This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No *837089*.

Topic: LC-SC3-CC-2-2018 of the Horizon 2020 work program: *Modelling in support to the transition to a Low-Carbon Energy System in Europe*

BUILDING A LOW-CARBON, CLIMATE RESILIENT FUTURE:
SECURE, CLEAN AND EFFICIENT ENERGY

Project number: *837089*

Project name: *Sustainable Energy Transitions Laboratory*

Project acronym: SENTINEL

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D8.1: Model protocol

Version: 1

Due date of deliverable: 11.2020 **Actual submission date: 25.02.2021**

Dissemination Level		
PU	Public	
CO	Confidential, only for members of the consortium (including the Commission Services)	X
EU-RES	Classified Information: RESTREINT UE (Commission Decision 2005/444/EC)	
EU-CON	Classified Information: CONFIDENTIEL UE (Commission Decision 2005/444/EC)	
EU-SEC	Classified Information: SECRET UE (Commission Decision 2005/444/EC)	

SENTINEL

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Contents

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Executive summary

The model intercomparison protocol serves to define the building blocks for a set of SENTINEL model runs (experiments). This includes a description of scenarios, shared assumptions and required inputs and outputs. The protocol is focused at key questions for European energy policy. The scenarios can also function as reference cases for other experiments looking into the impact of changes in policy, technological, economic or social circumstances.

The guiding policy questions are related to the EU 2050 Long-term strategy (European Commission, 2018a). In this strategy the EU aims to be climate-neutral by 2050, which means an economy with net-zero greenhouse gas emissions (European Commission, 2018b). To assess the impact of climate neutrality with a focus on the energy sector we have defined three scenarios:

1. The **current trends** scenario represents the current implementation of climate- and energy policies secured by the climate- and energy framework 2030. This scenario assumes that the EU does not increase ambition beyond the current 40% reduction target for 2030 relative to 1990. After 2030, it assumes equivalent mitigation effort.
2. The **climate neutrality** scenario represents implementation of the long-term climate neutrality goal by 2050 (net-zero GHG emissions by 2050) that is proposed by the EU in the Long-Term Strategy and Green Deal roadmap. In addition, the scenario also assumes that the economy-wide 2030 target to reduce total emissions by 55% relative to 1990 is achieved.
3. The **early neutrality scenario** (optional) assumes that neutrality is already achieved by 2040, in order to prevent the large-scale use of negative emissions and an increased ambition related to fair contributions calculations from the literature.

Scenarios are being developed in three rounds. Round one should give a picture of the full diversity of the participating models and includes a 'free experiment', where only economy-wide policy goals are used to calibrate future projections. These goals are different for each scenario and encompasses overall policy goals for 2030 and 2050 (see Table 1), translations to sector level goals, and policy instruments (see the protocol for details). Other model parameters do not need to be calibrated in this round. The model results will be used to determine which parameters will be fixed in the second round ('fixed experiment'), which again are input to the third round that will include 'in-depth experiments'. The current version of the protocol describes round one.

In the second and third round, model data needs to be harmonised to historical data until 2018 for electricity generation, final energy and GHG emissions for each sector. In addition,

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key parameters for projections will be fixed to ensure consistent projections and to provide an analysis of uncertainty.

Table 1 Most important calibration parameters for the three scenarios from the intercomparison protocol

	1990	2005	*Current trends*		*Climate neutrality*		Early neutrality
			2030*	2050	2030**	2050	2040
Total GHG emissions (incl. LULUCF) Mt CO_{2eq}	5413	4940	2870	1950	2435	<25	<25
Reduction 1990 (%)	---	9%	47%	64%	55%	Nearly 100	Nearly 100
Total GHG emissions (excl. LULUCF) Mt CO_{2eq}	5659	5164	3150	2130	2640	(350-500)	(350-500)
Total CO2 emissions Mt CO_{2eq}	4475	4319	<2400	< 1600	<2000	< 200	< 200

*Main instruments: ETS: -43% relative to 2005, Effort sharing: 30% relative to 2005, REN directive: 32% renewable final energy, Efficiency directive: 32.5% energy efficiency improvement.
**The values in here considered assume that the new targets, approved in September, will also apply to the UK despite having left the EU. It must be noted that the UK has recently approved more ambitious targets for 2030, comprising reductions of up to 68% in comparison with 1990 (UK Climate Change Committee, 2020).

Where more guidance is needed on calibration of parameters, we refer to the 1.5TECH scenario from the Clean Planet for All (European Commission, 2018b) and the MIX scenario from the impact assessment accompanying the 2030 Climate Target Plan (Commission, 2020a). These assessments include a detailed description of current trends and climate neutrality scenarios, including results for many variables. These results can be used in the first round to calibrate future scenario projections.

The focus of the scenario protocol is on the EU level, but model results on Member States (MS) level will also be used for comparison. Therefore, to enable comparison of model results, input and output data needs to be submitted to the SENTINEL database on EU level, whereas submission of Member State results is encouraged. EU results are required for the regions EU27 + UK and EU27+UK, Switzerland and Norway.

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The list of key output indicators (see Annex document) includes essential variables that need to be reported and will be collected in the intercomparison database. Data needs to be submitted in the IAMC format (Gidden and Huppmann, 2019). Translation of model results to this format can be done with the SENTINEL tool[1] (data format) that is currently being developed. It allows for EU and country wide annual results, but also includes possibilities to summarise temporal data with other time intervals (e.g., hourly). Preferably, all years between 1990 and 2050 are submitted to the database, but 2030 and 2050 are essential.

Annex documents

- SENTINEL models.xlsx

Specific SENTINEL project requirements

The results from the scenario model runs from round 2 will be used in work package (WP) 7 for the EU case study, and WP8 for model comparison (round 1-3). Scenario runs at EU level will be done by the participants of WP4 and WP8: Imperial (DESSTINNEE), Utrecht University (IMAGE), University of Aalborg (EnergyPLAN), University of Graz (WEGDYN), ETH Zürich (Calliope), Autonomous University of Barcelona (ENVIRO), and Central European University (HEB). Model development, model interlinkages and runs will be done in the specific work packages.

In this protocol we define three model rounds, that are linked to specific deliverables (see Table 2**Error! Reference source not found.**). Round one should give a picture of the full diversity of models, round two will investigate some key harmonisations, and round three will perform more detailed experiments to identify the uncertainty of parameter settings. The results for round two are used for the EU case study in WP7, whereas results for round three are used to assess uncertainty of model results for Deliverable 8.4.

Table 2 Planning for model rounds

Deliverable	Description	Deadline runs	Deadline deliverable
8.3	Free experiment runs	Month 24	Month 28 (D8.3)
7.2	Fixed experiment runs	Month 28	Month 33(D7.2)
8.4	In-depth experiments	Month 33	Month 36 (D8.4)

[1] https://sentinel-energy.github.io/sentinel-archive/

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1. Introduction

The European Union has a long history of climate policy implementation. First under the umbrella of environmental policy (Delbeke, Vis, 2016), but since 2000 as part of the European Climate Change Progamme (EU, 2000) that resulted in the energy,- and climate packages for 2020 and 2030 (Commission, 2014)[2]. Recently, the EU has published the European Green Deal (European Commission, 2019) showcasing a roadmap for 2050 to become climate neutral. Therefore, the EU has reconsidered the 2030 emission reduction target and is currently assessing how to update and change the current implemented policy instrument mix in line with the European Green Deal roadmap.

Within this context, the SENTINEL project is developing a framework existing of energy, economic and environmental models with details on specific parts of the energy system that can assess key EU policy questions. The strength of this framework is that it is based on interlinkages between different models that each perform well in specific sectors and/or countries.

To support the process of policy assessment and model development, the aim of the intercomparison exercise is to generate insights into uncertainty, modelling techniques and parameter choices. Insights into behaviour and variation are important when these models are used to advise policymakers, but validation of models is also key for model improvement and development. The comparison of models gives insights into certain types of uncertainty (e.g., technological, costs) and it identifies the strengths and weaknesses of specific models. Variation of results is informative as it indicates that a range of plausible outcomes (Kriegler et al, 2015).

As the identification of the modelling user needs in SENTINEL has shown, it is important to include real-world policy impacts in the modelling (Gaschnig et al., 2020). Next to that, engaged stakeholders have indicated other relevant issues for the modelling towards carbon neutrality, such as security of supply, cost-efficiency, impacts on the environment, water and raw material use, social acceptability, and factors understood as 'behavioural aspects, an extended perception of the "cost" term, and the consideration of clean/green innovations ranked highest' (idem).

To support the model comparison, this protocol serves to define the building blocks for the required model runs (experiments), including scenarios storylines, shared assumptions, inputs and outputs and shared databases. The scenarios could also function as reference cases for additional assessments of changes in economic, technological, or social circumstances.

[2] https://ec.europa.eu/clima/policies/strategies_en

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1.1 Aim of the intercomparison protocol

The aim of the intercomparison is to compare model results on variables that are important for the EU energy transition. The comparison will identify model strengths, identify uncertainties due to assumptions and parameter settings, and give insights into the logic and consistency of results. With this comparison we try to understand how differences in key socio-economic and technological related indicators may lead to a broad spectrum of results for energy consumption and associated emissions*.* This is done by comparing system models with more specific sector models. This will allow a reflection in terms of the suitability of the assumptions, methods and data input employed in models with larger special domain when applied to a lower scale. Based on this comparison, and with interaction of stakeholders for which discussions are organized in the SENTINEL project, policy advise can be given on model relevant topics, and models can be adjusted or extended to enable assessing more relevant energy transition topics.

The aim of the protocol is to specify experiments, inputs and outputs and the intercomparison database to make a consistent comparison of model results possible. The protocol describes the design of experiments consisting of scenario storylines linked to key policy questions and essential policy assumptions. In addition, it defines the historical data that needs to be harmonised, and the key input parameters for projections that need to be calibrated and a set of output variables, including the data format in which they will need to be reported.

The protocol will allow for comparison of models within the SENTINEL project, but also to compare with existing modelling tools, such as those used by the Commission (PRIMES, GEM-E3, Prometheus, POLES, POTENCIA) or other organisations (i.e., IEA World Energy Model, TIMES).

1.2 Modelling framework

The SENTINEL modelling framework consists of different model types (see Annex 9) that each need different inputs and outputs. Important interlinkages between models are identified and developed in the project. We make a distinction between energy system models (including macro-economic energy models), energy demand models, power sector models and social/environmental models (see Figure 1).

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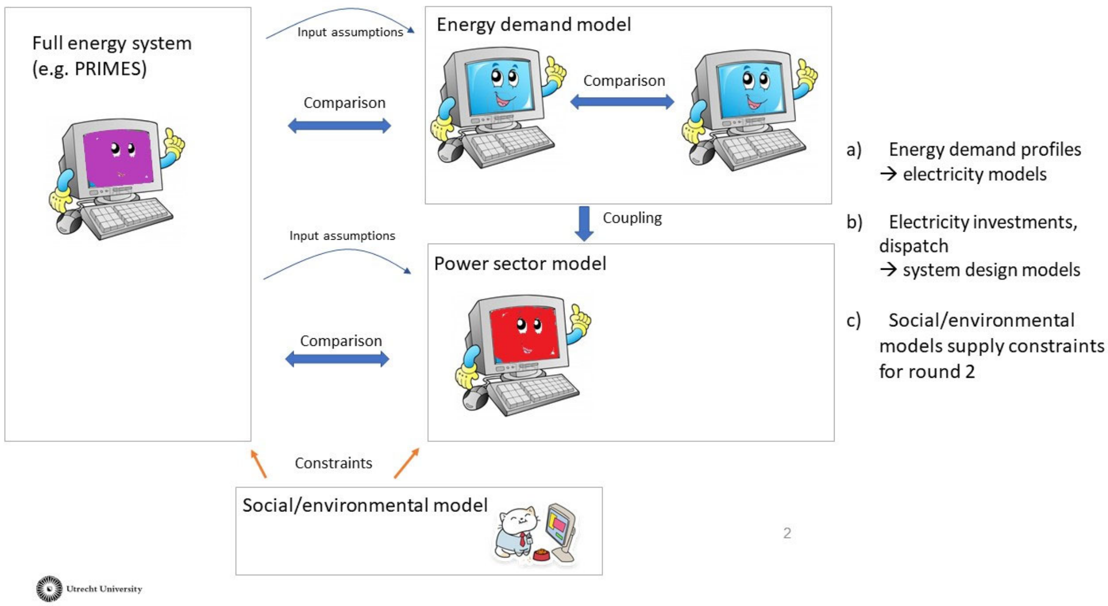

Figure 1 Types of models in SENTINEL framework

1.3 SENTINEL specific project information

The protocol aims to find a balance between information needed to derive consistent results, and the detailed data description and assumptions that are developed within the work packages 2 to 5 that deal with social and environmental transition constraints, energy demand, system design and economic impacts. In this way, it helps to avoid duplicating or making contradictive assumptions, inputs and outputs.

The protocol describes the inputs and outputs for three model rounds, and each round is linked to a deliverable in the SENTINEL project (see Table 3). In each round, the participating models run their model for a given set of inputs, and supply results to the intercomparison database. The model runs differ in terms of free and fixed parameters for harmonisation and possible scenario variants. Round 1 should give a picture of the full diversity between the models, round 2 will investigate some key harmonisations and serves as result for the EU case study (Deliverable 7.2), and round 3 will perform more detailed experiments (Deliverable 8.4) which aim to find how much influence different sectors and assumptions have.

Table 3 Planning for model runs

Deliverable	**Description**	**Deadline runs**	**Deadline deliverable**
8.3	Free experiment runs	Month 24	Month 28 (D8.3)

7.2	Fixed experiment runs	Month 28	Month 33(D7.2)
8.4	In-depth experiments	Month 33	Month 36 (D8.4)

These scenarios are designed and evaluated within WP8, but run within the dedicated work packages. The scenarios can also be used as starting points for variants that will be developed in the SENTINEL project, such as lifestyle change, or institutional barriers to implementation.

2 Design of experiments

The design of experiments includes a description of key policy questions, storylines and scenario parameters that enables to answer the posed policy questions. The result is a set of consistent scenarios that models can run, and which makes comparison of results possible.

The starting point for the scenario design is the list of key policy questions that relate to the 2050 long-term strategy. In this strategy the EU aims to be climate-neutral by 2050, which means economy-wide net-zero greenhouse gas emissions (European Commission, 2018b). This is in line with the Green Deal (European Commission, 2019) and the Mid-century Strategy (Commission, 2020b). Relevant policy questions in the context of this strategy are

- What are the characteristics of an EU climate-neutral pathway?
  - Per sector:
    - timing of carbon neutrality
    - speed of decarbonisation
  - Energy system requirements and costs
    - Role of specific technologies
    - Role of infrastructure, electricity/heat grids
    - Role of behaviour
  - Feasibility and barriers for implementation
  - What is the potential impact of behaviour?
- What are the trade-offs of the clean energy transition pathways between climate change targets and
  - Water resources protection targets as marked by the Water Framework Directive?
  - Raw Material resource targets as marked by the strategy for a circular economy?
- What are the main environmental impacts of the clean energy transition pathways?
- What are the economic consequences?
- What is the global carbon budget left if the EU implements carbon neutrality in the context of the Paris Agreement?

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- What are the roles of different actors (large and small, public and private) in influencing the scenario pathways?
- What are the key technological and institutional changes that are involved in each pathway, and what key engineering and social challenges arise?

To answer these questions, we define scenarios that enable to explore the future picturing different policy responses to climate change and evolve with different modes of policy implementation. The reference scenario 'current trends' represents the current progress on implementation of climate- and energy policies. The 'climate neutrality' scenario is linked to the long-term strategy, and together with the current trends scenario, this allows to give insights into the impact of proposed policies on the energy system needed to achieve the climate neutrality goal. In addition, we define the 'early neutrality' scenario where the EU aims to become climate neutral before 2050. The storylines for these scenarios describe the different images of the future, based on different progress of political, social and technological drivers.

Current trends: *Although the EU is currently a forerunner on climate it will only implement the current policies defined in the 2030 energy and climate framework. After 2030 no (global) deal is reached on strengthening policies, and climate policy will stay in line with keeping temperature below 2 ℃ (see* Table 4*). Therefore, the existing policy mix is continued leading to similar efforts after 2030 as in the period between 2020 and 2030. The world is divided, and climate policy is very much a domestic issue. EU citizens only take climate measures if this is cost-effective with a short payback period, and it does not lead to large layoffs in fossil dependent sectors. In terms of technology, blue and green hydrogen production, and smart grids face large barriers for implementation. Only current renewable technologies such as solar PV, wind and biomass are further implemented, and come down in terms of costs.*

Climate neutrality: *The EU implements its 2050 climate neutrality goals which was submitted to the UNFCCC in the Mid-century strategy. Therefore, the total net GHG emissions by 2050 will be around zero. This is also the goal in the sustainable roadmap 'Green Deal' that aims to boost the use of efficient resources, restore biodiversity and cut pollution. The aggregated impacts of all UNFCCC parties prove to be enough to hold the world well below 2 ℃ or 1.5 ℃. This does include overshoot and negative emissions in the second half of this century. Therefore, no ratcheting up of this ambition is necessary. More and more people start accepting the necessity of climate policies, and implementation speed increases. Promising technologies become ready for cost effective implementation, and behaviour changes leading to energy savings slowly settle in.*

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Early neutrality (optional): *The world chooses to ensure the 1.5 ℃ goal of the Paris Agreement, and to only accept a very limited amount or no negative emissions. In addition, the EU is increasing its ambition in line with burden sharing scenarios* (NewClimate Institute, 2019) *and the PAC scenario* (EEB and CAN Europe, 2020)*. This goal is translated to net zero GHG emissions by 2040 for the EU. The EU ensures that the ambitious climate policy has a bearable input on all citizens, although large social changes take place. All existing renewable technologies decrease in costs quickly, and innovative technologies for negative emissions are scaled rapidly.*

These descriptions focus especially on technological and policy circumstances (for a general overview of different targets see Table 4), but these scenarios could also function as starting point to develop pathways or variants. If so, for each scenario several pathways could be implemented. For example, it would be possible to describe the transition pathways using the 'action space' concept by Foxon (2013; 2010) to explore the dynamic interactions between choices made by different actors MUSTEC (Lilliestam et al., 2019). According to this concept, market, government and civil society logics dominate in different transition pathways.

Table 4 Global and EU reductions for the 2C and 1.5C scenario based on IPCC, EU reports and NewClimate report.

		2-degrees C	**1.5-degrees C**
Global	**IPCC**	(AR5) Global: -50% relative to 2010 Annex I: -80% to -95% below 1990 levels by 2050	(1.5 °C report) Global: -100% CO_2 relative to 2010 by 2050 -90% GHG relative to 2010 by 2050 -100% GHG relative to 2010 by 2070
EU			
	IPCC		-100% CO_2 relative to 2010 by 2070 -90% GHG relative to 2010 by 2050 -100% GHG relative to 2010 by 2070
	Policy target	-40% relative to 1990 by 2030 [-80%,-95%] relative to 1990 by 2050	
		(update) -80% relative to 1990	[-55%,-60%] relative to 1990 by 2030

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			-100% relative to 1990 by 2050
	Fair contribution		-100% relative to 1990 between 2030 and 2040 -150% relative to 1990 by 2050

The time horizon for all scenarios is from 1990 to 2050 (submission of results until 2100 are encouraged (see Section 4)). Furthermore, model input is specified on the aggregated EU level. The spatial dimension for the model outputs is the EU+UK and EU+UK, Switzerland, Norway and EU Member States (optional). The temporal dimension is annual (at least the years 2030 and 2050).

2.1 SENTINEL project specific information

Each scenario can encompass different pathways. Case-study specific storylines, including assumptions about developments, could result in analysis of different factors or of additional constraints in the scenarios. The design of these variants will take place in WP7, including social constraints provided by the QTDIAN tool and environmental constraints of the ENVIRO model.

3 Harmonisation of assumptions

Models participating in the modelling exercise implement the scenarios described in Section 2. The scenario storylines are translated to input parameters to harmonise model assumptions. As input to the three model rounds, we present different levels of harmonisation, that give models different levels of freedom for scenario development. Harmonisation of energy models is possible in regard to:

- Overall ambition level based on EU climate policy goals
- Historical data (including a reference year)
- EU policy instruments (translated to policy targets)
- Socio-economic parameters
- Energy parameters on efficiency and costs

3.1 Harmonisation of overall policy goals

Each scenario has an EU policy goal attached that represents the mitigation ambition level of the scenario. These goals need to be achieved by the model implementation and is the main input for the models (see Table 5). The goals are:

- Current trends scenario:
    - minimum of 40% reduction of GHG emissions (incl. LULUCF CO_2) relative to 1990
    - and continuation of progress until 2050

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- Climate neutrality scenario:
  - minimum of 55% reduction (relative to 1990) by 2030,
  - net-zero GHG emissions by 2050
- Early neutrality scenario:
  - net-zero GHG emissions by 2040

Based on the EU documents (Commission, 2020a; European Commission, 2018b), these goals can be translated to sector level targets (see Section 8.1 and 8.2).

Table 5 Economy-wide emissions targets per scenario

	1990	2005	*Current trends*		*Climate neutrality*		Early neutrality
			2030*	2050	2030**	2050	2040
Total GHG emissions (incl. LULUCF) Mt CO_{2eq}	5413	4940	2870	1950	2435	<25	<25
Reduction 1990 (%)	---	9%	47%	64%	55%	Nearly 100	Nearly 100
Total GHG emissions (excl. LULUCF) Mt CO_{2eq}	5659	5164	3150	2130	2640	(350-500)	(350-500)
Total CO2 emissions Mt CO_{2eq}	4475	4319	<2400	< 1600	<2000	< 200	< 200

*Main instruments: ETS: -43% relative to 2005, Effort sharing: 30% relative to 2005, REN directive: 32% renewable final energy, Efficiency directive: 32.5% energy efficiency improvement.

**The values in here considered assume that the new targets, approved in September, will also apply to the UK despite having left the EU. It must be noted that the UK has recently approved more ambitious targets for 2030, comprising reductions of up to 68% in comparison with 1990 (UK Climate Change Committee, 2020).

3.2 Harmonisation of historical data

A consistent reference year and dataset is defined for harmonisation of the modelling results. This is done, because emissions and energy trajectories calculated by different models differ in source and reference year for historical emissions, what can result in large uncertainties (Gidden et al., 2018; Rogelj et al., 2011). Modellers are encouraged to harmonise historical energy use and GHG emissions in the model as part of the model runs. Harmonisation afterwards is possible but comes with larger uncertainties. The base year for harmonisation is 2018. If harmonisation is not possible beforehand, results will be

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harmonised afterwards with the Aneris tool[3]. We recommend using data sources from the European Environment Agency (EEA) and Eurostat:

- EEA Indicators
  https://www.eea.europa.eu/data-and-maps/indicators
- EEA data and maps
  https://www.eea.europa.eu/data-and-maps
- Eurostat – European Statistical Recovery Dashboard
  https://ec.europa.eu/eurostat/web/main/data/database

Different levels of harmonisation are taking place in the three model rounds. Each level includes the harmonisation assumptions from the higher levels. Harmonisation to historical data is especially requested for round 2 and 3 and should include the variables from Table 6.

Table 6 Harmonisation of historical input data

<table>
<tr><th>Sector</th><th></th><th>Variable</th></tr>
<tr><td colspan="3">Whole economy</td></tr>
<tr><td>Energy consumption</td><td colspan="2">Primary Energy|</td></tr>
<tr><td>GHG emissions</td><td colspan="2">Emissions|<Kyoto gases>|</td></tr>
<tr><td colspan="3">Buildings</td></tr>
<tr><td rowspan="3">Residential</td><td colspan="2">Final Energy|Buildings|Residential|</td></tr>
<tr><td>Heating</td><td>Final Energy|Buildings|Residential|Heating</td></tr>
<tr><td>Appliances</td><td>Final Energy|Buildings|Residential|Appliances</td></tr>
<tr><td rowspan="3">Commercial</td><td colspan="2">Final Energy|Buildings|Commercial</td></tr>
<tr><td>Heating</td><td>Final Energy|Buildings|Commercial|Heating</td></tr>
<tr><td>Appliances</td><td>Final Energy|Buildings|Commercial|Appliances</td></tr>
<tr><td colspan="3">Industry</td></tr>
<tr><td>Energy</td><td colspan="2">Final Energy|Industry</td></tr>
<tr><td rowspan="2">Emissions</td><td>Energy</td><td>Emissions|<Kyoto gases>|Energy|Industry</td></tr>
<tr><td>Process emissions</td><td>Emissions|<Kyoto gases>|Processes</td></tr>
<tr><td colspan="3">Transport</td></tr>
<tr><td rowspan="2">Road</td><td>Energy</td><td>Final Energy|Transportation|Road</td></tr>
<tr><td>Emissions</td><td>Emissions|<Kyoto gases>|Energy|Transportation|Road</td></tr>
<tr><td rowspan="2">Rail</td><td>Energy</td><td>Final Energy|Transportation|Rail</td></tr>
<tr><td>Emissions</td><td>Emissions|<Kyoto gases>|Energy|Transportation|Rail</td></tr>
<tr><td></td><td>Energy</td><td>Final Energy|Transportation|Navigation</td></tr>
</table>

[3] http://software.ene.iiasa.ac.at/aneris/#documentation

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Navigation	Emissions	Emissions|<Kyoto gases>|Energy|Transportation|Navigation
Aviation	Energy	Final Energy|Transportation|Aviation
	Emission	Emissions|<Kyoto gases>|Energy|Transportation|Aviation
Secondary energy vectors		
Generation	Electricity	Generation|Electricity
	H2	Generation|H2
	Heat	Generation|Heat
	P2G and P2GL[4]	Generation|P2G and Generation|P2L
Emissions	Electricity	Emissions|<Kyoto gases>| Energy|Supply|Electricity|
	H2	Emissions|<Kyoto gases>| Energy|Supply|H2
	Heat	Emissions|<Kyoto gases>| Energy|Supply|Heat
	P2G and P2L	Emissions|<Kyoto gases>| Energy|Supply|P2G Emissions|<Kyoto gases>| Energy|Supply|P2L

3.3 Harmonisation of projections: calibration to input parameters

To implement the scenarios, models will need to be calibrated with different parameters. In round 1, no specific parameters are prescribed, with the exception of the overall policy goals, and the targets linked to the policy instruments for the current trends scenario (see Table 7). In the next protocol update and rounds, more harmonisation parameters, such as socio-economic and energy parameters will be added.

Where more guidance is needed on model calibration, we refer to the 1.5TECH scenario from the Clean Planet for All (European Commission, 2018b) and the MIX scenario from the impact assessment accompanying the 2030 Climate Target Plan (Commission, 2020a). These assessments include a detailed description, including results for many variables in a climate neutrality scenario. These results can be used to calibrate future scenario projections.

The 2030 climate & energy framework includes many existing policy instruments and targets. The main instruments are the emission trading system (ETS) that aims to reduce GHG emissions by 43% relative to 2005 in the electricity, industry sector and aviation sector. In addition, the effort sharing legislation aims to reduce GHG emissions by 30% relative to 2005 levels and applies to those GHG emission not covered by ETS. Two other important EU targets to include are the 32% renewable final energy target by 2030, and the 32.5% efficiency improvement by 2030. Other policy instruments and linked targets are found in Table 7 and more details in the Annex 8.2.

Table 7 Policy instruments included in the 2030 EU climate and energy framework

Economy-wide	Energy Efficiency Directive

[4] P2G and P2L refer to power to gas and power to liquid fuels.

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	Effort sharing
	Renewable Energy Directive
	F-gas Regulation
Energy supply/industry	Emission Trading System
	Innovation fund
Transport	CO_2 performance standards cars and vans
	CO_2 performance standards trucks and busses
	Renewable Energy Directive
	Fuel Quality Directive
	Car Labelling Directive
	Shipping Strategy
	Emission Trading System (Aviation)
Buildings	Buildings Directive
AFOLU	Effort sharing (LULUCF)
ENVIRONMENT	Water Framework Directive
	Strategy for a circular economy
	Habitats Directive/Biodiversity Strategy

Candidates harmonisation parameters for the next round are

Sector	**Variable**
Electricity	Installed capacities of fossil/non-fossil
Heating	Installed capacities
Fossil fuel production	CO_2/CH_4 intensity (in terms of GJ)
Transport:	Efficiency of cars, Efficiency of trucks Efficiency of shipping Efficiency of aviation
Buildings	Insulation Heating/cooling efficiency Appliance efficiency
Industry	
- Steel	Energy use per tonne of steel produced
	Process emissions
- Cement	Energy use per tonne of cement/clinker production
	Process emissions
- Chemicals	

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3.4 SENTINEL project specific information

The EU reports that can be used for calibration can be found on the SENTINEL PARTNERS drive (SENTINEL PARTNERS\WP8\protocol\EU reports).

The scenario runs will consist of three rounds. Results from the first round will be used by the ENVIRO model to calculate environmental impacts with a focus on energy supply and use of raw materials. In addition, the results of the free experiments from round 1 will be used to identify the most important parameters. Based on this analysis, additional harmonisation parameters will be included in the scenario description, and model protocol will be updated. This also holds for harmonisation to historical data, which is especially important for round 2.

The modelling exercise is done with different types of models (see Figure 1). The protocol relies on the work done in the work packages 2-6. It might be necessary that certain model input should come from other participating models (in round 2 and 3). This is for example the case for electricity models that need energy demand patterns. The database allows to include intermediate results. In addition, these intermediate results might be used by external models a later stage in the project.

4 Reported outputs and model inputs

Requested model outputs are described in detail in the Annex 'List of key indicators for the intercomparison exercise'. It includes a list of key technical, economic and environmental indicators for different stages of the energy supply and consumption value chain. Especially for energy supply and demand models, we urge the modellers to also submit greenhouse gas emissions, which can be calculated by applying standard emission factors from the IPCC (2006)to the energy use variables. The list of indicators is categorised into:

- Fuel consumption for final energy uses,
- Fuel consumption and generation outputs for secondary energy carries,
- Economic indicators for the transformation sector,
- Primary energy consumption,
- Sectorial and total Kyoto gas and air pollutant emissions.

In addition, model teams should provide data regarding key data inputs and assumptions in their models, for the aimed time horizon and the reference year:

- Demographic and socio-economic indicators,
- Techno-economic performance indicators,
- Climatic assumptions,
- Historical data (for the reference year).

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These indicators follow the IEA format (IEA, 2020) and uses the 100yr Global Warming Potentials (GWP) from the IPCC AR5 report (IPCC, 2014).
Preferably, all years between 1990 and 2050 are submitted to the database, but 2030 and 2050 are essential. We request results for the following geographical regions:

- EU+UK
- EU+UK, Switzerland, Norway
- Individual Member states (if available)

If these region aggregations are not exactly available in your model, please use downscaling techniques to obtain the required geographical coverage. One way is to shift the entire pathway up or down to match the historical level in a reference year (e.g., 2018). See the 'constant offset' method in the Aneris tool for more details. This is, of course, only valid if the regional coverage is not very different from the one required.

5 Data format and intercomparison database

To enable data to be useable for the modelling community both within and outside the SENTINEL project, and to involve other models in the modelling exercise, we develop an intercomparison database. Proposed output variables are described in the annex "List of key indicators for the intercomparison exercise". The aim is to collect results in the IAMC format used in the Pyam model (IIASA, 2020), which is a standardised tabular timeseries format to exchange scenario data. Model teams will need to use the SENTINEL data transfer routine, developed by WP6, to report the outputs and inputs considered in the simulation runs. In summary, this routine will enable to look up the indicators from your model results and translate it to the appropriate format to be incorporated in the intercomparison database.

The database format (see Section 4) will also provide for submitting results for other European countries (e.g., Norway, Switzerland), and European regions such as the Nordic region. In addition, output data with more frequent temporal dimensions (e.g., hourly) are submitted using statistics (e.g., mean, percentile).

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7 Indicators

7.1 Introduction

This document is aimed at presenting a possible list of variables to be included in the SENTINEL's scenario intercomparison database. The IAMC (Integrated Assessment Modelling Consortium) reporting format[5] is planned to be used for the development of the database, as a way to fairly confront results from different models.

The modelling teams should provide data at national granularity or for the whole EU27+UK. If the models were based on regions or macro-regions, the participants should ensure that the geographical domain for the presented data fit with the afore mentioned options. The modellers could inform yearly values for the variables in the database, covering the whole interval between the reference year, 2030, and 2050 or reporting data for these three years only. For some indicators, hourly data for key periods may be also useful (e.g.: winter or summer average hourly electricity load).

In the different sections of this annex, the proposed variables to be included in the database are listed. An identifier code has also been assigned for each of them following the IAMC nested structure. **Section 1** focusses on the final energy uses. The definitions for the energy carriers are presented in **Section 2** considering the IEA (International Energy Agency)'s national energy balances[6] and novel vectors that are envisaged to be part of the future energy matrix. Key variables for the transformation sector are enumerated in **Section 3** while indicators for primary energy consumption, investments, secondary energy prices and emissions are included in **Section 4**. **Section 5** covers main technical, socio-economic data inputs for the models. The selected units for the variables are indicated in **Section 6.**

[5] Further detailed information can be found at https://pyam-iamc.readthedocs.io/en/stable/data.html

[6] The IEA (International Energy Agency) national energy balances presents fuel consumption for different energy uses. Documentation available at: http://wds.iea.org/wds/pdf/WORLDBAL_Documentation.pdf

7.2 Final energy uses

Final energy uses listed below are comprehensive and it could be the case that some models will not be providing fuel inputs for all the proposed sub-categories. The modelling teams could report data up to the second or third nested level (shaded rows in the tables), based on their model's sectorial coverage and capabilities. Considering the different type of mitigation options and policies for the building sector, it would be beneficial if the participants could inform energy consumption for heating, cooling and appliances. Regarding transportation, especially road transport, the modellers should distinguish between passenger and freight transport modes. This is because different sets of technologies and fuels are forecasted to be introduced in each of these two sub-categories.

7.2.1 Buildings

7.2.1.1 Residential and Commercial

Residential	**Heating**		*Final Energy|Buildings|Residential|Heating*
		Space heating	*Final Energy|Buildings|Residential|Heating|Space heating*
		Water heating	*Final Energy|Buildings|Residential|Heating|Water heating*[7]
	Cooking		*Final Energy|Buildings|Residential|Cooking*
	Cooling		*Final Energy|Buildings|Residential|Cooling*
	Appliances		*Final Energy|Buildings|Residential|Appliances*
		Lighting	*Final Energy|Buildings|Residential|Appliances|Lighting*
		White	*Final Energy|Buildings|Residential|Appliances|White*[8]
		Others	*Final Energy|Buildings|Residential|Appliances|Oth*[9]
Commercial	**Heating**		*Final Energy|Buildings|Commercial|Heating*
		Space heating	*Final Energy|Buildings|Commercial|Heating|Space heating*
		Water heating	*Final Energy|Buildings|Commercial|Heating|Water heating*
	Cooking		*Final Energy|Buildings|Commercial|Cooking*
	Cooling		*Final Energy|Buildings|Commercial|Cooling*
Commercial	**Appliances**		*Final Energy|Buildings|Commercial|Appliances*
		Lighting	*Final Energy|Buildings|Commercial|Appliances|Lighting*
		White	*Final Energy|Buildings|Commercial|Appliances|White*
		Others	*Final Energy|Buildings|Commercial|Appliances|Oth*

[7]Energy used for increasing water temperature for non-space heating neither nor cooking purposes.
[8] Large energy consumption appliances such as washing machines, freezers, fridges, etc.
[9] Other type of appliances excluding the so called "White" and lighting.

7.2.2 Agriculture

Agriculture	*Final Energy|Agriculture*

7.2.3 Industry

Industries	*Final Energy| Industries*		
	Light industries	**Food and tobacco**	*Final Energy|Industriesl|Light|FoodToba*
		Paper, pulp and print	*Final Energy|Industries|Light|Papuprint*
		Textile and leather	*Final Energy|Industries|Light|TextLeath*
		Construction	*Final Energy|Industries|Light|Const*
	Heavy Industries	**Iron and steel**	*Final Energy|Industries|Heavy|Ironsteel*
		Chemical and petrochemical	*Final Energy|Industries|Heavy|Chemical*
		Non-ferrous metals	*Final Energy|Industries|Heavy|NonFer*
		Non-metallic minerals	*Final Energy|Industries|Heavy|NMM*
		Transport equipment and Machinery	*Final Energy|Industries|Heavy|TEQM*
		Mining and quarrying	*Final Energy|Industries|Heavy|TEQM*
		Others	*Final Energy|Industries|Heavy|OTH*

7.2.4 Transportation

7.2.4.1 Road transport

Transportation	**Road**	**Passenger**	*Final Energy|Transportation|Road|Passenger*	
			Passenger cars	*Final Energy|Transportation|Road|Passenger|PC*
			Two-wheels	*FinalEnergy|Transportation|Road|Passenger|TW*
			Buses and coaches	*FinalEnergy|Transportation|Road|Passenger|Buses and coaches*
		Freight	*Final Energy|Transportation|Road|Freight*	
			Heavy duty vehicles	*FinalEnergy|Transportation|Road|Freight|HDV*

			Light duty vehicles	*FinalEnergy|Transportation|Road|Freight |LDV*

7.2.4.2 Rail

Final Energy	**Rail**	*Final Energy|Transportation|Rail*	
		Passenger	*Final Energy|Transportation|Rail|Passenger*
		Freight	*Final Energy|Transportation|Rail|Freight*

7.2.4.3 Navigation[10] and aviation[11]

Final Energy	**Navigation**	*Final Energy|Transportation|Navigation*	
		Passenger	*Final Energy|Transportation|Navigation|Passenger*
		Freight	*Final Energy|Transportation|Navigation|Freight*

Final Energy	**Aviation**	*Final Energy|Transportation|Aviation*	
		Passenger	*Final Energy|Transportation|Aviation|Passenger*
		Freight	*Final Energy|Transportation|Aviation|Freight*

[10] Navigation includes domestic navigation for passengers and domestic and international for freight, following the criteria defined in PRIMES EU Reference 2016 and the EU Long Term Strategy scenarios.
[11] Aviation considers domestic and international flights.

7.3 Primary and secondary energy carriers

For each final energy use and set of transformation technologies, the modelling teams should inform consumption data for the fuels proposed in the following list. The selection for the energy vectors was conducted on the basis of the energy carriers included in the IEA's national energy balances and our assumptions for vectors to be incorporated in the future energy matrix. It may be the case that some models use a different fuel classification or level of aggregation. As a way to easing comparability, the next fuel clusters have also been defined: **Coal, Oil, Oil|Bio, Gases, Gases|Bio, Gases|Hydrogen, Solid Bio and waste, Electricity, Heat, Nuclear, Solar, Wind** and **Other Renewables**. Modellers can opt between provide data for the individual fuels or for the clusters.

Fuels and clusters	Identifiers
Coal (if no detail)[12]	*|Coal|*
Brown coal (if no detail)[13]	*|Coal|Brown*
Sub-bituminous coal	*|Coal|Brown|Sub-bituminous coal*
Lignite	*|Coal|Brwon|Lignite*
Hard coal (if no detail)[14]	*|Coal|Hard coal*
Anthracite	*|Coal|Hard coal|Anthracite*
Coking coal	*|Coal|Hard coal|Coking coal*
Other bituminous coal	*|Coal|Hard coal|Others*
Patent fuels	*|Coal|Hard coall|Anthracite*
Coal products[15]	*|Coal|Coal products*
Coke oven coke	*|Coal|Coal products|Coke*
Gas coke	*|Coal|Coal products|GasCo*
Coal tar	*|Coal|Coal products|Tar*
BKB	*|Coal|Coal products|BKB*
Gas works gas	*|Coal|Coal products|GWGS*
Coke oven gas	*|Coal|Coal products|Coke gas*
Blast furnace gas	*|Coal|Coal products|BFG*

[12] It includes all possible types of coal types. This category is employed if the models can't further disaggregate among the different sub-categories for coal fuel type.
[13] All types of non-hard coal and non-derivative products. Subcategory to be used when the modellers could not supply data in a higher level of disaggregation.
[14] All types of hard coal fuels. Subcategory to be considered when the modellers can't report further detailed information.
[15] Fuels derived from coal secondary processes.

Other recovered gases	*|Coal|Coal products|Others*
Liquids[16]	*|Liquids|*
Fossil liquid fuels[17]	*|Liquids|Fossil*
Biogenic liquid fuels[18]	*|Liquids|Bio*
Oil shale and oil sands	*|Liquids|Fossil|Shale*
Crude	*|Liquids|Fossil|crude*
NGL	*|Liquids|Fossil|NGL*
Refinery feedstock	*|Liquids|Fossil|Refstock*
Additives/blending components	*|Liquids|Fossil|Add*
Refinery gas	*|Liquids|Fossil|ReffGas*
Ethane	*|Liquids|Fossil|Ethane*
Liquefied petroleum gases (LPG)[2]	*|Liquids|Fossil|LPG*
Motor gasoline excl. biofuels	*|Liquids|Fossil|Gasoline*
Aviation gasoline	*|Liquids|Fossil|Jet*
Gasoline type jet fuel	
Kerosene type jet fuel excl. biofuels	*|Liquids|Fossil|Kero*
Other kerosene	
Gas/diesel oil excl. biofuels	*|Liquids|Fossil|Diesel*
Fuel oil	*|Liquids|Fossil|Fuel Oil*
Naphtha	*|Liquids|Fossil|Naptha*
White spirit & SBP	*|Liquids|Fossil|WSP*
Lubricants	*|Liquids|Fossil|Lub*
Bitumen	*|Liquids|Fossil|Bit*
Paraffin waxes	*|Liquids|Fossil|waxes*
Petroleum coke	*|Liquids|Fossil|Petcoke*
Other oil products	*|Liquids|Fossil|Others*
Biogasoline	*|Liquids|Bio|Biogasoline*

[16] To be used if the models could not provide more disaggregated fuel consumption for fossil or biogenic liquid fuels. If that were the case, the participants should indicate a possible fossil and biogenic share or an approximate figure for the fossil CO_2 emission factor.
[17] Subcategory to be reported when no further details are available for fossil liquid fuels.
[18] Subcategory to be reported when no further details are available for bio-liquid fuels.

Biodiesels	*|Liquids|Bio|Biodiesel*
Bio jet kerosene	*|Liquids|Fossil|Bio|Jet*
P2L[19](power to liquids)	*|Liquids|Bio|P2L* *|Liquids|Fossil|P2L*
Gases[20]	*|Gases|*
Fossil gaseous fuels[21]	*|Gases|Fossil*
Biogenic gaseous fuels[22]	*|Gases|Bio*
Natural Gas	*|Gases|Fossil|Natural Gas*
Biomethane	*|Gases|Bio|Biomethane*
Biogas	*|Gases|Bio|Biogas*
Gas, from power to gas[23]	*|Gases|Bio|P2G* *|Gases|Fossil|P2G*
Syngas	*|Gases|Bio|Syngas* *|Gases|Fossil|Syngas*
Hydrogen[24]	*|Gases|Bio|Hydrogen* *|Gases|Fossil|Hydrogen*
Solid bio and waste	*|Solid bio and waste|*
Primary solid biomass	*|Solid bio and waste|Primary solid biomass*
Waste[25]	*|Solid bio and waste|Waste non renew or*

[19] Liquid fuels obtained using H_2 from renewable ("Bio") or fossil ("Fossil") generated electricity.
[20] To be considered if the models could not provide more disaggregated fuel consumption for fossil or biogenic gaseous fuels. If that were the case, the participants should inform a possible fossil and biogenic share or an approximate figure for the fossil CO_2 emission factor.
[21] Sub-category to be reported if no further details are available for fossil originated fuel gases. It may include natural gas, fossil based syngas and P2G.
[22] Sub-category to be used if no further details are available for biogenic fuel gases. It could group: biogas, biomethane, syngas from solid biomass thermo-chemical conversion and renewable based power to gas fuels.
[23] Methane produced using H_2 from electricity. It is considered "Bio" when electricity is renewable sourced or "Fossil" when the electricity comes from fossil fuelled power plants.
[24] Obtained as a product of thermochemical conversion of fossil and biogenic solid fuels or derived from water electrolysis. For the latter, the classification between fossil and biogenic will depend on whether power is produced using renewable vectors.
[25] Including: municipal, agriculture, industrial and hazardous waste.

	|Solid bio and waste|Bio|Waste
Nuclear	*|Nuclear|*
Wind	*|Wind|*
Solar	*|Solar|*
Others renewables	*|Oth renewables|*
Hydro	*|Oth renewables|Hydro*
Tide, wave and ocean	*|Oth renewables|Ocean*
Geothermal	*|Oth renewables|Geothermal*
Electricity[26]	*|Electricity|*
Heat[27]	*|Heat|*

[26] Electricity as a secondary vector consumed by the different final energy uses.
[27] Heat for final energy uses.

7.4 Transformation processes

Transformation processes considered in here are mostly related to the production of secondary energy vectors (electricity, heat, H_2 and power to fuels). The variables to be separately reported are: installed capacity, secondary energy vector generation and fuel input for the conversion technologies. While this is a quite extensive and detailed list and since this level of disaggregation may not be present in all the models, the participants could provide the afore mentioned variables for clusters of fuel inputs (shaded in the table below).

The proposed nested structure, using the IAMC format, enables the comparison among models with different fuel and technological disaggregation level. For example, a model (M1) could report the electricity generation installed capacity in steam cycle based plants fuelled with solid primary biomass (*Capacity|Electricity|Solid bio and waste|Boiler|Solid primary biomass*) or in gasification plants (*Capacity|Electricity|Solid bio and waste|Gasification|Solid primary biomass*). Other model (M2) could provide data for the total installed capacity for fuel (*Capacity|Electricity|Solid bio and waste|…|Solid primary biomass*). A third model (M3) could inform the total installed capacity for electricity generation using solid biomass and waste(*Capacity|Electricity|Solid bio and waste*). Data from these three models will be comparable at the third nested level (*Capacity|Electricity|Solid bio and waste*).

Electricity, H_2, power to fuels and heat[28]	**Capacity, yearly generation and fuel consumption**[29]	**Primary solid biomass and waste types**[30]		*Capacity|Electricity|Solid bio and waste*
			Boilers	*Capacity|Electricity|Solid bio and waste|Boiler|…*
			Boilers, CCS	*Capacity|Electricity|Solid bio and waste|Boilers|CCS|..*
			Gasification	*Capacity|Electricity|Solid bio and waste|Gasification|..*
			Gasification, CCS	*Capacity|Electricity|Solid bio and waste|Gasification|CCS|…*
		Coal and derivative fuels		*Capacity|Electriciy|Coal*
			Subcritical	*Capacity|Electriciy|Coal|Combustion|SC|..*
			Subcritical, CCS	*Capacity|Electriciy|Coal|Combustion|SC|CCS|..*
			Supercritical	*Capacity|Electriciy|Coal|Combustion|SP|..*
			Supercritical, CCS	*Capacity|Electriciy|Coal|Combustion|SP|CCS|..*
			USC[31]	*Capacity|Electriciy|Coal|Combustion|USC|..*
			USC, CCS	*Capacity|Electricity|Coal|Combustion|USC|CCS|..*

[28] Based on model capabilities, the modellers should provide data for: installed capacity, total yearly generation and fuel input for conversion processes covering electricity, power based fuels, heat and H_2. The identifiers for electricity are displayed in the table. In the case of other secondary energy vectors, the suggested structure would be Capacity|H_2, Capacity|P2G, Capacity|P2L and Capacity|Heat.

[29] Installed capacity (in GW), yearly generation (EJ/year) and fuel consumption (EJ/year) for the production of each of the four above mentioned secondary energy vectors. The table shows the codes for capacity. For generation, the code structure would be Generation|Electricity, Genration|Hydrogen, Genration|P2G, Generation|P2L and Generation|Heat. For fuel consumption, for each secondary energy vector, the codes to be used would be: Secondary energy|Electricity, Secondary energy|Hydrogen, Secondary energy|P2G, Secondary energy|P2L and Secondary energy|Heat.

[30] The technologies included are common for: primary solid biomass, renewable and non -renewable waste.

[31] USC refers to ultra-supercritical coal fuelled power plants.

<table>
<tr><td rowspan="34">Electricity, H_2, power to fuels and heat</td><td rowspan="34">Capacity, yearly generation and fuel consumption</td><td rowspan="2">Coal and derivative fuels</td><td>Gasification</td><td>Capacity|Electriciy|Coal|Gasification|..</td></tr>
<tr><td>Gasification, CCS</td><td>Capacity|Electriciy|Coal|Gasification|CCS|..</td></tr>
<tr><td rowspan="8">Liquid fuels</td><td></td><td>Capacity|Electricity|Liquids|…</td></tr>
<tr><td>Boilers</td><td>Capacity|Electricity|Liquids|Boilers|..</td></tr>
<tr><td>Boilers, CCS</td><td>Capacity|Electricity|Liquids|Boilers|CCS|..</td></tr>
<tr><td>Gas turbines</td><td>Capacity|Electricity|Liquids|Gas turbines|..</td></tr>
<tr><td>Gas turbines, CCS</td><td>Capacity|Electricity|Liquids|Gas turbines|CCS|..</td></tr>
<tr><td>Gas engines</td><td>Capacity|Electricity|Liquids|Gas engines|..</td></tr>
<tr><td>Gas engines, CCS</td><td>Capacity|Electricity|Liquids|Gas engines|CCS|..</td></tr>
<tr><td></td><td></td></tr>
<tr><td rowspan="9">Gaseous fuels[32]</td><td></td><td>Capacity|Electricity|Gaseous fuels|…</td></tr>
<tr><td>Boilers, CCS</td><td>Capacity|Electricity|Gaseous fuels|Boilers|</td></tr>
<tr><td>Boilers, CCS</td><td>Capacity|Electricity|Gaseous fuels|Boilers|CCS|..</td></tr>
<tr><td>Gas turbines</td><td>Capacity|Electricity|Gaseous fuels|Gas turbines|..</td></tr>
<tr><td>Gas turbines, CCS</td><td>Capacity|Electricity|Gaseous fuels|Gas turbines|CCS|..</td></tr>
<tr><td>Gas engines</td><td>Capacity|Electricity|Gaseous fuels|Gas engines|..</td></tr>
<tr><td>Gas engines, CCS</td><td>Capacity|Electricity|Gaseous fuels|Gas engines|CCS|..</td></tr>
<tr><td>Fuel cells,</td><td>Capacity|Electricity|Gaseous fuels|Fuel cells|..</td></tr>
<tr><td>Fuel cells, CCS</td><td>Capacity|Electricity|Gaseous fuels|Fuel cells|CCS|..</td></tr>
<tr><td>Nuclear</td><td colspan="2">Capacity|Electricity|Nuclear|</td></tr>
<tr><td rowspan="3">Solar</td><td colspan="2">Capacity|Electricity|Solar</td></tr>
<tr><td>PV</td><td>Capacity|Electricity|Solar|PV</td></tr>
<tr><td>CSP</td><td>Capacity|Electricity|Solar|CSP</td></tr>
<tr><td rowspan="2">Wind</td><td>Onshore</td><td>Capacity|Electricity|Wind|Onshore</td></tr>
<tr><td>Offshore</td><td>Capacity|Electricity|Wind|Offshore</td></tr>
<tr><td rowspan="4">Others renewables</td><td></td><td>Capacity|Electricity|Oth renewables</td></tr>
<tr><td>Ocean</td><td>Capacity|Electricity|Oth renewables|Ocean</td></tr>
<tr><td>Geothermal</td><td>Capacity|Electricity|Oth renwables|Geothermal</td></tr>
<tr><td>Hydro</td><td>Capacity|Electricity|Oth renewables|Hydro</td></tr>
<tr><td>International transmission [33]</td><td colspan="2">Capacity|Electricity|International transmission</td></tr>
<tr><td rowspan="4">Storage</td><td></td><td>Capacity|Storage</td></tr>
<tr><td>Pumped hydro</td><td>Capacity|Electricity|Storage|Pumped hydro</td></tr>
<tr><td>Batteries</td><td>Capacity|Electricity|Storage|Batteries</td></tr>
<tr><td>Others</td><td>Capacity|Electricity|Storage|Oth</td></tr>
</table>

[32] Energy conversion processes are common to natural gas, biogas, biomethane, syngas bio and syngas fossil.
[33]Capacity for transboundary electricity transport.

Some of the models can predict the hourly generation for secondary energy vectors, mainly electricity. Including hourly profiles for each country would lead to a very large database however this information is key for the design of the future energy system. It is proposed to consider: the mean hourly value across a year *(Mean*), the maximum, *(Max*), the minimum (*Min*), the mean load for summer (*Summer mean*) and winter (*Winter mean)*. Other possible indicators could be: the average for the 25% percentile (P25) and the average for the 50% percentile (P50).

Generation	**Electricity**	**Mean**	*Generation|Electricity|Year Mean*
		Maximum	*Generation|Electricity|Year Max*
		Minimum	*Generation|Electricity|Yeay Min*
		Summer, mean	*Generation|Electricity|Summer Mean*
		Winter, mean	*Generation|Electricity|Winter Mean*
		P25	*Generation|Electricity|P25*
		P50	*Generation|Electricity|50*

Generation	**Heat**	**Mean**	*Generation|Heat|Year Mean*
		Maximum	*Generation|Heat|Year Max*
		Minimum	*Generation|Heat|Yeay Min*
		Summer, mean	*Generation|Heat|Summer Mean*
		Winter, mean	*Generation|Heat|Winter Mean*
		P25	*Generation|Heat|P25*
		P50	*Generation|Heat|P50*

Generation	**Hydrogen P2G P2L**	**Mean**	*Generation|Hydrogen|Year Mean*
		Maximum	*Generation|Hydrogen|Year Max*
		Minimum	*Generation|Hydrogen|Yeay Min*
		Summer, mean	*Generation|Hydrogen|Summer Mean*
		Winter, mean	*Generation|Hydrogen|Winter Mean*
		P25	*Generation|Hydrogen|P25*
		P50	*Generation|Hydrogen|P50*

7.5 Economic, environmental and primary energy consumption indicators

7.5.1 Investments and prices

Some of the models, participating in the comparison exercise, can be used for exploring economic aspects related to technology deployment in the future energy matrix. To keep consistency **with Section 3**, the same combination of fuel and energy conversion processes will be considered for reporting the required capital investment costs. For example, in the case of power plants with primary solid biomass boiler as part of the generation island, the identifier will be: *Investment|Generation|Electricity| Solid bio and waste|Boiler|Solid primary biomass.* Investment for the transmission of secondary fuels and CO_2 transport will be also included in the database.

Investment	**Transmission**	**Electricity**	*Investment|Transmission|Electricity*
		CO_2	*Investment|Transmission|CO_2*
		Hydrogen	*Investment|Transmission|Hydrogen*
		P2G	*Investment|Transmission|P2G*
		P2L	*Investment|Transmission|P2L*
		Heat	*Investment|Transmission|Heat*
		Transboundary electricity	*Investment|Transmission|Transboundary electricity*

Some of the models can predict the hourly price for secondary energy vectors, mainly electricity. The same reasoning than for hourly demand and generation can be applied.

Price	**Electricity**	**Mean**	*Price|Electricity|Year Mean*
		Maximum	*Price|Electricity|Year Max*
		Minimum	*Price|Electricity|Yeay Min*
		Summer, mean	*Price|Electricity|Summer Mean*
		Winter, mean	*Price|Electricity|Winter Mean*
		P25	*Price|Electricity|P25*
		P50	*Price|Electricity|P50*

		Mean	*Price|Heat|Year Mean*
		Maximum	*Price|Heat|Year Max*

Price	**Heat**	**Minimum**	*Price|Heat|Yeay Min*
		Summer, mean	*Price|HeatSummer Mean*
		Winter, mean	*Price|Heat|Winter Mean*
		P25	*Price|Heat|P25*
		P50	*Price|Heat|P50*

Price	**Hydrogen**	**Mean**	*Price|Hydrogen|Year Mean*
		Maximum	*Price|Heat|Year Max*
		Minimum	*Price|Heat|Yeay Min*
		Summer, mean	*Price|HeatSummer Mean*
		Winter, mean	*Price|Heat|Winter Mean*
		P25	*Price|Heat|P25*
		P50	*Price|Heat|P50*

7.5.2 Emissions

The intercomparison database will also include greenhouse gas and air pollutant emissions. Some models may consider all IPCC reporting categories[34], others may focus on the energy demand and supply chain or on particular subcategories within the latter. The following table illustrates the identifiers for the so called "Kyoto gases"[35]. Modellers could report other compounds following the proposed structure.

[34] Microsoft Word - V1_Ch8_Reporting_Guidance_final_v3.doc (iges.or.jp)

[35] Kyoto gases include fossil CO2, methane, N2O and F-gases.

<table>
<tr><td rowspan="7">Energy[36]</td><td rowspan="7">Demand</td><td rowspan="6">Buildings</td><td rowspan="3">Residential</td><td rowspan="3">Heating</td><td colspan="2">Emissions|<Kyoto gases>[37]|Energy|Demand|Buildings|Residential| Heating</td></tr>
<tr><td>Space</td><td>Emissions|<Kyoto gases>|Energy|Demand|Buildings| Residential| Heating|Space heating|Fuel</td></tr>
<tr><td>Water</td><td>Emissions|<Kyoto gases>|Energy|Demand|Buildings| Residential| Heating|Water heating|Fuel</td></tr>
<tr><td rowspan="3">Commercial</td><td rowspan="3">Heating</td><td colspan="2">Emissions|<Kyoto gases>|Energy|Demand|Buildings|Commercial| Heating</td></tr>
<tr><td>Space</td><td>Emissions|<Kyoto gases>|Energy|Demand|Buildings| Commercial|Heating|Space heating|Fuel</td></tr>
<tr><td>Water</td><td>Emissions|<Kyoto gases>|Energy|Demand|Buildings| Commercial|Heating|Water heating|Fuel</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">Emissions|<Kyoto gases>|Energy|Transportation|Road|Passenger</td></tr>
</table>

[36] Emissions from fuel combustion. The “Energy” sub-category is equivalent to 1.A in IPCC Guidelines.
[37] Sum of fossil C_{O2}, methane and N_2O emissions, expressed in CO_2 equivalents.

		Transportation	**Road**	**Passenger**	**Passeng er cars**	*Emissions|<Kyoto gases>|Energy|Transportation|Road |Passenger|Passenegr cars|Fuel*
					Two wheels	*Emissions|<Kyoto gases>|Energy|Transportation|Road| Passenger|Two wheels|Fuel*
					Buses and coaches	*Emissions|<Kyoto gases> Energy|Transportation|Road| Passenger||Buses and coaches|Fuel*
				Freight Freight	*Emissions|<Kyoto gases>|Energy|Transportation|Road|Freight*	
					Light duty	*Emissions|<Kyoto gases>|Energy|Transportation|Road| Freight| Light Duty*
					Heavy duty	*Emissions|<Kyoto gases>|Energy|Transportation|Road |Freight| Heavy Duty*
			Rail	*Emissions|<Kyoto gases>|Energy|Transportation|Rail|Passenger*		
				Passenger	*Emissions|<Kyoto gases>|Energy|Demand|Transportation|Rail| Passenger|Fuel*	

<table>
<tr><td rowspan="11">Energy</td><td rowspan="10">Demand</td><td rowspan="7">Transportation</td><td></td><td>Freight</td><td>Emissions|<Kyoto gases>|Energy|Demand|Transportation|Rail|Freight|Fuel</td></tr>
<tr><td rowspan="3">Navigation</td><td colspan="2">Emissions|<Kyoto gases>|Energy|Transportation|Navigation</td></tr>
<tr><td>Passenger</td><td>Emissions|<Kyoto gases>|Energy|Demand|Transportation|Navigation|Passenger|Fuel</td></tr>
<tr><td>Freight</td><td>Emissions|<Kyoto gases>|Energy|Demand|Transportation|Navigation|Freight|Fuel</td></tr>
<tr><td rowspan="3">Aviation</td><td colspan="2">Emissions|<Kyoto gases>|Energy|Transportation|Aviation</td></tr>
<tr><td>Passenger</td><td>Emissions|<Kyoto gases>|Energy|Demand|Transportation|Aviation|Passenger| Fuel</td></tr>
<tr><td>Freight</td><td>Emissions|<Kyoto gases>|Energy|Demand|Transportation|Aviation|Freight|Fuel</td></tr>
<tr><td rowspan="3">Industry</td><td colspan="3">Emissions|<Kyoto gases>|Energy|Industry</td></tr>
<tr><td>Light</td><td colspan="2">Emissions|<Kyoto gases>|Energy|Demand|Industry|Light|Fuel</td></tr>
<tr><td>Heavy</td><td colspan="2">Emissions|<Kyoto gases>|Energy|Demand|Industry|Heavy|Fuel</td></tr>
<tr><td></td><td>Electricity</td><td colspan="3">Emissions|<Kyoto gases>|Energy|Supply|Electricity|Fuel</td></tr>
</table>

<table>
<tr><td></td><td>Supply</td><td>H_2</td><td></td><td>Emissions|<Kyoto gases>|Energy|Supply|H_2|Fuel</td></tr>
<tr><td></td><td></td><td>Heat</td><td></td><td>Emissions|<Kyoto gases>|Energy|Supply|Heat|Fuel</td></tr>
<tr><td></td><td></td><td>Syngas</td><td></td><td>Emissions|<Kyoto gases>|Energy|Supply|Syngas|Fuel</td></tr>
<tr><td>Non-energy[38]</td><td colspan="4">Emissions|<Kyoto gases>Non-energy|</td></tr>
<tr><td></td><td>Fugitive emissions[39]</td><td colspan="3">Emissions|<Kyoto gases>|Non-energy|Fugitive|</td></tr>
<tr><td></td><td></td><td>Liquid fuel production</td><td></td><td>Emissions|<Kyoto gases>|Fugitive|Liquid fuel production</td></tr>
<tr><td></td><td></td><td>Gaseous fuel production</td><td></td><td>Emissions|<Kyoto gases>|Fugitive|Gaseous fuel production</td></tr>
<tr><td></td><td>Processes[40]</td><td></td><td colspan="2">Emissions|<Kyoto gases>|Processes</td></tr>
<tr><td></td><td></td><td>Minerals</td><td colspan="2">Emissions|<Kyoto gases>|Processes|Minerals</td></tr>
<tr><td></td><td></td><td></td><td>Cement</td><td>Emissions|<Kyoto gases>|Processes|Minerals|Cement</td></tr>
<tr><td></td><td></td><td></td><td>Lime</td><td>Emissions|<Kyoto gases>|Processes|Minerals|Lime</td></tr>
<tr><td></td><td></td><td></td><td>Glass</td><td>Emissions|<Kyoto gases>|Processes|Minerals|Glass</td></tr>
<tr><td></td><td></td><td></td><td>Others</td><td>Emissions|<Kyoto gases>|Processes|Minerals|Others</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">Emissions|<Kyoto gases>|Processes|Chemicals</td></tr>
<tr><td></td><td></td><td></td><td>Ammonia</td><td>Emissions|<Kyoto gases>|Processes|Chemicals|Ammonia</td></tr>
</table>

[38] Non-energy includes emissions from non-combustion related processes (all chapters from IPCC Guidelines, except 1).
[39] Non combustion emissions derived from fuel exploration, extraction, production and transport.
[40] Non combustion emissions from industrial processes.

Non-energy	**Processes**	**Chemicals** **Chemical production and use**	**Nitric acid production**	Emissions|<Kyoto gases>|Processes|Chemicals|Nitric acid
			Adipic acid	Emissions|<Kyoto gases>|Processes|Chemicals|adipic acid
			Caprolactal/ glycoxal	Emissions|<Kyoto gases>|Processes|Chemicals|Caprolactam
			Carbide	Emissions|<Kyoto gases>|Processes|Chemicals|Carbide
			Titanium oxide	Emissions|<Kyoto gases>|Processes|Chemicals|TiO_2
			Soda Ash	Emissions|<Kyoto gases>|Processes|Chemicals|Soda Ash
			Petrochemicals	Emissions|<Kyoto gases>|Processes|Chemicals|Petrochemicals
			Others	Emissions|<Kyoto gases>|Processes|Chemicals|Others
		Metals	Emissions|<Kyoto gases>|Processes|Metals|	
			Iron and steel	Emissions|<Kyoto gases>|Processes|Metals|Iron
			Ferroalloys	Emissions|<Kyoto gases>|Processes|Metals|Ferroalloys
			Aluminium	Emissions|<Kyoto gases>|Processes|Metals|Aluminium
			Magnesium	Emissions|<Kyoto gases>|Processes|Metals|Magnesium
			Lead	Emissions|<Kyoto gases>|Processes|Metals|Lead
			Zinc	Emissions|<Kyoto gases>|Processes|Metals|Zinc
			Others	Emissions|<Kyoto gases>|Processes|Metals|Others

<table>
<tr><td rowspan="7"></td><td rowspan="3"></td><td>Non energy and solvent use</td><td colspan="3">Emissions|<Kyoto gases>|Processes|Non-energy and solvent</td></tr>
<tr><td>Electronics</td><td colspan="3">Emissions|<Kyoto gases>|Processes|Electronics</td></tr>
<tr><td>Others</td><td colspan="3">Emissions|<Kyoto gases>|Processes|Others</td></tr>
<tr><td rowspan="4">AFOLU</td><td colspan="4">Emissions|<Kyoto gases>|AFOLU</td></tr>
<tr><td rowspan="2">Agriculture</td><td>Livestock</td><td>Fermentation</td><td>Emissions|<Kyoto gases>|AFOLU|Agriculture|Livestock|Fermentation</td></tr>
<tr><td>Livestock</td><td>Manure management</td><td>Emissions|<Kyoto gases>|AFOLU|Agriculture|Livestock| Manure management</td></tr>
<tr><td>Land use</td><td colspan="3">Emissions|<Kyoto gases>|AFOLU|Land use</td></tr>
<tr><td rowspan="6">Non-energy</td><td rowspan="6">AFOLU</td><td rowspan="6">Aggregated and non CO_2</td><td>Biomass burning</td><td colspan="2">Emissions|<Kyoto gases>|Aggregated and non CO_2|Biomass burning</td></tr>
<tr><td>Liming</td><td colspan="2">Emissions|<Kyoto gases>|Aggregated and non CO_2|Liming</td></tr>
<tr><td>Urea application</td><td colspan="2">Emissions|<Kyoto gases>|Aggregated and non CO_2|Urea application</td></tr>
<tr><td>N_2O managed soils</td><td colspan="2">Emissions|<Kyoto gases>|Aggregated and non CO_2|N_2O managed soils</td></tr>
<tr><td>Rice</td><td colspan="2">Emissions|<Kyoto gases>|Aggregated and non CO_2|Rice</td></tr>
<tr><td>Others</td><td colspan="2">Emissions|<Kyoto gases>|Aggregated and non CO_2|Others</td></tr>
</table>

		Others	Emissions|<Kyoto gases>|AFOLU|Others
	Waste	Emissions|<Kyoto gases>|Waste	
		Solid waste disposal	Emissions|<Kyoto gases>|Waste|SWD
		Biological treatment	Emissions|<Kyoto gases>|Waste|Biological treatment
		Incineration	Emissions|<Kyoto gases>|Waste|Incineration
		Wastewater	Emissions|<Kyoto gases>|Waste|Wastewater
		Others	Emissions|<Kyoto gases>|Waste|Others
	Indirect N_2O	Emissions|<Kyoto gases>|Indirect N_2O	

7.5.3 Other environmental indicators

As part of the different runs and the protocol evolution process, other environmental indicators associated with raw material and water consumption and biodiversity aspects are expected to be included in the dataset, supplementing the information for combustion related emissions and key non energy sectors This will be assessed after the second modelling run.

7.5.4 Primary energy resource consumption

Data for fuel disaggregated total primary energy consumption will be also included in the database. Having access to this information will enable to explore the penetration of renewable sources across the whole energy system under the assumptions of different scenarios and models. Total primary energy includes the consumption of primary energy vectors for satisfying final energy uses and as inputs for the production of secondary energy carriers. The modelling teams could report this information in a detailed way, on the basis of the IEA fuel definition, or else considering the fuel clusters defined as follows.

.

Coal and derivatives	**Coal**	*Primary energy|Coal|*
	Coal, CCS[41]	*Primary energy|Coal|CCS*
	Brown,	*Primary energy|Coal|Brown*
	Brown, CCS	*Primary energy|Coal|Brown|CCS*
	Hard	*Primary energy|Coal|Hard*
	Hard, CCS	*Primary energy|Coal|Hard|CCS*
	Coal derivatives	*Primary energy|Coal|Coal products*
	Coal derivatives, CCS	*Primary energy|Coal|Coal products|CCS*
Liquid fuels	**Liquids Fossil**	*Primary energy|Liquids|Fossil*
	Liquids Fossil, CCS	*Primary energy|Liquids|Fossil|CCS*
	Liquids biogenic	*Primary energy|Liquids|Bio*
	Liquids biogenic, CCS	*Primary energy|Liquids|Bio|CCS*
	Natural Gas	*Primary energy|Gases|Natural gas|*

[41] It would be useful if modellers could inform the total primary energy consumption associated with fuels being operated in combustion technologies with installed CCS processes.

Gaseous fuels	**Natural Gas, CCS**	*Primary energy|Gases|Natural gas|CCS*
	Biogas	*Primary energy|Gases|Bio|Biogas*
	Biogas, CCS	*Primary energy|Gases|Bio|Biogas|CCS*
	Biomethame	*Primary energy|Gases|Bio|Biomethane*
	Biomethane, CCS	*Primary energy|Gases|Bio|Biomethane|CCS*
Solid bio and waste	**Solid primary biomass**	*Primary energy|Solid bio and waste|Solid primary biomass*
	Solid primary biomass, CCS	*Primary energy|Solid bio and waste|Solid primary biomass*
Solid bio and waste	**Waste Renewable,**	*Primary energy|Solid bio and waste|Solid primary biomass|Waste Renewable*
	Waste Renewable, CCS	*Primary energy|Solid bio and waste|Solid primary biomass|Waste Renewable|CCS*
	Waste non renewable	*Primary energy|Solid bio and waste|Waste non renewable*
	Waste non renewables, CCS	*Primary energy|Solid bio and waste|Waste non renewable|CCS*
Nuclear	*Primary energy|Nuclear*	
Wind	*Primary energy|Wind*	
Solar	*Primary energy|Solar*	
Other renewables	*Primary energy|Oth renewables*	
	Geothermal	*Primary energy| Oth renewables|Geothermal*
	Hydro	*Primary energy| Oth renewables|Hydro*

7.6 Key model inputs

The participants are requested to provide data for the most significant inputs to their models. This will allow to spot those variables that lead to larger variations among the results, setting the basis for the data input harmonisation experiments.

Inputs	**Demographic indicators**	**Population**	*Population*
		Household numbers	*Households*
		Area per household	*Area per household*
	Economic indicators	**GDP per capita**	*GDP per capita*
		Value added, agric	*Value added|Agriculture*
		Value added, heavy industry	*Value added|Heavy industry*
		Value added, light industry	*Value added|Light industry*
		Value added, serv	*Value added|Services*
	Efficiency	**Building envelope effc. increase**[42]	*Building envelope effc. increase*
		Heat pump, effc. increase	*Heat pump effc. increase*
		Industrial, effc. increase (heavy ind)	*Heavy industry effc. increase*
		Industrial, effc. increase (light ind)	*Light industry effc. increase*
		Road transport passenger, effc. increase[43]	*Road transport passenger effc. increase*
		Road transport freight, effc. increase[44]	*Road transport freight effc. increase*
		Rail passenger, effc. increase	*Rail passenger effc. increase*
		Rail freight, effc. increase	*Rail freight effc. increase*
		Air passenger, effc. inc	*Air passenger effc. increase*

[42] The modellers could distinguish between increase in building envelope efficiency for the residential and the commercial sector. Proposed identifier: *Building envelope effcc. increase|Residential or Building envelope effc.increase|Commercial.*

[43] Modellers could provide data for different types of vehicles and fuels. Example: *Road transport passenger eff increase|PC|Gasoline or Road transport passenger eff increase|PC|Electricity.*

[44] Participants can further specify changes in efficiency, for example, increase in efficiency for diesel fuelled high duty vehicles by using the identifie: *Road transport freight effc. increase|Heavy Duty|Diesel.*

Inputs		**Air freight, effc. increase**	*Air freight effc. increase*
		Sea passenger, effc. increase	*Sea passenger effc. increase*
		Sea freight, effc. increase	*Sea freight effc. increase*
	Electrification[45]	**Elec share for residential heating**	*Electricity shares|Heating|Residential*
		Elec share for commercial heating	*Electricity shares|Heating|Commercial*
		Elec share road transport[46]	*Electricity shares|Road transport*
		Elec share rail transport	*Electricity shares|Rail transport|*
	Climatic variables, wind and solar data	**HDD**	*Heating degree days*
		CDD	*Cooling degree days*
		Wind, capacity factor	*Wind, capacity factor*
		Solar, capacity factor	*Solar, capacity factor*
	Fuel and carbon prices	**Oil price**	*Fuel prices|Oil|*
		Nat Gas price	*Fuel prices|Natural gas*
		Coal price	*Fuel prices|Coal*
		Carbon price	*Fuel prices|Carbon price*
	Conversion technologies	**Efficiency conv technologies [47]**	*Efficiency|Conversion techno*
		Levelised cost conv technologies[48]	*Levelised|Electricity|Conversion techno* *Levelised|Heat|Conversion techno* *Levelised|Hydrogen|Conversion techno*
	Energy statistics (reference year)	**Final energy consumption**	*Final energy|Sector|Subsector*
		Secondary energy consumption	*Secondary energy|Sector|Subsector*
		Primary energy consumption	*Primary energy|Sector|Subsector*

7.7 List of units

For each of the key variables considered in the database, the next units are proposed.

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[45] Share of electricity in total fuel consumption.
[46] It will depend on the model features.
[47] Participants could provide this information for the different conversion technologies for the production of secondary fuels, described in Section 3. For example, the identifier for the efficiency of solid biomass fuelled steam cycle based power plants would be*: Efficiency|Soli bio and waste| Boiler|Solid primary biomass.*
[48] Modellers could supply data for the levelised cost of the different conversion technologies for the production of secondary energy vectors. For example, a participant could report the model assumptions for the levelised cost of electricity associated with coal supercritical plants with CCS. To do so, the proposed identifier would be;: ELevelised|Electricity|Coal|Boiler|SC|CCS.

Variable		Unit
Energy consumption	*Primary*	**EJ/y or EJ/h**[49]
	Secondary	
	Final energy uses	
Installed capacity for generation[50]	*Electricity*	**GW_e**
	H_2	**GW_{th}**
	Heat	**GWt_h**
	P2G and P2L	**GW_{th}**
	Storage (electricity/heat)	**GW_e/GW_{th}**
Transmission (installed capacity)	*Electricity*	**GW_ekm**
	H_2	**GW_{th}km**
	Heat	**GW_{th}km**
	P2G and P2L	**GW_{th}km**
	CO_2	**tonCO_2km**
Generation and transmission (capital investment costs)[51]	*Electricity*	**billion US$2017/y or total billion US$20157**
	H_2	
	Heat	
	P2G and P2L	
	CO_2	
Secondary energy vectors (Generation)	*H_2*	**EJ_{th}/y or EJ_{th}/h**
	Heat	
	P2G	
	Electricity	**EJ_e/y or EJ_e/h**
Hourly prices	*Electricity*	**US$2017/$MWh_e$**
Hourly prices	*H_2*	**US$2017/$GJ_{th}$**
	Heat	**US$2017/$GJ_{th}$**
	P2G	
Emissions	*Kyoto gases (as a whole)*	**Mton CO_{2eq}/y**
	Individual Kyoto gases	**Mton/y**
	Air pollutants	

[49] Depending whether the data is reported at yearly or hourly temporal granularity.
[50] In the case of electricity, the installed capacity is the one corresponding to the net plant output. For H_2 and power to fuels, the installed capacity could be calculated considering the total amount of fuel that the plant could produce (in mass or volume) multiplied by the fuel low heating value.
[51] Capital investment costs for generation and transmission of secondary energy vectors and CO_2 to be expressed in billions of US$ at 2017 PPP.

Water	*Extraction*	**m^3**
	Metabolic Rate	**m^3/h**
Raw Materials	*Material 1*	**ton**
	Material n	**ton**
Land use	*Land type 1*	**ha**
Demographic variables	*Population*	**million hab**
	Number of households	**million**
	Area per household	**m^2/household**
Economic variables	*Value added*	**billion US$2017/y**
	GDP per capita	**kUS$ 2017/habitant**
Increase in efficiency	*Building envelope efficiency*	**Percentage (%) in comparison with reference year**
	Road transport, passenger	
	Road transport, freight	
	Rail transport, passenger	
	Rail transport, freight	
	Navigation, transport	
	Navigation, passenger	
	Aviation, transport	
	Aviation, freight	
	Heavy industry	
	Light industry	
Electrification	*Residential, heating*	**Percentage (%) defined on the basis of the sectorial final energy consumption.**
	Commercial, heating	
	Road transport, passenger	
	Road transport, freight	
	Rail	
Climatic variables	*Heating/ cooling degree day*	**days*difference of temperature[52]**
	Wind/ Solar capacity factor	**Percentage (%)**
	Oil	**US$2017/GJ**
	Natural Gas	

[52] Considering the region of interest, 15 or 18 degree could be considered, based on the definition of the Hotmaps tool (https://gitlab.com/hotmaps/climate/HDD_ha_curr/blob/master/README.md)

Fuel and carbon prices	*CO_2*	**US$2017/ ton CO_2**
Conversion technologies **Conversion technologies**	*Efficiency*	**Percentage (%)**
	Levelised Cost	**US$2017/ MWh_e (electricity)** **US$2017/GJ** **(Heat, H_2 and P2G)**

8 APPENDIX

8.1 Split up of climate neutrality goals to sectors based on EU documents

Table 1. General overview for total GHG emissions and energy consumption

	Current trends		*Climate neutrality*[53]		*Early neutrality*
	2030	**2050**	**2030**	**2050**	**2040**
Total GHG reductions (incl LULUCF) Mt CO_{2eq}	< 2900	< 2000	< 2400	< 25	< 25
Reduction 1990 (%)	47%	64%	55%	Nearly 100	Nearly 100
Total GHG reductions (excl LULUCF) Mt CO_{2eq}	< 3100	< 2000	< 2700	(350-500)	(350-500)
Fossil CO_2 emissions ($MtCO_{2eq}$)					
Total	<2400	< 1600	<2000	< 200	< 200
Residential	< 200	< 130	< 137	< 15	< 15
Road transport	< 720	< 460	< 680	< 20	< 20
Tertiary	< 82	< 80	< 74	< 20	< 20
Industry	< 590	< 500	< 572	< 60	< 60
Power	< 500	< 246	< 330	< 20[54]	< 20
Total primary energy consumption (Mtoe)	< 1300	< 1300	< 1175	1000-1400	1100-1300
Total final energy consumption (Mtoe)	< 1050	< 900	< 800	< 700	< 700

Table 2. Energy demand in buildings and fuel basket

	Current trends		**Climate neutrality**	
	2030	**2050**	**2030**	**2050**
Reduction in useful energy				

[53] The figures presented in the tables for 2030, under the assumption climate neutrality scenario, are based on applying the EU wide caps to the UK too. However, it must be noted that the UK has defined more ambitious targets, which comprise total GHG emission reduction of 68% by 2030 in comparison with 1990 (CCC, 2020).
[54] Scenarios forecast negative emission power production to attain carbon neutrality.

for space heating (compared with 2015)	32%	54.5%	> 32%	> 60%
Share of electricity in heating fuel baskets	12%	22%	> 12%	> 30%
Commercial				
Reduction in useful energy for space heating (compared with 2015)	27%	40%	> 27%	> 40%
Share of electricity in heating fuel baskets	30%	50%	> 30%	>50%
Other vectors for combustion based heat generation				
In Baseline scenario, natural gas and solid biomass are still the most consumed fuels. In the other scenarios, a high incorporation of e-gases and biomethane is assumed Higher penetration of non-fossil energy vectors by 2030 in the UK when considering nationally defined objectives[55].				

Table 3. Shares in total number of units per vehicle type

	Current trends		Climate neutrality	
	2030	**2050**	**2030[56]**	**2050**
Cars				
Gasoline type	40%	20%	40%	0.5%[57]
Diesel type	40%	22%	35%	0.5%
Gaseous	4%	5%	5%	0
Plug in hybrid	6%	18%	5%	2.0%
Electric	9%	30%	15%	80%
Fuel cell	1%	5%	0%	17%
Light duty vehicles[8]				
Gasoline	5%	3%	4%	---
Diesel	83%	50%	80%	3%

[55] According to the UK decarbonisation pathways, presented in the Sixth Carbon Budget, heat pumps are expected to significantly contribute to heat demand in buildings. The ban for sales of fossil fuelled boilers is forecasted to occur between 200-2032 whilst H_2 is foreseen to play a key role for heating too.
[56] In the UK, the sale of newly manufactured fossil fuelled units is forecasted to be banned from 2030 onwards. Fleet is expected to be made up by 80% of battery vehicles and the remaining is plug in hybrid.
[57] Mostly vehicles being operated using e-fuels and biofuels.

Gaseous	--	---	--	--
Plug in hybrid	6%	21%	6%	2%
Electric	5%	25%	9.5%	80%
Fuel cell	1%	1%	0.5%	15%
<u>Heavy duty vehicles and buses</u>				
Gasoline	--	--		--
Diesel	80%	50%	73%	35%
Gaseous	5%	20%	9%	30%
Plug in hybrid	15%	25%	17%	20%
Electric	--	2.5%	0.5	10%
Fuel cell	--	2.5%	0.5	5%

Table 4. Fuel basket and efficiency increase for other categories within the transport sector

Rail				
	Current trends		**Climate neutrality**	
	2030	**2050**	**2030**	**2050**
Passenger rail transport, electricity in fuel basket	< 87%	87%	< 95%	95%
Freight rail transport, electricity in fuel basket	< 77%	77%	< 88.5%	88.5%
Navigation				
Efficiency increase in comparison with 2015	12%-13%			
Fuel basket				
Fossil liquid	>= 87%	87%	Between 43.5% and 87%	43.5%
LNG	< 13%	13%	To be estimated aiming at fulfilling emission reductions and demand	12.5%
Bioliquids	--	--		39%
E-liquids	--	--		5%
H_2	--	--		--
Aviation				
Efficiency increase in comparison with 2015	25%	39%	> 25%	42%
Fossil fuels	100%	95%	Lower penetration of	Between 40.7% and 45.5%

			fossil fuels than in 2030 for current trends	
Biokerosene	--	5%	Higher penetration than in 2030 for current trends	Between 27.1 and 43.5%
E-fuels	--		< 14%	Between 10% and 31%

Table 5. Fuel basket and efficiency increase for the industrial sector

	Current trends		**Climate neutrality**	
	2030	**2050**	**2030**	**2050**
Efficiency increase	10%	11-12%	12%	> 22% and < 31%
Fuel basket	Decrease of natural gas consumption in favour of electricity and e-gases.			

Table 6. Shares of fuel based installed capacity for power generation

	Current trends		**Climate neutrality**	
	2030	**2050**	**2030**[58]	**2050**
Wind	27.4%	40.7%	33.3%	38.5%[8]
Solar	14.5%	20.3%	13.3%	44.0%
Nuclear	19.3%	5.4%	13.3%	2.8%
Fossil	22.6%	20.0%	20.0%	5.5%
BECCS	--	--	---	1.8%
Others	16.1%	13.6%	20.0%	7.3%

[58] UK new targets involve that 60% of generated power relies on renewable sources whist it is assumed that H_2 and CCS will be deployed for a significant share of natural gas generation. New nuclear power plants are envisaged to be built too (CCC, 2020).

8.2 EU policies for current trends

Sector	Policy	Coverage sectors	Policy goal
Economy-wide	Energy Efficiency Directive	Economy-wide	20% energy efficiency improvement target for 2020
			=1483 Mtoe of primary energy or 1086 Mtoe of final energy
			32.5% energy efficiency improvement in 2030
			=1273 Mtoe of primary energy and 956 Mtoe of final energy
	Effort sharing	Non-ETS: transport, buildings, agriculture, waste	10% reduction in total emissions from the sectors covered by 2020 compared with 2005 levels
			and of 30% by 2030 compared with 2005 levels
	Renewable Energy Directive	Economy-wide	At least 32% of final energy consumption by 2030
	F-gas Regulation	Economy-wide	By 2030 F-gas emissions are decreased by two-thirds compared with 2014 levels.
Energy supply/industry	Emission Trading System		In 2020, emissions from sectors covered by the system will be 21% lower than in 2005
			In 2030, emissions from sectors covered by the EU ETS will be cut by 43% from 2005 levels
	Innovation fund		ETS revenues are invested in innovations
Transport	CO2 performance standards cars and vans	cars	Average fleet-wide standard for new registrations of 95 gCO2/km in 2021
			15% reduction of average fleet-wide standard of new registrations relative to 2021 by 2025
			37.5% reduction of average fleet-wide standard of new registrations relative to 2021 by 2030
			15 % low emissions share of the new passenger cars by 2025
			35 % low emissions share of the new passenger cars by 2030
		vans	Average fleet-wide standard for new registrations of 147 gCO2/km in 2020

			15% reduction relative to 2021 by 2025
			31.5% reduction relative to 2021 by 2030
			15% reduction of average fleet-wide standard of new registrations relative to 2020 by 2025
			30% reduction of average fleet-wide standard of new registrations relative to 2020 by 2030
	CO2 performance standards trucks and busses	large lorries	Start 2021
			15% reduction relative to 2020 by 2025
			30% reduction relative to 2020 by 2030
			Credit system for low emission trucks
		smaller lorries, buses, coaches and trailers.	Start 2023
			Targets are not decided yet
	Renewable Energy Directive		10 % share of energy from renewable sources in transport in Community energy consumption by 2020
			Renewable energy for final consumption of energy in the transport sector is at least 14 % by 2030
	Fuel Quality Directive		Reduction of the greenhouse gas intensity of transport fuels by a minimum of 6% by 2020
			on a life-cycle basis against a 2010 baseline of 94.1 gCO2eq/MJ
			Biofuels sustainability criteria
	Car Labelling Directive		Labelling
	Shipping Strategy		Labelling
			Supporting IMO greenhouse gas strategy
	Emission Trading System (Aviation)		CO_2 emissions from aviation have been included in the EU ETS) since 2012 (flights within EU)
Buildings	Buildings Directive		all new buildings must be nearly zero-energy buildings (NZEB) from 31 December 2020
			Since 31 December 2018, all new public buildings already need to be NZEB

			Energy efficient renovations to at least 3% per year of buildings owned and occupied by central governments
			Minimum energy efficiency standards and labelling for appliances
AFOLU	Effort sharing (LULUCF)		Net LULUCF emissions for each MS are zero or lower
			The scope is extended from only forests today to all land uses (and including wetlands by 2026)
Environment	**Water Framework Directive**		
	Strategy for a circular economy		
	Habitats Directive/Biodiversity Strategy		

8.3 EU policy documents

Clean Planet for all
https://ec.europa.eu/clima/policies/strategies/2050_en
A Clean Planet for all A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy
https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018DC0773
In depth analysis
IN-DEPTH ANALYSIS IN SUPPORT OF THE COMMISSION COMMUNICATIONCOM(2018) 773
https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf

2030 Climate Target Plan
https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018DC0773

COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Stepping up Europe's 2030 climate ambition Investing in a climate-neutral future for the benefit of our people COM/2020/562 final
https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0562

Impact assessment

COMMISSION STAFF WORKING DOCUMENT IMPACT ASSESSMENT Accompanying the document COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Stepping up Europe's 2030 climate ambition Investing in a climate-neutral future for the benefit of our people SWD/2020/176 final
https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020SC0176

Supplementary Information

https://ec.europa.eu/clima/sites/clima/files/eu-climate-action/docs/2030_climate_target_plan_figures_en.xlsx

2050 long-term strategy
Strategy
https://ec.europa.eu/clima/policies/strategies/2050_en
https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf

Green Deal
https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en
https://ec.europa.eu/info/sites/info/files/european-green-deal-communication-annex-roadmap_en.pdf

Climate law
https://ec.europa.eu/clima/policies/eu-climate-action/law_en

Mid-century strategy to UNFCCC
https://unfccc.int/documents/210328

Transition pillars

- GHG emissions
  https://ec.europa.eu/clima/sites/clima/files/docs/pages/vision_1_emissions_en.pdf
- Economic
  https://ec.europa.eu/clima/sites/clima/files/docs/pages/vision_4_economic_en.pdf
- Industrial
  https://ec.europa.eu/clima/sites/clima/files/docs/pages/vision_2_industrial_en.pdf
- Societal
  https://ec.europa.eu/clima/sites/clima/files/docs/pages/vision_3_social.pdf

2030 climate & energy framework
https://ec.europa.eu/clima/policies/strategies/2030_en
Framework targets

- 40% reduction of GHG emissions relative to 1990
- 32% share of renewables
- 32.5% energy efficiency improvement

- EU ETS
  - Industry/electricity production
- EU non-ETS
  - CO2 performance standards transport
    https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R0631&from=EN7
    https://ec.europa.eu/clima/policies/transport/vehicles/heavy_en
  - Biofuel standard
  - Building directive
- General
  - Renewable energy directive
    - Renewable electricity
    - Renewable energy use in transport
  - Energy efficiency directive
- UK targets, approved in December 2020
  - GHG emission reductions of 68% by 2030 in comparison with 1990.

- Ban for sales of newly manufactured fossil fuelled units for cars and light duty vehicles.
- Bans for sales of newly natural gas boilers in buildings.
- 60% of renewably generated power.
- Further details in policies can be found in the Sixth Carbon Budget. Available at: Policies-for-the-Sixth-Carbon-Budget-and-Net-Zero.pdf (theccc.org.uk)

9 SENTINEL models

A detailed description can be found in the Annex (SENTINEL models.xlsx)

Table 8 Participating models in SENTINEL project

Model type	Model	Description	Institute
Social/environmental	QTDIAN	Quantification of Technological Diffusion and Social Constraints allows for the explicit definition of transition constraint scenarios.	ETHZ
	ENVIRO	Is a checker of the coherence between energy system configurations and environmental policy objectives including water use, emissions, and raw materials considering the life cycle and network environmental impacts and natural resource use of different energy technologies.	UAB
	ATOM	Can simulate the expected effectiveness of technology adoption under policy schemes, and can quantify uncertainties related to agents' preferences and decision-making criteria	UPRC
Energy demand	DESSTINEE	An energy system model with focus on the electricity system. It is designed to test assumptions about the technical requirements for energy transport, and the economic challenge to develop the infrastructure.	Imperial
	BEVPO	Analyses the trips that are undertaken by EVs. It allows modelers to analyse the interactions of Battery EVs with local electricity grids.	ETHZ
	HEB	Analyses the building energy use and CO2 emissions. Using a performance-oriented approach, the performance of whole systems (e.g. buildings) is studied, and these values are used as inputs in the scenarios.	CEU
	DREEM	Serves as an entry point in Demand-Side Management modelling in the building sector. By expanding the computational capabilities of existing Building Energy System models, assesses the benefits and limitations of demand-flexibility.	UPR
System design	EnergyPLAN	Analyses the energy, environmental, and economic impact of various energy strategies. The key objective is to model a variety of options so that they can be compared with one another.	AAU

	Calliope	A framework to build energy system models as mathematical optimisation problems. It is designed to analyse systems, with particular attention given to variable renewable generation.	ETHZ
	IMAGE	An integrated modelling framework of interacting human and natural systems. It is suited to large scale and long-term assessments of interactions between human development and the natural environment, and integrates a range of sectors, ecosystems, and indicators.	UU
Economic impacts	EMMA	A techno-economic model of the integrated north-western European power system. It models both dispatch of and investment in power plants, minimizing total costs with respect to investment, production, and trade decisions.	HSG
	BSAM	Simulates the Day-Ahead Scheduling of wholesale electricity markets. Simulates the bids for electricity generation, sets market rules, and calculates residual loads and necessary RES curtailment. Using the generators' bids solves the Security Constrained Unit Commitment and Economic Dispatch problems.	UPRC
	WEGDYN	It is a computable general equilibrium (CGE) model that depict the whole economy, separated into different production sectors and demand agents.	UGR