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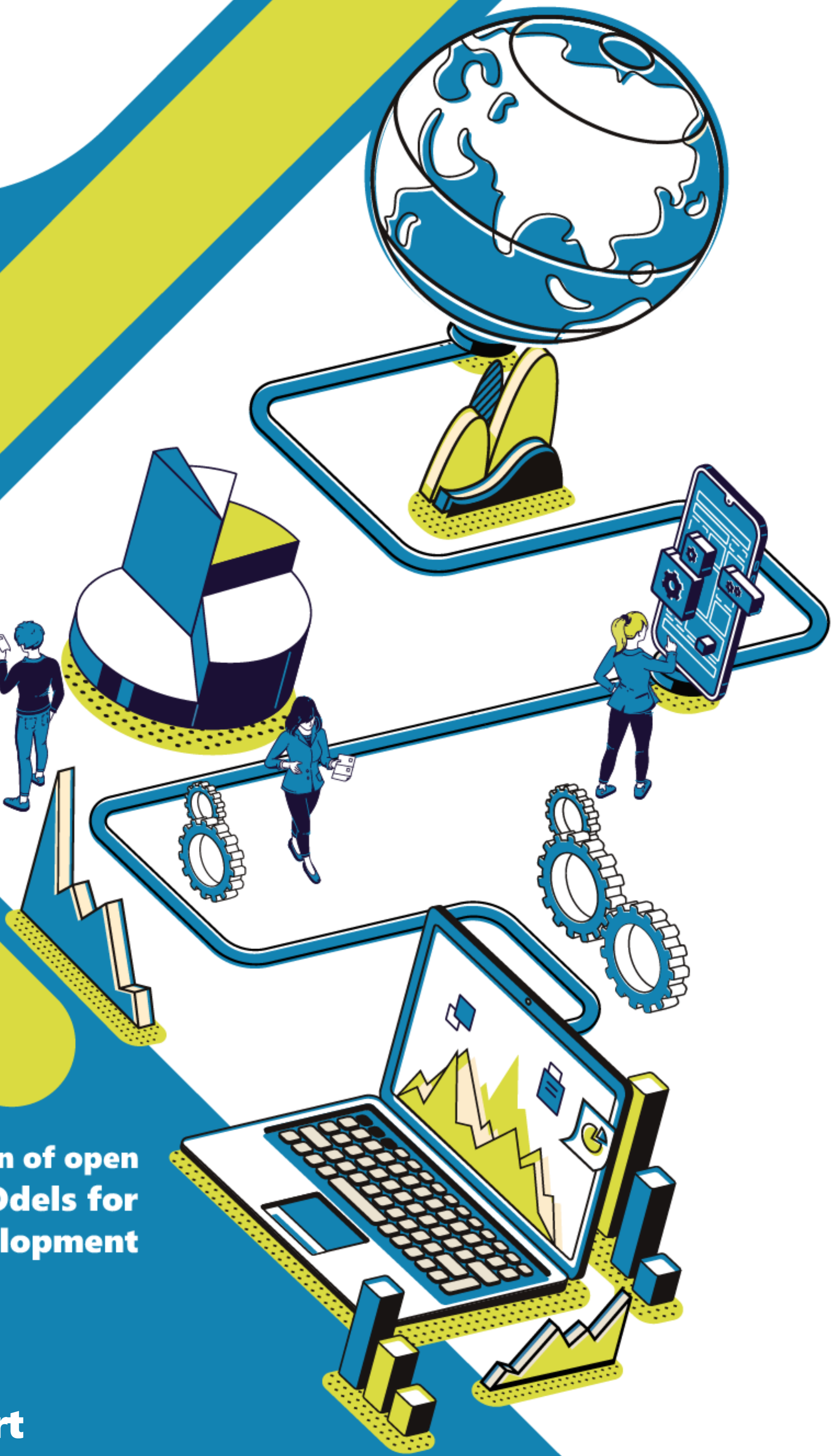

Delivering the next generation of open Integrated Assessment MOdels for Net-zero, sustainable Development

OMNIA Technical Report

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1 OMNIA model technical draft

This report constitutes the technical draft for the OMNIA model, which is associated with the first version of the model released under MS8 of the DIAMOND project. Section 1 presents the core part of the technical drafts for OMNIA, including features and characteristics of the released model, the sectoral design and input data used, and a manual to guide new users also elaborating on hardware and software requirements to run the model. Section 2 describes the testing phase, which accompanied this release of the model. Finally, an initial action plan and next step phase targeting the second part of the project is proposed in Section 3.

1.1 General introduction

The Open-source MuNdus Integrated Assessment model (OMNIA) is a customised, open-access global Integrated Assessment Model (IAM) based on the TIMES framework. The TIMES framework can be used to model local, national or multi-regional energy systems, providing a technology-rich basis for estimating how energy system operations evolve in the long run, with a multiple-period time horizon (Loulou and Labriet, 2007), it is developed and maintained by the Energy Technology Systems Analysis Programme (ETSAP), one of the Collaboration Programmes of the International Energy Agency. It is used in over 70 countries. OMNIA is a global, multi-regional, energy system model which combines an energy system representation of different regions with options to mitigate CO_2 and non-CO_2 greenhouse gases, including methane (CH_4) and nitrous oxide (N_2O). The OMNIA model integrates and expands the open-source TIMES-GEO model developed by University College Cork and E4SMA in the context of the CHIMERA project, serving as a foundation to the OMNIA model (Github repository: TIMES-GEO). OMNIA is developed under the Diamond EU-project, and the first version of the model is released in July 2025. The model is available on Github at the link https://github.com/CLIMATE-DIAMOND/OMNIA . The model is published with the open-source licence "Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International Public License"(https://creativecommons.org/licenses/by-nc-sa/4.0/).

The released version includes multiple improvements to the global TIMES-GEO model, such as a new regional disaggregation and an updated calibration against 2019 based on the UNSD energy balances and energy statistics (United Nations (a), 2025; United Nations (b), 2025)(United Nations (a), 2025; United Nations (b), 2025). Moreover, the latest energy demand projections' dependent upon the Shared Socioeconomic Pathway 2 (Fricko et al., 2017; Riahi et al., 2017)(Fricko et al., 2017; Riahi et al., 2017) were incorporated. The OMNIA model includes key improvements to the design of the global energy system. First, the representation of the supply of fuels and fuel transformation processes is enriched, including mining and extraction of primary energy, multiple primary energy conversion processes such as refinery plants and inter-regional trades. The supply sector also includes alternative energy sources, such as hydrogen and bioenergy. Second, the technology datasets have been expanded for all sectors represented in the energy system. For example key technologies needed to decarbonise hard-to-abate demand sectors are included, as well as a range of energy service applications (vehicular transport, building heating and cooling). Third, the temporal representation of energy demand and supply is increased to properly model the increased penetration of weather-dependent renewables, storage, and new demand technologies, expanding the time slices to 20. In addition, OMNIA includes a new water module, to evaluate the interdependence between energy production and water consumption. Finally, OMNIA is also designed to allow a soft link with other sectoral models, aiming to provide a tool capable of assessing policy impacts across energy, environmental, and social dimensions. More details about the design of each specific sector and possible soft links are described in Section 1.2.3.

OMNIA can generate outputs related to technological pathways, investment patterns, energy flows, commodity pricing and abatement costs, by adopting a least-cost approach, informing about optimal timing and regional effort sharing decisions. The flexibility of the TIMES framework enables users to model diverse scenarios by adapting the main key drivers, such as socio-economic trends, technology development, and policy questions. Diverse constraints can be included to analyse multiple scenarios, such as carbon emissions caps, subsidies for specific technologies, renewable targets, and technology phase-outs. The current version of the model does not present a specific policy scenario implemented, but some controls to the energy system behaviour are included.

1.2 Model overview

1.2.1 Introduction

The model is developed using a Reference Energy System (RES), which is a network-based topology that represents the interdependencies between technologies and energy flows within the energy system. The RES distinguishes the energy system into two main parts: the supply and demand sides. The supply side includes the upstream and power sector and focuses on the provision and transformation of energy into useful fuels. It encompasses fuel mining and energy potential assessments, the extraction of fuels, and regional trades of fuel sources. It also includes conversion processes that transform primary energy into secondary forms, such as refineries, the hydrogen supply chain, and power plants, along with all transformations explicitly accounted for in the energy system. The demand side focuses on energy usage across various end-use sectors, including residential, services, transportation, industry, and agriculture. The energy system described in the RES encompasses all the energy flows, also referred to as commodities, necessary to meet the system's sectoral demands, from primary energy sources through secondary energy carriers to final or useful energy. The energy that flows in the system is produced or consumed by a dedicated "technology", with the RES encompassing a comprehensive range of existing and envisaged energy technologies, also called processes, involved in the production, transformation, trade, and utilisation of energy flows, as well as, several technologies required to meet service demands in the energy system. The OMNIA model includes the accounting of GHG combustion and process emissions, and primary material consumptions, such as clinker and scrap aluminium. Finally, a water module is available, accounting for the water needs which can be activated by the user. Each sector is modelled as a stand-alone module, and further details are available in the sections below. Given the modelling scope and the requirements, the model has the following general characteristics:

Regional configuration: This model is designed to represent the full Global energy system, and it is configured in 28 regions. More information about the modelled regions and the country-level disaggregation is available in Table 4.

The base year (or start period): The base year for OMNIA is 2019, meaning that the model is calibrated based on this historical year. Therefore, all the data collected and elaborations for calibrating the model (detailed in the following section) refer to the year 2019 and to the regional configuration.

Temporal scope (Time horizon): The scenario time horizon extends until 2050. However, the time horizon of the model is adjustable, so it can be extended/reduced to any year in the future, provided that all the necessary exogenous inputs are defined until that year (e.g., GDP projections, population projections).

Temporal scope (Period durations)*:* TIMES solves the optimisation problem of the energy system over several periods, and each period can extend over a variable number of years. The delivered model is set and tested to run scenarios for the following periods: 2019, 2020, 2025, 2030, 2035, 2040, 2050. The model is flexible, and the duration of the periods can be changed according to the modeller's needs.

Temporal scope (Time-slices)*:* In OMNIA, 20 time slices are defined, featuring a combination of 4 seasonal and 5 daily time slices, defined in Table 1.

Discount Rate*:* A general discount rate of 5% is used in the calculation of present value of cash flows in the model horizon.

Table 1: Timeslice codes: seasons (Q). daynite (B)

Season	Daynite Blocks
Q1: January to March	B1: block 1 (h01 to h05)
Q2: April to June	B2: block 2 (h06 to h09)
Q3: July to September	B3: block 3 (h10 to h14)
Q4: October to December	B4: block 4 (h15 to h19)
	B5: block 5 (h20 to h24)

Emission granularity: The model tracks the main sources of greenhouse gases from both combustion in the energy sector and industrial processes, namely carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). These can also be reported as carbon dioxide equivalent emissions (CO_{2eq}).

Mitigation and adaptation technologies: more than 6000 technologies and 600 commodities are part of the energy system represented in the RES.

Naming convention*:* All the elements that are part of the RES are defined in the model with a specific code-name convention. The naming convention facilitates the model development, as well as provides a clear, tidy, and transparent model structure. Moreover, this also facilitates the data automation routines processing data inputs, data outputs, and results. A full description of the naming convention is provided in the PDF document "OMNIA Naming conventions" released with the model and is available on the GitHub repository.

Table 4 OMNIA regional disaggregation

Model regions	Description	List of countries
AFE	Eastern Africa	Ethiopia, Kenya, Sudan, Mauritius, Eritrea, South Sudan, Burundi, Comoros, Djibouti, Madagascar, Réunion, Rwanda, Somalia, Uganda
AFN	Northern Africa	Egypt, Algeria, Morocco, Libya, Tunisia
AFW	Western Africa	Democratic Republic of the Congo, Cote d Ivoire, Ghana, Cameroon, Gabon, Benin, Senegal, Togo, Niger, The Republic of Congo, Burkina Faso, Cape Verde, Central African Republic, Chad, Equatorial Guinea, Gambia, Guinea, Guinea-Bissau, Lesotho, Liberia, Malawi, Mali, Mauritania, Sao Tome and Principe, Seychelles, Sierra Leone, Swaziland
AFZ	Southern Africa	Tanzania, Angola, Mozambique, Zimbabwe, Zambia, Botswana, Namibia, South Africa
NIG	Nigeria	Nigeria
RUS	Russian Federation	Russian Federation
ASC	Central Asia	Kazakhstan, Uzbekistan, Turkmenistan, Azerbaijan, Mongolia, Georgia, Kyrgyzstan, Armenia, Tajikistan, Afghanistan
ASE	Southeast Asia	Thailand, Malaysia, Singapore, Myanmar, Cambodia, Brunei Darussalam, Lao People's Democratic Republic, Democratic People's Republic of Korea, Cook Islands, East Timor, Fiji, French Polynesia, Kiribati, Macau, Maldives, New Caledonia, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Vanuatu
CHN	China Mainland	People's Republic of China, Hong Kong
IDN	Indonesia, Philippines, Vietnam	Indonesia, Philippines, Vietnam
IND	India	India
ASO	South Asia	Bangladesh, Nepal, Sri Lanka, Pakistan, Bhutan
JPN	Japan	Japan
SKT	South Korea	South Korea

ANZ	Australia and New Zealand	Australia, New Zealand
USA	United States	United States
CAN	Canada	Canada
LAM	Latin America	Argentina, Venezuela, Colombia, Peru, Trinidad and Tobago, Ecuador, Guatemala, Cuba, Bolivia, Dominican Republic, Honduras, Paraguay, Uruguay, Costa Rica, El Salvador, Haiti, Panama, Nicaragua, Jamaica, Curacao, Suriname, Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, Bermuda, British Virgin Islands, Cayman Islands, Dominica, Falkland Islands (Malvinas), French Guiana, Grenada, Guadeloupe, Cooperative Republic of Guyana, Martinique, Montserrat, Puerto Rico, Saba, Saint Eustatius, Saint Kitts and Nevis, Saint Lucia, Saint Pierre and Miquelon, Saint Vincent and the Grenadines, Sint Maarten, the Turks and Caicos Islands
BRA	Brazil	Brazil
MEX	Mexico	Mexico
CHL	Chile	Chile
ENE	Non-EU Eastern Europe	Ukraine, Belarus, Serbia, Bosnia and Herzegovina, Moldova, Republic of North Macedonia, Kosovo, Albania, Montenegro
ENW	Non-EU Western Europe	Norway, Switzerland, Iceland, United Kingdom, Gibraltar
EUE	Eastern Europe Union	Poland, Czech Republic, Romania, Hungary, Bulgaria, Slovak Republic, Croatia, Lithuania, Slovenia, Estonia, Latvia
EUW	Western Europe Union	Germany, Netherlands, Belgium, Sweden, Austria, Finland, Denmark, Ireland, Luxembourg
EUM	Mediterranean-Europe Union	France, Italy, Spain, Greece, Portugal, Cyprus, Malta
MEA	Middle East (Gulf States)	Iran, Saudi Arabia, United Arab Emirates, Iraq, Qatar, Kuwait, Oman, Bahrain, Yemen
MDA	Mediterranean Asia	Turkey, Israel, Syrian Arab Republic, Jordan, Lebanon

1.2.2 Sectoral structure

1.2.2.1 Upstream

The Upstream sector regroups all processes related to primary fuel production and transformation, i.e., fossil fuel extraction and transformation, imports and exports of fuels and products, biofuel production, hydrogen production and synthetic fuel production.
Within fossil fuel extraction and transformation, the supply chains are structured as follows:

1. Cumulative reserves and resources
2. Extraction processes
3. Processing processes (there can be one or several)
4. Delivery processes to consumption end points

On the other hand, the supply chains for the three other groups are simpler and include only two steps:

5. Production process
6. Delivery process

Fossil fuel activities

For each fossil fuel, modelling encompasses a representation of reserves, as well as the extraction and processing steps. Both process-based emissions and fugitive emissions are accounted for , with the representation fugitive emissions being improved. Delivery processes are then attached to the output commodity. The implemented fossil fuel commodities are depicted below:

- Coal: two types of coal are modelled, namely lignite and other coal types. The extraction chain for lignite and other coal type is similar and are represented by a single extraction process for each type of coal. Additionally, coal liquefaction and gas-to-liquids plants are modelled as processing processes.
- Crude oil: from a conventional extraction process or from enhanced oil recovery (EOR). Representation of crude oil reserves has been improved for both conventional extraction and EOR to take into consideration its specific reserve capacity. EOR is an extraction process that uses carbon dioxide, along with other additives, to extract oil from wells that cannot be recovered using traditional extraction methods. These methods allow storing carbon dioxide in depleted oil fields and enable the extraction of oil that would otherwise remain untapped. Part of the carbon dioxide used by the process is sequestered into the field and another part is released and can be vented, recycled to be reused in an EOR process or sent to another sequestration process.
- Natural gas: including natural gas as well as natural gas liquids with an extraction process and a separate processing process that consume wet natural gas and separate it into dry natural gas and natural gas liquid. The model also includes the liquefaction and regasification processes to produce liquified natural gas and transform it back into natural gas after trading for example.
- Coke plant: The implementation of coke oven plants has not changed significantly. The only improvement is the inclusion of the by-product 'coke oven gas'.
- Uranium
- Biomass feedstock: five feedstocks are being modelled, namely forest residues, crops grown for energy, agricultural residues, oil crops (1st generation crops biodiesel) and cereals (1st generation crops ethanol). A supply curve for these five commodities is developed from the soft-link with MAgPIE.
- All other fossil fuel processing plants has been regrouped under a process named "Other processing plants".

An initial stage in the extraction chain has been added, corresponding to the reserve of each fossil fuel. For each commodity a supply curve is employed with at least three levels, to depict the cumulative reserve of the commodity with increasing cost.

Then, for each reserve commodity, we have an extraction process that consumes energy and produces the corresponding commodity, as well as any additional commodity and emissions. Depending on the type of commodity, we included additional processing steps, such as a liquefaction process for natural gas.

The refinery process has been improved by extracting the fuel used for hydrogen production and implementing hydrogen production outside of the refinery process. This is because hydrogen production is expected to become a key sector in decarbonization pathways. A separate hydrogen sector has been created, which allows implementing different hydrogen production technologies and let the model choose the production technologies based on cost-optimal optimisation and GHG emissions. Also, we are modelling the energy input using energy services such as boiler and HVAC systems. This enables the model to decarbonise energy used in the refinery based on the cost of energy services by replacing conventional ones with low emission alternatives using electricity or biomass. The oil products share is based on UNSD Energy balance (United Nations (b), 2025)(United Nations (b), 2025) and slightly relaxed in future timesteps. The proposed implementation is illustrated in Figure 1.

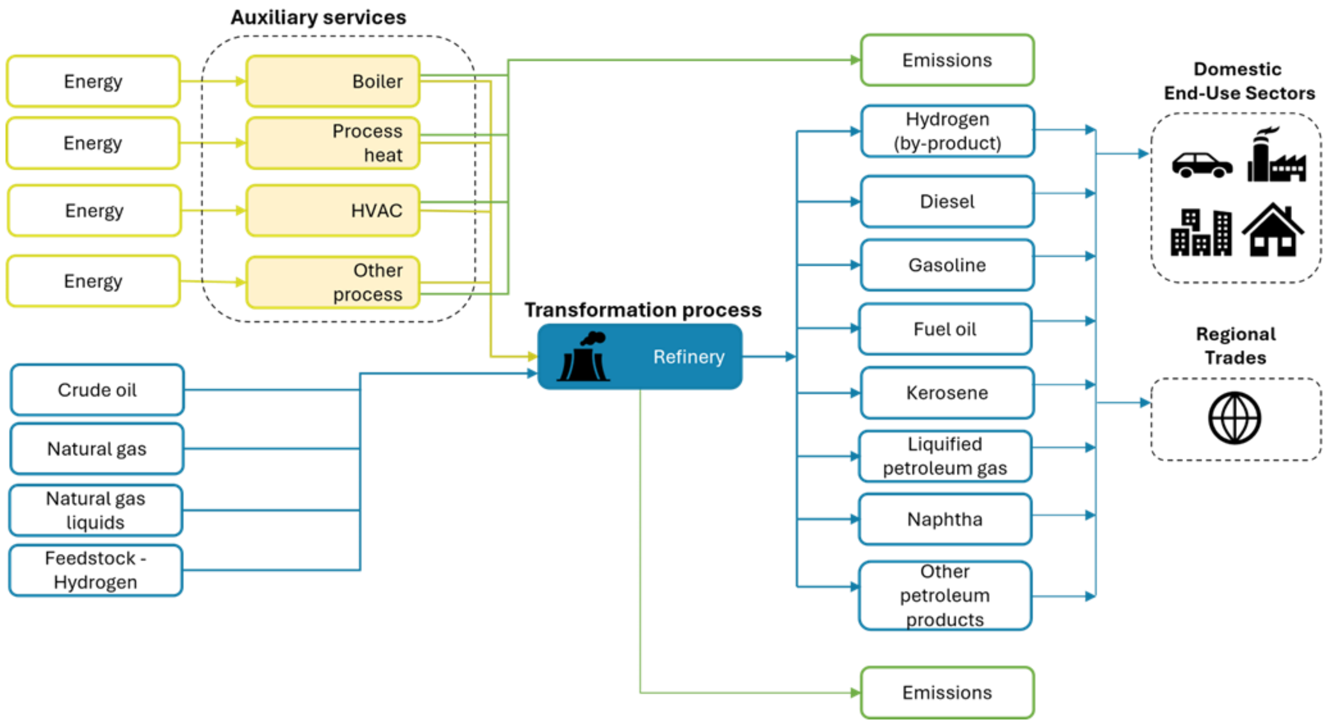

Figure 1. Refinery representation

Moreover, delivery processes of crude oil, natural gas and natural gas liquids have been enhanced by implementing a pipeline system, considering energy consumption and related costs. Note that deliveries between model regions are modelled through import/export processes through the endogenous trade module in TIMES. These processes represent the trade infrastructure between regions (ships, pipelines, …) based on investment cost parameters, fix and variable O&M cost parameters and a stock parameter or bound on activity to limit trade capacities.

Finally, accounting of upstream sector emissions has been improved by incorporating all fugitive emissions. These include fugitive emissions from coal mining (associated with the coal extraction process), oil activities (related to the oil extraction process and oil pipelines) and natural gas activities (linked to natural gas extraction process and natural gas pipeline). Based on computational complexity, we may introduce technologies that decrease venting and flaring emissions in next versions of the model.

Alternative fuel activities

The representation of alternative fuels has been improved by including biofuel, hydrogen and synthetic fuels production. For biofuels, the production processes have been implemented for key biofuels such as biodiesel, bio-gasoline/renewable gasoline, ethanol, cellulosic ethanol, renewable diesel and renewable natural gas. These processes require inputs of raw biomass from both first-generation sources (such oil crops and cereals) or second-generation sources (such as forest residues, agricultural residues, energy crops). These input flows are coupled with the MAgPIE model using a supply curve for reserves of this feedstock available each year.

Regarding hydrogen, current production is often included as part of upstream or industry processes using hydrogen. For example, the use of fuel to produce hydrogen for the refining process is included in the overall fuel use for refining. However, this fuel has been separated, and hydrogen production is now modelled outside of upstream and industry processes. This allows us to explore decarbonisation options for hydrogen production. The main hydrogen production technologies have been implemented, such as steam methane reforming (with and without carbon capture), autothermal reforming (with carbon capture), electrolysis, biomass gasification (with and without carbon capture) and coal gasification (with and without carbon capture). Hydrogen production can be centralised or decentralised (i.e., produced on-site directly in the sector that uses it). Following the production step, modelling includes hydrogen transmission steps and hydrogen storage options. In this hydrogen sector, different conversion (and reconversion) processes have been implemented such as liquefaction or ammonia conversion. Commodities can then be used for different end-use (e.g., transport) or for trade purposes.

Finally, e-fuels (or synthetic fuels) are fuels that can replace their fossil equivalents without the need for any changes or adaptations in technology. They are produced using hydrogen and carbon dioxide, which can be captured from CCS technologies or DAC. Emissions of these fuels are like those of their fossil equivalent, but since they are produced from carbon dioxide, their overall emissions balance is close to neutral. There are various types of synthetic fuels available, as well as different production methods. We implemented three different e-fuel production pathways: synthetic methane, synthetic liquid fuels (turbo jet fuel, and diesel), synthetic methanol. Figure 2 showcases the implementation of both hydrogen and synthetic fuels modules.

Table 2. Key data sources for upstream sector (non-comprehensive)

Description	Source
Fossil fuel reserves and historic production data	(Energy Institute, 2023) (Energy Institute, 2024)
Fossil fuel processing techno-economic parameters	(Favennec, 2022) (Khwanpruk, Sriudom, & U-tapao, 2015) (Panos & Kannan, 2016) (Zhang, Meerman, Benders, & Faaij, 2020) (Agarwal, et al., 2020)
Enhanced oil recovery techno-economic parameters	(Abuov, Serik, & Lee, 2022) (Kwak & Kim, 2017)
Liquefaction capacity, Regasification terminal capacity, trade between regions	(International Gas Union, 2020)
Hydrogen consumption in refineries by types and world regions	(International Energy Agency, 2023)
Biofuel production techno-economic parameters	(Brown, Wright, & Brown, 2010) (Diederichs, Mandegari, Farzad, & Görgens, 2016) (Moret, Peduzzi, Gerber, & Maréchal, 2016) (Swanson, Platon, Satrio, & Brown, 2010) (NREL, 2011)
Hydrogen pathway techno-economic parameters	(International Energy Agency, 2021) (International Energy Agency, 2019) (NREL, 2020)
Pipelines techno-economic parameters	(Global Energy Monitor, 2024) (Global Energy Monitor, 2023)
Fugitive emissions computation and factors	(IPCC, 2007)

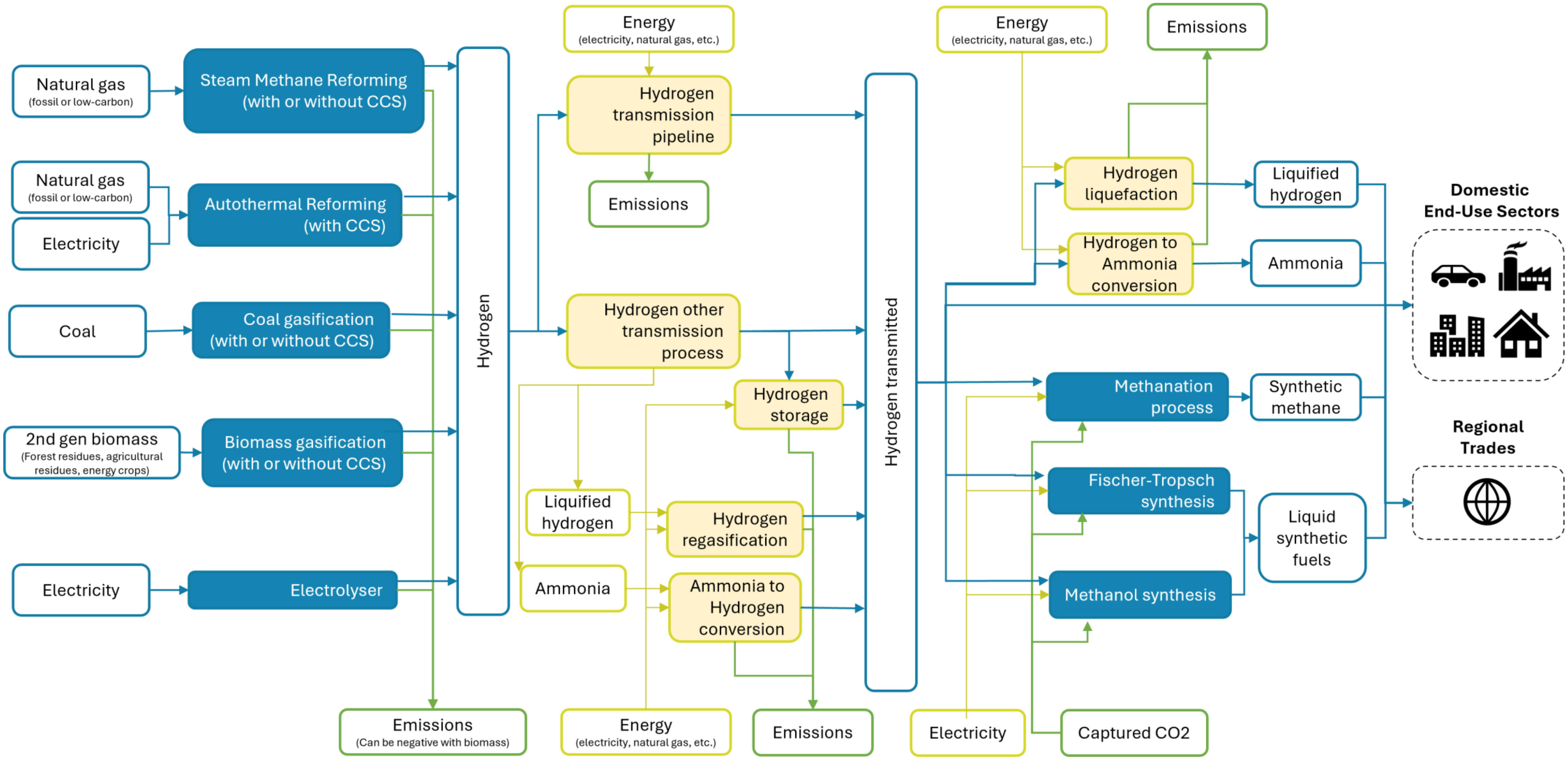

Figure 2. Hydrogen and synthetic fuels modules implementation

1.2.2.2 Power

The power sector represents the generation, transmission and storage of electricity. It is designed following the structure presented in Figure 3, which is a more detailed and updated version of the sector designed in the TIMES-GEO model. For each region, the existing generation plants are aggregated by technology type and fuel type, and are distinguished between centralised and decentralised plants. The types of plants included are thermal power plants (THE), combined heat & power (CHP), heat producer plants (HPL) and renewable power plants (photovoltaic, wind onshore, wind offshore, concentrated solar power, hydro, ocean). The calibration of electricity and heat generation and fuel consumption is based on the UNSD Energy balance (United Nations (b), 2025), and the capacity disaggregation is based on the elaboration of IRENA statistics (IRENA, 2022). The efficiency and capacity factor of base-year technologies are derived from input data. Electricity and heat generated are delivered to the demand sectors through technologies that represent the transmission and distribution; these technologies account for the average regional energy losses due to the transmission and distribution of energy carriers. Data are based on the UNSD Energy balance (United Nations (b), 2025) .

Electricity and heat commodities are characterised at the most detailed temporal resolution, using day-nite and seasonal timeslices as outlined in Table 1. The model incorporates electricity generation profiles by timeslice for renewable-based electricity and heat production. This approach enables accurate representation of the intermittent nature of renewable energy throughout the year, leveraging the model's highest temporal granularity. The renewable generation profiles are derived from processed data available in the Plexos-world database (Brinkerink & Deane, 2020).

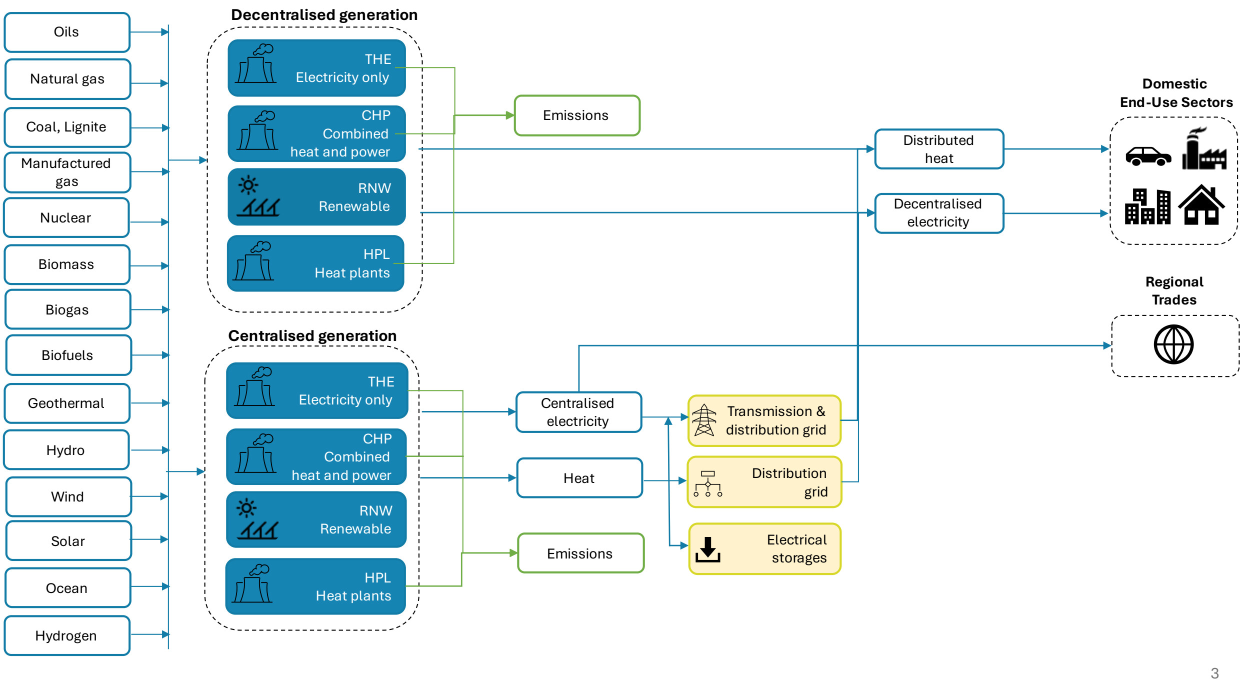

Figure 3. Power sector representation

Key developments and updates made to the OMNIA power sector with respect to TIMES-GEO consist of:

- Improving the power technologies decommissioning profiles,
- New commodities and technologies,

- Improving the design of renewable energy technologies.

Power Plant Decommissioning Profiles

The decommissioning profiles are based on a more detailed, data-driven method, incorporating information from the Global Energy Monitor (GEM) database. This GEM-based database covers more than 90% of global power plant capacity and includes detailed commissioning year data for each plant (Global Energy Monitor, 2025). This improvement allows for the decommissioning of specific capacity percentages each year, based on actual plant lifespans rather than a generic average.

Introduction of Manufactured Gas Commodity

In addition to the already designed fuels in the power sector, a new commodity, Manufactured Gas, has been introduced into the power sector model. This commodity aggregates three types of gases that were previously part of the natural gas commodity: Blast Furnace Gas, Coke Oven Gas, and Gasworks Gas.

This disaggregation allows for a more accurate assessment of emissions, as the individual properties of these gases differ significantly from natural gas. By considering these gases separately, the model can evaluate plant emissions with higher precision. Additionally, a new set of technologies has been developed to handle the consumption of manufactured gas in power sector, adopting the same techno-economic characteristics as the natural gas technologies.

New Storage Technology: Pumped Hydro

The already existing pumped hydro storage plants have been added to the model as electricity storage technologies. Pumped Hydro offers significant potential for large-scale energy storage by using water to store energy in the form of potential energy, which can be converted back to electricity as needed. Modelling of this technology has been elaborated using a detailed study by the National Renewable Energy Laboratory (National Renewable Energy Laboratory (NREL), 2023), which provides cost data, efficiency rates, and performance parameters, which have been integrated into the model.

New Structure for Renewable Technologies: Solar and Wind

The potential of renewable solar and wind energy has been divided into four tiers for wind technologies and three tiers for solar technologies, with each tier assigned a different availability factor and a maximum potential of installations. This allows the model to prioritise installations from tiers with the highest availability factors first, moving to lower tiers only as capacity expands.

Updated technology database in power sector

The underlying assumptions of these updated or newly technologies are based on techno-economic inputs drawing from the technology database used for the EU reference scenario developed by the European Commission (European Commission, 2021)(European Commission, 2021). These include investment costs for new generation capacity, maintenance costs, technical efficiencies and expected lifetime. New technologies for power generation include both conventional thermal and CHP power plants and renewable power plants, like wind turbines and solar photovoltaic, and alternative technologies like hydrogen fuel cells and carbon capture and storage options (CCS).

Table 3. Key data sources for power sector

Description	Source
Energy consumption and electricity generation	(United Nations (b), 2025)(United Nations (b), 2025)

Electricity and heat own consumptions and grid losses	UN Energy Balance (United Nations (a), 2025)(United Nations (a), 2025), UN Energy Statistics (United Nations (b), 2025)(United Nations (b), 2025)
Power plant capacity	Irena (IRENA, 2022)(IRENA, 2022)
New power plants decommissioning profiles	Global Energy Monitor (GEM) (Global Energy Monitor, 2025)(Global Energy Monitor, 2025)
New storage technology: Pumped hydro	NREL data (National Renewable Energy Laboratory (NREL), 2023)(National Renewable Energy Laboratory (NREL), 2023)
New structure for Renewable Technologies: Solar and Wind	(Chu & Hawkes, 2020)(Chu & Hawkes, 2020)
New power plants	European Commission database (European Commission, 2021) (European Commission, 2021)

1.2.2.3 Industry

A general approach to industry representation in OMNIA is based on the following principles. It represents full sectoral coverage, including all industrial uses of energy, as defined by the global energy balance used. Model development has taken account of data availability, and in some cases the representation has been simplified in the absence of data. The design is aligned with the model's purpose, which focuses on exploring energy system scenarios under climate policy. Finally, a stronger focus has been placed on the largest energy-consuming sectors, with implications for the modelling approach taken, which can be summarised as:

7. *Detailed sector process approach* – Applied to large energy and carbon intensive sectors such as aluminium, iron and steel, and cement. Here, individual processes are represented e.g., EAF (secondary steel) and integrated plant (primary steel). Such an approach is particularly relevant where key alternative technologies for cleaner production are crucial and need to be explicitly represented.
8. *Generic energy service approach* – In this approach, the level of different energy services required to produce a unit of industrial output is determined e.g., high and low temperature heat, drying, motor drive, other services. This does not represent technologies explicitly but rather the energy flows. From a mitigation perspective, the key levers are fuel switching and efficiency gains.

Here, we provide an overview of the modelling approach for aluminium and non-ferrous metal, steel, and cement and non-metallic minerals. These sectors are chosen due to their global emissions footprint, and the focus of DIAMOND on circular economy analysis for these sectors, as per Tasks 4.1 and 5.4.

Aluminium and non-ferrous metals

Aluminium production is disaggregated from the non-ferrous metals sector and split into primary and secondary (i.e., recycling) production. The key steps in primary aluminium production are aggregated into one process, i.e., refining, anode production and smelting, and process CO_2 emissions from the anode are accounted for. A base year primary pathway is developed by using historical data on production, average energy intensity and specific fuel inputs (see Table 4).

Future low carbon routes then rely on electrically / hydrogen powered boilers and calciners with conventional or inert anodes (to remove process emissions). Anode production can switch to hydrogen for its thermal inputs and process CO_2 emissions can be captured via CCS. These simplified low carbon options account for ~98% of total energy and ~99% of emissions in the aluminium supply chain. A secondary aluminium production option is modelled with a scrap input which may be defined by a particular scenario. The recycling option requires electricity and thermal energy inputs (using fossil fuels) in the base year but with hydrogen and electricity options in future.

The basic structure of the aluminium sector is shown below in Figure 4. The rest of the non-ferrous sector then follows the generic energy service approach and is composed of high temperature heat, machine drive and other services.

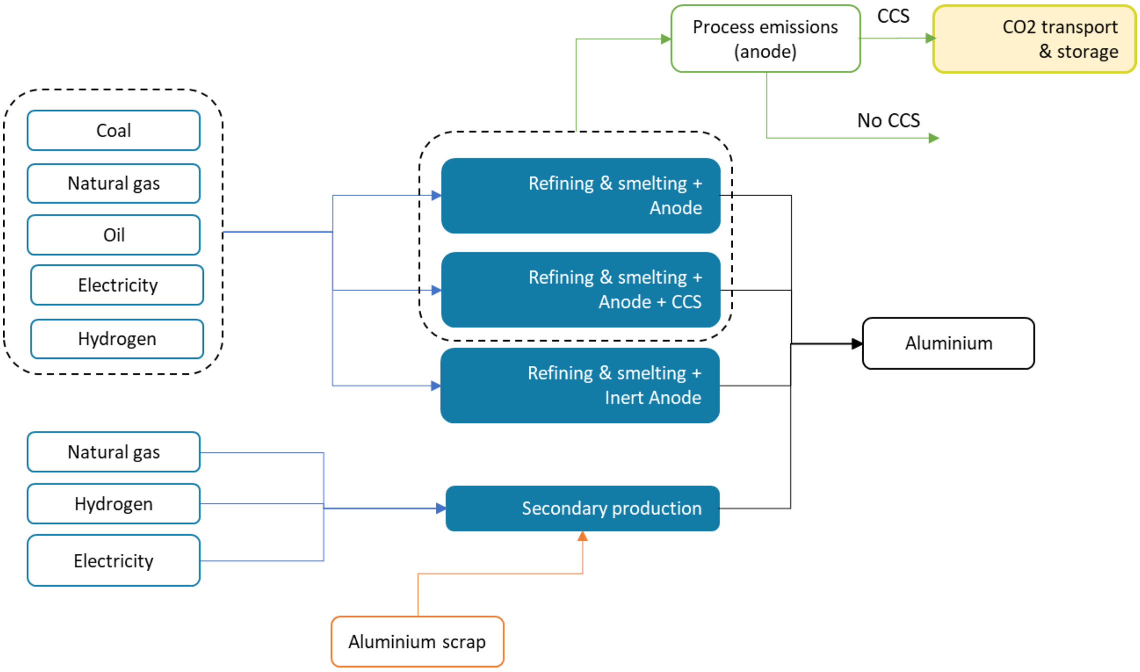

Figure 4. Aluminium sector representation

Key data sources for the aluminium sector are provided in Table 4.

Table 4. Key data sources for the aluminium sector

Dataset	Description	Source
Production statistics	Primary production available from the US Geological Survey. Secondary production provided at regional level and disaggregated to national level	USGS aluminium statistics (USGS, 2024) UCL MFA based on IAI, (IAI, 2024)
Historic input energy mix	Energy consumption for primary aluminium production Energy consumption for secondary aluminium production	International Aluminium data (IAI, 2019; Peppas, 2023)
Technology parameterization	Data aggregated as necessary e.g. refining and smelting considered together.	Mission Possible Partnership(MPP, 2023) European Aluminium (European Aluminium, 2023)

Steel

The steel production sector includes three main pathways for steel production, two of which are classified as primary steel pathways, while the third one is a secondary production pathway based on melting down recycled steel in an Electric Arc Furnace (EAF). The two primary production pathways are Blast Furnace-Basic Oxygen Furnace (BF-BOF) and Directly Reduced Iron-Electric Arc Furnace (DRI-EAF). Both pathways essentially involve removing oxygen from the iron ore, in a process called 'reduction', to produce iron. The blast furnace route relies on coke and coal as the reducing agent, producing molten 'hot metal' or pig iron. This process is highly energy intensive and results in very high levels of emissions. To produce steel, the pig iron is fed into a basic oxygen furnace, where the carbon content is further reduced, from 4-5% down to 0.25%. DRI uses an alternative reduction approach, using natural gas to produce the required syngas (CO plus H_2), with iron left in a solid state. Avoiding melting at this stage reduces the energy requirements and associated emissions. The produced sponge iron is then melted down in an EAF to produce crude steel.

The structure of the steel sector is largely based on (Steve Pye et al., 2022) and is shown below in Figure 5. BF-BOF is modelled as a single integrated process, as is DRI with EAF. This approach means that pig and sponge iron are not represented as explicit commodities in the model. While a simplification, the lack of trade representation of these commodities is appropriate, given that these commodities are scarcely traded. Scrap steel is not traded either. Note that insights on trade will be provided via the linkage with ENGAGE (under Task 4.1).

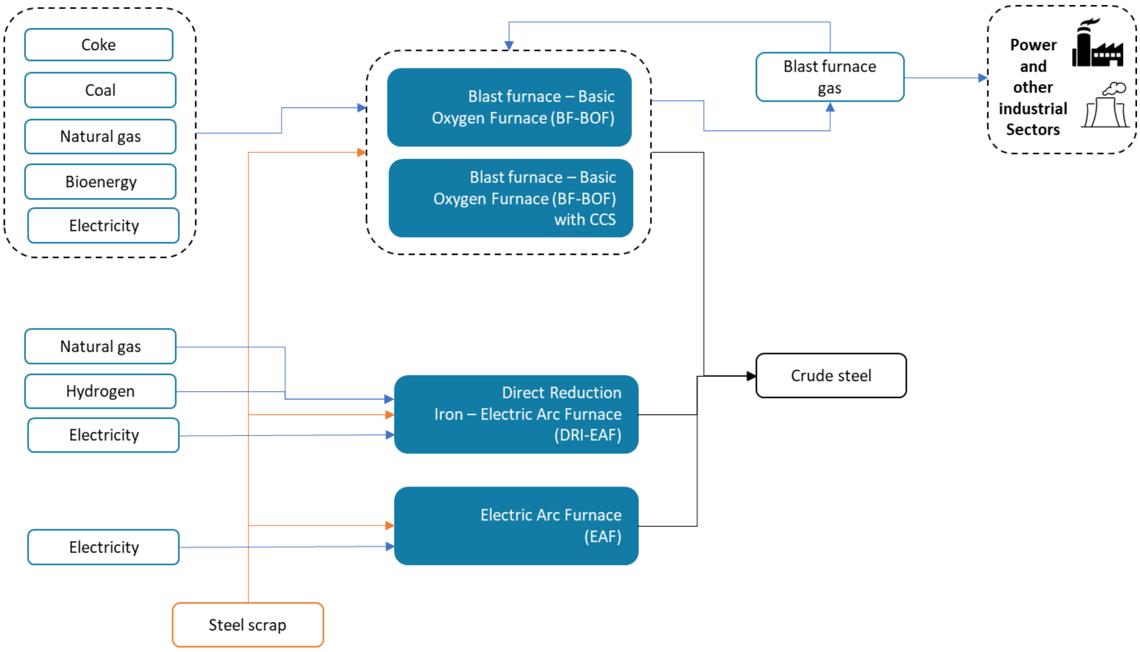

Figure 5. Steel sector representation

Key data sources are summarised in Table 5. Production statistics for the steel sector are taken from PIOLab (Wieland et al., 2022), while energy benchmarks are primarily sourced from the IEA (IEA, 2020). Technology cost estimates are sourced from a range of literature where we can determine individual cost components(Fischedick, Marzinkowski, Winzer, & Weigel, 2014)(van Sluisveld, de Boer, Daioglou, Hof, & van Vuuren, 2021; Vogl, Åhman, & Nilsson, 2018). Costs do not change over time but are rather estimates of fully commercialised production pathways; learning effects are applied as per the approach in (Steve Pye et al., 2022).

Table 5. Key data sources for the steel sector

Dataset	Source
Production statistics	PIOLab (Wieland et al., 2022)
Energy benchmarks	IEA (IEA, 2020)
Technology cost estimates	(Fischedick et al., 2014; van Sluisveld et al., 2021; Vogl et al., 2018)
Learning effects	(Steve Pye et al., 2022)

Cement and non-metallic minerals

The cement sector is disaggregated from the non-metallic minerals sector and modelled to represent two key parts of the cement production process: clinker production in rotary kilns (based on wet and dry kiln technology), and cement production, involving the mixing of clinker with other aggregates. From an emissions perspective the clinker production is the dominant emission source, producing both process and combustion related CO2 emissions. Process emissions are generated via the calcination process, where calcium carbonates are decomposed into calcium oxides, lime and CO_2 by the addition of heat. Combustion emissions come from the use of fossil fuels necessary to generate the significant energy required to heat the raw materials (limestone aluminosilicate clay) to well over 1000 °C. The clinker is cooled down and then mixed with gypsum. The mixture is finally milled into a fine powder to produce cement.

The structure of the cement sector is shown in Figure 6 below. The structure features the current stock of dry and wet kiln technologies, and investment options that include more efficient kilns and those with CCS. The grinding process also has the option to use lower clinker blends, to produce low clinker cement. Differences in clinker-cement ratios between regions are captured to reflect current production practices.

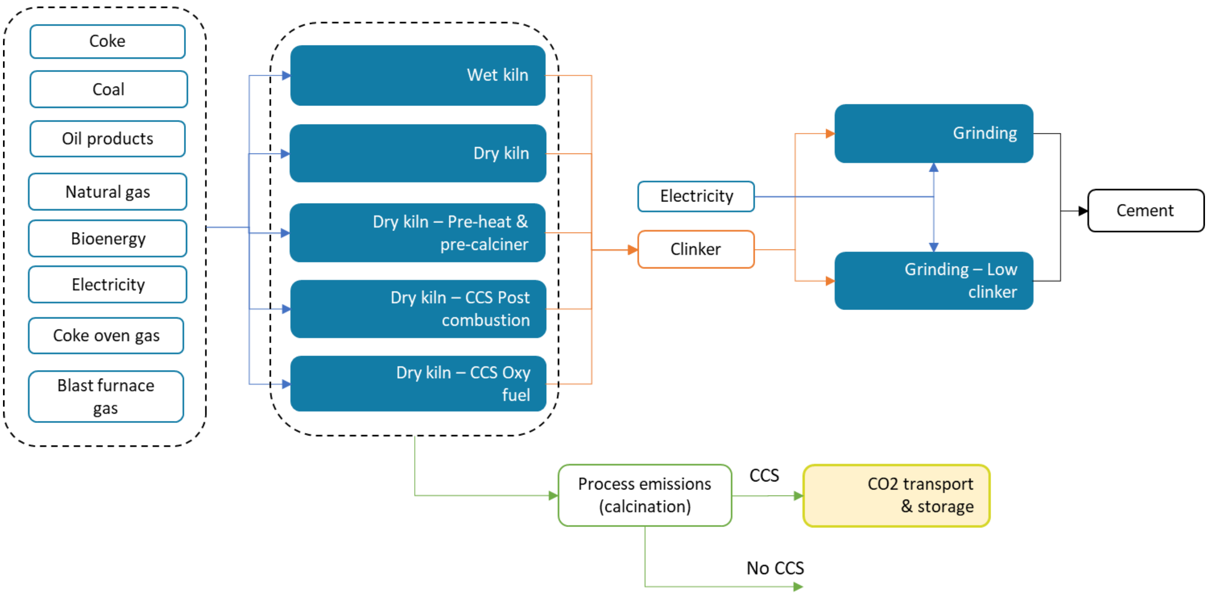

Figure 6. Cement sector representation

Key data sources for the cement sector are provided in Table 6 below.

Table 6. Key data sources for the cement sector

Dataset	Description	Source
Production statistics	Cement and clinker production by country, 2000-2023	GCP-CEM - The Global Carbon Project CEMent-process emissions dataset (Andrew, 2019)
Process emissions (from clinker production)	Process emissions, 2000-2023	GCP-CEM - The Global Carbon Project CEMent-process emissions dataset (Andrew, 2019)
Energy per tonne produced benchmarks	Data metric provided directly by GCCA, based on their GNR project. Only selection of countries provided.	Getting the Numbers Right (Global Cement and Concrete Association) (GCCA, 2024) IEA roadmap (IEA, 2018b)
Technology costs	Current and future technology cost estimates	(Lerede, Bustreo, Gracceva, Saccone, & Savoldi, 2021)

1.2.2.4 Residential and services

In OMNIA, the global residential and service sectors are comprehensively modelled across all 28 OMNIA regions, offering a more spatially detailed and technology-rich representation than in the original TIMES-GEO model.

The residential sector features twelve energy commodities, including electricity, fossil fuels, district heating, and renewable sources such as geothermal and concentrated solar power (CSP), which are consumed across six key end uses: thermal uses, air conditioning, cooking, lighting, electric appliances, and "other uses". To represent the difference of energy consumption patterns in high geospatial energy intensity zones, which represent high density urban, versus low intensity residential zones, the 28 OMNIA regions were further disaggregated. Specifically, each region was split into high and low thermal intensity thermal zones for thermal and cooling energy uses, resulting in a total of 56 sub-regional zones. This zonal distinction allows the model to reflect variations in heating and cooling demand due to spatial, climatic and socioeconomic differences among the OMNIA regions. Overall, the residential sector end uses represented are the following (Figure 7):

1. Thermal uses for high (THH) and low (THL) thermal intensity zones
2. Air conditioning for high (ACH) and low (ACL) thermal intensity zones
3. Cooking (CK), lighting (LIG), electric appliances (EAP), and other uses (OTH)

The service sector is also modelled across the 28 OMNIA regions using the same set of twelve fuel types and a parallel set of end uses: thermal uses, air conditioning, cooking, lighting, electric appliances, street lighting, and other uses. Unlike the residential sector, however, the service sector has not been further zonally disaggregated nor recently enhanced beyond the original TIMES-GEO structure. Despite this, it remains fully integrated into OMNIA's broader energy system, ensuring consistency in cross-sectoral energy analysis and enabling scenario comparisons that involve both household and commercial energy demands.

Residential energy demand is modelled as a consumption sector where household technologies act as processes that convert energy into useful services such as space heating, space cooling, water heating, cooking, and lighting. The model incorporates the following processes corresponding to their respective service demands (Figure 8):

4. Thermal uses (TH)
5. Air conditioning (AC)

6. Cooking (CK), lighting (LIG), street lighting (SLIG), electric appliances (EAP), and other uses (OTH)

The residential and service's demands are measured in [PJ] for all end uses except for lighting that is measured in [M units].

Together, the residential and service sector representations in OMNIA provide a high level of spatial, temporal, and technological granularity, supporting robust scenario analysis for global energy transitions. These improvements enable OMNIA to capture a wide range of energy consumption behaviours, infrastructure constraints, and regional decarbonisation pathways across building-related sectors.

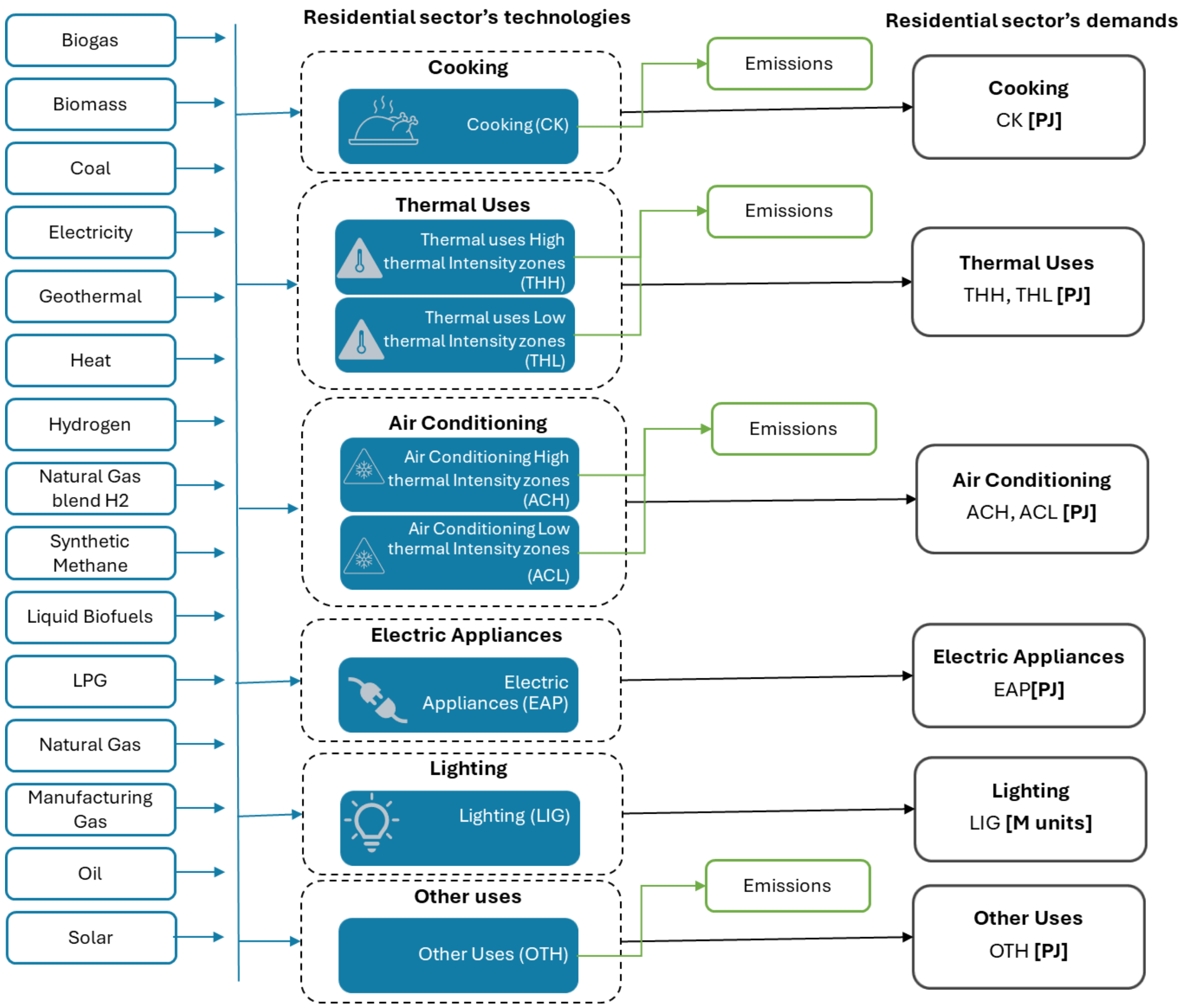

Figure 7. Residential Sector representation

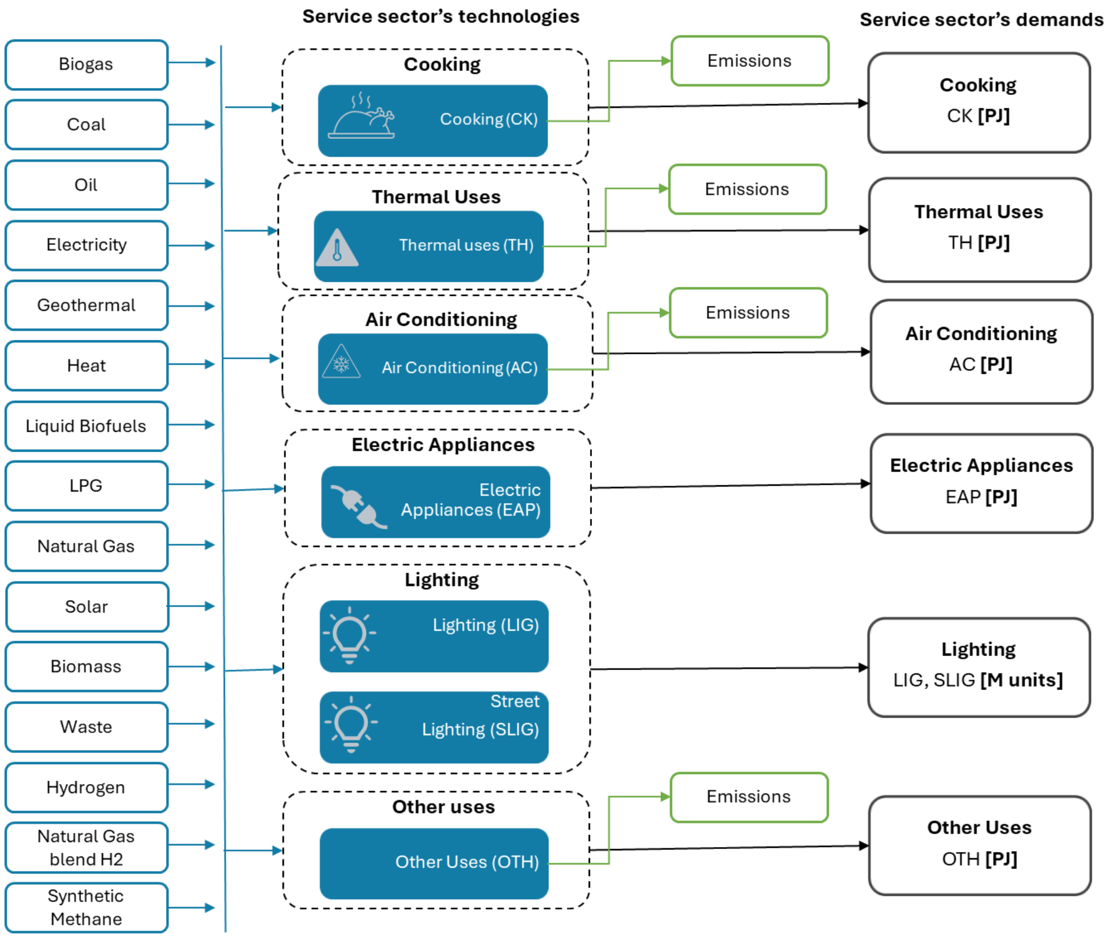

Figure 8. Service sector representation

Key improvements in the residential sector

Each OMNIA region was divided into two zones based on energy intensity, the high-intensity and low-intensity zones, driven by thermal demands. This segmentation allows for more accurate modelling of heating and cooling needs in regions with different energy consumption profiles. The division was performed based on spatiotemporal energy consumption simulation data across the countries of the world (Sachs, Moya, Giarola, & Hawkes et al., 2019)(Sachs, Moya, Giarola, & Hawkes et al., 2019). Moreover, to improve the level of modelling detail, temporal profiles for heating and cooling demands were generated based on OMNIA's time slices, offering detailed insights into hourly and seasonal behaviours for heating and cooling across the two intensity zones within each region (Sachs *et al.*, 2019). Each region and zone has distinct heating and cooling profiles, which vary across seasons and affect fuel consumption for end uses. These profiles consider demand changes within each season. This data is used as input to the model, enhancing its precision and accounting for demands shifts.

Base year design and future residential and service technologies

The residential sector's model includes key end-use technologies representative of the residential sector's processes. The base year and future residential technologies for the residential sector in the OMNIA model are presented in Figure 9. The model includes 34 existing (ordinary) technologies for the base year 2019, disaggregated by end use: thermal uses, air conditioning, cooking, electric appliances, lighting, and other uses.

To simulate technological changes in the future, OMNIA's residential sector includes 114 future technologies, categorised as ordinary, improved, and advanced variants of the base-year technologies. Among the thermal technologies for the high intensity thermal zones district heating is also included, since the high intensity thermal zones represent high populated urban areas where district heating could be a likely scenario. Therefore, four extra thermal technologies for the high Intensity zones were introduced to the model to account for the use of district heating in high energy intensity zones. This framework allows the OMNIA model to represent the residential sector's energy demand with high spatial, temporal, and technological granularity, aiding in understanding energy consumption patterns and potential efficiency improvements.

The base year and future technologies for the service sector respectively are presented in Figure 10. The model includes 23 existing (ordinary) technologies for the base year 2019, covering the main end uses: thermal uses, air conditioning, cooking, lighting, electric appliances, street lighting, and other uses. These technologies reflect energy use across multiple fuel types, including electricity, fossil fuels, and renewables. The model also includes 35 future technologies for the service sector that represent improved and advanced versions of the base-year technologies, supporting transitions to more efficient and low-emission systems.

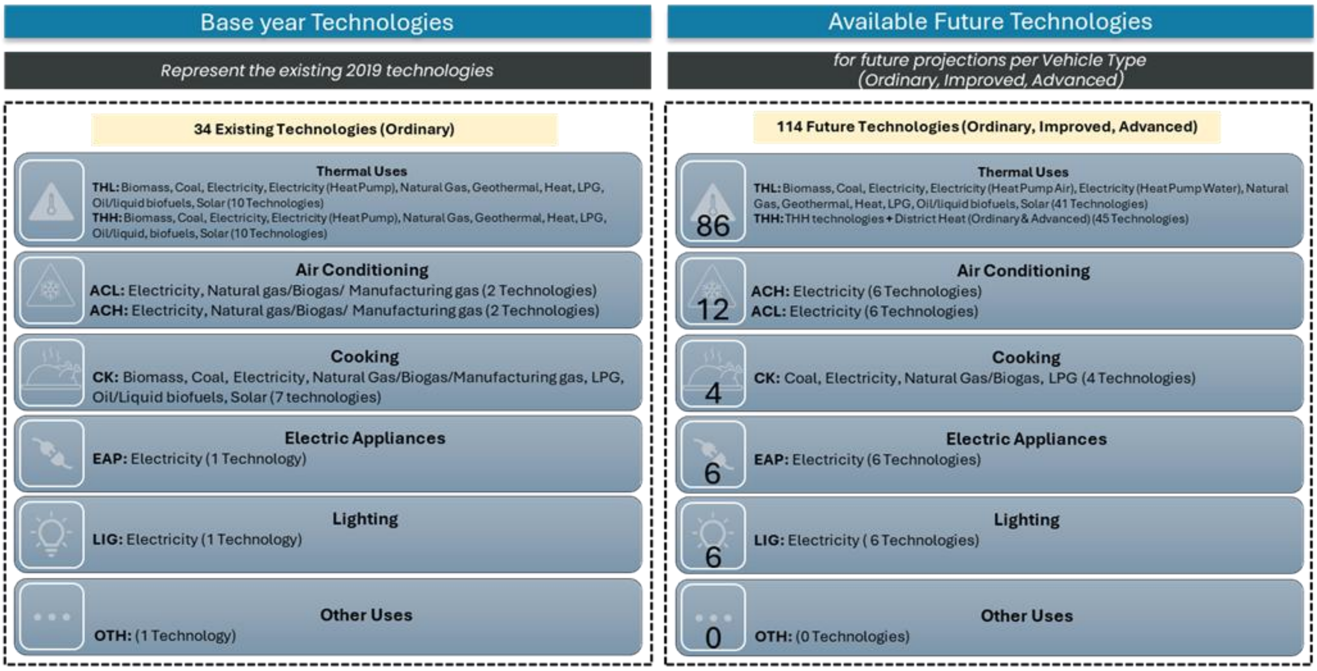

Figure 9. Base year and future available residential sector's technologies

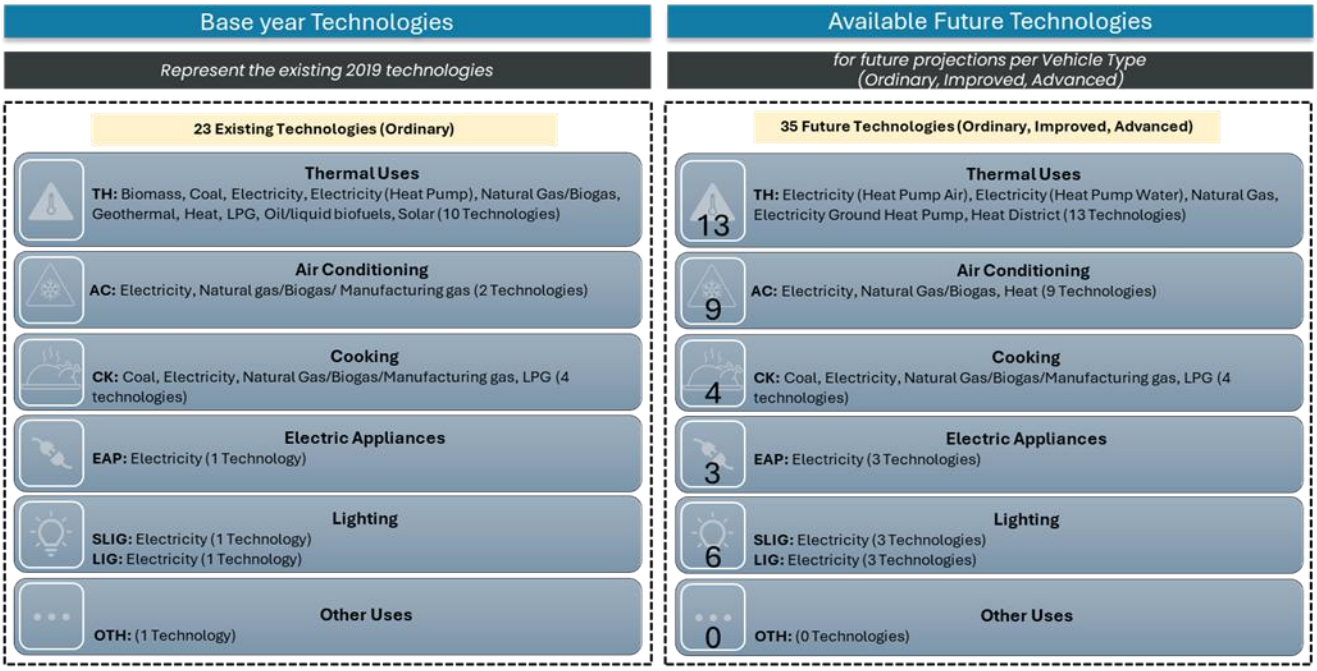

Figure 10. Base year and future available service sector's technologies

1.2.2.5 Transport

In OMNIA the global transport sector is modelled across the 28 OMNIA regions, offering an improved disaggregated and technology-rich transport system compared to the TIMES GEO model. The model captures both passenger and freight transport across all modes, using 2019 fleet stock data for the base year. The sector's technology rich model allows for long-term simulation of fuel switching, and energy efficiency improvements.

Specifically, the global energy consumption for transport has 11 energy commodities, including both fossil and renewable fuels, and is mapped by transport mode (road, rail, aviation, navigation). Transport services are modelled as a consumption sector, with transport vehicles acting as processes that convert energy into transport services. The model includes the following processes corresponding to their respective transport modes (Figures 11 and 12):

7. **Road:** Cars, buses, motorbikes, LCVs, medium and heavy trucks.
8. **Rail:** Passenger, freight, and high-speed electric.
9. **Aviation:** Disaggregated into domestic/international and further into short/long flights.
10. **Navigation:** Disaggregated into domestic/international and further into short/long freight trips and passenger trips.

Then, the transport service demand, was expressed in mode-specific service units, i.e., [Bvkm/PJ] for road transport, and for non-road transport, [Bpkm/PJ] for passenger transportation, and [Btkm/PJ] for freight transportation respectively. Within this framework, Figure 11 represents the road transport sector and Figure 12 the non-road transport sector (Rail, Aviation, Navigation), with their respective processes and service demand units.

Key Improvements in transport and data inputs

The key improvements made in the representation of the transport sector of OMNIA on top of the TIME-GEO transport sector are as follows:

1) Type of transport vehicle Breakdown by Fuel: The share of energy consumption for different types of vehicles (e.g., cars, buses etc) by fuel type was detailed according to modeler sense/assumptions, the TIMES-GEO workbook of the transport sector (VT_GEO_TRA), and by using of a chart that presents the shares of different transport types for different cities worldwide (MobiliseYourCity Secretariat, 2022)(MobiliseYourCity Secretariat, 2022).

2) Technologies for Aviation and Shipping: 2020 EU Reference scenario data were used to provide the technoeconomic values for aviation and shipping including future fuels. For the fuels that didn't exist in the database assumptions were made (European Commission, 2021)(European Commission, 2021).

3) Share of long and short trips and passenger navigation for domestic and banker: Another improvement made is that navigation is now split in short and long trips and passenger trips for both domestic and international navigation. This is because, the use of electric shipping technology is most likely to be used for smaller ships and shorter trips, and domestic passenger trips. Data from the IMO (International Marine Organisation) report for the year 2019 provided the shares of the global share between long trips with large ships, short trips with small ships, and passenger trips which were used together with assumptions, to create the energy consumption shares between different types of shipping globally (IMO Data Collection System, 2019)(IMO Data Collection System, 2019).

4) Short and long flights: Aviation was also split into domestic and international flights drawing data from the energy balance of UN. Aviation was further disaggregated into long and short flights for both domestic and international flights to allow the model to choose technologies in a disaggregated way. This was done to allow the model to leverage the potential use of different technologies depending on whether the flight is short (<500 km) or long (>500. For example, long flights are unlikely to be fully battery electric, or hydrogen-based, whereas short flight can be (OpenFlights Database, 2014)(OpenFlights Database, 2014).

5) High Speed Electric Rail: High speed rail was included in the model, to account for the efficiency differentiation of the sector. Logical assumptions were made for the share of high speed electric trains in the whole fleet. Then, the technoeconomic values of high-speed rail was introduced in the model (European Commission, 2021)(European Commission, 2021).

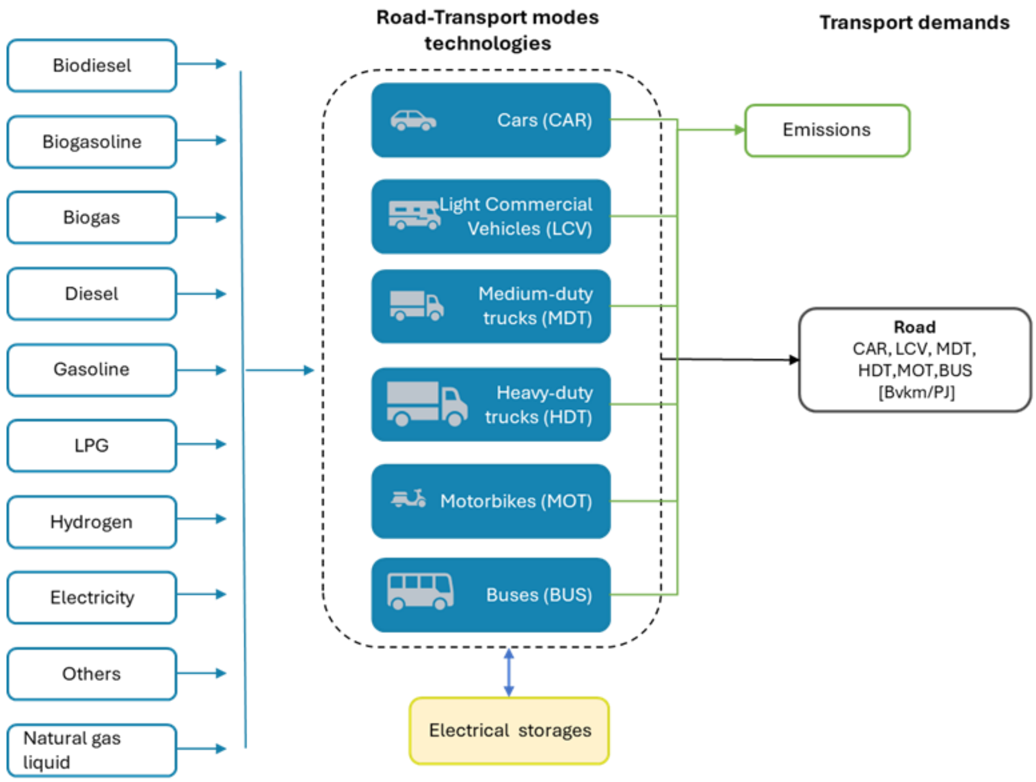

Figure 11. Road technologies representation in transport sector

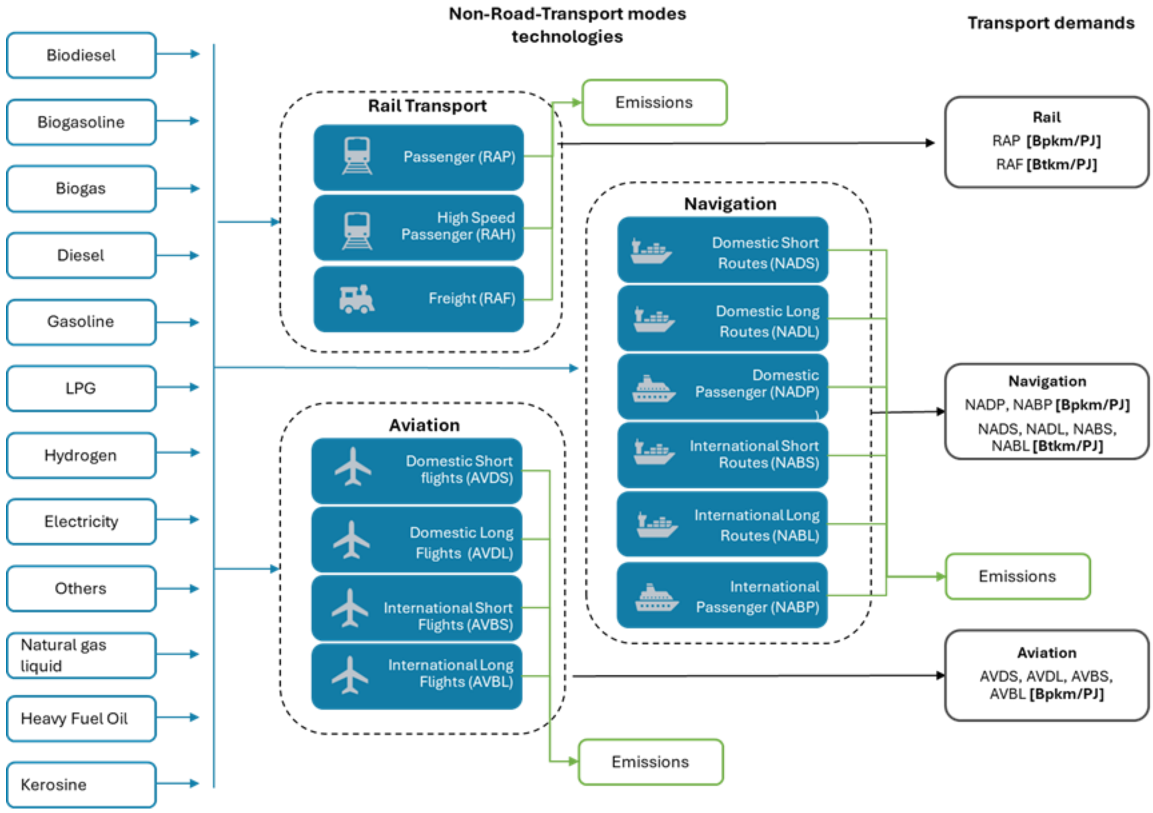

Figure 12. Non-road technologies representation in transport sector.

Base Year and Future Technologies Transport

The transport sector's model includes key end-use technologies representative of the transport sector's processes. The base year and future transport technologies of the OMNIA model are presented in Figures 13 and 14 respectively. The model includes 101 existing (ordinary) technologies for the base year 2019, disaggregated by mode and vehicle type across road, rail, aviation, and navigation. These technologies reflect the use of conventional fuels such as gasoline, diesel, LPG, natural gas, and electric power, as well as hybrid technologies.

To capture technological evolution, OMNIA's transport sector is rich in future technologies enabling the model to choose across multiple decarbonisation pathways. A total of 281 future technologies is defined for scenario projections as presented in Figure 14. These include ordinary, improved, and advanced variants of base-year technologies with the addition of hydrogen, electric technologies for all transport modes. This comprehensive technology database enables the TIMES-VEDA framework to simulate long-term decarbonisation, fuel switching, and efficiency improvements in the global transport sector.

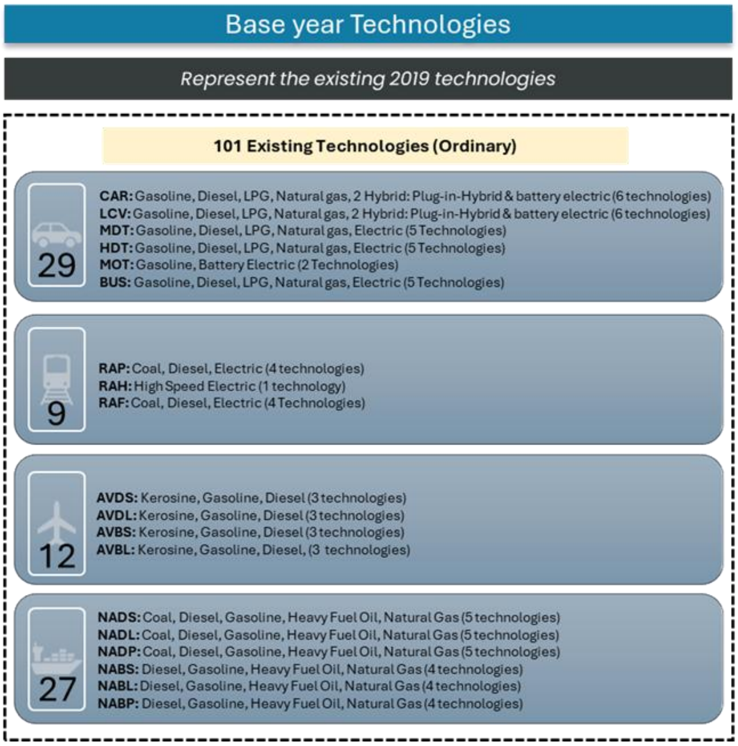

Figure 13. Base year technologies for the transport sector.

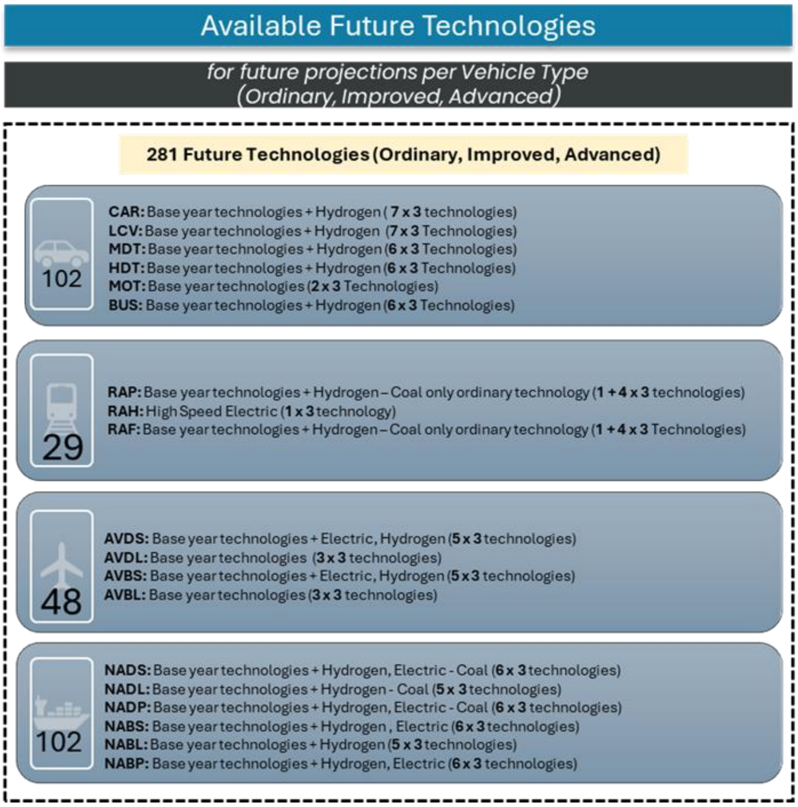

Figure 14. Available future technologies for transport sector

1.2.2.6 Agriculture

This sector focuses on agricultural processes, notably encompassing the energy consumption and produced emissions related to agriculture, forestry and fishing activities, such as from stationary plants, off-road vehicles, and machinery used in the sector. This module does not cover the activities related to the production of agricultural fertilisers, which are part of the industry mode (and specifically the chemical industry). Moreover, this sector does not include activities related to land management, conservation and ecosystem, which are considered part of the Agriculture, Forestry and Other Land Uses (AFOLU) sector, not covered in OMNIA.

This sector is represented with an **aggregated approach**. In this approach, a generic technology covers all the energy flows in the sector to deliver the agricultural energy demand (Figure 15). From a mitigation perspective of the sector, along the time horizon, the main key lever is fuel switching to alternative or renewable fuels. Data needed in this sector is presented in the table below.

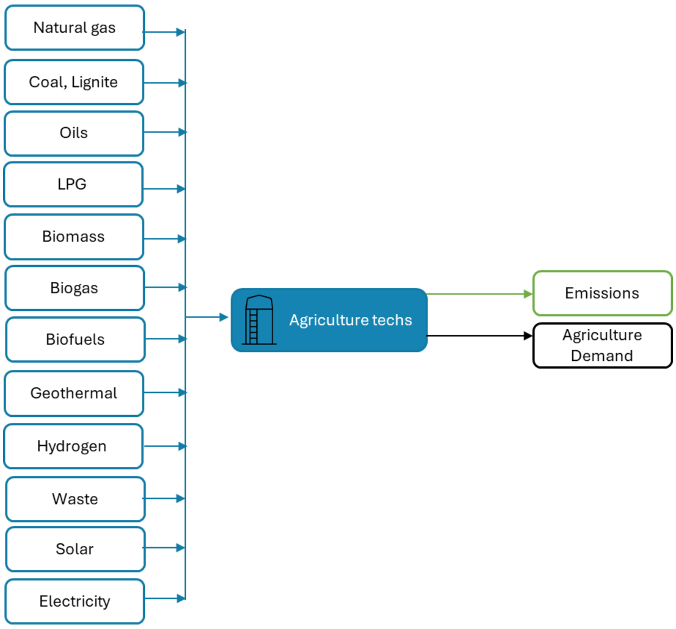

Figure 15. Agriculture sector representation

Table 7. Key data source for the agriculture sector

Description	Source
Energy consumptions	UN Energy Balance (United Nations (a), 2025)(United Nations (a), 2025), UN Energy Statistics (United Nations (b), 2025)(United Nations (b), 2025)

1.2.3 Soft-links with other models and other novelties

1.2.3.1 Approach for updated demand projections

A standardised approach in demand projections for use in energy system models is to exogenously impose demand drivers obtained from other models (e.g., GEM-E3 (JRC, 2025), MSA (Kypreos & Lehtila, 2014)) or from reputable sources (O'Neill et al., 2017). Typical drivers include projections for population, GDP, GDP per capita, number of households, and sectoral outputs (Loulou, Goldstein, Kanudia, Lettila, & Remme, 2016).

The reference demand scenario is built by choosing elasticities of demands to their respective driver, for each region of the model. For example, in TIAM-UCL (S. Pye et al., 2020), each energy service demand (ESD) is projected from 2005 to 2100 based on the general expression:

$$ESD_t = ESD_{t-1}\left(\frac{X_t}{X_{t-1}}\right)^{\alpha_t}$$

Where α is the elasticity linking driver X to the ESD, that allows to adjust the strength of the relationship between the two. For alternate scenarios, the response of demands to changing conditions can be adjusted through elasticities.

In OMNIA, we aim to reduce the reliance on single variable elasticity, often based on historical data or modellers assumptions, by further unpacking demand drivers and introducing sectoral-specific ones. The general expression adopted is the following:

$$ESD_t = ESD_0 \left(\frac{X_{1,t}}{X_{1,0}}\right)^{\alpha_1} \cdot \left(\frac{X_{2,t}}{X_{2,0}}\right)^{\alpha_2} \cdot \ldots \cdot \left(\frac{X_{N,t}}{X_{N,0}}\right)^{\alpha_N} + \beta$$

The total number of drivers N depends on the specific driver considered. The parameters α and β still allow some freedom to decouple the demand projection from the driver. However, by using multiple drivers, we aim to reduce the reliance on expert evaluation and introduce a direct linkage to the relevant drivers.

Drivers can be grouped in two categories:

11. *Primary drivers* represent the impacts of socio-economic development on end-use demand and include population, GDP, and GDP per capita. Primary drivers are defined per country and aggregated at regional level, and represent the basis for building demand projections, for example based on SSP scenarios.
12. *Intermediate levers* are used to provide additional flexibility and adjust the demand to reflect the impacts of sector-specific, service-oriented drivers (e.g., heating or cooling degree days, floor space per capita) while maintaining consistency with primary drivers. Future projections of intermediate levers vary depending on factors such as geographic location, economic development, population density. Intermediate levers can be estimated based on historical development trends or obtained from other sectoral-specific studies

Finally, for specific subsectors energy service demands can be obtained through a detailed modelling approach to improve the projection accuracy.

Primary drivers

Projections for primary drivers are based on the recommendations of WP3 Data Harmonisation Protocol (see D3.2). Drivers considered are population, GDP and GDP per capita. Table 8 summarises the data sources used. Growth rates are computed for the relevant OMNIA regions and set of years. As the IIASA dataset SSP Basic drivers v3.1 does not have data for Venezuela's GDP, data is obtained from the GCAM model projections.

Table 8. Data sources for primary drivers

Dataset	Description
SSP Basic drivers v3.1 (IIASA, n.d.-a, n.d.-b)	Historical data (1950/1980-2020) plus SSPs projections (2025-2100) for: 1) Population 2) GDP PPP 3) Urbanisation rates
IMF WEO (10/2024) (International Monetary Fund, 2024)	Historical data and short-term GDP growth projections (1980-2029)
GCAM	GDP projections for Venezuela

Intermediate drivers

Intermediate drivers are defined per each sector and are based on various sources. A summary of the drivers considered in the first version of the model, with some additional detail, is provided in Table 9. Both the residential and commercial sectors use heating degree days (HDD) and cooling degree days (CDD) to project heating and cooling demand. CDD are also used to estimate project AC penetration rates, also included as an additional driver. Similarly, the penetration rate of electrical appliances is considered in the residential sector, as well as floor area per capita. Specific demand projections are considered for the steel and aluminium sectors, based on global scenarios defined in the literature, as in the case of the aviation sector, where data from the NAVIGATE project has been adapted to OMNIA's regions. Finally, we use IEA data to project the share between public and private road transport shares.

Table 9. Intermediate drivers list with brief description and data sources

Driver	Description	Sectors
Floor area per capita	(Zhang et al., 2024) defines three scenarios, based on different levels of renovation	Residential
HDD and CDD	Based on CICERO's METEOR model (Sanderson, Sandstad, & normansteinert, 2025)	Residential, commercial
AC penetration	Logit function based on income. Different function per average CDD in each region. Based on data from (Colelli, Wing, & Cian, 2023; IEA, 2018c)	Residential, commercial
Electrical appliances penetration	Modelled diffusion of main electrical appliances in the residential sector (McNeil & Letschert, 2010).	Residential
Steel demand	Based on scenarios outlined in (Steve Pye et al., 2022)	Industry
Aluminium demand	Based on global scenarios from the Internal Aluminium Institute (International Aluminium Institute, 2021)	Industry
Aviation	Domestic and international projections based on modelling from the NAVIGATE project (Dray et al., 2019)	Transport
Road transport share	Private/public road mode of transport based on data from IEA MoMo (IEA, 2018a)	Transport

1.2.3.2 Water module

A simple water module is included in OMNIA through a soft link with MAgPIE, providing water consumed in the agriculture and livestock sector. Water consumed in the agriculture and livestock sector depends on the food demand which is calculated using socio-economic indicators and share of the population with different per capita kcal requirements based on body mass index. The water module includes supply of water from different sources: fresh water, saline water and ground water. Fresh surface water is obtained from rivers, lakes, and other natural bodies of water, while groundwater is sourced from underground aquifers. In areas facing a scarcity of freshwater or groundwater resources, seawater can be converted into fresh water through desalination processes. This method is crucial for ensuring a steady supply of potable water, particularly in arid regions or those with limited access to freshwater sources.

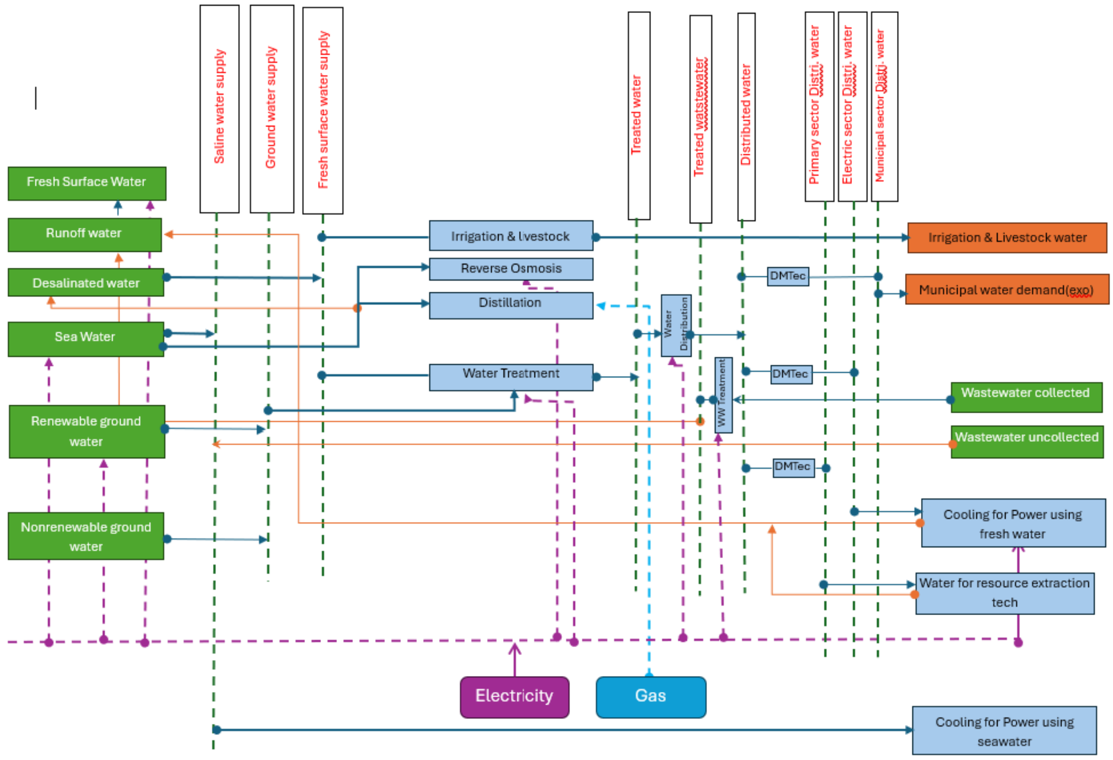

Figure 16. Water module design

We consider four distinct categories of water demand in this water module:

I. Irrigation and Livestock Water Demand: This category encompasses the water required for agricultural irrigation and livestock.
II. Municipal Water Demand: This involves water consumption for residential, commercial, and industrial use within urban areas.
III. Water Demand for Primary Energy Extraction: This includes the water needed for processes related to the extraction of energy resources, such as oil and gas.
IV. Water Demand for Cooling in the Power Sector: This pertains to the water used for cooling in thermal power plants, which is essential for maintaining operational efficiency.

Water used in the industrial sector (outside energy extraction) is not included in this version. Integration may be considered in future versions of the model if it is deemed necessary for addressing research questions in this project. Water trade is also not represented in this module. The water resource available in each region is taken from MAgPIE to maintain the consistency between the two models, while municipal water demand is calculated based on socioeconomic indicators such as GDP, urbanisation and population using the equation used in (Hejazi, Edmonds, Chaturvedi, Davies, & Eom, 2013)(Hejazi, Edmonds, Chaturvedi, Davies, & Eom, 2013). Demand in the power sector is intricately linked to the amount of power generated and the efficiency of the cooling equipment utilised. Consequently, an increase in power output typically results in a corresponding increase in cooling water demand. Similarly, the mining sector's water requirements are directly related to its production levels, highlighting the interdependence between water and resource extraction processes.

Freshwater undergoes a comprehensive treatment process before it is distributed for various uses, including residential, commercial, and industrial applications, each of which demands a significant amount of energy. The energy requirements for municipal water treatment vary based on several factors, including the source of the water—whether it's drawn from rivers, lakes, or underground aquifers—the specific methods employed for purification, and the unique local environmental conditions. Once used, wastewater is collected and subjected to rigorous treatment processes to ensure it meets safety standards before being released back into natural water bodies. While some of this treated wastewater can be recycled for further use, the recycling component is not addressed in the current water module. Energy used for water extraction, treatment and distribution is linked with the energy inputs in the energy module of the OMINA model. The energy use factors are generally obtained from the latest peer-reviewed publications.

1.2.3.3 Industrial sector circular economy

Most IAMs lack detailed representations of material flows across supply chains and product lifecycles. This limits their ability to capture the effects that circular economy strategies (e.g., reuse and recycling of materials) may have on commodity demands and decarbonisation strategies.

To address this, we establish a linkage between OMNIA and ENGAGE. OMNIA provides a detailed representation of industrial technologies and their energy consumption, while ENGAGE represents economy-wide trade and material flows from resource extraction to recycling. Linking the two models enables a more complete assessment of how circular economy policies could affect emissions, energy demand, and economic activities across sectors and regions. Details can be found in D4.1. Here we summarise the core process.

The linkage is bidirectional and iterative. OMNIA passes the energy system configuration and mitigation pathways to ENGAGE, which in turn adjusts upstream and downstream markets to reach economic equilibrium. These changes, for example in material demand and GDP (calculated endogenously in ENGAGE), are fed back into OMNIA to refine the energy service demand and regional production. Figure 17 summarises the conceptual flow of information between the two models. The process is iterated until convergence. The stopping criteria will be case specific and will require an *ad hoc* tuning process. In any case, due to time constraints, the linkage will be constrained to either 5 iterations or to a threshold value of less than 5% change in the energy system and demand generator after n iterations.

At the core of the linkage are shared assumptions that are exogenously imposed on both models, i.e. socioeconomic pathways, technology costs and efficiencies, climate policies (i.e., carbon pricing), and material demand and stock dynamics, ensuring consistency across models on key scenarios assumptions.

The linkage enables OMNIA to assess the implications of different decarbonisation pathways and net-zero targets in an integrated framework alongside circular economy policies, helping to identify synergies, trade-offs, and rebound effects from an economy-wide perspective. At the same time, it allows ENGAGE to incorporate detailed energy system dynamics into macroeconomic analysis, supporting a more comprehensive evaluation of how decarbonisation and circular economy strategies affect economic performance, sectoral transitions, trade, and regional welfare. This modelling framework supports the assessment of policies such as recycled content mandates, incentives for scrap-based production, material efficiency improvements, and trade restrictions to promote local reuse. It can also be applied to analyse alternative climate scenarios, including those consistent with 2°C or 1.5°C targets, as well as pathways involving temperature overshoot.

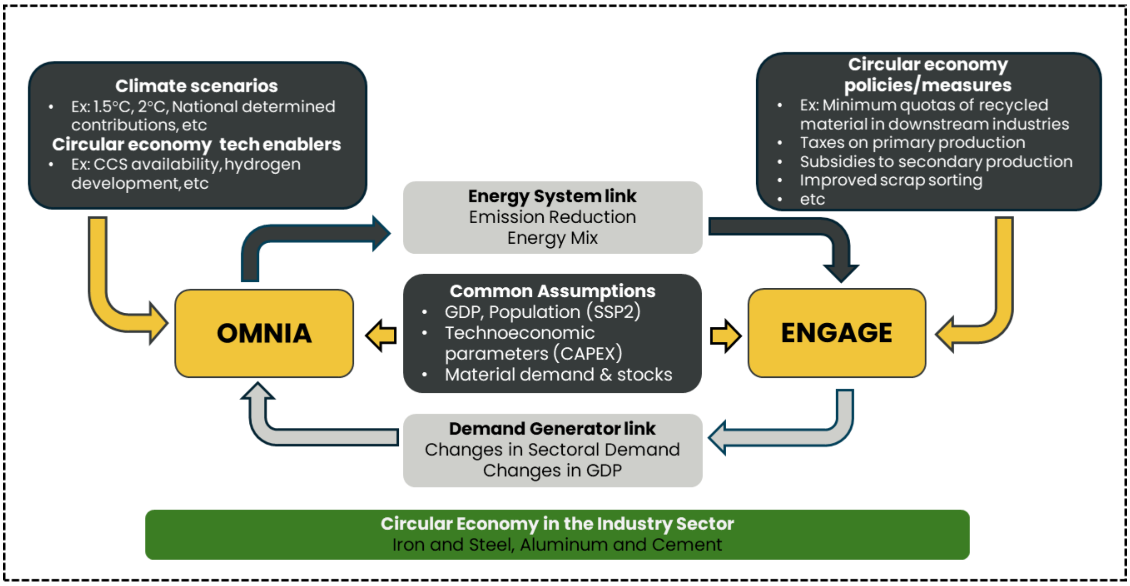

Figure 17. Diagram of the conceptual linkage and information flow between ENGAGE and OMNIA.

1.2.3.4 Interaction between energy system and land-use

The link between OMNIA and MAgPIE focuses on two critical interactions, see Figure 18:

i. Bioenergy demand and supply,

ii. Land Use and Land Use Change GHG emissions and GHG prices.

OMNIA provides MAgPIE with the level of biomass and bioenergy demand and CO_2 prices under different scenarios of socio-economic and global temperature evolution, while MAgPIE provides the costs and related GHG emissions when producing the requested amount of bioenergy under the same socio-economic and global temperature scenarios.

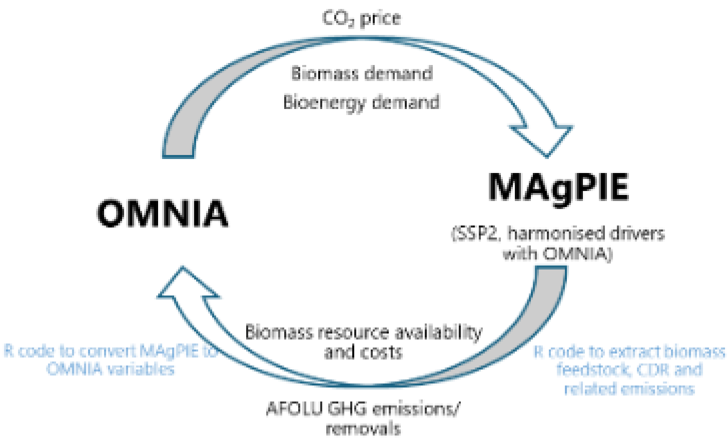

Figure 18. Soft-linking between OMNIA and MAgPIE. OMNIA provides MAgPIE with the level of biomass and bioenergy demand and CO2 prices, while MAgPIE provides costs and related GHG emissions when producing the requested amount of bioenergy under the same socio-eco.

Biomass as feedstock (primary energy) is composed of energy crops (crops purposely cultivated for energy), food crops (which provide 1st generation biofuels, e.g., ethanol), and solid biomass (encompassing agricultural and forest residues). Biomass feedstock is then converted to different forms of energy, which are then utilised in diverse end-use sectors. MAgPIE provides OMNIA with different types of biomass, along with the associated prices, hence enhancing the level of detail for each type of biomass represented in **Error! Reference source not found.** below. The data collected from MAgPIE on the variables of interest includes amount (EJ/yr), cost (US$2017/EJ), and emissions (Mt CO_2/yr). Note that the emissions are to be exported per sector overall, i.e., land-use or agriculture, rather than per individual crop.

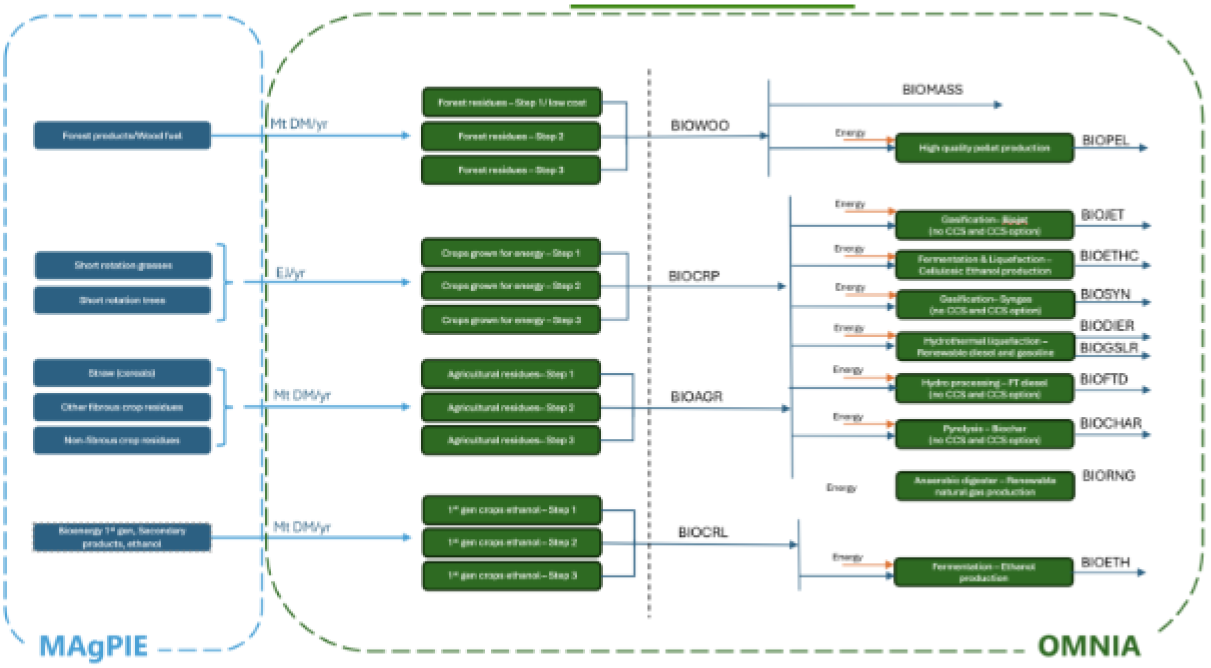

Figure 19 Detailed representation of the MAgPIE to OMNIA mapping, including the different types of biomass and bioenergy and associated costs. For instance, 'agricultural residues' in OMNIA come from three different types of crop residues in MAgPIE, i.e. cereal straw, rice husks (fibrous residues) and other crop residues (non-fibrous residues).

1.2.3.5 Physical climate impacts

OMNIA can be soft-linked with a climate impact model, METEOR, developed under the DIAMOND EU-project by CICERO. OMNIA can deliver the GHG emissions (CO_2, CH_4 and SO_2, NO_2) to the SILICONE model (internal to CICERO) used to estimate the remaining emission gases. Once all emissions' trajectories for a given scenario are estimated, they will be inputted into the METEOR climate model to estimate spatially resolved physical variables like temperature and precipitation, and these physical variables can be included in the damage function. The soft-link allows assessing changes in heating and cooling demand, land crop yields, and other climate change-related impacts.

The variation in heating and cooling degree days can be inputted into OMNIA in the residential sector to develop scenarios that consider regional climate impacts. Variation on crop yields can be input in MagPie and indirectly impact the bioenergy supply availability.

1.2.3.6 Behavioural changes impact

OMNIA can be soft-linked with a behavioural change model developed by UNIBAS (Universitat Basel). The university is going to develop a specific module on behavioural changes under the DIAMOND EU-project to be linked to several IAMs. The soft-link covers the following aspects:

- Adoption of insulation in households

- BEVs adoption.

The UNIBAS module will provide as outputs the societal groups more prone to these two behaviours. These outputs will be converted into the share of the population that is willing to adopt house insulation and EVs and will be integrated into OMNIA demand drivers, and into market shares for electric vehicles adoption, which will be integrated into OMNIA transport constraints.

1.2.3.7 Power infrastructure investments in Europe

OMNIA can be soft-linked with openTEPES model, a decision support model for defining the integrated generation, storage, and transmission expansion plan of an electric system (more information here, OpenTepes). The soft-link covers the following aspects:

- Electricity corridors in Europe: openTepes provides information about the electricity infrastructure costs and the cross-border country electricity flows for a specific target year. The values can be provided for the European regions in OMNIA and the neighbouring regions connected to Europe. This information can be implemented in the OMNIA model by modifying the trade parameters for specific regions or used as a benchmark of OMNIA model results.

1.3 Model Manual

1.3.1 Software and hardware requirements

1.3.1.1 Software requirements

The OMNIA model is a TIMES model generator; the TIMES source code is available under a GNU GENERAL PUBLIC LICENSE v. 3.0 and can be accessed directly from Github and Zenodo. TIMES uses a data handling system, VEDA2.0, which is a proprietary, robust model management system which handles all aspects of working with TIMES. A fully functional 60-day evaluation version can be provided (other information about VEDA2.0 installation is available at: VEDA Installation). In addition to VEDA2.0, TIMES models use the GAMS programming language. GAMS is proprietary software, and a valid license is required. Some purchase options for the GAMS version for TIMES and VEDA2.0 are available here. Moreover, for most of the TIMES model applications, a linear programming (LP) solver will be appropriate; more advanced features require the use of a mixed integer programming (MIP) solver or a non-linear solver (NLP). Solvers may be open source or proprietary and are either integrated as part of the GAMS system or should be capable of being called from GAMS. VEDA 2.0 supports multiple solvers; the usual solver used to run TIMES models is the proprietary solver CPLEX, but the framework also allows to run also with GUROBI (proprietary), CBC and others (free and open sources).

Finally, the OMNIA model is designed using Excel files, which VEDA uses in the background, thus, MS Office is a prerequisite software. The data input and data elaboration in OMNIA are handled directly in the Excel files or through Python scripts, information is available in each model template and additional information about data elaboration and scripts are available in the GitHub repository under the folder “Data and elaboration”.

1.3.1.2 Hardware requirements

Hardware needed depends on the size and complexity of models, but here is a configuration suitable for typical TIMES models under Veda2.0:

1. CPU: A Minimum of 4 cores is recommended for STANDARD and ADVANCED licenses. 8 - 16 would be desirable for larger models

2. RAM: 4-8 GB is enough for Veda, but GAMS needs more RAM for larger models. 32 GB would accommodate most models
3. HDD: 500GB - 1TB free space for Veda and GAMS files

1.3.2 How to run the model with VEDA 2.0

The following steps are required to run the OMNIA model on VEDA 2.0.

1. Loading the model: From the **Start Page**, load the model into the VEDA 2.0 software by clicking on the folder button and indicating the folder path where the model is located.

2. Synchronising the model: All the model files should now be listed on the Navigator page. They initially appear with an orange background. By clicking on the synchronisation button, the process should start. At the end of the process, the files' background changes to blue. Double-clicking on the file's name, the corresponding Excel workbook opens which can be modified. After every modification, it is necessary to repeat the synchronisation process. For multiple modifications, it is suggested that a synchronisation from scratch is performed by clicking the **Start from scratch** button on the top left of the Navigator page.

3. Browsing the model: Once the model is synchronised, it is possible to browse all the data loaded on the **Browse** page. This step is suggested to check if the data from the Excel workbooks is correctly loaded. VEDA will use the data displayed on this page to run the scenario.

4. Running the scenario: Modelled scenarios are solved from the Run Manager page (Figure 20). First, it is necessary to create a *Case* (in the bottom window of the page) and then create a *scenario group* by selecting only the needed files from the **Scenario Groups** window. By double-clicking on the created case, it is possible to set the preferred configuration (horizon, scenario group, etc.) before clicking on the **Solve** button. In the *Settings* window, it is possible to set the configuration of the solver and define the folder where the results will be located.

5. Visualising the results: The results of the solved cases can be navigated in the **Results** page. Tables can be manually created by selecting the preferred elements (attributes, process and commodity sets, periods, regions, etc.). Graphs can also be created to help visualise the results.

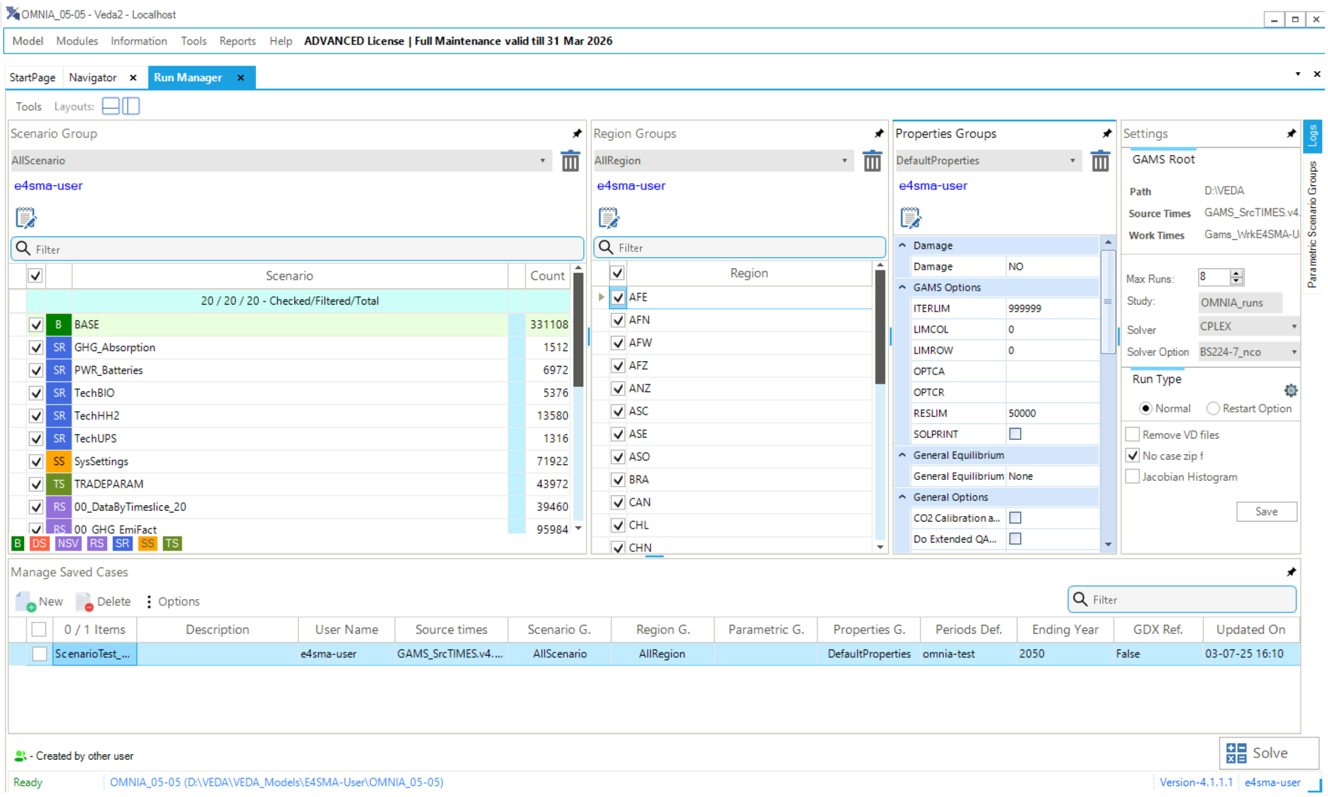

Figure 20. Example of Run Manager page in VEDA 2.0

1.3.3 Scenarios case

The OMNIA model is delivered with one modelling case scenario:

- The **Test scenario** aims to showcase the functionality of the OMNIA model. The outputs of this scenario are not intended to interpret the possible future pathway of the Global energy system, but rather to evaluate the core model functionalities.

The SuppXLS folder contains all the regular scenario files (called Scenario Files in the VEDA nomenclature) in which the inputs and assumptions for the different modelling scenarios can be managed.

These scenario files can include the definition of parameters that are necessary to run the model (**Root parameters**) or the assumptions regarding the customised scenarios (**Scenario parameters**). The files containing the Root parameters must always be selected to run the model, while the Scenario parameters can be selected according to the scenario characteristics. Scenario parameters have been added to ensure that the results of this *Test Scenario* are not solely driven by cost optimisation, which could lead to a rapid switch in technology or fuel that does not reflect realistic trends, but they do not directly represent any policy constraint scenario. All the root scenarios and all the scenario files in the folder SuppXLS are combined to build the **Test scenario**. Table 10 briefly describes each file included in the SuppXLS folder.

Table 10:. Inputs to the OMNIA modelling scenarios

File name	Description	Parameters
Scen_00_DataByTimeslice_20	This template holds assumptions regarding the timeslice definition and production and consumption intra-annual profiles.	Root

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the European Union

Scen_00_DemandProjections_SSP2	This template holds assumptions regarding the demand projections of sector end uses.	Root
Scen_00_GHG_EmiFact.xlsx	This template describes the GHG emission factors used in the model	Root
Scen_00_Potentials	This template holds assumptions regarding the renewable energy technical potentials, primary production bounds, and CO2 storage limits on the future imports and exports of energy commodities.	Root
Scen_00_PWR_CAP-Reserve	This template describes the capacity reserve in the power sector.	Root
Scen_00_PWR_CAP-Retirement	This template describes the retirement profiles of existing power technologies	Root
Scen_00_IND_Setup	This template contains the constraints (UC) controlling industry sector behaviour. Specifically, for chemicals, wood products, paper and pulp, other industries, non-energy and other uses.	Scenario
Scen_00_IND_IIS_AL_CM_INF_Setup	This template contains user constraints (UC) controlling specific industry sector behaviour. Specifically, for iron and steel, aluminium, non-ferrous metals, cement and non-metallic minerals	Scenario
Scen_00_PWR_Setup	This template contains the constraints (UC) controlling the power sector behaviour.	Scenario
Scen_00_RES_COM_Setup	This template contains the constraints (UC) controlling the residential and services sectors' behaviour.	Scenario
Scen_00_TRA_Setup	This template contains the constraints (UC) controlling the transport sector behaviour.	Scenario

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