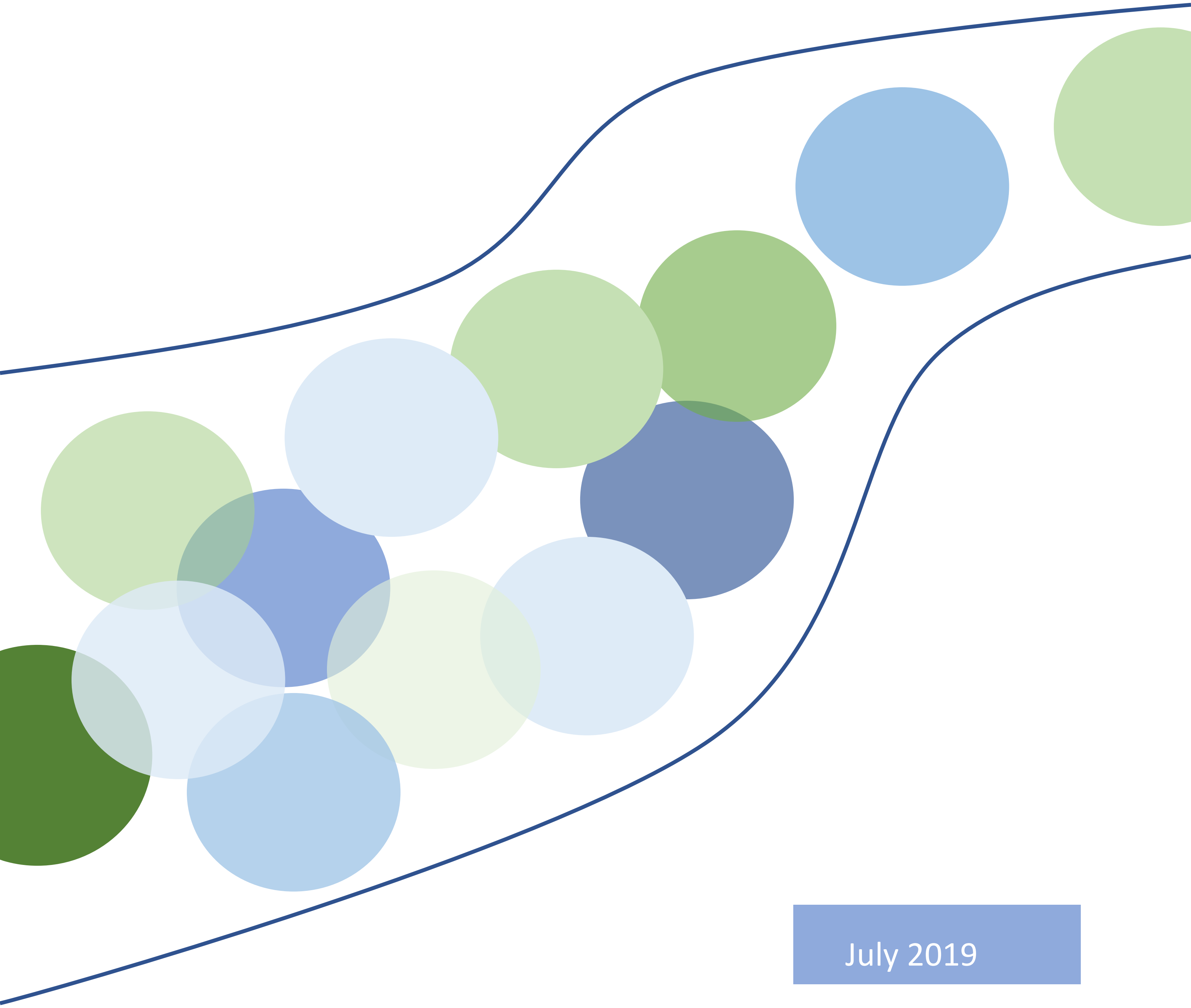
D7.3

OSeMBE – An open-source engagement model



July 2019

About this report

This report presents the Open Source energy Model Base for the European Union (OSeMBE), built in the Open Source energy Modelling SYStem (OSeMOSYS). It is the deliverable 7.3 originating from T7.3 Development of Open-source Engagement Model based on OSeMOSYS in the REEEM grant agreement. This report describes the long-term planning power-sector model, its rationale and the scenario runs that have been developed and performed under T7.3. Furthermore, a chapter is dedicated to the future development of the model. The report closes with a section on the potential future uses of OSeMBE as engagement model and research infrastructure.

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About REEEM

REEEM aims to gain a clear and comprehensive understanding of the system-wide implications of energy strategies in support of transitions to a competitive low-carbon EU energy society. This project is developed to address four main objectives: (1) to develop an integrated assessment framework (2) to define pathways towards a low-carbon society and assess their potential implications (3) to bridge the science-policy gap through a clear communication using decision support tools and (4) to ensure transparency in the process.

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1 Introduction

Anthropogenic climate change and increased awareness of health hazards in human's daily life and their long-term effects are main drivers for the transition to a low carbon energy system. There exist several technological options to meet current and future energy demands while ensuring that impacts on health and environment are reduced. All bear impacts on economies, societies and environment in different ways. Additionally, they will have implications on the future structure of the energy system, energy security and reliability of supply. Taking all this aspects together an integrated planning, that includes techno-economic analyses with strong interconnections between different planning stages as well as involvement of the public and key stakeholders is necessary (IRENA 2017b). A public dialogue requires publicly available information and transparency of tools and data used to allow an informed debate about options and alternatives and to foster acceptance of measures taken.

The Open-Source energy MOdelling SYStem (OSeMOSYS) stands for an approach of full data transparency and easy as well as freely accessible tools (Howells et al. 2011). Within the H2020 project REEEM OSeMOSYS was used to build an Open Source energy Model Base of the European Union (OSeMBE), representing – in its first release - the electricity demand and supply systems of the EU28+2 (Norway and Switzerland) countries and their interconnections. OSeMBE is purposefully designed as an engagement model. As such, it aims to illustrate to expert and non-expert stakeholders key dynamics of the transition to a low-carbon EU energy system featured in TIMES PanEU, however leaving out its detail and complexity.

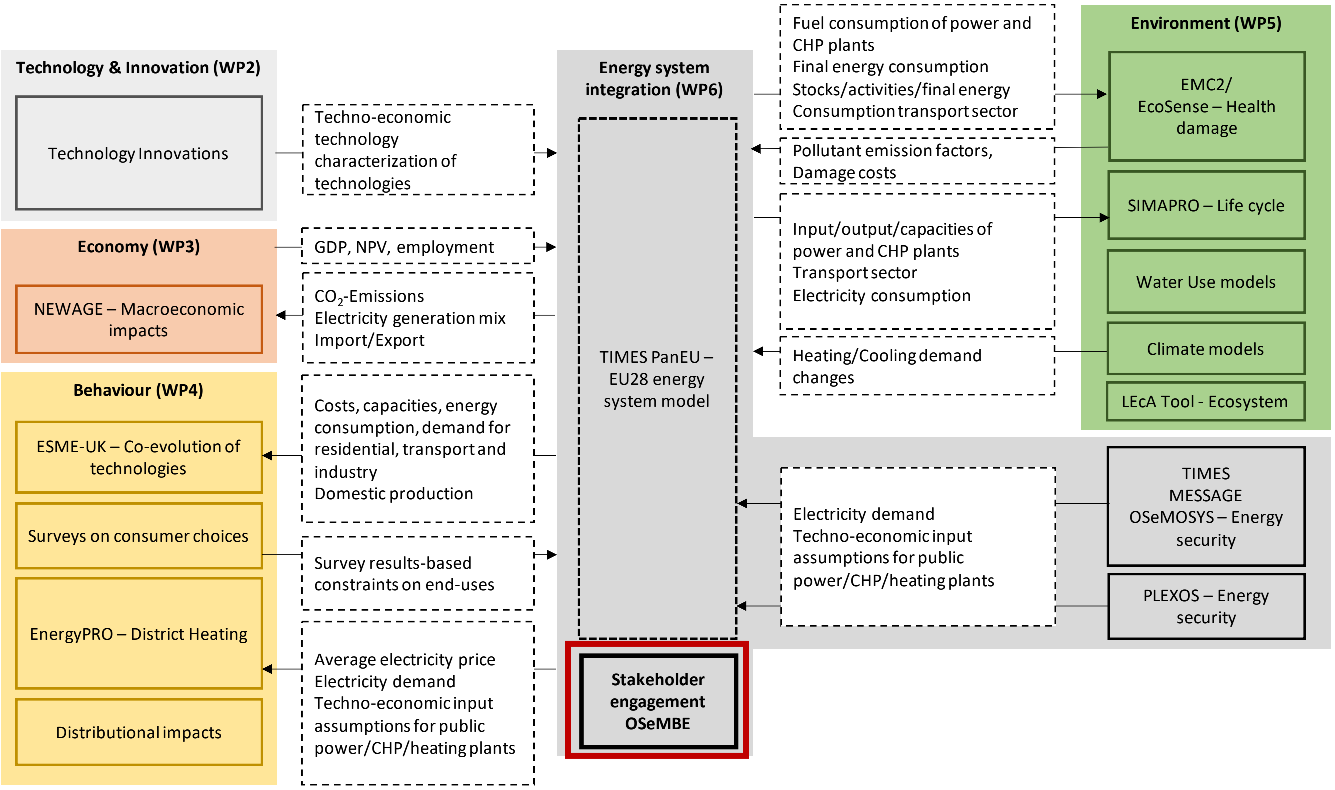


Figure 1. REEEM modelling framework

2 OSeMBE in brief

The Open Source energy MOdelling SYStem (OSeMOSYS) was used to build OSeMBE. Its structure includes the 28 EU member states, Norway and Switzerland as connected regions. Each region has a set of technologies and fuels available and can exchange electricity with its neighbours. The energy resources considered are: liquid biofuels, solid biomass, coal, geothermal energy, heavy fuel oil, natural gas, oil, oil shale, solar energy, uranium, waste, waves, and wind. The model distinguishes between domestic resources and imported resources. The resources can be converted to electricity by using combined cycle power plants (PPs), CHP PPs, fuel cells, gas cycle PPs, integrated gasification combined cycle PPs, internal combustion engines, nuclear reactors of generation II and III, solar photovoltaic, steam cycle PPs, and wind turbines. The model covers the years 2015 to 2050. Every year is divided into five seasons and one typical day per season. Each day is further divided into three parts. To allow the analysis of the environmental impact of the power system, CO_2 and PM 2.5 are considered.

The key output metrics of OSeMBE in REEEM relate to economic, environmental and social impacts of the transition to a low-carbon EU electricity system. They are:

- Economic: Discounted investment per citizen, this indicator is available for entire Europe and per country, which allows to compare the investment needs among countries.
- Environmental: CO_2 per citizen. The carbon intensity per citizen allow the comparison in between countries but also the comparison over time. Of interest is not only what the countries might reach in 2050 but also the different starting situations in 2015
- Social: Levelised Cost of Electricity (LCOE) – do not indicate the final price. However, the LCOE gives a good indication on the cost for electricity generation which have an impact on the final price.

Table 1 summarises the characteristics of OSeMBE into a Fact sheet, also shared on the Open Energy Platform.

Table 1. Fact sheet OSeMBE

	Item	OSeMBE
1	**General Information**	
1.01	Model name	The Open-Source energy Model Base for the European Union
1.02	Acronym	OSeMBE
1.03	Institution(s)	KTH
1.04	Author(s) (institution, working field, active time period)	Hauke Henke (KTH, all, 2016 onwards)
1.05	Current contact person	Hauke Henke
1.06	Contact (e-mail)	haukeh@kth.se
1.07	Website	http://www.osemosys.org/osembe.html

1.08	Primary purpose	(Stakeholder) engagement in energy modelling
1.09	Support / Community / Forum	Website: http://www.osemosys.org/osembe.html Forum: https://groups.google.com/forum/#!forum/osemosys
1.1	Framework	OSeMOSYS
1.11	User Documentation	http://osemosys.readthedocs.io/en/latest/
1.12	Developer/Code Documentation	http://www.osemosys.org/get-started.html
2	**Openness**	
2.01	Open Source	The source code is available at: http://www.osemosys.org/get-started.html
2.02	License	Modelling framework: Apache License 2.0, more information Model data: Open Data Commons Attribution License 1.0, more information
2.03	GitHub	https://github.com/HauHe/OSeMBE
2.04	Data provided	The model data is available at: http://www.osemosys.org/osembe.html
2.05	Number of developers	1
2.06	Number of users	2
3	**Software**	
3.01	Modelling software	GNU MathProg
3.02	External optimizer	GLPK, CPLEX
3.03	GUI	Model Management Infrastructure (MoManI), available here
4	**Coverage**	
4.01	Modelled energy sectors (final energy)	Electricity
4.02	Modelled demand sectors	National electricity
4.03	Modelled energy commodities	Bio fuel (BF), Biomass (BM), Coal (CO), Electricity (EL), Electricity 1 (E1), Electricity 2 (E2), Geothermal (GO), Heavy fuel oil (HF), Hydro (HY),

		Natural gas (NG), Nuclear (NU), Ocean (OC), Oil (OI), Oil Shale (OS), Sun (SO), Uranium (UR), Waste (WS), and Wind (WI)
4.04	Modelled technology types: components for generation or conversion	Combined cycle (CC), Combined heat and power (CH), Carbon Capture and Storage (CS), Conventional (CV), Distributed PV (DI), Dam (DM), Pumped Storage (storage not modelled, considering the capacity with identical characteristics as hydro dam) (DS), Fuel cell (FC), Gas cycle (GC), Generation 2 (G2), Generation 3 (G3), Internal combustion engine with heat recovery (HP), Offshore (OF), Onshore (ON), Steam cycle (ST), Utility PV (UT), Wave power (WV)
4.05	Modelled technologies: components for transfer, infrastructure or grid	Transmission and distribution (TD), trans-border electricity transmission, oil refinery (RF)
4.06	Network representation	Net transfer capacities
4.07	Modelled technologies: Components for storage	-
4.08	Changes is efficiency	Defined exogenously, it can change across years
4.09	Geographic resolution	Austria (AT), Belgium (BE), Bulgaria (BG), Switzerland (CH), Cyprus (CY), Czech Republic (CZ), Germany (DE), Denmark (DK), Estonia (EE), Spain (ES), Finland (FI), France (FR), Greece (GR), Croatia (HR), Hungary (HU), Ireland (IE), Italy (IT), Lithuania (LT), Luxembourg (LU), Latvia (LV), Malta (MT), Netherlands (NL), Norway (NO), Poland (PL), Portugal (PT), Romania (RO), Sweden (SE), Slovenia (SI), Slovakia (SK), United Kingdom (UK)
4.1	Time resolution	5 seasons; one typical day per season; Night, Day, and Peak
4.11	Observation period	2015 to 2050
5	**Mathematical properties**	
5.01	Model class	Mono-objective LP
5.02	Mathematical objective	Net present cost minimisation over the whole space and time domain
5.03	Typical computation time	30 hours
5.04	Typical computation hardware	RAM and CPU (256GB, 3.5 GHz and 4 cores)
6	**Model integration and general data information**	
6.01	Interfaces	MoManI (only for data entering at the moment)

6.02	Model file format	.txt file
6.03	Integration with other models	No
6.04	Input/output data file format	Input data on a separate .txt file in form of matrices and called by the solver along with model file; all outputs of the model on another .txt and selected outputs on a csv file
6.05	Data input	Annual electricity demand by country, demand profile by timeslice, technology performance and cost data, generation constraints, emission constraints and costs
6.06	Model specific properties	Model simple to understand and accessible to all kinds of users, long pre-processing time to build the matrix of the LP, simplified system structure
6.07	Primary outputs	Global net present cost of the system, capacity and generation mix in every country, year, and time slice, primary fuels consumption
7	**References**	
7.01	Validation	Done based on IEA statistics for electricity generation by country for the years 2015 and 2016.
7.02	Literature and data sources	(EC 2014; Andersson, Boulouchos, and Bretschger 2011; EPA 2015; IEA 2014; EC 2016; IEA ETSAP 2010; IRENA 2015c, 2015b; S&P Global Platts 2015; EWEA 2016; IRENA 2017a, 2015a; IEA-ETSAP and IRENA 2013; DECC 2015; World Nuclear Association 2016; ENTSO-E 2018; Staffell and Pfenninger 2016; Pfenninger and Staffell 2016b; Bosch, Staffell, and Hawkes 2017; Pfenninger and Staffell 2016a; EEA 2018; Eurostat 2018; EEA 2016; CenSES and FME 2015; CenSES and IFE 2015; SFOE 2018, 2015; Geothermie-Schweiz n.d.; Schweizerischer Wasserwirtschaftsverband 2016; OECD 2015; Norwegian Ministry of Petroleum and Energy 2015; Tuuleenergia.ee 2015; VTT 2015; Siyal et al. 2015; Open Power System Data 2019; Statistics Estonia 2018; World Nuclear Association 2019, 2017; IEA 2018) See below for more details
7.03	Publications	1. Henke, H., Howells, M., Shivakumar, A., (2018) "The Base for a European Engagement Model – An Open Source Electricity Model of seven Countries around the Baltic Sea", CYSENI2018, ISSN 1822-7554, May 2018, Pages 226-247, link

		2. Henke, H., (2018) “An indicative study on the opportunities of Pan-European electricity exchange in context of a decarbonised economy”, IEW2018, presentation, link

3 Sample Reference Energy System

A common approach in (energy systems) modelling is to represent the modelled system in a graphical way to indicate the system boundaries and the elements considered. In Figure 2, the Reference Energy System (RES) of Germany is shown as representative of the RES of all countries in OSeMBE. The RES is kept slightly simpler than in the model for the sake of clarity. Most fuels can be converted to electricity in different types of power plants.

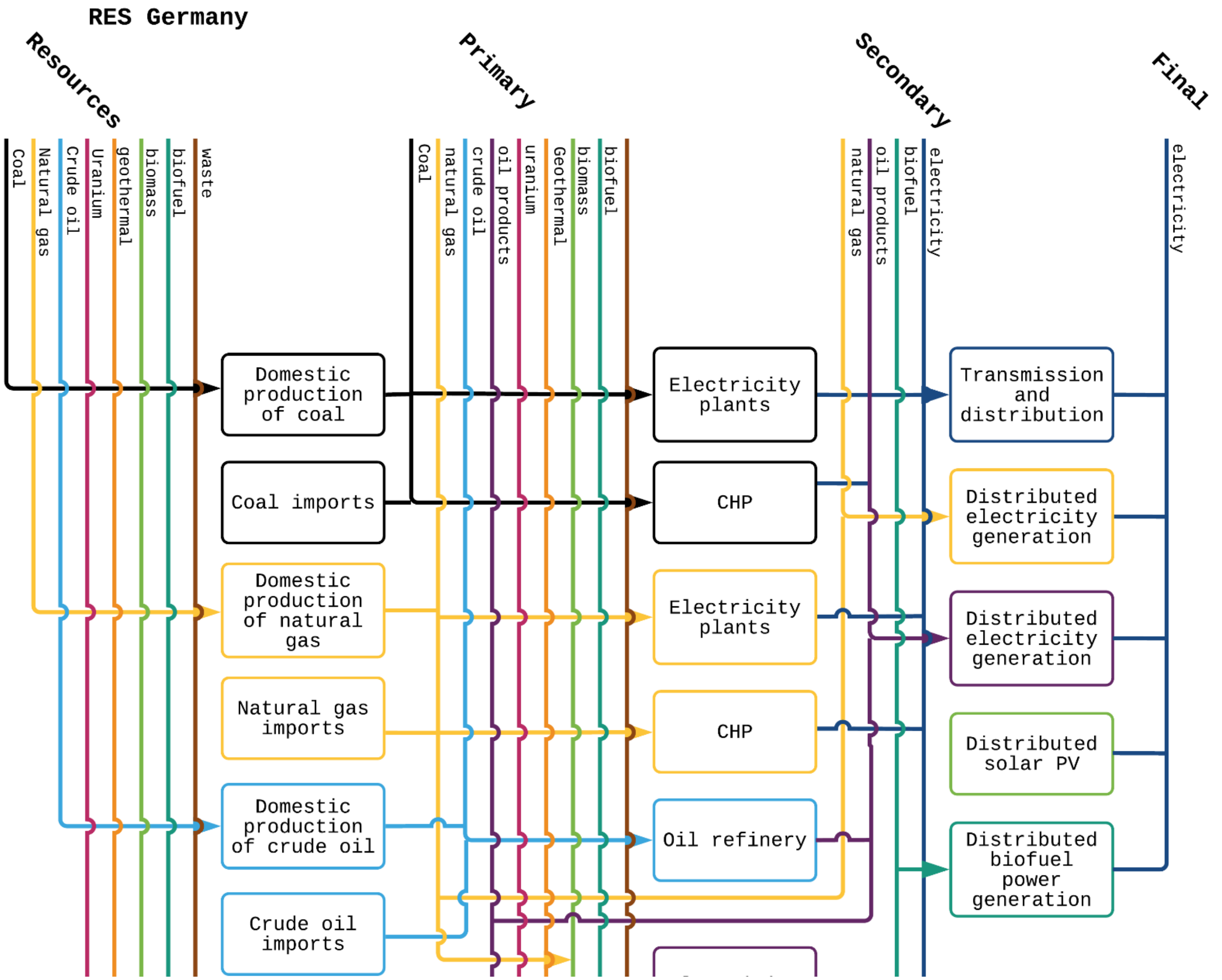
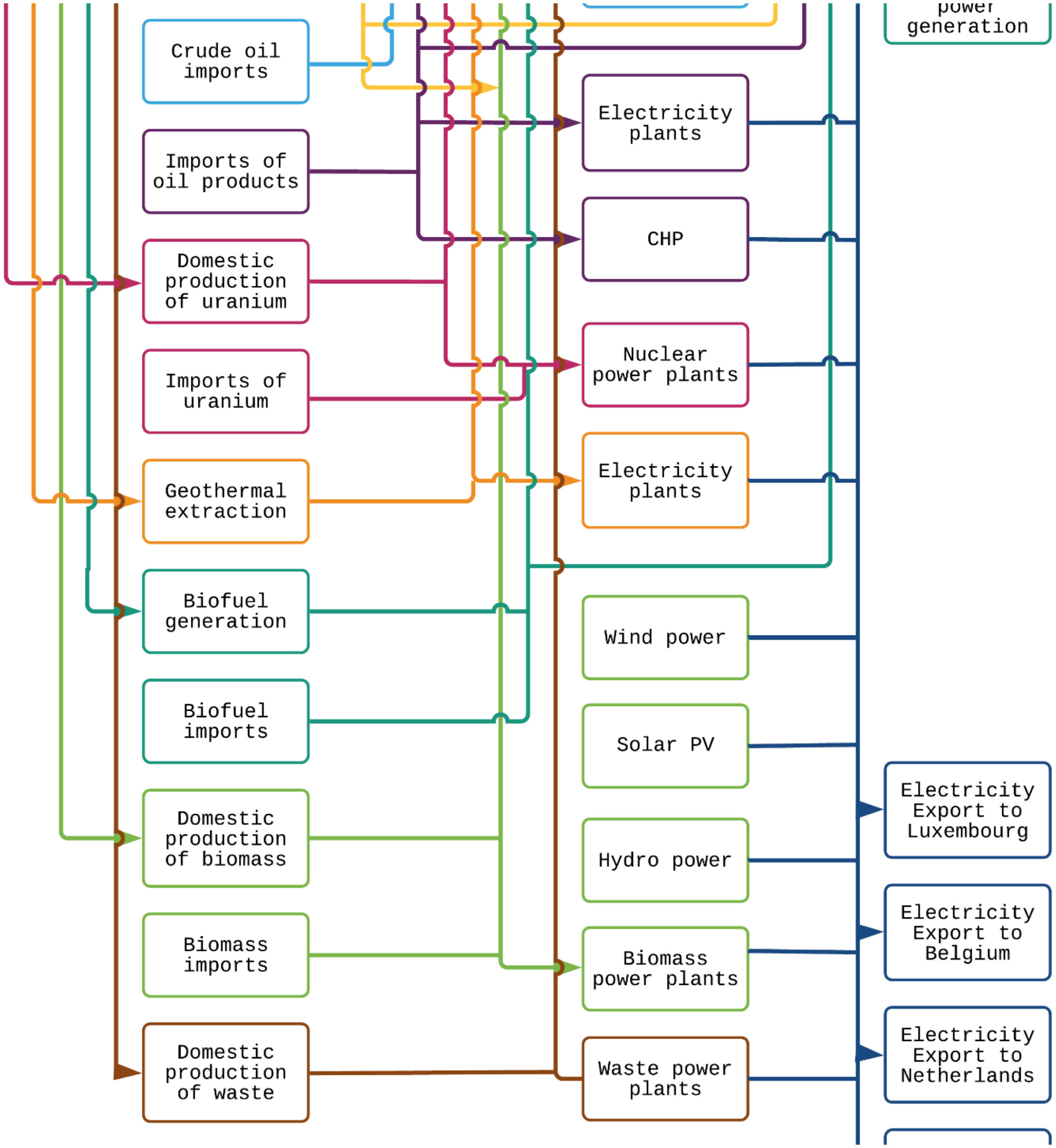
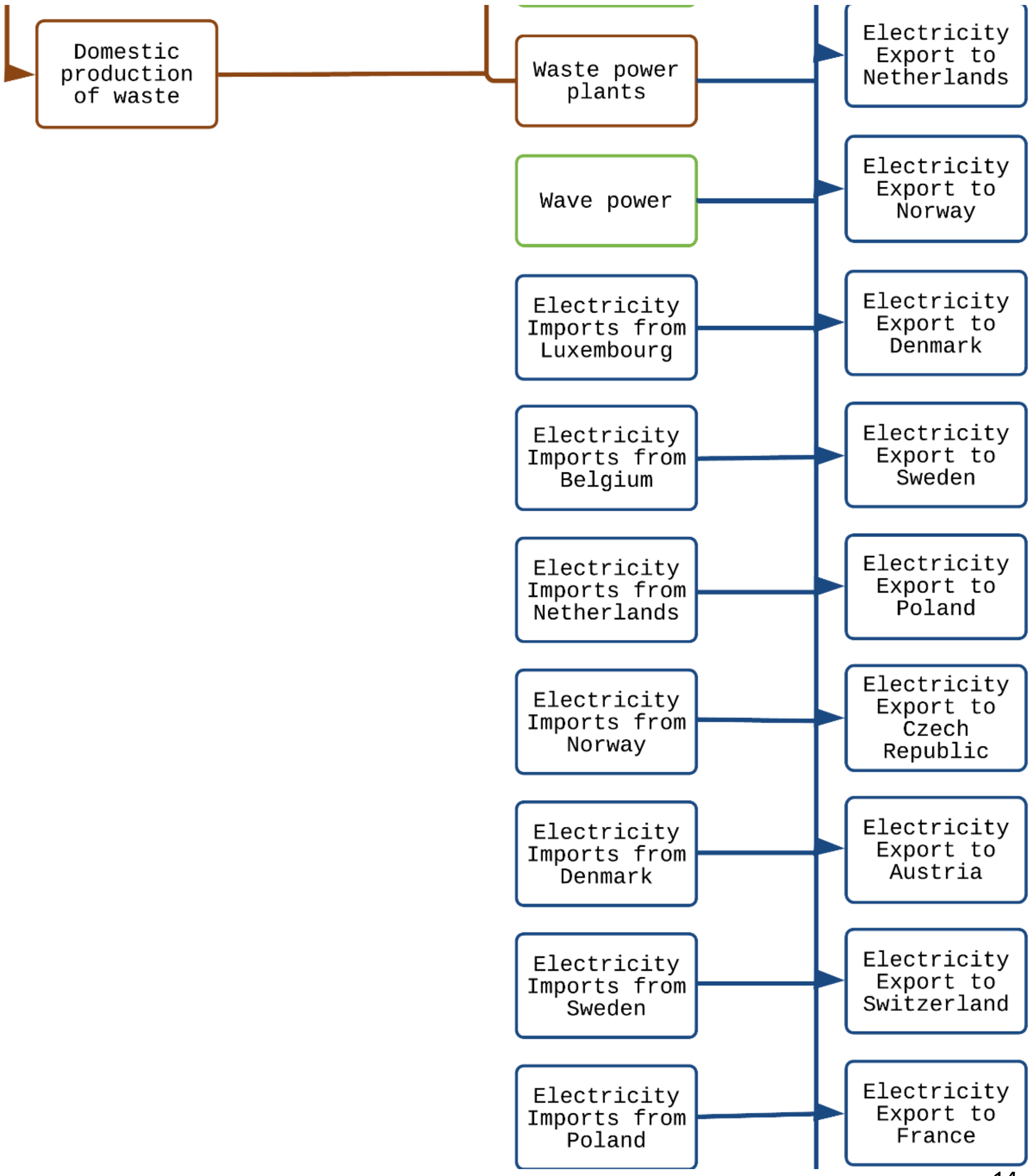


Figure 2. Reference energy system Germany


power generation
Crude oil imports
Imports of oil products
Domestic production of uranium
Imports of uranium
Geothermal extraction
Biofuel generation
Biofuel imports
Domestic production of biomass
Biomass imports
Domestic production of waste
Electricity plants
CHP
Nuclear power plants
Electricity plants
Wind power
Solar PV
Hydro power
Biomass power plants
Waste power plants
Electricity Export to Luxembourg
Electricity Export to Belgium
Electricity Export to Netherlands



Domestic production of waste

Waste power plants

Wave power

Electricity Imports from Luxembourg

Electricity Imports from Belgium

Electricity Imports from Netherlands

Electricity Imports from Norway

Electricity Imports from Denmark

Electricity Imports from Sweden

Electricity Imports from Poland

Electricity Export to Netherlands

Electricity Export to Norway

Electricity Export to Denmark

Electricity Export to Sweden

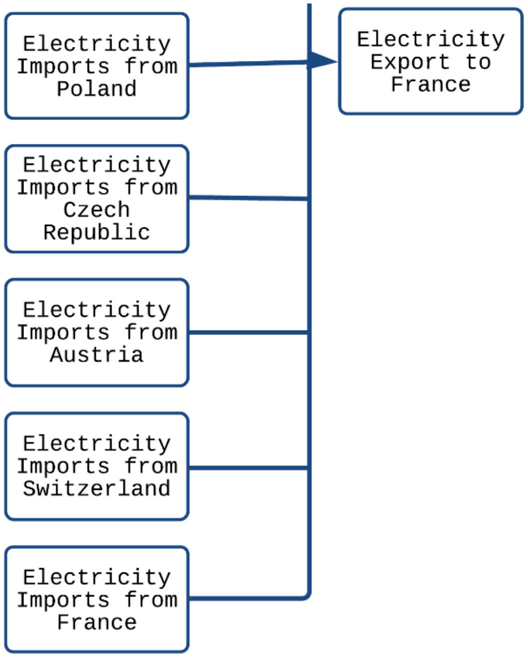
Electricity Export to Poland

Electricity Export to Czech Republic

Electricity Export to Austria

Electricity Export to Switzerland

Electricity Export to France


Electricity Imports from Poland
Electricity Imports from Czech Republic
Electricity Imports from Austria
Electricity Imports from Switzerland
Electricity Imports from France
Electricity Export to France

4 Naming convention

4.1 Technology naming

Technologies in OSeMBE are named according to the following structure:

Table 2. Technology naming convention

AA	BB	CC	D	E	F		AABBCCDEF
Country	Commodity	Technology/connected country	Energy level	Age	Size	→	Technology name

The codes for the modelled countries, commodities, and technologies can be found in Table 1. The energy level is either *P* if a primary energy commodity is the output, or *F* if final electricity is the output, *I* indicates an import technology, and *X* an extraction or generation technology.

4.2 Commodity naming

Commodities in OSeMBE are named according to the following structure:

Table 3. Commodity naming convention

AA	BB		AABB
Country	Commodity	→	Commodity name

The codes for the modelled countries and commodities can be found in Table 1.

5 Main data sources

Table 4. Data sources

	Source(s)
Demands	(EC 2016; CenSES and IFE 2015; CenSES and FME 2015; Andersson, Boulouchos, and Bretschger 2011)
Resource availability	(EC 2016; EWEA 2016; Geothermie-Schweiz n.d.; IRENA 2015c, 2015b; Norwegian Ministry of Petroleum and Energy 2015; CenSES and FME 2015; OECD 2015; Pfenninger and Staffell 2016b; Schweizerischer Wasserwirtschaftsverband 2016; Siyal et al. 2015; Staffell and Pfenninger 2016; Tuuleenergia.ee 2015; VTT 2015; World Nuclear Association 2016)
Fuel prices	(DECC 2015; World Nuclear Association 2016; IRENA 2015a; IEA-ETSAP and IRENA 2013; Statistics Estonia 2018)
Technology cost	(EC 2014; IEA 2014; EPA 2015)
Existing power generation capacities	(S&P Global Platts 2015; Open Power System Data 2019; EWEA 2016, 2014, 2012, 2010)
Trans-border transmission capacities	(ENTSO-E 2018)
Demand profiles	(ENTSO-E 2018)
Solar and wind fluctuation	(Pfenninger and Staffell 2016a, 2016b; Staffell and Pfenninger 2016; Bosch, Staffell, and Hawkes 2017)

6 Validation

An initial validation of the results of OSeMBE has been carried out. The results of the years 2015 and 2016 were compared to historical capacity and electricity supply mix of EU28+2 indicated by IEA (IEA 2018) and Open Power System Data (Open Power System Data 2019), and the model assumptions were iteratively revised where necessary. Specific aspects that were addressed are listed in Table 5.

Table 5. Measures taken during calibration

Issue	Measure taken
Very large capacity investments in single years	TotalAnnualMaxCapacityInvestment, implemented for technologies in countries where large investments observed in general a limit of 5 GW per technology year and country, for Nuclear 3 GW per country and year
Significant share of Coal in the UK	Consideration of UK Carbon price floor of 18£/tonCO2
Very low levels of natural gas usage	For the first six years (2015-2020) introduction of TotalTechnologyAnnualActivityLowerLimit for Gas import and extraction technologies to maintain at least the gas demand of 2015 following IEA numbers. Namely in BE, DE, DK, ES, FI, FR, GR, HR, HU, IT, LV, NL, PL, PT, RO, SI, SK, UK
Large shares of electricity by solar PV in Austria, Switzerland, Czech Republic, Germany, France, and Luxembourg	Country specific limits for electricity generation by solar PV
Large investments into Nuclear power in Czech Republic, Poland and Slovenia	After comparison with governmental plans, implementation of TotalAnnualMaxCapacity limits for Poland and Slovenia for alignment with plans
Very low domestic electricity production in Estonia	Addition/consideration of Estonian oil shale.
Missing natural gas on Cyprus and Malta	Addition/consideration of plans and existing LNG terminals, pipelines and exploration

7 Scenario runs for REEEMgame

In REEEM, deliverable ‘D7.4 the Online Energy Systems Learning Simulation’, also called the REEEMgame, aims to provide the user insights into the system dynamics in the power sector of the EU28+2 and the impact of high-level political decisions, technology development, bilateral cooperation and public and private investments.

In the REEEMgame the user is asked to makes decisions concerning the amount of CO2 reduction per year, the increase of electricity transmission capacities between countries, and measures for further reductions of the cost of renewable energy technologies. The decision for the emission reduction pace reflects a high-level political decision and it needs to be made in 2020, 2030 and 2040. The decision on measures to reduce the cost of renewable energy technologies in 2020. Finally, the decision on increased electricity transmission capacities reflects a mix of private and public infrastructure investments made to comply with the Ten-Year development plan of ENTSO-E and it is allowed in 2030.

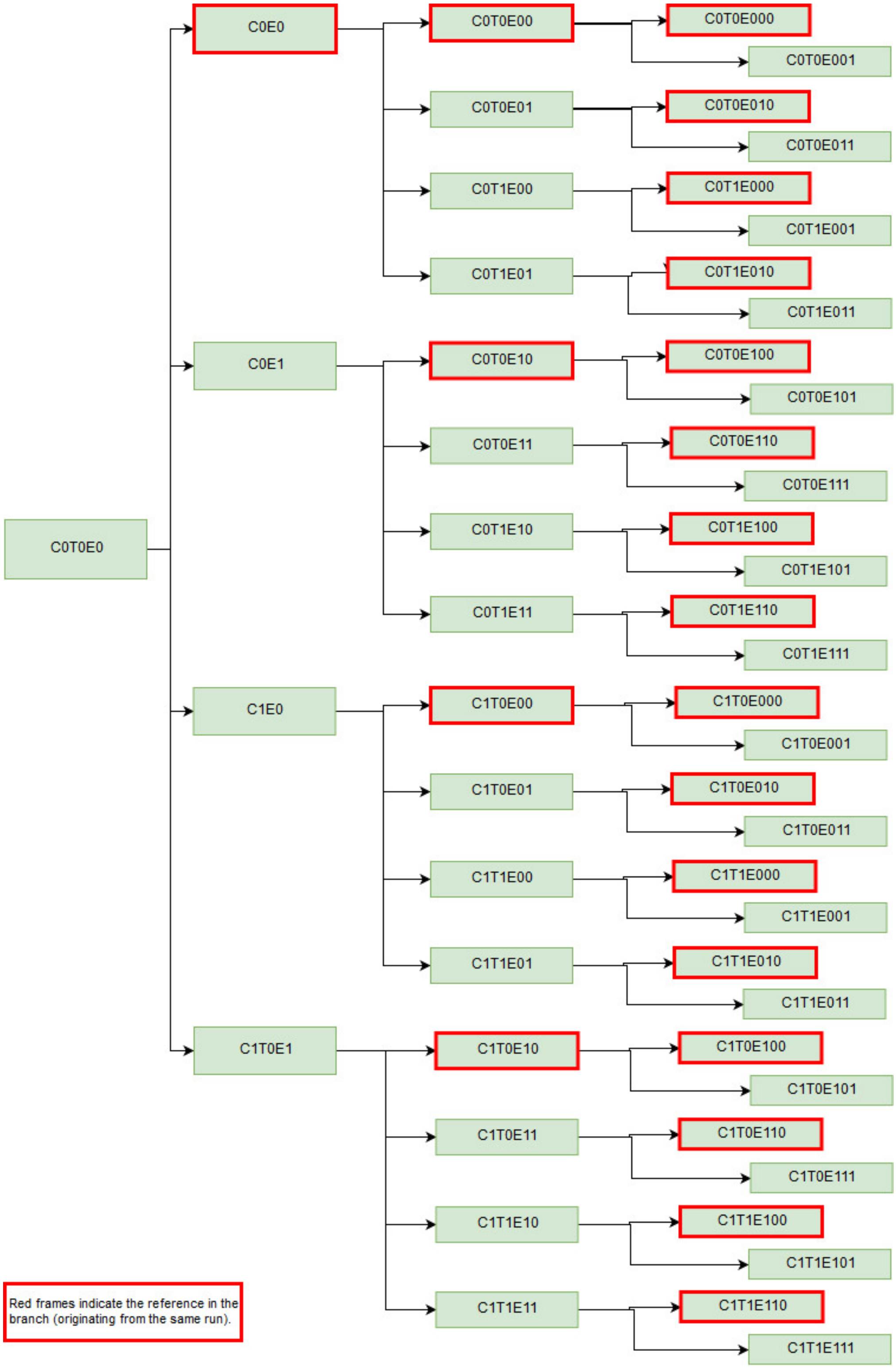
The scenario tree that results from the combination of all the above decisions consists of 32 scenarios and it is shown in Figure 3. The Figure is split into four columns. From left to right the columns show the years 2015, 2020, 2030, and 2040 and indicate the scenarios that exist at each point in time. It shows that each decision option offered creates one more scenario, i.e. when running the model the scenarios should be in line before each decision point. However, the modelling system OSeMOSYS assumes perfect foresight in its common formulation. This means that if input data is modified from a certain point in time onwards, e.g. from one of the decision points in the game, the results will also be affected in the years before the decision point. To avoid this and to keep the scenarios in line, the scenarios that split up from a reference scenario at a decision point are equipped with boundary conditions concerning the installed capacity of power plants. These upper and lower boundary conditions are derived from the installed power plant capacity in the reference scenario and are applied from the start of the modelling period in 2015 until the decision point where the scenario departs from the respective reference case. The scenarios marked with a red frame in Figure 3 serve as reference scenario for scenarios that start in the same year and which are indicated below the respective reference scenario. The naming of the scenarios indicates the decisions made. The composition of the naming is shown in Table 6. The letters indicate the decision variable and the numbers the decision made. For emissions all decisions are indicated, i.e. the first number after the “E” indicates the decision in 2020. The next second the decision in 2030 and the last the decision in 2040.

Table 6. Decision variables and decision options

Decision variable		Decision options	
C	Measures for reducing the cost of renewable energy (RE) technologies	**0**	No, no further measures for the development of RE technologies
		1	Yes, further measures for the development of RE technologies
T	Investment in trans-boundary grid capacity	**0**	No, the TYNDP of ENTSO-E will not be realised by 2035
		1	Yes, the TYNDP of ENTSO-E will be realised by 2035
E	Pace of CO_2 reduction	**0**	EU ETS emission reduction pace
		1	Higher pace of emission reduction than in EU ETS

An insightful challenge during the scenario runs arose from two scenarios that showed infeasibilities when applying the capacity limits. Both scenarios are originating at decision points in 2040. In both cases, the decision in 2040 is to increase the pace of emission reductions. This lead to the guess that carbon negative technologies might be needed to be able to meet the targets. Therefore, three types of Carbon Capture and Storage (CCS) technologies were added to OSeMBE. These technologies run on either coal, natural gas or biomass. In the first two cases the CCS, is reducing the CO2 emissions in comparison to conventional power plants with the same fuel. In the case of biomass, the application of CCS is considered to create negative emissions. This assumption considers that the CO_2 that has been absorbed by the plants is only partly re-emitted to the atmosphere.

After the addition of the CCS technologies, the two previously infeasible scenarios became feasible and showed use of CCS for reaching the stringent decarbonisation targets. This issue indicates how important not only the right decisions concerning emission abatement are ***but also the right timing***. This consideration is reflected in the REEEMgame.



Red frames indicate the reference in the branch (originating from the same run).

Figure 3. OSeMBE scenario runs for REEEMgame

8 Future development

The first version of OSeMBE is kept simple due to its purpose as an engagement model. The future development does not aim to change this purpose, nor the fundamental structure. Nevertheless, several aspects can be improved or added without changing the generic structure. In the following, the planned and potential next steps in the model development are described.

8.1 Extension and interaction with other European countries

To increase the accuracy of the model, especially in countries at the borders of the EU, the representation of the electricity exchange with neighbouring countries will be one of the next developments, followed by representation of the entire countries themselves.

8.2 Technology addition and representation

The previously intended addition of storage showed not possible with the current version of OSeMOSYS due to too high computational requirements. It needs to be seen if further code improvements in the modelling framework will allow the addition of storage technologies.

For the current version of OSeMBE the focus in the development has been put on the representation of the power generation technologies. However, electricity transmission systems are represented very simplified. This could be improved. A first step could be to consider the cross border projects suggested by the Ten Year Network Development Plan (TYNDP) by ENTSO-E with their full cost characteristics.

On the resource side the representation of coal could be worth considering. Currently, OSeMBE considers one generic type of coal. Differentiating between hard coal and lignite could draw a more precise picture of the future of coal in Europe, especially in countries with a large share of power generation by coal.

8.3 Data improvement

Without changes in the model structure, data improvements are possible. Technology cost data and fuel prices are so far mostly generic. For certain aspects, such as the price of domestic resources, such data could be made country-specific to improve the accuracy. Additionally, fuel conversion processes like oil refineries could be represented in more detail.

8.4 Sector addition

Of potential interest is also the addition of sectors like heating and cooling, or transport. However, in this context, the abovementioned computational limitations need to be considered. Adding more sectors could broaden the scope and allow the analysis of sector coupling options for decarbonisation.

8.5 Extraction and integration of country models

An interesting feature could be the development of a procedure to extract single or multi country models from OSeMBE. With these model case studies or further development could performed. Such improvements then could be added to OSeMBE by reintegrating the country or regional model into OSeMBE. In this way the EU28+2 model could first provide the starting point for a case study, but would then also get improved by such a case study. Furthermore such a feature could be used in teaching. Students could perform analysis on single countries, but all together they perform analysis on Europe. Such a procedure would need to be accompanied by a version control procedure, potentially on GitHub.

9 Engagement and openness

OSeMBE is directly used in REEEM as the basis for the REEEMgame (see a description of the scenario runs in Section 7). The REEEM Game is an option for engagement with stakeholders or in academia to increase understanding of the energy system and doesn’t require modelling knowledge. But the model itself is also available to the public, stakeholders and academia. Especially in the latter, the model will be used for educational purposes to provide the base for in-course case studies but also to work on answering research questions in thesis projects and workshops.

The openness of the model facilitates easy access and usage of the model for the above described purposes. To continue the model’s development, to foster engagement and usage of the model, a potential goal is to integrate the model within the OpTIMUS community (www.optimus.community) and to build a community of users and developers around the model.

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