline scenario.

Inflation

Variable type: extraction

Inflation is taken directly from NiGEM model outputs. Units have been converted to express inflation as a percentage rather than a percentage point change relative to the baseline scenario.

Unemployment

Variable type: extraction

Unemployment is taken directly from NiGEM model outputs. Units have been converted to express unemployment as a percentage rather than a percentage point change relative to the baseline scenario.

Productivity

Variable type: extraction

Productivity is taken directly from NiGEM model outputs.

Climate damages and policy costs

Variable type: extraction

Damages are taken directly from NiGEM model outputs. Damages have been converted into monetary units to increase accessibility. Damages are presented both on an annual and cumulative basis, the latter being calculated as the cumulative sum of all physical damages and policy costs in any year post 2020.

Carbon prices

Variable type: extraction

Carbon prices are taken directly from source for all scenarios. Carbon prices by region are available directly from extracted outputs for NGFS scenarios. The carbon price for NGFS scenarios is the shadow price of carbon, which corresponds to the level of ambition of all climate-related policies to achieve the level of decarbonisation associated with the scenario. The shadow carbon price summarises the impact of all climate policies, and does not represent a price that would be faced directly by companies. For IEA scenarios, regions are classified as “advanced”, “developing” or “selected developing” and assigned a carbon price. The carbon price for IEA scenarios is an explicit carbon price, such as through a carbon tax or an emissions trading system.

House prices

Variable type: extraction

House prices are taken directly from source for all NiGEM scenarios. Prices are available for the NiGEM model in Western Europe, Australia, Canada, New Zealand, and the United States. Estimates for other regions are not available in this iteration of the catalogue.

Energy intensity

Variable type: extraction

Energy intensity is either extracted directly from source or calculated using directly extracted outputs. It can be measured in terms of a primary energy requirement per unit of GDP or final consumption requirement per unit of GDP.

Non-CO_2 emissions

Variable type: extraction

Non-CO_2 emissions are extracted directly from source where available.

3.3 Scenario descriptions

Descriptions of the climate scenarios included in the Catalogue are listed in Table 3**.**

Table 3 Scenario overview

Institution/ Author	Scenario	Scenario Family	Scenario description
	Below 2°C	Paris Aligned Well-Below 2°C	This scenario assumes that optimal carbon prices in line with the long-term targets are implemented immediately after 2020 and keeps the 67-percentile of warming below 2°C throughout the 21st century.

Institution/ Author	Scenario	Scenario Family	Scenario description
NGFS (V3.1)	Current Policies	Current Policies/BAU	The Current Policies scenario assumes that only currently implemented policies are preserved and no further climate action is taken.
	Delayed transition	Paris Aligned Well-Below 2°C	This scenario assumes that the next 10 years see a "fossil recovery" and thus follow the trajectory of the current policies scenario until 2030, and only thereafter countries with a clear commitment to a specific net-zero policy target at the end of 2020 are assumed to meet the target, representing regional fragmentation. Regionally fragmented CO2 prices converge to global price near 2070 to keep the 67-percentile of warming below 2°C in 2100, which also allows for temporary overshoot.
NGFS (V3.1)	Divergent Net Zero	Paris Ambitious 1.5°C	This scenario assumes that optimal carbon prices in line with the long-term targets are implemented immediately after 2020 to bring the median temperature below 1.5°C in 2100, after a limited temporary overshoot. Policy pressure and mitigation efforts are unevenly distributed across sectors, with stronger mitigation action taking place in the Transport and Buildings sectors relative to reflect consumer-oriented measured being preferred by policy makers.
	Nationally Determined Contributions (NDCs)	Current Policies/BAU	The NDCs scenarios assumes that currently pledged unconditional NDCs are implemented fully, and respective targets on energy and emissions in 2025 and 2030 are reached in all countries. The long-term policy assumption beyond current NDC target times (2025 and 2030) is that climate policy ambition remains comparable to levels implied by NDCs. This however does not clearly constrain the level of policy ambition, so long-term deviations across models are quite high.
	Net Zero 2050	Paris Ambitious 1.5°C	This scenario foresees global CO2 emissions to be at net-zero in 2050. Furthermore, countries with a clear commitment to a specific net-zero policy target at the end of 2020 are assumed to meet this target. This scenario assumes that optimal carbon prices in line with the long-term

Institution/ Author	Scenario	Scenario Family	Scenario description
			targets are implemented immediately after 2020.
IEA	Net Zero Energy 2050	Paris Ambitious 1.5°C	The Net Zero Energy 2050 (NZE) scenario sets out a pathway for the global energy sector to achieve net zero CO2 emissions by 2050. It doesn't rely on emissions reductions from outside the energy sector to achieve its goals. Universal access to electricity and clean cooking are achieved by 2030. The scenario aims to show what is needed across the main sectors by various actors, and by when, for the world to achieve net zero energy related and industrial process CO2 emissions by 2050 while meeting other energy-related sustainable development goals such as universal energy access.
	Announced Pledges Scenario	Paris Aligned Well-Below 2°C	The Announced Pledges Scenario (APS) assumes that all climate commitments made by governments around the world, including Nationally Determined Contributions (NDCs) and longer-term net zero targets, as well as targets for access to electricity and clean cooking, will be met in full and on time. The scenario aims to show how close do current pledges get the world towards the target of limiting global warming to 1.5 °C, it highlights the "ambition gap" that needs to be closed to achieve the goals agreed at Paris in 2015. It also shows the gap between current targets and achieving universal energy access.
	Stated Policies Scenario	Current Policies/BAU	The Stated Policies Scenario (STEPS) represents a more conservative outlook on climate action where not all announced policies are assumed to be met, looking instead at policies currently in place or under development. Carbon prices are restricted to a few regions and grow gradually. Emissions stabilise and begin to decrease gradually by 2030, leading to global warming of approximately 2.6C by 2100 and increasing thereafter.[16] The scenario provides a benchmark to assess the potential

[16] IEA. (2022).

Institution/ Author	Scenario	Scenario Family	Scenario description
			achievements and limitations of recent developments in energy and climate policy.
UN PRI (IPR)	Required Policy Scenario	Paris Ambitious 1.5°C	The Required Policy Scenario (RPS) is a stringent scenario explicitly designed to assess the policy gap to limit global warming to 1.5°C. Additional policy ambition is achieved through additional performance standards and subsidies.
	Forecast Policy Scenario	Paris Aligned Well-Below 2°C	The Forecast Policy Scenario (FPS) lays out the policies that are likely to be implemented in the 2020's that result in global warming limited to 2°C and quantifies their impact on the real economy, energy use sectors and land use to 2050.
Bloomberg New Energy Outlook (NEO 2022)	Net Zero Scenario (NZS)	Paris Aligned Well-Below 2°C	The NEO 2022 NZS Scenario describes an economics-led evolution of the energy economy to achieve net-zero emissions in 2050. This scenario combines faster and greater deployment of renewables, nuclear and other low carbon dispatchable technologies in power with the uptake of cleaner fuels in end-use sectors, most notably hydrogen and bioenergy. Taking a sector-led approach, it describes a credible pathway to meet the goals of the Paris Agreement.
	Economic Transition Scenario (ETS)	Current Policies/BAU	The Economic Transition Scenario is NEO 2022 baseline assessment of how the energy transition might evolve from today as a result of cost-based technology changes. In ETS, which assumes no new policy action to accelerate the clean energy transition, the rapid growth of renewable energy and electrification of transport eliminate about half of the world's energy-related emissions in 2050, against a baseline where no such transition takes place. Despite these rapid gains for clean energy, the Economic Transition Scenario falls far short of achieving net zero by mid-century. By 2050, emissions have fallen 29%, but unabated coal, oil and gas still emit 24.6 gigatons of CO2 per year. The result is a trajectory consistent with 2.6C of global warming, breaching the goals of the Paris Agreement.

Institution/ Author	Scenario	Scenario Family	Scenario description
IRENA	World Energy Transitions Outlook 1.5°C Scenario	Paris Ambitious 1.5°C	The International Renewable Energy Agency (IRENA) provides transition modelling of the energy system with a focus on renewables. The 1.5 Scenario is an orderly transition to limit global warming to 1.5°C by the end of the century with a focus on renewables. It reaches net zero energy emissions in 2050.
	Global Renewables Outlook Transforming Energy Scenario	Paris Aligned Well-Below 2°C	The International Renewable Energy Agency (IRENA) provides transition modelling of the energy system with a focus on renewables. The Transforming Energy Scenario is an orderly transition to limit global warming to well below 2°C by the end of the century with a focus on renewables.
AR6 Scenario Explorer and Database hosted by IIASA, in collaboration with IAMC and IPCC Working Group III	3,131 scenarios based on 188 modelling frameworks from the IPCC AR6 scenario explorer and database – filtered to vetted scenarios only	All families	The scenario explorer presents an ensemble of quantitative climate change mitigation pathways underpinning chapter 3 of the IPCC's 6th Assessment Report published by the Intergovernmental Panel on Climate Change (IPCC). It includes 3,131 quantitative scenarios with data on socio-economic development, emissions, energy and land use, with 188 unique modelling frameworks which are globally and nationally comprehensive.
Riahi et al (2017)[17]	SSP_SSP3 (Low Growth Scenario)	Paris Ambitious 1.5°C	SSP_SSP3 (Low Growth Scenario) is characterized by regional rivalry. The scenario builds on the narrative that nationalism, concers about compettivness and security, leads to low international priority for addressing environmental concerns causing environmental degreadation and low economic growth. It provides a scenario for climate transition with a different GDP projection than the vetted scenarios from international institutions. The 1.5 Scenario is an orderly transition to limit global warming to 1.5°C by

[17]Riahi, K., Van Vuuren, D. P., Kriegler, E., Edmonds, J., O'neill, B. C., Fujimori, S., ... & Tavoni, M. (2017). The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Global environmental change*, *42*, 153-168

Institution/ Author	Scenario	Scenario Family	Scenario description
			the end of the century while limiting GDP growth.
Riahi et al (2017)[18]	R2p1_SSP5-PkBudg900 (High Growth Scenario)	Paris Ambitious 1.5°C	R2p1_SSP5-PkBudg900 (High Growth Scenario) is characterized by fossil-fuel led economic growth. It assumes that a push for economic and social development is coupled with the exploitation of abundant fossil fuel resources, leading to rapid growth of the global economy. It a scenario for climate transition with a different GDP projection than the main scenarios published by the NGFS, IEA, IRENA, BNEF and UN PRI.

Note: BAU: Business as usual

Source: Vivid Economics

3.4 Model descriptions

Description of the climate models included in the Catalogue are listed in Table 4.

Table 4 Model overview

Model	Defining characteristic	Model description	Catalogued scenarios
GCAM5.3+ (NGFS)	Economic agents are myopic, meaning that decisions are made irrespective of the future and are only informed by past and present circumstances.[18]	GCAM is a partial equilibrium model of the energy and land sector. It assumes that economic agents are self-interested and myopic. Consequently, the model solves for the least-cost (or maximum profits) outcome in a particular period without consideration of how current decisions affect costs or profits in future periods.[19]	- Net Zero 2050 - Divergent Net Zero - Below 2°C - Delayed Transition - NDCs - Current Policies
REMIND-MAgPIE 3.0-4.4 (NGFS)	The energy component of the model uses an intertemporal optimisation algorithm (perfect foresight).	REMIND-MagPIE combines a general equilibrium model on the energy sector and the macroeconomy under perfect foresight with a partial equilibrium model on the	- Net Zero 2050 - Divergent Net Zero - Below 2°C

[18] Richters et al. (2022). NGFS Climate Scenarios Database Technical Documentation V. https://www.ngfs.net/sites/default/files/media/2022/11/21/technical_documentation_ngfs_scenarios_phase_3.pdf

[19] Richters et al. (2022).

Model	Defining characteristic	Model description	Catalogued scenarios
		land sector. The majority of mitigation options reside in the energy sector which operates with perfect foresight. This implies that economy-energy nexus is constructed to maximise welfare for economic agents over the entire century.[20]	- Delayed Transition - NDCs - Current Policies
NiGEM (NGFS)	An econometric model where outputs are estimated using econometric equations of historical behaviour.	NiGEM is the leading global general equilibrium macroeconomic model. Countries and regions are linked together through trade and capital markets. The model reflects key dynamics and elasticities of individual countries and is updated with quarterly data such that there is a balance between the "theoretical underpinnings that guide economies towards long-run market clearing equilibria, and data-driven individual country characteristics that fit the main characteristics of real-world data outturns."[21]	Each scenario with Remind inputs & GCAM inputs - Net Zero 2050 - Divergent Net Zero - Below 2°C - Delayed Transition - Nationally Determined Contributions (NDCs) - Current Policies
Global Energy and Climate Model (IEA)	The Global Energy and Climate Model (GEC) is a bottom-up partial-optimisation model that models energy demand, supply, transformation, and prices.	The GEC Model is a bottom-up partial-optimisation model covering energy demand, energy transformation and energy supply. The model uses a partial equilibrium approach, integrating prices sensitivities. It shows the transformation of primary energy along energy supply chains to meet energy service demand, the final energy consumed by the end-user. The various supply, transformation	- Net Zero Energy 2050 - Announced Pledges Scenario - Stated Policies Scenario

[20] Richters et al. (2022). NGFS Climate Scenarios Database Technical Documentation V. https://www.ngfs.net/sites/default/files/media/2022/11/21/technical_documentation_ngfs_scenarios_phase_3.pdf

[21] Richters et al. (2022).

Model	Defining characteristic	Model description	Catalogued scenarios
		and demand modules of the model are dynamically soft-linked: consumption of electricity, hydrogen and hydrogen-related fuels, biofuels, oil products, coal and natural gas in the end use sector model drives the transformation and supply modules, which in turn feed energy prices back to the demand module in an iterative process.	
Inevitable Policy Response (IPR)	IPR includes a detailed policy forecast based on 'inevitable' policies to limit global warming.	IPR creates policy forecast and then uses a suite of models to estimate the impacts of these policies on energy and land.	- Forecast Policy Scenario - Required Policy Scenario
BNEF NEO 2022	Built from bottom-up, sector-level economic modelling and analysis of key sectors.	This bottom-up, sector-by-sector modelling exercise is BloombergNEF's long-term scenario analysis on the future of the energy economy covering electricity, industry, buildings and transport and the key drivers shaping these sectors until 2050.	- Net Zero Scenario - Economic Transition Scenario
Renewable Energy Roadmap (IRENA)	The Renewable Energy Roadmap (REMap) approach creates normative scenarios of technology penetration.	The Renewable Energy Roadmap (REMap) approach involves using a parametric model with a focus on energy technologies. Like WEM, the REMap approach does not follow a solution concept. However, REMap does not model policies and rather develops a normative scenario built on penetration of renewable energy technologies across different sectors. The land use system is not integrated with the energy system and socioeconomic pathways are exogenous.	- 1.5°C Scenario - Transforming Energy Scenario
Various models from the AR6 Scenario Explorer and Database	Not applicable – the models from the IAMC 1.5°C scenario ensemble database are similar in that they are	Not applicable –the models originate from a plurality of different institutions and/or authors.	Various models from the IPCC AR6 - 1.5°C scenario ensemble data

Model	Defining characteristic	Model description	Catalogued scenarios
hosted by IIASA, in collaboration with IAMC and IPCC Working Group III	all integrated assessment models (IAMs), meaning that climatic, economic and energy (and possibly land use) systems are modelled simultaneously. However, the models originate from a plurality of different institutions and/or authors and are unlikely to share a single defining characteristic.		release hosted by IIASA

Source: Vivid Economics