REIMBURSABLE ADVISORY SERVICES (RAS): CONSTRUCTION OF ECONOMIC MODELING TOOLS AND BUILDING CAPACITY IN MODELING FOR SUSTAINED GROWTH IN THE SLOVAK REPUBLIC

USER'S GUIDE TO THE CPS MODEL

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This User Manual and the ***CPS Model*** *described within, are products of E3 Modelling prepared under Contract No. 7182219/2017 between the World Bank Group and E3 Modelling. The User Manual is solely intended for the members of the World Bank Group and Slovakian CMT which are involved in this Contract. Distribution of the User Manual and the* ***CPS Model*** *to others outside the above group is strictly forbidden.*

Contents

1. Introduction

The **CPS Model** has been developed by E3-Modelling in the context of Contract 7182219/15.02.2017 between E3-Modelling and the World Bank.

This document is the User's Manual to the **CPS Model** (Compact-PRIMES Single Country model). It aims to serve as a methodological and technical guide to users so that they become fully equipped to utilize the **CPS,** appreciate its' unique features and comprehend the mathematical approach implemented within.

The model, developed in the General Algebraic Modelling System (GAMS)[1], is a fully-fledged energy demand and supply model, designed as a single-country compact tool.

The model allows users to assess the impact of European and national climate and energy policy decisions with a horizon up to 2050. The model includes key energy sector metrics at a detailed level: demand of energy by sector, modelling of energy efficiency possibilities, energy and electricity use, technology capacities, power generation, cogeneration, energy supply technology and energy form mix, fuel prices and system costs from an end-user perspective, investments by sector and energy-related CO_2 emissions.

The CPS model runs up to 2050 and the electricity model performs hourly simulations. The model structure permits linkages with the external (outside the country) markets, to get international fuel prices, carbon prices of ETS etc. It allows for a flexible definition of technological parameters and technological learning, overall efficiencies, and specific investment lead times for technologies.

The model is actor and market oriented, and so it represents individual actors' decisions in supply and demand of energy and the balancing of their decisions in simultaneous markets cleared by prices. In this way, the model explicitly projects energy forms' prices into the future as derived from cost minimization in the supply side and the price-elastic behaviors of demanders for energy. In this sense the model has no overall objective function, but as economic theory suggests, the simultaneous market clearing under perfect competition conditions leads to an overall optimum of economic welfare, which coincides with minimum cost of energy for the end-users. In the energy supply sectors, the model performs a detailed breakdown of cost categories, such as capital, operational, emission-related and maintenance costs. All external assumptions, including fossil fuel prices, price elasticities, technological or policy constraints are presented in a transparent manner and can be tested in sensitivity analysis.

A substantial part of the mathematics of CPS are derived from the well-known PRIMES[2] model, a large-scale modular system of sub-models, covering multiple countries also developed within our group.

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[1] https://www.gams.com/

[2] PRIMES (Price-Induced Market Equilibrium System) energy system model is a development of the Energy-Economy Environment Modelling Laboratory at National Technical University of Athens (http://www.e3mlab.eu/e3mlab/PRIMES%20Manual/The%20PRIMES%20MODEL%202016-7.pdf).

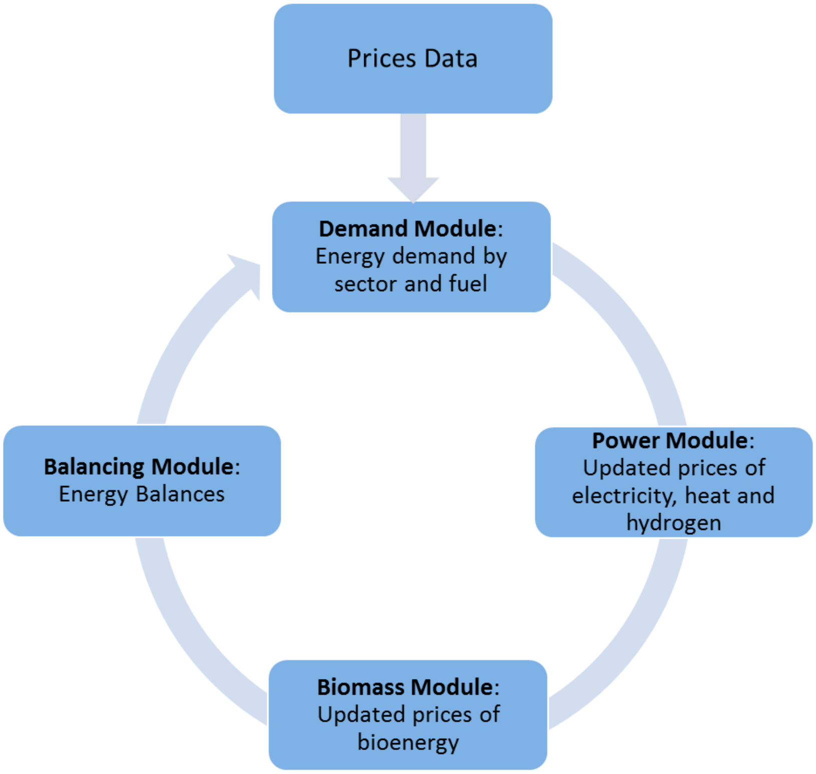


Figure 1 Schematic of the CPS model structure

The CPS comprises four Modules:

- Demand Module: The Demand Module projects energy demand and investments in the industrial, domestic and transport sectors, as well as refineries.
- Power Module: The Power Module includes all necessary mathematical formulations for projecting energy supply. It includes detailed and distinct representations of the Slovak power system, including district heating plants (boilers and CHP plants). The Power Module also accounts for the steam and power produced in the industrial sector (industrial boilers and CHP).
- Biomass Module: The Biomass Module projects the primary energy-feedstock consumption required to satisfy the demand for bioenergy from all demand sectors, as well as the power-heat generation system.
- Balance Module: The Balance Module receives the results of energy consumption from the CPS Demand, Power and Biomass Modules and produces the annual energy balances.

The four modules communicate as shown in Figure 1, and iterate in order to reach a market equilibrium.

The following paragraphs provide further details on the outputs of each Module:

- Demand Module:
  - Energy Demand by sector and fuel

  - CO_2 emissions by sector
  - Energy Savings, Energy and Carbon Intensity
  - Costs (capital, fuel, non-fuel, emissions & taxation costs)
  - Investments & Investment Expenditures
- Power Module:
  - Power & Heat Generation by plant type
  - Fuel Consumption by plant type and fuel
  - CO_2 emissions & Carbon Intensity by plant type
  - Costs of electricity & heat supply (capital, fuel, non-fuel, emission & taxation, grid costs)
  - Capacity Expansion & Investment Expenditures by plant type
- Biomass Module:
  - Production of Bioenergy per fuel
  - Price of Bioenergy per fuel
  - Net Imports of Biomass Feedstock & Bioenergy
  - Domestic Production of Biomass Feedstock
  - Capacity Expansion per Biomass Technology
- Balance Module:
  - Energy balance for each projection year (End-use approach)

The simulation results are dynamic over time and are influenced by factors which are exogenously specified. The user can easily build multiple scenarios to assess a variety of parameters. Input data for each scenario include the following:

- GDP, Income per capita, population
- Fuel availability constraints (e.g. renewables potential, domestic reserves for fossil fuels, import limitations)
- Technology characteristics (energy conversion rates, CAPEX, OPEX)
- Taxes and subsidies
- Discount rates
- Technology standards
- Emission, renewables and energy efficiency regulations
- Targets for emissions, renewables and energy efficiency
- Perceived or hidden costs
- Exogenous investments, decommissioning or retrofitting of power and heat plants.

The next Chapters highlight the features of the CPS Model.

A brief description of each Chapter is listed below. Appendices III, IV and V offer a detailed listing of the mathematical formulation of Demand, Power and Biomass Modules.

- Chapter 2 Starting and Executing the CPS model describes the mechanics of using the graphical user interface in order to run an existing scenario, create a new scenario, check for possible errors in the model run and view scenario results.
- Chapter 3 Input and Output Data describes the information inserted in the Model and the form and content of the results' files.
- Chapter 4 Overview of the CPS Demand Module describes the main principles of the CPS Demand Module and guides the user towards the formulation of alternative scenarios related to influencing and projecting energy demand.
- Chapter 5 Overview of the CPS Power Module describes the main principles of the CPS Power Module and guides the user towards the formulation of alternative scenarios related to power supply.
- Chapter 6 Overview of the CPS Biomass Module describes the main principles of the CPS Biomass Module and guides the user towards the formulation of alternative scenarios related to biomass supply.
- Appendix I CPS Model's Sets
- Appendix II Sectoral structure of the demand sectors
- Appendix III Mathematical formulation of the Demand Module
- Appendix IV Mathematical formulation of the Power Module
- Appendix V Mathematical formulation of the Biomass Module

2. Starting and Executing the CPS model

This Chapter provides instructions for starting and executing the CPS Model through the custom-made CPS Graphical User Interface (hereinafter CPS GUI). The Chapter is structured as follows:

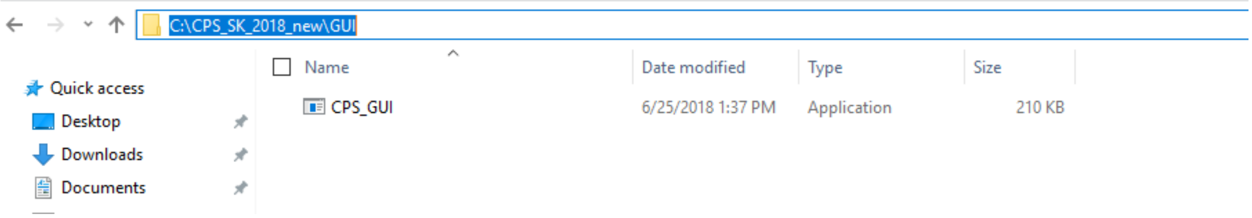
- Section 2.1: Starting the CPS GUI
- Section 2.2: The CPS GUI Features
- Section 2.3: Locating the CPS Model Subfolders and the respective Gams Files
- Section 2.4: The structure of the *Scenario name* subfolder

Note that the CPS user may alternatively omit the GUI and run directly the model through GAMS interface.

2.1 Starting the CPS GUI

Before running the CPS GUI for the first time, the user needs to install the CPS Model and all its' Modules (including the CPS GUI) in drive C or D, in a predefined directory named CPS_SK_2018_new.

The CPS GUI runs by double clicking upon the CPS_GUI application located in the path CPS_SK_2018_new\GUI, see Figure 2.



Name	Date modified	Type	Size
CPS_GUI	6/25/2018 1:37 PM	Application	210 KB

Figure 2 Location of the CPS_GUI Application file

Alternatively, the CPS user can access the CPS GUI through a shortcut created on the desktop (or in any other location that the CPS user is comfortable with)

2.2 The CPS GUI features

The CPS GUI is a facilitator, which allows the user to access and interact with the CPS Model in a simple and user friendly way, through a variety of graphical icons.

The CPS GUI allows the CPS user to perform the following:

- Create a new CPS Scenario
- Run a CPS Scenario
- Perform an error checking analysis. The error check functionality reports on any errors that may have prohibited the successful conclusion of a scenario's run
- Create the final reporting files and view the final results

The next paragraphs provide further details.

For the purposes of the next paragraphs it is assumed that the CPS user has already loaded the CPS GUI as described in Section 2.1 Starting the CPS GUI.

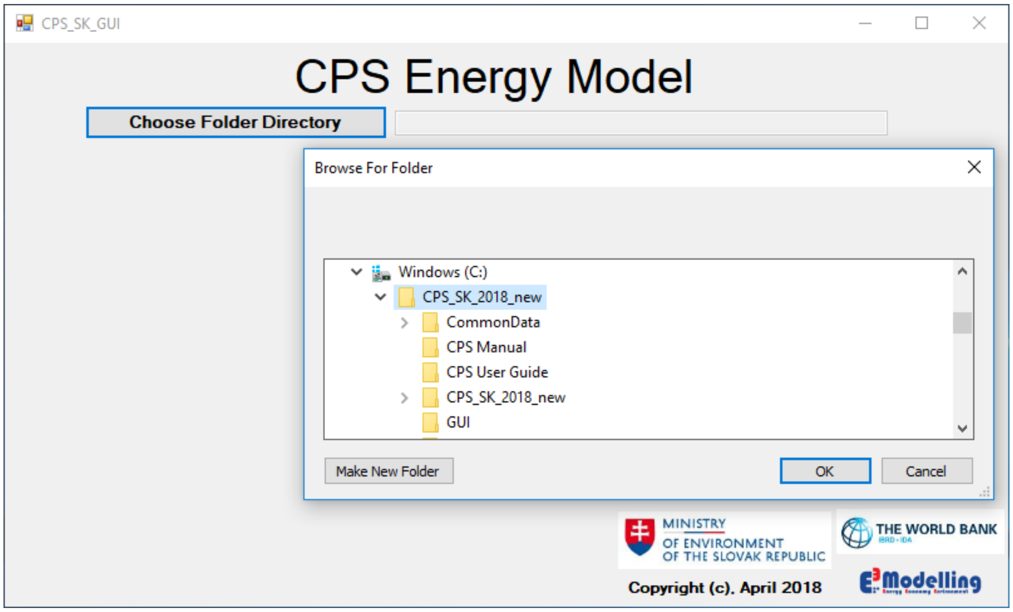
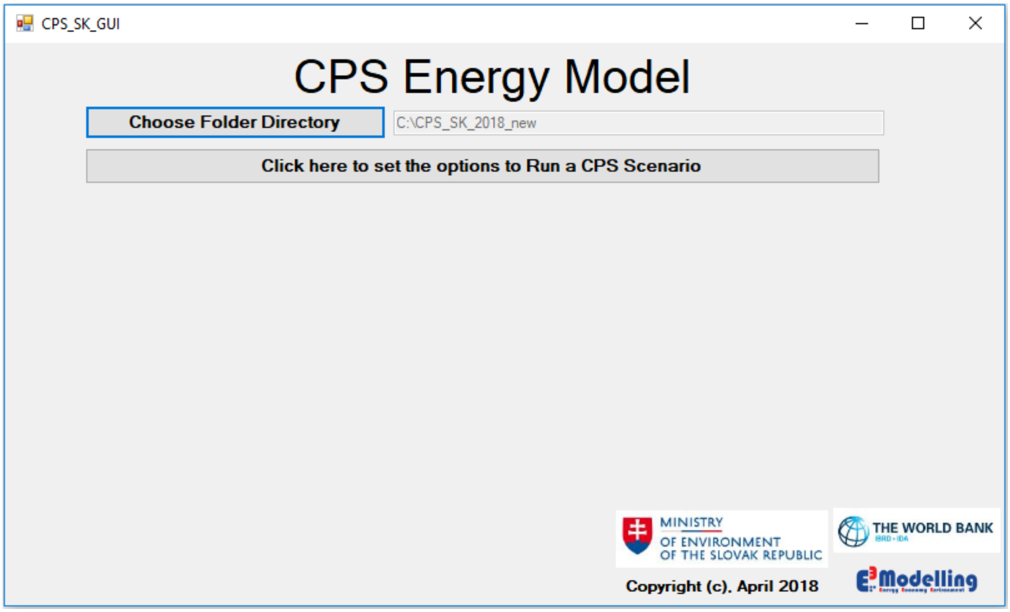


Figure 3 Starting with CPS GUI, step 1, choose folder directory

2.2.1. Preparing a Scenario with the CPS GUI

To run a Scenario with the CPS GUI, the CPS user should do the following:

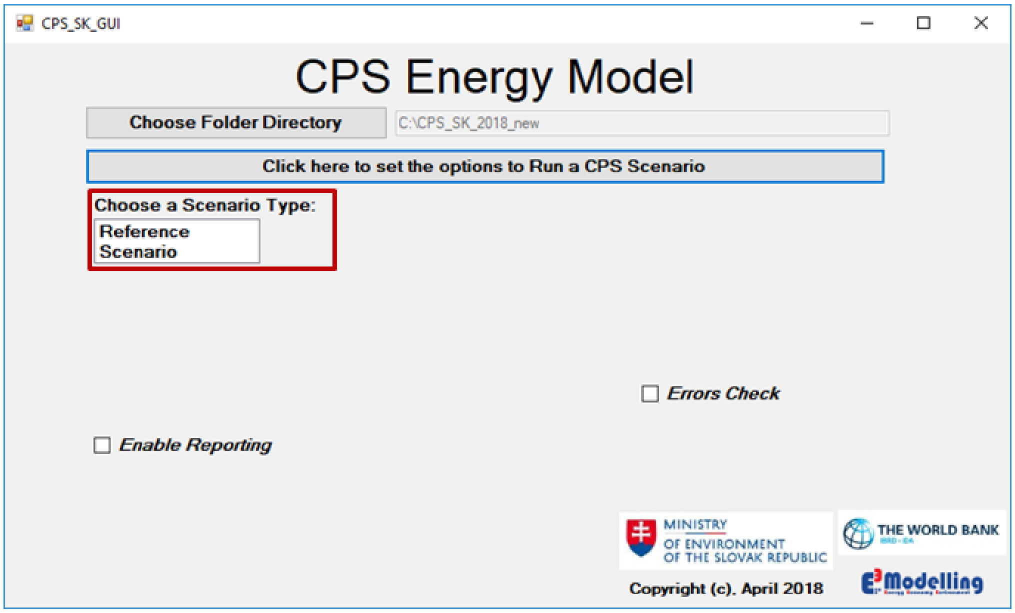
- Press the "**Choose Folder Directory**" pushbutton. Select the corresponding folder from the browsing window that will appear. Eligible folder directories are named "CPS_SK_2018_new" (e.g. C:\ CPS_SK_2018_new or D:\ CPS_SK_2018_new), see Figure 3;
- Press the "**Click here to set the options to run a CPS Scenario**" pushbutton, see Figure 4.
- Select the type of scenario to be run by selecting from the "**Choose a scenario type**" list from the two available options (see Figure 5):
  - Reference
  - Scenario



C:\CPS_SK_2018_new

Copyright (c). April 2018

Figure 4 Starting with CPS GUI, step 2



C:\CPS_SK_2018_new

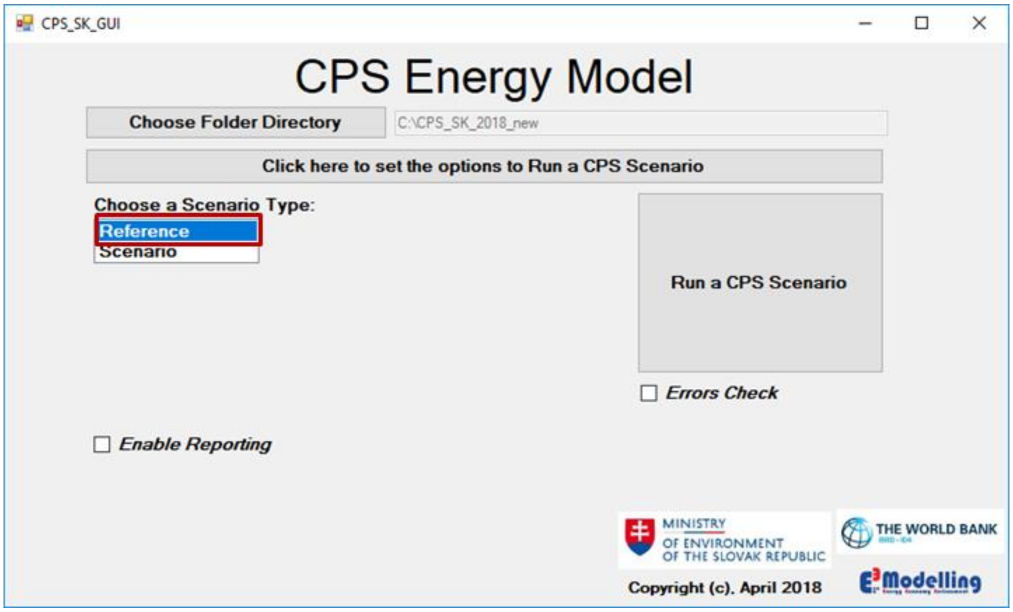
Choose a Scenario Type: Reference Scenario

☐ Errors Check

☐ Enable Reporting

Copyright (c). April 2018

Figure 5 Starting with CPS GUI, step 3, choose a scenario type



C:\CPS_SK_2018_new

Choose a Scenario Type: Reference

Figure 6 Starting with CPS GUI, running a reference scenario

2.2.2. Defining a Scenario Type and a new Scenario with the CPS GUI

The CPS GUI allows the user to select between the following Scenario Types:

- **Reference:** A Reference Scenario represents a current situation scenario (for example a Reference Scenario is a scenario that includes all adopted national and EU policies up to 2020)
- **Scenario:** Other (decarbonization) Scenario

To run a Reference Scenario, the CPS user needs to select the “Reference” from the list, as shown in Figure 6.

To run a decarbonization scenario, the CPS user needs to select the “Scenario” type, as shown in Figure 7. Upon this specific selection, further options regarding the run of a decarbonization scenario will appear. These options are explained below.

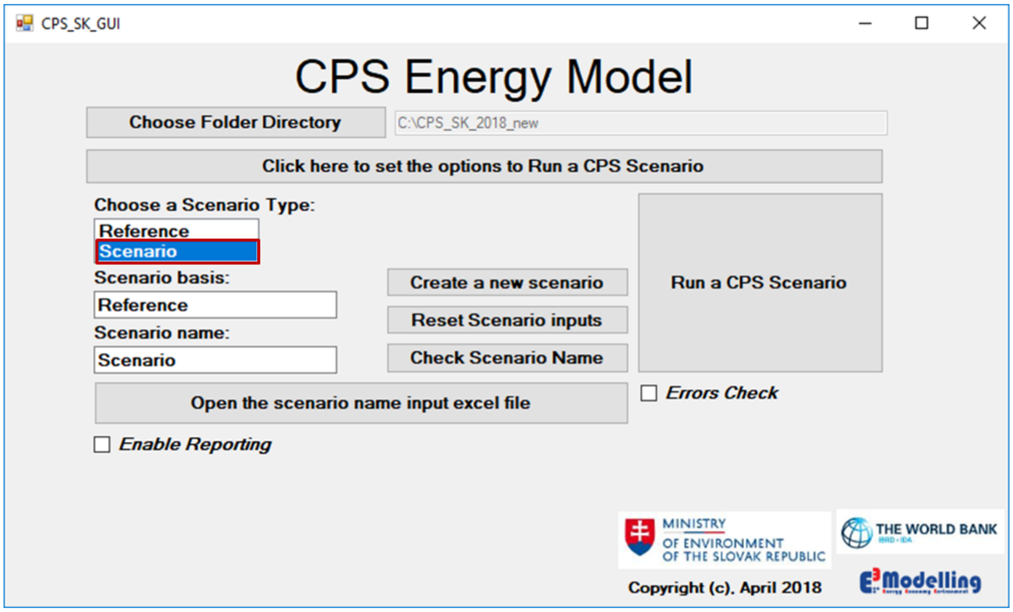


Figure 7 Starting with CPS GUI, running a decarbonization scenario

To create a new Scenario, the CPS user takes the following actions as shown in Figure 8:

- Types the name of the Scenario basis in the **Scenario basis** text box.
- Types the Scenario Name in the **Scenario Name** text box.
- Clicks the “**Check scenario name**” pushbutton.

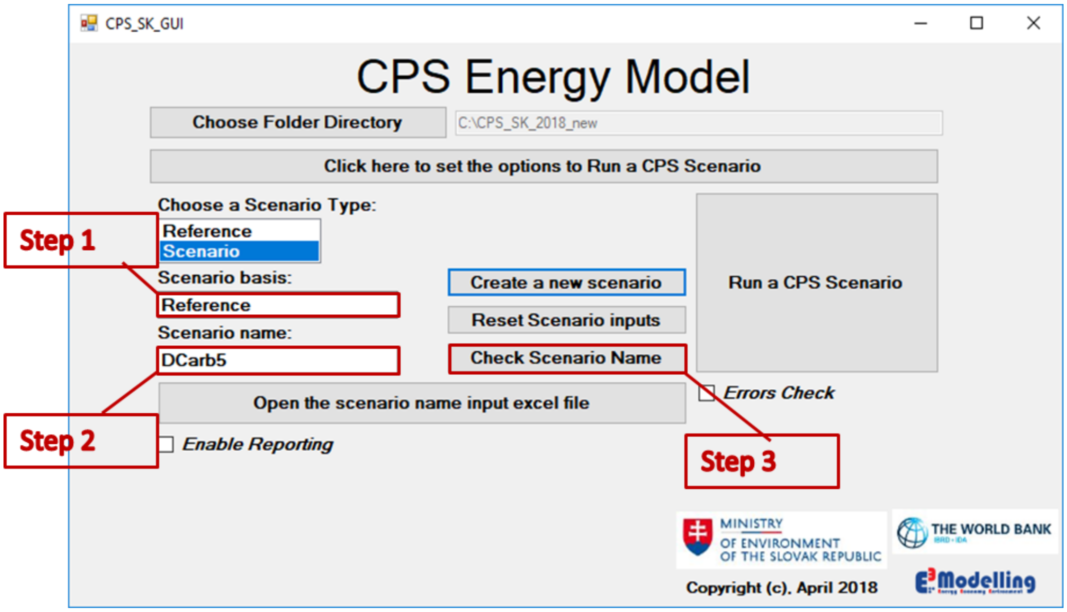
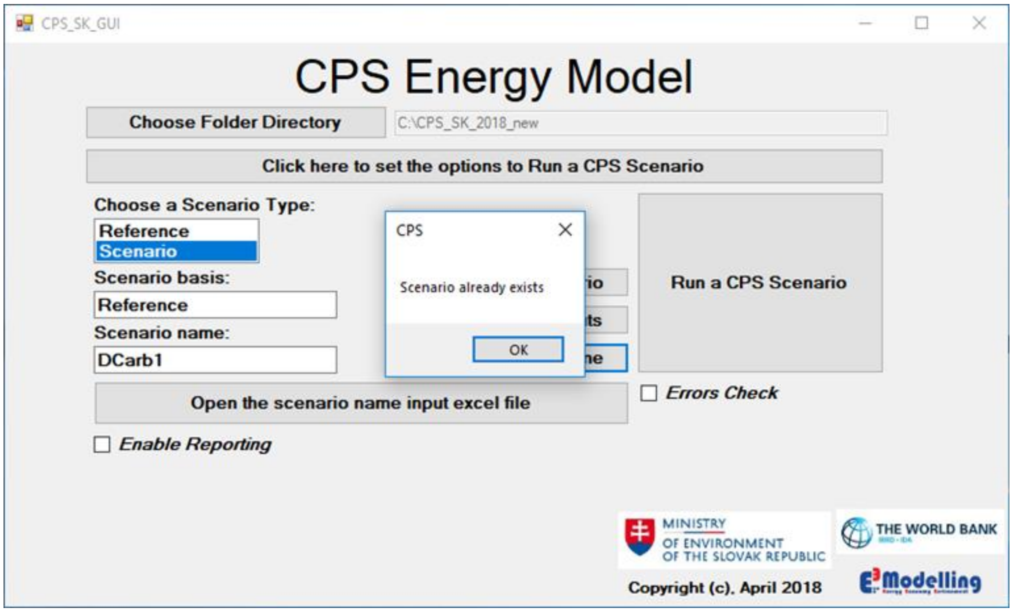


Figure 8 Creating a new scenario

By pressing the "**Check scenario name**" pushbutton the CPS user instructs the GUI to search for a subfolder named after the Scenario name (hereinafter *Scenario name subfolder*). In case that a *Scenario name subfolder* is found in the "Scenarios" folder of the CPS directory then a notification message will appear on the screen, as shown in Figure 9.



C:\CPS_SK_2018_new

Choose a Scenario Type: Reference / Scenario (selected: Scenario)

Scenario basis: Reference

Scenario name: DCarb1

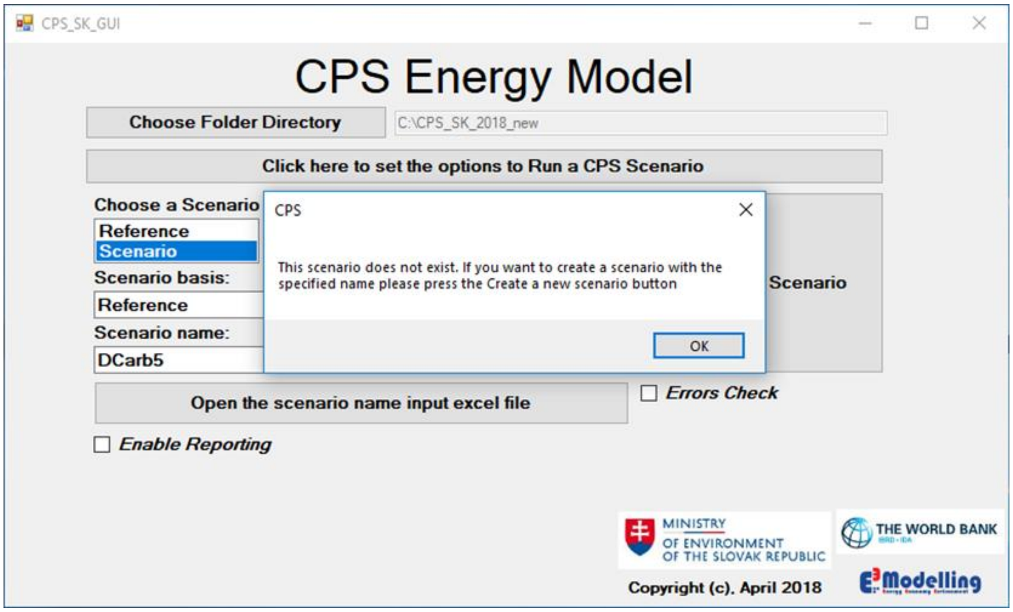
CPS

Scenario already exists

OK

Figure 9 Message confirming that the decarbonization scenario typed by the CPS user in the Scenario name text box exists

In case that a *Scenario name subfolder* does not exist in the "Scenarios" folder, a message prompting the CPS user to create a new scenario will appear, Figure 10.



C:\CPS_SK_2018_new

Choose a Scenario: Reference / Scenario (selected: Scenario)

Scenario basis: Reference

Scenario name: DCarb5

CPS

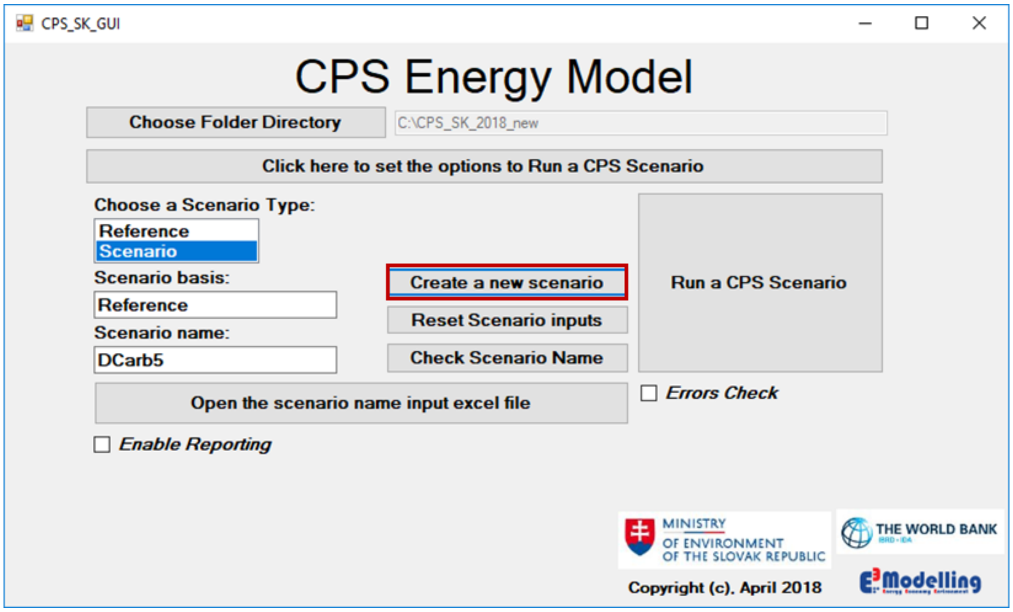
This scenario does not exist. If you want to create a scenario with the specified name please press the Create a new scenario button

OK

Figure 10 Message confirming that the decarbonization scenario typed by the CPS user in the Scenario name text box does not exist

- If the *Scenario name subfolder* does not exist, the CPS user presses the "**Create a new scenario**" pushbutton, Figure 11. This action generates the required new subfolder. Further subfolders are also created within the *Scenario name Folder*. The "**Create a new scenario**" action also copies the Input excel files of the **Scenario Basis** in the Scenario Folder. All input files are placed in the "Inputxlsx" subfolder.

The user can access the input files, by pressing the "**Open the scenario name input excel file**" pushbutton, which opens the relevant input files in Excel.



C:\CPS_SK_2018_new

Choose a Scenario Type:
Reference
Scenario

Scenario basis: Reference

Scenario name: DCarb5

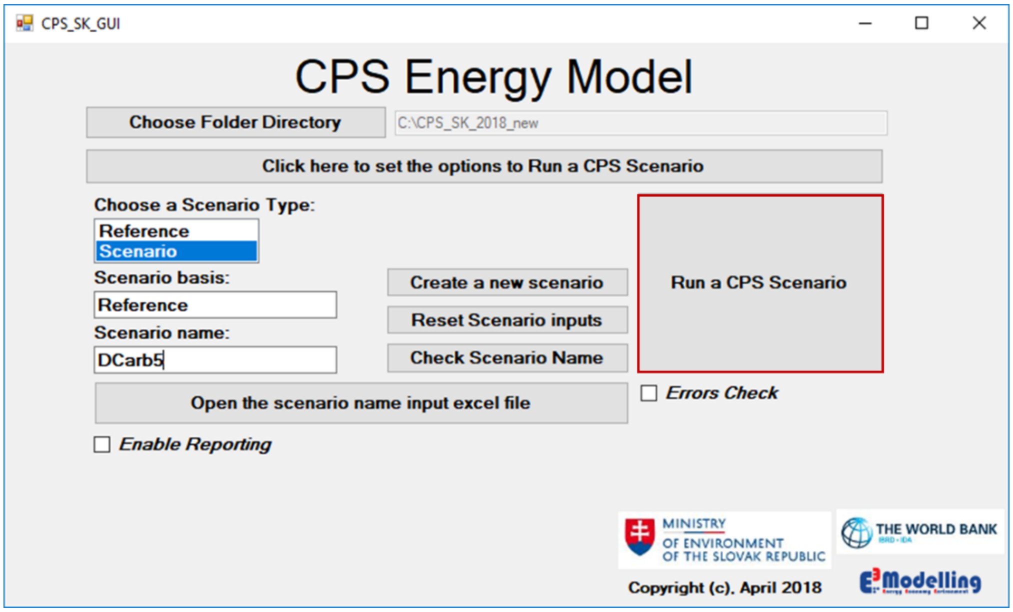
☐ Errors Check

☐ Enable Reporting

Figure 11 CPS GUI, creating a new scenario

2.2.3. Running a CPS scenario

To run a CPS scenario, the CPS user clicks the "**Run a CPS Scenario**" pushbutton, Figure 12.



C:\CPS_SK_2018_new

Choose a Scenario Type: Reference / Scenario (selected: Scenario)

Scenario basis: Reference

Scenario name: DCarb5

☐ Errors Check

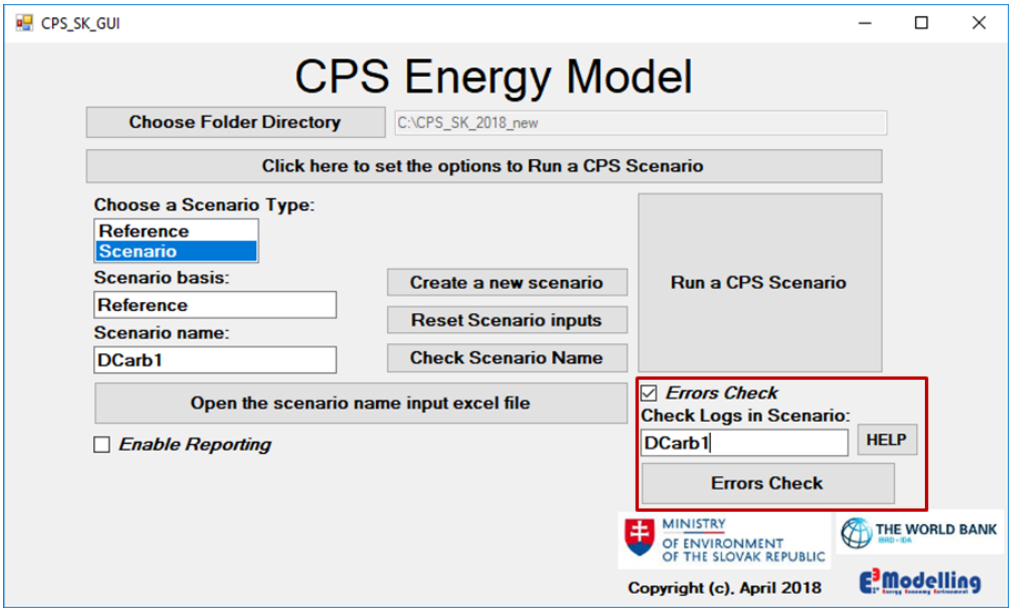
☐ Enable Reporting

Figure 12 CPS GUI, running a CPS scenario

2.2.4. Checking for runtime errors

The CPS user should always check for any runtime errors. The CPS GUI has been purposely designed to allow such a check through a very straightforward process.

Following the end of a GUI CPS run, the CPS user selects the "**Errors Check**" checkbox. Upon checkbox selection, the "**Check logs in Scenario**" option will appear, as shown in Figure 13.



C:\CPS_SK_2018_new

Choose a Scenario Type: Reference / Scenario (selected: Scenario)

Scenario basis: Reference

Scenario name: DCarb1

☑ Errors Check

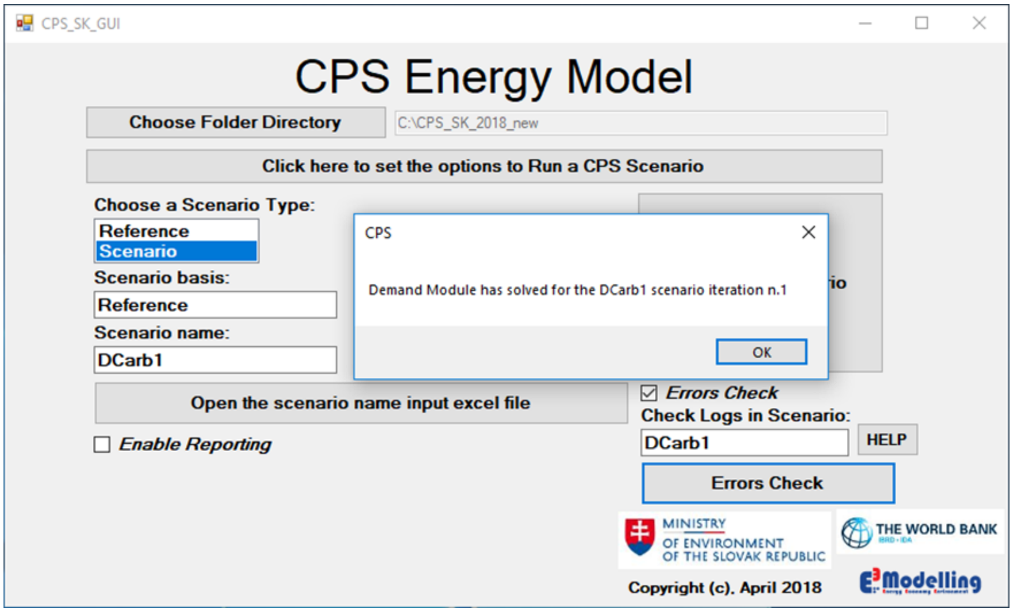
Check Logs in Scenario: DCarb1

☐ Enable Reporting

Figure 13 CPS GUI, error check

The user can either type the Scenario name to be checked or press the "Help" pushbutton, to select a Scenario by selecting the *Scenario name subfolder* from a browser window.

Then, the CPS user must press the "**Errors Check**" pushbutton. The CPS GUI proceeds in a detailed check of the status files of Demand Module for all iterations. The status files are output text files that are created by the Demand Module after completion of every iteration of the model run, indicating whether the module has or has not solved. It also checks all the log files of Power, Biomass and Balance Module, in order to trace possible error notifications. In case the scenario has run without errors a verification message appears on the screen, as shown in Figure 14 (e.g. for the 1st iteration) and Figure 15. In case error notifications are found in the log files, then an appropriate message informs the user on the type of the errors that have occurred.



C:\CPS_SK_2018_new

Choose a Scenario Type: Scenario

Scenario basis: Reference

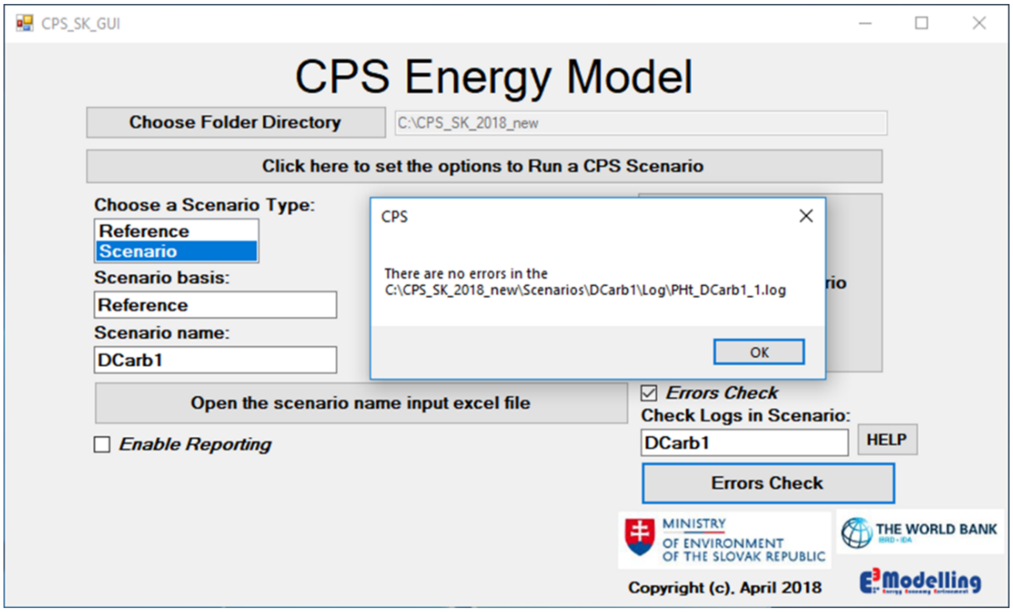
Scenario name: DCarb1

Check Logs in Scenario: DCarb1

CPS

Demand Module has solved for the DCarb1 scenario iteration n.1

Figure 14 CPS GUI, Message informing the user of normal completion of the Demand Module



C:\CPS_SK_2018_new

Choose a Scenario Type: Reference / Scenario (selected: Scenario)

Scenario basis: Reference

Scenario name: DCarb1

☐ *Enable Reporting*

☑ *Errors Check*

Check Logs in Scenario: DCarb1

CPS

There are no errors in the
C:\CPS_SK_2018_new\Scenarios\DCarb1\Log\PHt_DCarb1_1.log

Figure 15 CPS GUI, Message informing the user of no encountered errors in the Power Module

2.2.5. Reporting

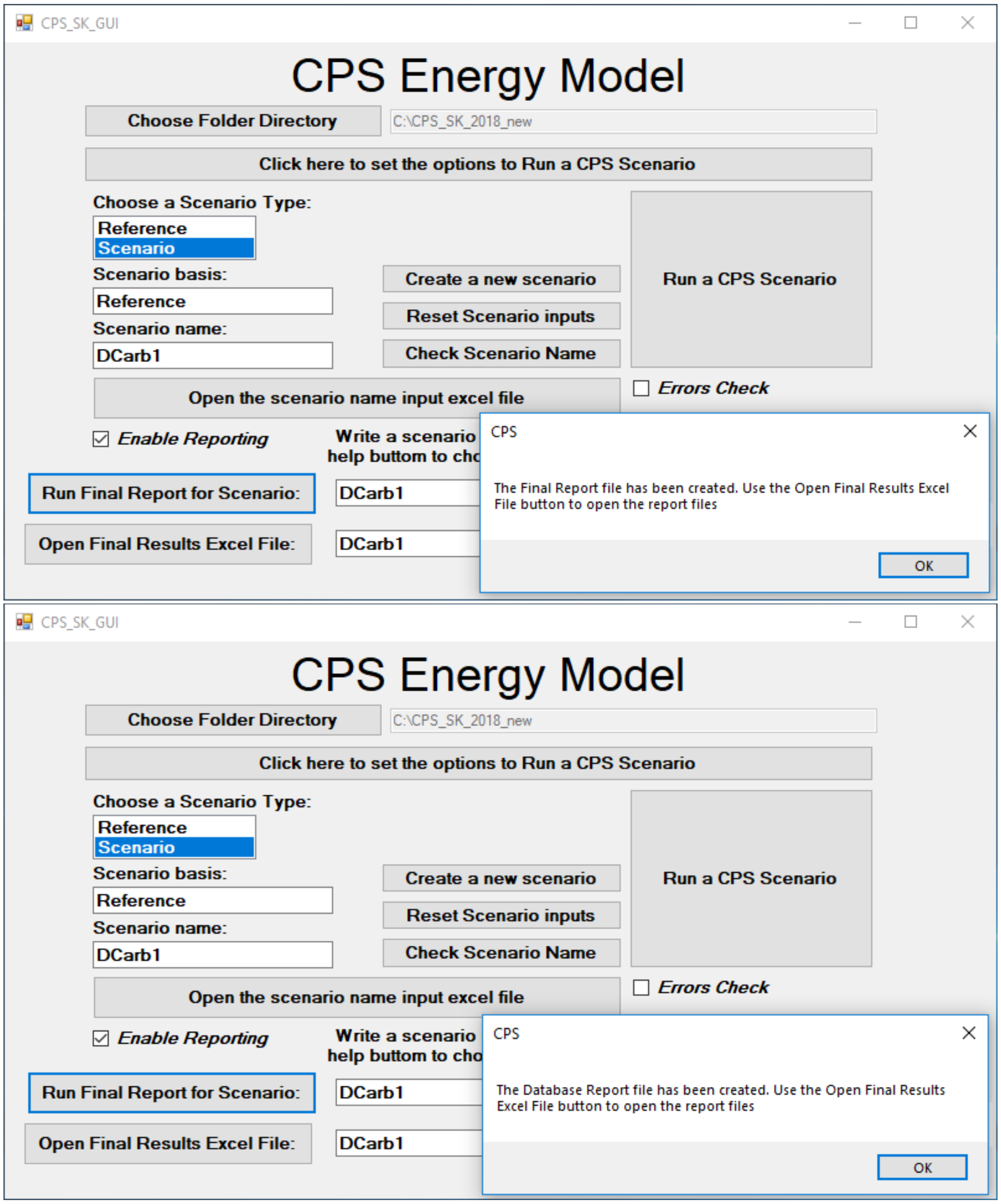
The “**Enable Reporting**” checkbox allows the user to access the Final Results Excel Files, see Figure 16.

The procedure is completed in three simple steps as follows:

1) After clicking the “**Enable Reporting”** check box, the user types the name of the Scenario to be processed in the corresponding field. Alternatively, the user may click the help pushbutton and select the *Scenario name subfolder*.

2) Then, the user clicks the “**Run Final Report for Scenario**” pushbutton. Two messages informing the user that the “the final report/database report file has been created” will appear on the screen, see Figure 16.

3) The user can then press the “**Open Final Results Excel File**” pushbutton to gain access to the report excel files.



C:\CPS_SK_2018_new

Scenario basis: Reference

Scenario name: DCarb1

Run Final Report for Scenario: DCarb1

Open Final Results Excel File: DCarb1

The Final Report file has been created. Use the Open Final Results Excel File button to open the report files

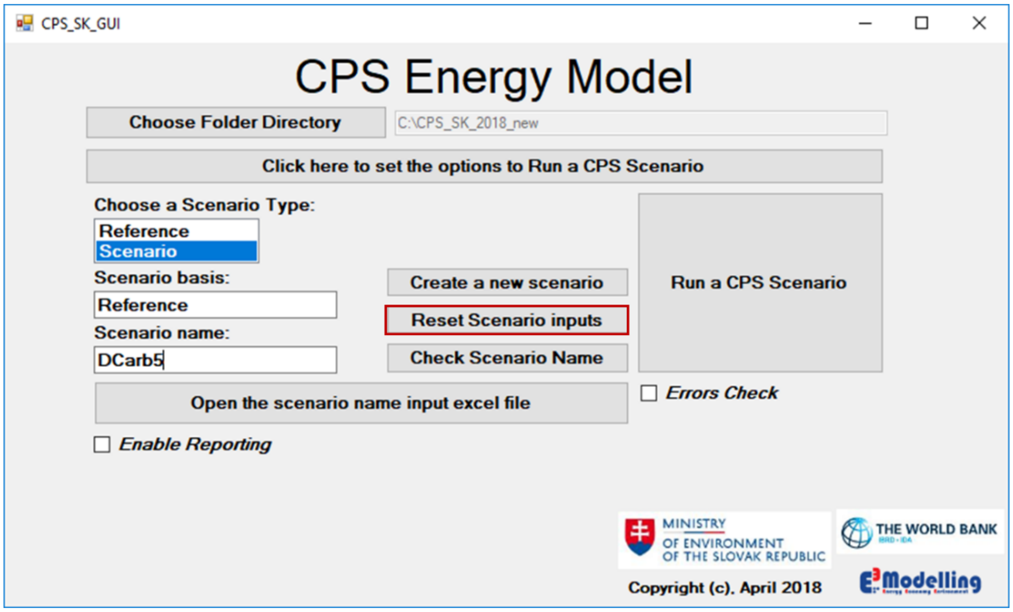
The Database Report file has been created. Use the Open Final Results Excel File button to open the report files

Figure 16 CPS GUI, Creation of results files

2.2.6. Resetting Scenario Inputs

The CPS GUI also provides a reset inputs option, see Figure 17.

By clicking on the "**Reset Scenario inputs**" pushbutton, the user resets all parameters included in the input excel files to the values of the Scenario basis. This is a very useful functionality provided by the GPS GUI, as it allows the user to quickly reset all changes (including potential errors) and start again the Scenario definition.



C:\CPS_SK_2018_new

Choose a Scenario Type: Scenario

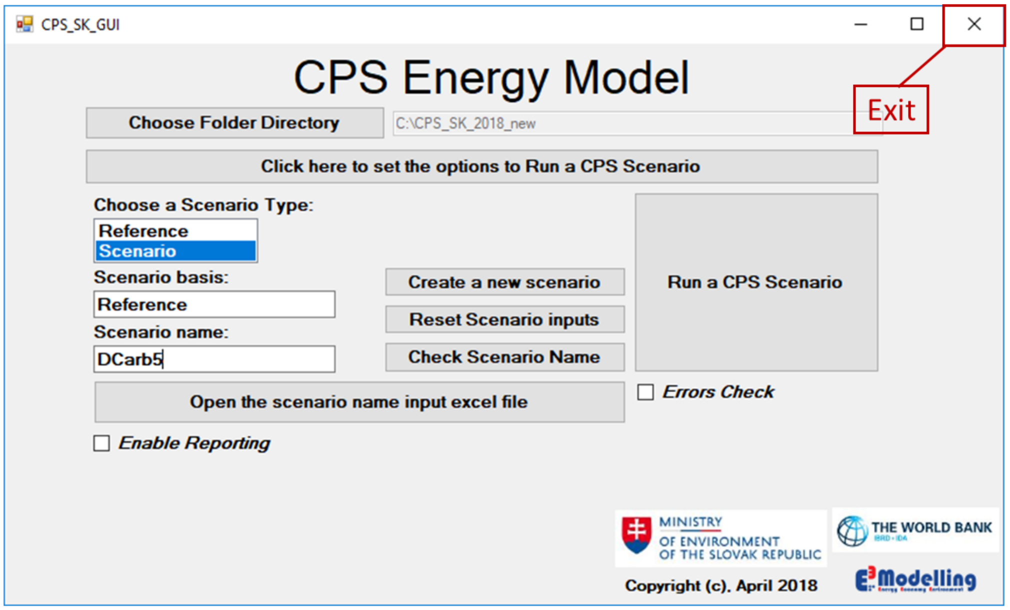
Scenario basis: Reference

Scenario name: DCarb5

Figure 17 CPS GUI, Resetting the Scenario input file

2.2.7. Exiting the GUI CPS Model

The user may exit the GUI by clicking the "**Exit**" pushbutton.



C:\CPS_SK_2018_new

Choose a Scenario Type: Scenario

Scenario basis: Reference

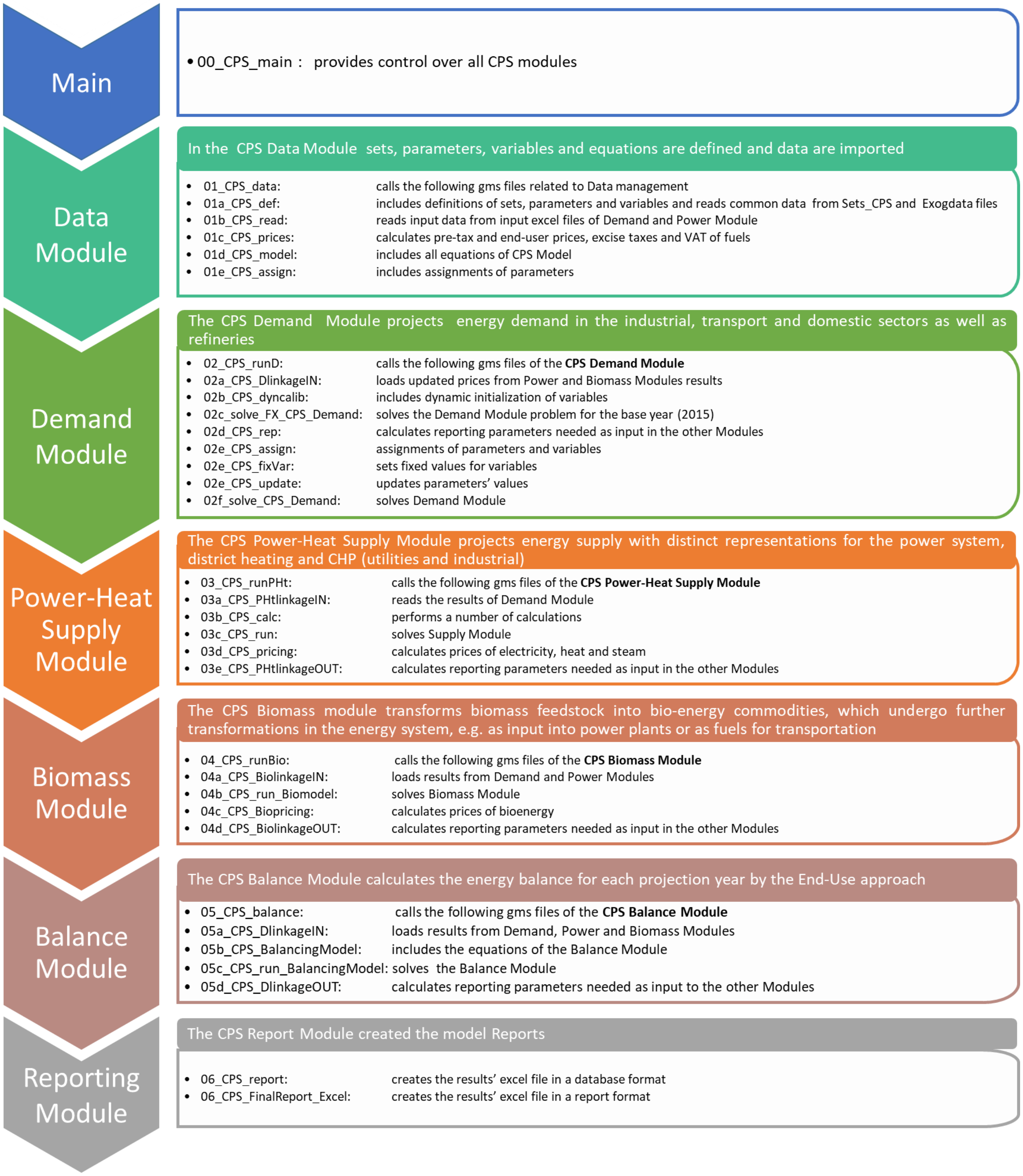
Scenario name: DCarb5

Figure 18 Exiting the CPS GUI

2.3 Locating the CPS Model Subfolders and the respective GAMS Files

The CPS Model folder structure comprises 5 subfolders:

1. The **CommonData subfolder** which includes the excel input files that are common between scenarios. These are the **Sets_CPS** and **Exogdata** excel files, described further in section 3.1 Common Input Data.
2. The **GUI subfolder** which includes the GUI application file.
3. The **Model subfolder** which includes all gams (.gms) files of the model, the corresponding gams project and the solver option files that are used by the CPS model. The overview of the gams files comprising the model, as well as the way the CPS Modules are linked with each other are shown in Figure 19.
4. The **Scenarios subfolder** which contains the *Scenario name subfolders* (i.e. subfolders for every scenario that has been created, e.g. Reference, DCarb1, DCarb2 subfolders). The structure of the *Scenario name* subfolder is explained below, in Section 2.4 The structure of the *Scenario name* subfolder.
5. The **Templates subfolder** which includes the excel template files for the Final Report and Database excel files, which include the results of a scenario's run.



Main

- 00_CPS_main : provides control over all CPS modules

Data Module

In the CPS Data Module sets, parameters, variables and equations are defined and data are imported

01_CPS_data:	calls the following gms files related to Data management
01a_CPS_def:	includes definitions of sets, parameters and variables and reads common data from Sets_CPS and Exogdata files
01b_CPS_read:	reads input data from input excel files of Demand and Power Module
01c_CPS_prices:	calculates pre-tax and end-user prices, excise taxes and VAT of fuels
01d_CPS_model:	includes all equations of CPS Model
01e_CPS_assign:	includes assignments of parameters

Demand Module

The CPS Demand Module projects energy demand in the industrial, transport and domestic sectors as well as refineries

02_CPS_runD:	calls the following gms files of the **CPS Demand Module**
02a_CPS_DlinkageIN:	loads updated prices from Power and Biomass Modules results
02b_CPS_dyncalib:	includes dynamic initialization of variables
02c_solve_FX_CPS_Demand:	solves the Demand Module problem for the base year (2015)
02d_CPS_rep:	calculates reporting parameters needed as input in the other Modules
02e_CPS_assign:	assignments of parameters and variables
02e_CPS_fixVar:	sets fixed values for variables
02e_CPS_update:	updates parameters' values
02f_solve_CPS_Demand:	solves Demand Module

Power-Heat Supply Module

The CPS Power-Heat Supply Module projects energy supply with distinct representations for the power system, district heating and CHP (utilities and industrial)

03_CPS_runPHt:	calls the following gms files of the **CPS Power-Heat Supply Module**
03a_CPS_PHtlinkageIN:	reads the results of Demand Module
03b_CPS_calc:	performs a number of calculations
03c_CPS_run:	solves Supply Module
03d_CPS_pricing:	calculates prices of electricity, heat and steam
03e_CPS_PHtlinkageOUT:	calculates reporting parameters needed as input in the other Modules

Biomass Module

The CPS Biomass module transforms biomass feedstock into bio-energy commodities, which undergo further transformations in the energy system, e.g. as input into power plants or as fuels for transportation

04_CPS_runBio:	calls the following gms files of the **CPS Biomass Module**
04a_CPS_BiolinkageIN:	loads results from Demand and Power Modules
04b_CPS_run_Biomodel:	solves Biomass Module
04c_CPS_Biopricing:	calculates prices of bioenergy
04d_CPS_BiolinkageOUT:	calculates reporting parameters needed as input in the other Modules

Balance Module

The CPS Balance Module calculates the energy balance for each projection year by the End-Use approach

05_CPS_balance:	calls the following gms files of the **CPS Balance Module**
05a_CPS_DlinkageIN:	loads results from Demand, Power and Biomass Modules
05b_CPS_BalancingModel:	includes the equations of the Balance Module
05c_CPS_run_BalancingModel:	solves the Balance Module
05d_CPS_DlinkageOUT:	calculates reporting parameters needed as input to the other Modules

Reporting Module

The CPS Report Module created the model Reports

06_CPS_report:	creates the results' excel file in a database format
06_CPS_FinalReport_Excel:	creates the results' excel file in a report format

Figure 19 Overview of CPS gams files and linkage

2.4 The structure of the *Scenario name* subfolder

The *Scenario name* subfolder includes 7 subfolders:

1. **Inputxlsx**: containing the input excel files of the scenario
2. **Inputgdx**: containing the input data that are relevant to the scenario in gdx format. The input gdx files are created by the model during runtime
3. **Outputxlsx**: containing the results of the model run in excel format
4. **Outputgdx**: containing the results of the model run in gdx format
5. **Lst:** containing the lst files of the model run. Lst files are created at every iteration of the model run, hence the corresponding numbers at the end of the files' names
6. **Log:** containing the log files of the model run. Log files are created at every iteration of the model run, hence the corresponding numbers at the end of the files' names
7. **Save:** containing intermediate work files

3. Input and Output Data

3.1 Common Input Data

As described in Section 2.3 Locating the CPS Model Subfolders and the respective Gams Files, the **CommonData** subfolder contains two excel files, **Sets_CPS** and **Exogdata.** Both files are essential for the CPS Model to run.

These files contain information which are common between scenarios. The data types included in these files are *sets* and *parameters*. Before proceeding it is useful to clarify the meaning of *sets* and *parameters* in GAMS.

3.1.1. Definitions

The definition of sets as mentioned in GAMS User's Guide[3] is presented in Box 1 Definition of sets in GAMS.

Box 1 Definition of sets in GAMS

> ***Sets:*** *Sets are the basic building blocks of a GAMS model, corresponding exactly to the indices in the algebraic representations of Models*

For example, the set "SW" is the set of technology categories incorporated in the CPS Model and includes the technology types shown in Table 1.

Table 1 Elements of set SW

Technology type	Description
ORD	Ordinary
ORI	Ordinary-Improved Intermediate
IMR	Improved
IMA	Improved-Advanced Intermediate
ADV	Advanced
ADF	Advanced-Future Intermediate
FUT	Future

A parameter is a data type, which enables the data entry of list oriented data. The dimensions (or indices) of a parameter are sets. For example, the capital cost of an equipment is inserted in the Model in the form of a parameter. The values of this parameter depend on the equipment (e.g. blast furnace, appliance for material preparation, electric arc), the technology category of the equipment (ordinary, improved, advanced) and the running year. Thus, capital cost is a parameter defined upon the sets of processes, technology categories and years.

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[3] https://www.gams.com/24.8/docs/userguides/GAMSUsersGuide.pdf

3.1.2. Sets_CPS.xlsm

The excel file **Sets_CPS** includes sets and parameters that constitute the core of the CPS Model. Table 2 below presents a selected/indicative list of the sets included in the Sets_CPS file, in order to familiarize the user. All sets included in Sets_CPS.xlsm can be found in Appendix I.

Table 2 Sets included in Sets_CPS.xlsm

Universal CPS Sets	Description
Year_all	Set of all years that may be used in the Model: from 1960 to 2050 in 5-year steps
Year	Set including the basis year 2015 (year of calibration) and projection years 2020 to 2050
Fuel_all	Set of all fuels used in the Model
Demand Module Sets	**Description**
SA	Set of demand sectors upper level
SB	Set of demand sectors second level
SC	Set of demand sectors third level
SD	Set of demand sectors fourth level
SE	Set of supply of demand sectors upper level
SF	Set of supply of demand sectors second level - supply processes
EP	Set of self-producing equipment/cokery
AG	Set of representative agents
SW	Set of technology categories
TC	Set of equipment vintages in 5-year steps
Stndrds	Set of types of standards
SF_F	Mapping of input fuels used in supply processes of demand sectors (ex. heat recovery)
SA_SF	Mapping of supply processes SF and demand sectors SA
foutprimary	Set of fuels that are primary outputs of self-producing equipment
foutsecondary	Set of fuels that are secondary outputs of self-producing equipment
lifecat	Set of lifetime categories
SF_HER	Mapping of supply processes SF eligible for heat recovery and HER fuel
Power Module Sets	**Description**
hour	Set of typical hours
day	Set of typical days
plant	Set of all plants of Power Module
cluster	Set of labels of unit clusters
unit	Set of power plants
unit_region	Set of locations of units
unit_limit	Set of power plants with operation constraints in unit commitment
indCHP	Set of onsite CHP power plants
storage	Set of storage facilities
PtoX	Set of power to X plants
dhh	Set of district heating plants producing heat
CCS	Set of plants with a carbon capture and storage possibility
ancillary_all	Set of ancillary services
ancillary_up	Set of upward ancillary services
ancillary_down	Set of downward ancillary services
load_type	Set of types of load
hour_day	Mapping of hours belonging to the same day
fuel_dhh	Subset of fuels used in district heating plants
fuel_limit	Subset of fuels with a nonlinear cost supply curve
cleanfuel	Subset of clean fuels
type_dhh	Set of types of district heating plants

type_limit	Set of types of plants with nonlinear cost supply curves
type_storage	Set of types of storage power plants with nonlinear cost supply curves
level	Set of levels in the cost supply curves
mapday	Mapping of hours in days
hour_seq	Mapping indicating the sequence of hours
fuelplant_init	Mapping of fuels used by a plant

For example, set Fuel_all includes, among others, the following fuels:

Table 3 Elements of Fuel_all set

Fuel	Fuel description	Fuel	Fuel description	Fuel	Fuel description
GSL	Gasoline	BMS	Biomass Solids	H2F	Hydrogen
GDO	Diesel	WSD	Waste Solids	HER	Self-produced heat recovery
KRS	Kerosene	BGS	Biogas	NUC	Nuclear
LPG	LPG	WSG	Waste Gas	HYDR	Hydro
RFO	Fuel Oil	BFC	Biofuel conventional	WON	Wind onshore
CRO	Crude oil	BFA	Biofuel advanced	WOF	Wind offshore
NGS	Natural Gas	SOL	Solar	TID	Tidal
HCL	Hard Coal	GEO	Geothermal	WSLD	Waste solid
CKE	Coke	ELC	Electricity	WLQD	Waste liquid
CKE_self	Self-produced Coke	HET	Heat	WGAS	Waste gas
LGN	Lignite	STM	Self-produced Steam	FDS	Feedstock

The parameters included in Sets_CPS.xlsm are presented in Table 4:

Table 4 Parameters of Sets_CPS.xlsm

Demand Module Parameters	Description
TcHist	Histogram/mapping between vintages and lifetime categories
Stock	Stock of vehicles in thousand vehicles in 2015
Occupancy	Occupancy factor in passengers or tons per vehicle-trip
fopportunity	Ratio denoting fraction of price of marketed fuel saved due to self-production of fuels
Power Module Parameters	**Description**
ImpExp	Net Imports product pattern [%]
respattern	Hourly pattern for variables RES generation [%]
elecpattern	Hourly pattern for electricity demand [%]
heatpattern	Hourly pattern for heat demand [%]
netimportspattern	Net Imports pattern [%]
onsitechpelecpattern	Electricity generation pattern from onsite CHP plants [%]
sectors_alloc	Mapping of sectors and voltage type [%]
first	Mapping between days and first hour of each day
last	Mapping between days and last hour of each day
freq_hour	Annual frequency of a typical hour
freq_day	Annual frequency of a typical day
sectors_load_type	Mapping of demand sectors and load types [%]

3.1.3. Exogdata.xlsx

The **Exogdata** input file includes exogenous data inserted in the CPS Model in the form of parameters. Exogdata includes consumption data of previous years by demand sector and process, as well as exogenous parameters used in the Balance Module and the fuel blend of industrial plants. A detailed description of the parameters included in Exogdata.xlsx can be found in Table 5.

Table 5 Parameters of Exogdata.xlsx

Parameters	Description
Exogdata	Fuel consumption of all processes of demand sectors for years 2015 to 2050. 2015 values are used for calibration purposes, while future years' values are used for initialization purposes
Blend	Predefined fuel shares for fuels consumed in industrial CHP plants and boilers
Balance_rep_exog	Projection of Energy Consumption in Mines & Patent Fuel/Briquetting plants, in Oil and Gas Extraction and Non specified Transport balance sectors used for the first iteration of the Power Module
BAL_PAR	Exogenous trends used for the calculation of the energy balances in Balance Module
Balance_rep_Exog2015	Consumption of purchased (not produced by industrial plants) steam in certain industrial sectors for year 2015

The values of the above parameters are derived from Eurostat balances for past years, and PRIMES' projections for future years, using the results of the Reference Scenario 2016 (https://ec.europa.eu/energy/sites/ener/files/documents/20160713%20draft_publication_REF2016_v13.pdf).

The information existing in the input excel files **Sets_CPS** and **Exogdata** are **not** to be changed by the user and should remain as provided by E3Modelling for every existing or to be created scenario.

3.2 Output Data

The results files of the CPS Model are created by pressing the "**Run Final Report for Scenario**" pushbutton, as mentioned in section 2.2.5 Reporting, and are placed in the outputxlsx subfolder of the corresponding scenario folder (e.g. D:\CPS_SK_2018_new\Scenarios\DCarb1\outputxlsx). The results are presented in two excel files, each one having a different form:

- **Final Report**: Results presented in a Report Form, suitable for a printed version of the CPS outputs (e.g. file name: FinalReport_DCarb1.xlsx)
- **Database:** Results presented in a Database Form (e.g. file name: DCarb1_db.xlsm)

3.2.1. Final Report file

The **Final Report** excel file consists of 23 sheets. Each sheet's name and contents is described below:

- Scenario_Assumptions
  - Macroeconomic drivers (GDP, Population, GDP per capita)
  - International fuel prices of hard coal, crude oil and natural gas
  - Sectoral Value Added for all sectors
  - Key policy drivers

        - Carbon price for ETS sectors
        - Carbon value for non-ETS sectors
        - Average renewable value
        - Average energy efficiency value
- Summary&Indicators
    - Key Policy indicators
        - Total CO_2 emissions from energy combustion (% change w.r.t. 2005)
        - CO_2 emissions of ETS sectors (% change w.r.t. 2005)
        - CO_2 emissions of non-ETS sectors (% change w.r.t. 2005)
        - Overall RES share (%)
        - RES-H&C share (RES share in heating and cooling)
        - RES-E share (RES share in electricity generation)
        - RES-T share (RES share in transport)
        - Primary energy savings w.r.t. the respective year value of PRIMES 2007 baseline projection (%) for years 2020-2030
        - Energy Intensity of GDP (in MWh/M€)
        - Carbon Intensity of GDP (in $tnCO_2$/M€)
        - Import Dependency %
    - Key energy results
        - Primary energy production per fuel type
        - Net imports for electricity and fuels
        - Gross inland consumption for electricity and fuels
        - Final energy demand in Non Energy sector
        - Total final energy consumption per fuel
        - Power generation per fuel type
        - CO_2 emissions per sector
        - Average electricity price
    - Key economic results for Industry, Households, Tertiary and Transport
        - Capital, non-fuel and fuel costs
        - Emission and energy taxation costs
        - Subsidies
- Fuel_Prices
    - Pre-tax price
    - Excise tax
    - VAT
    - End user price

  per fuel and sector
- Industry
    - Sectoral Value Added per industrial sector

- Physical output indicator (for certain sectors)
- Fuel consumption per sector and fuel
- CO_2 emissions per sector
- Energy intensity per sector
- Carbon intensity per sector
- For industrial CHP plants and boilers:
  - Fuel consumption per sector and fuel
  - Gross electricity production
  - Steam production
  - CO_2 emissions per sector

- Sheets of industrial sectors: Iron&Steel to Other_Industries
  - Sectoral Value Added
  - Direct use of fuels per fuel
  - CO_2 emissions
  - For industrial CHP and boilers:
    - Installed capacity
    - Investments
    - Electricity production (for industrial CHP only)
    - Steam production
    - Fuel consumption per fuel type
    - Total CO_2 emissions of industrial plants
  - Energy savings
  - Carbon Intensity
  - System costs
  - Investment expenditures
  - For Iron & Steel, Non Ferrous, Chemicals, Building Materials and Paper & Pulp sectors the physical output indicator is also being reported
- Non_energy
  - Sectoral Value Added
  - Final energy demand by fuel
- Residential & Tertiary
  - Private consumption
  - Population
  - Final energy demand (per use and fuel)
  - CO_2 emissions
  - Energy savings
  - Energy efficiency indicator (Useful energy over Final energy demand)
  - Energy intensity
  - Carbon intensity

    - System costs
    - Investment expenditures
- Transport
    - Transport activity separated in passenger and freight transport
    - Final energy demand per transport activity and fuel
    - CO_2 emissions
    - Specific energy consumption per transport activity
    - System costs
    - Investment expenditures per transport activity
    - Stock of vehicles per type of vehicle and fuel consumed
- Power_Generation
    - Domestic consumption of electricity per demand sector
    - Transmission and Distribution Losses
    - Storage and Demand Response Losses
    - Self-Consumption of power plants
    - Consumption of electricity in Power to X units
    - Exports of electricity
    - Total Gross Demand for electricity
    - Total Gross Domestic Power Generation
    - Total Supply of electricity
    - Gross Electricity Generation per plant type
    - Net Electricity Generation per plant type
    - Net Installed Capacity per plant type
    - Capacity Expansion per plant type
    - Fuel Consumption per fuel (for thermal power plants)
- Heat_Generation
    - Domestic Consumption of heat
    - District Heating Losses
    - Total Gross Demand for Heat
    - Total Gross Domestic Heat Generation
    - Total Supply of Heat
    - Heat Generation per plant type
    - Net Installed Capacity per plant type
    - Capacity Expansion per plant type
    - Fuel Consumption per fuel
- PowerGeneration-Costs
    - Costs of electricity and heat supply
        - Capital, non-fuel and fuel costs
        - Emission and energy taxation costs

        - Other costs/revenues
        - Transmission and distribution costs
        - Fees related to RES support
    - Investment Expenditures in Electricity, CHP & Heating Plants per plant type
    - Investment Expenditures for Storage per storage type
    - Investment Expenditures for Power to X plants
    - Average cost of electricity generation
    - Additional supply costs
    - Pre-tax average price of electricity
    - Excise tax and VAT on electricity
    - After-tax average price of electricity
- PowerGeneration-Indicators
    - Ratio of provided ancillary services over domestic electricity consumption including transmission and distribution losses
    - Shares of various plant types (Carbon free generation, Renewables, Variable renewables, CHP, CCS) in net electricity generation
    - CO_2 emissions
    - CO_2 emissions captured
    - Carbon Intensity per plant type (e.g. Thermal power plants, Industrial Boilers, District Heating heat plants and Total power generation)
- Biomass_Supply_Model
    - Demand of bioenergy per fuel
    - Domestic production of Biomass Feedstock
    - Net Imports of Biomass Feedstock
    - Net imports of Bioenergy
    - Bioenergy Production
    - Installed Capacity of Biomass Technologies
    - Capacity Expansion of Biomass Technologies
    - Fuel Consumption
    - Total Cost of Biomass Supply
    - Commodity Price per fuel type
- TransformationP_EnBR
    - For cokery and refineries
        - Capacity
        - Investments
        - Input Fuel
        - Output Fuel
    - Energy consumption of Energy branch
        - Self-consumption in Electricity, CHP and Heat plants

        - Self-consumption in Storage plants (losses)
        - Direct Fuel Consumption in Refineries
        - Fuel Consumption in Coke-Oven and Gas-Works Plants
        - Fuel Consumption in Mines and Patent Fuel\Briquetting Plants
        - Fuel Consumption in Oil and Gas Extraction
    - For CHP plants and boilers of Refineries
        - Installed capacity
        - Steam production
        - Fuel consumption per fuel
        - Gross Electricity Production (CHP only)
    - Energy Savings
    - Energy intensity production related (GWh consumed over GWh_{fuel} produced)
    - CO_2 emissions of the Energy Branch
    - CO_2 emissions of CHP Plants and boilers of Refineries

3.2.2. Database file

The **database** file includes all information presented in the Final Report file in database form, plus two additional sheets: Balance_db and Baldat_2015_db. The former presents the energy balances for each year as calculated by the CPS Balance Module, through the application of the ***End Use*** approach. The latter presents the energy balance of 2015, as calculated by the CPS Balance Module using the so called ***Baldat approach***. Both the End-Use and the Baldat approach are further explained at the end of this section.

- Scenario_Inputs
    - Includes the information in Scenario_Assumptions sheet of Final Report
- Summary_db
    - Includes the information in Summary&Indicators sheet of Final Report
- Fuel_Prices
    - Includes pre-tax prices, excise tax, VAT and end user prices per fuel & sector
- Demand_db
    - Includes the results of the Demand Module for all demand sectors, existing also in sheets Iron&Steel to Transport of Final Report
- PowerHeat_db
    - Includes the results of the Power Module, existing also in sheets Power_Generation to PowerGeneration-Indicators of Final Report
- Biomass_Supply_db
    - Includes the results of the Biomass Module, similar to Biomass_Supply_Model sheet of Final Report
- Balance_db

  - Includes the Energy Balances of every projection year following the *End Use* approach. The assumptions of the End Use balancing approach are explained below.
- Baldat_2015_db
  - Includes the calculated energy balance of 2015 following the *Baldat* approach of Eurostat. The assumptions of the Baldat balancing approach are explained below.
- TransProcesses_db
  - Includes results regarding transformation processes (cokery, refineries, energy branch), similar to TransformationP_EnNR sheet of Final Report.

3.2.3. Approaches used in Energy Balances Reporting

Energy Balances reported in sheets Balance_db and Baldat_2015_db have been calculated by the implementation of two approaches: the End Use approach (sheet Balance_db) and the Baldat approach (sheet Baldat_2015_db).

Details of each approach and additional information concerning the structure of each Excel sheet are provided below:

- End Use approach (sheet Balance_db):
  - Fuel consumption for the production of electricity and steam in industrial CHP and boilers are reported in columns labelled "Transformation input – Industrial CHP" and "Transformation input – Industrial Boilers" respectively
  - Steam and electricity output from industrial plants (meaning the steam and electricity produced in the industrial plants) are reported in columns labelled "Transformation output – Industrial CHP" and "Transformation output – Industrial Boilers"
  - The column labelled "Energy Consumption" represents fuel consumption and includes only the fuels *directly* consumed in industrial sectors (including refineries) by the processes of these sectors, including the **entire** amount of steam and electricity consumed, which could be either steam and electricity produced by the industrial plants or purchased from the market
    - Label "Energy Consumption" of industrial sectors does **not** include the fuel consumption for the **production** of electricity and steam in industrial plants

  The End Use accounting approach is appropriate for modelling self-production of energy, but End Use data are not fully available. Therefore the required process of calibration of the model in the basis year (2015) has been done via the use of the available energy balances of 2015 in Baldat approach, and the results of the calibration are available in the sheet Baldat_2015_db of the database file.
- Baldat approach (sheet Baldat_2015_db, official EUROSTAT approach):
  - Industrial Boilers
    - Fuel consumption for the production of steam is reported in the column labelled "Energy Consumption" of each industrial sector

    - The steam output of industrial boilers is not reported
- Industrial CHP plants
    - Fuel consumption in industrial CHP plants is split into fuel consumption for the production of steam and fuel consumption for the production of electricity
    - Fuel consumption for the production of steam from industrial CHP is reported, for each industrial sector, in the column labelled “Energy Consumption”
    - The steam output of industrial CHP plants is not reported
    - Fuel consumption for self-production of electricity is reported in the column labelled “Transformation input – Industrial CHP” and is *not* included in “Energy Consumption” label of industrial sectors
    - Electricity output of industrial CHP appears in label “Transformation output – Industrial CHP” and is also included in “Energy Consumption” label of industrial sectors

Thus, label “Energy Consumption” for industrial sectors includes fuels consumed for the production of steam in industrial plants, but not fuel consumption for the self-production of electricity. Moreover, “Energy Consumption” label includes only the amount of steam distributed (purchased from third parties), and *not* the amount of steam produced from industrial CHP and boilers, as well as the total amount of electricity consumed (self-produced and purchased).

4. Overview of the CPS Demand Module

This chapter provides an overview of the main principles of the CPS Demand Module.

- Section 4.1: Basic concepts in the CPS Demand Module
- Section 4.2: Mathematical Structure, unknown variables and exogenous parameters
- Section 4.3: Model features, considerations and assumptions
- Section 4.4: Policy Focus – Demand
- Section 4.5: Explaining the demand-related scenario input file

4.1 Basic concepts in the CPS Demand Module

The CPS Demand Module includes all necessary mathematical formulations for projecting energy demand in the industrial, transport, residential and tertiary sectors, as well as refineries. For each energy demand sector, a representative decision-making agent (or numerous agents for certain sectors) is considered to operate.

In general, demand is modelled in terms of useful energy services (such as heating, electric appliances, mobility, raw material preparation, metal melting etc.) and in terms of final energy commodities, ensuring energy balance between useful and final energy. Figure 20 provides a very simple illustrative example relating useful energy to the energy input in a process. In the example, energy input reflects final energy demand (here electricity), which is converted to useful energy (here light).

Box 2 Definition of useful energy

Useful energy: *The portion of final energy which is actually available to the consumer for the respective use after the energy conversion. In final energy conversion, electricity becomes for instance light, mechanical energy or heat.*

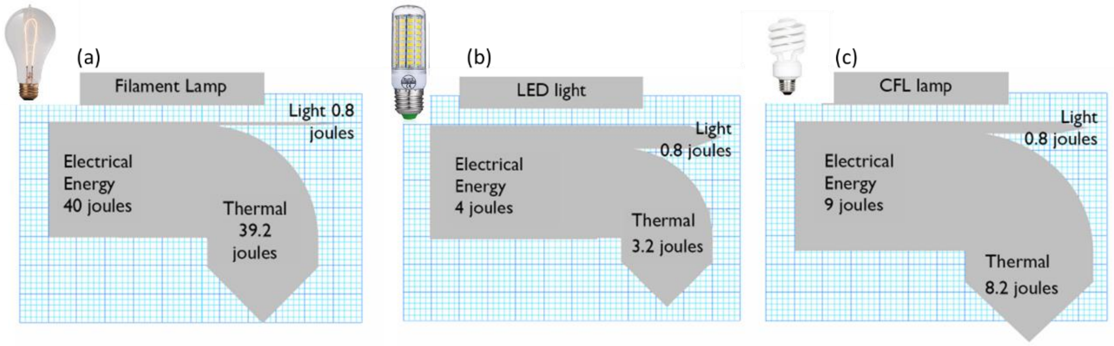


Figure 20 Illustrative example of the conversion of energy input to useful energy. For all cases (a) – (c), useful energy is equal to 0.8 J. The more efficient the conversion of energy input to useful energy, the less energy input is needed

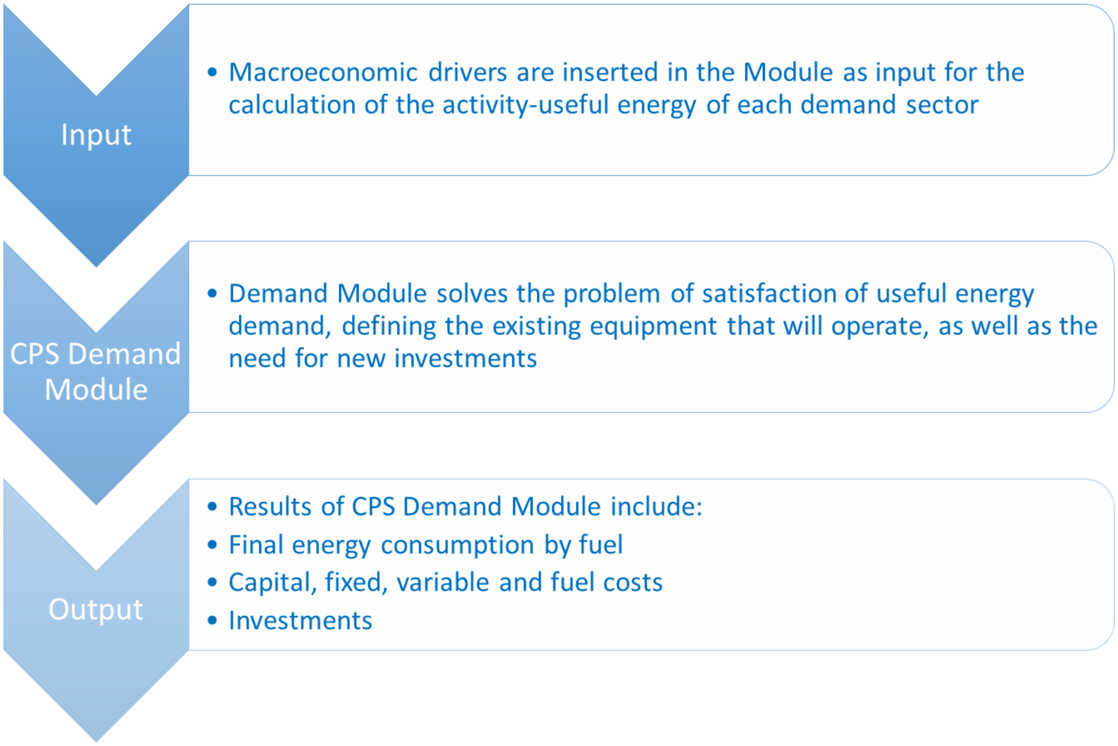
Energy efficiency investments may reduce demand for useful energy, as simplistically shown in Figure 20. The costs of such energy efficiency investments are included in the investment expenditures and annuity payments accounting of the CPS Demand Module.

The calculation sequence of the CPS Demand Module is:

a) Macroeconomic drivers are inserted as input
b) Activity-useful energy per demand subsector is then computed
c) Technology equipment is employed to meet useful energy demand. Final energy demand, in the form of purchased fuels or self-produced energy forms, is calculated in order to meet the demand for useful energy
d) The need for new investments is derived from the demand for useful energy and the capacity of the existing equipment. The choice of the investments' characteristics is based on cost minimization criteria.

The reader is referred to Appendix III for a detailed mathematical representation. The Demand Module's mathematical formulation is a mixed complementarity problem, which concatenates the individual optimization problems, written in the form of Kuhn-Tucker conditions.

Figure 21 shows the basics of the CPS Demand Module. The Module is based on concluding a number of choices, such as choice of technology, fuel, investment and premature replacement.



- Macroeconomic drivers are inserted in the Module as input for the calculation of the activity-useful energy of each demand sector

- Demand Module solves the problem of satisfaction of useful energy demand, defining the existing equipment that will operate, as well as the need for new investments

- Results of CPS Demand Module include:
- Final energy consumption by fuel
- Capital, fixed, variable and fuel costs
- Investments

Figure 21 CPS Demand Module basics

4.2 Mathematical structure, unknown variables and exogenous parameters

4.2.1. Mathematical structure

The basic mathematical problem of the Demand Module is to calculate the final energy that needs to be consumed by the demand sectors in order to satisfy the sectors' activity, whether that corresponds to physical output, e.g for some industrial sectors, or energy services, as in the case of heating/cooking/appliances etc. for the domestic sector, or demand for passenger/tonne-kilometers in the transport sector. In order to project final energy demand/consumption, the CPS Demand Module decomposes each sector in subsectors (sets SA to SF of Table 2), following the structure of a nesting tree:

- Initially, macroeconomic drivers, such as GDP per capita and Income per capita are inserted in the Demand Module as an input defined exogenously.
- The first level of the nesting tree, corresponding to set SA, represents the most aggregated form of the demand sectors.

> *It must be noted that level SA is used in the Demand Module* ***solely as a modelling tool*** *for the avoidance of scaling problems during the model run. Set SA is incorporated in the model in order for the demand sectors to run sequentially (separately) and not simultaneously.*

- In the second level SB of the nesting tree, sectors of level SA are split in subsectors representing a more detailed categorization, e.g. Iron & Steel splits in Integrated Steelworks and Electric Arc, Chemicals are decomposed in Fertilizers & Petrochemicals and Pharmaceuticals & Cosmetics and Tertiary splits in Services and Agriculture. At this level, ***the macroeconomic drivers are converted to demand for activity-useful energy for each subsector of level SB, through the use of an econometric function***.
- At the third SC and fourth SD level of the tree, activities are allocated in further subsectors, which may be complementary or substitutable. For example, Services subsector consists of 5 subsectors, which are: Electric Uses, Lighting, Heating, Air Cooling and Water heating & Cooking. In the case of Services, the subsectors are complementary to each other. However, in the case of Land/Water passenger transport, the demand for passenger-kilometers can be satisfied by inland navigation, private passenger transport, public passenger transport or rail, which are substitutable subsectors belonging to the third level SC. In fourth level SD, the subsector of private transport is further split in cars and 2 wheelers, whilst public transport is split in metro/tram and road transport, where substitutability also applies.

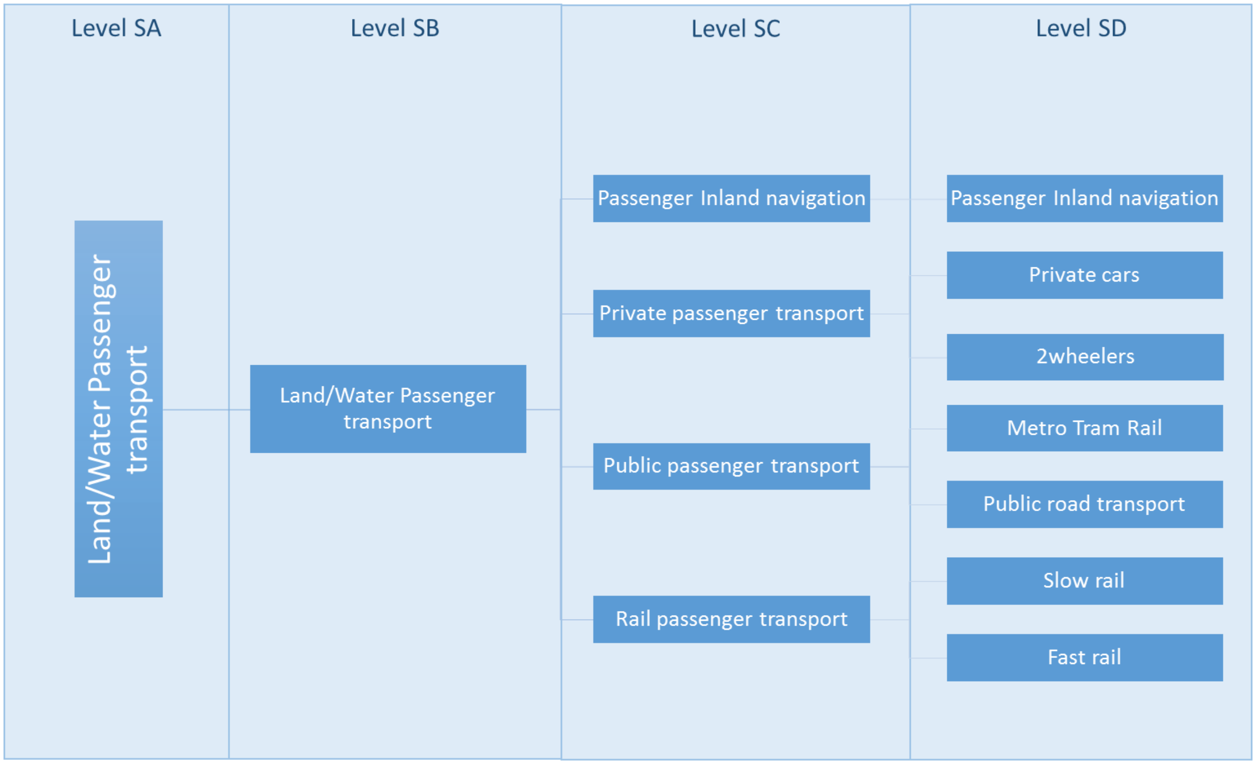


Figure 22 depicts the whole structure of Land/Water passenger transport sector from level SA to SD.

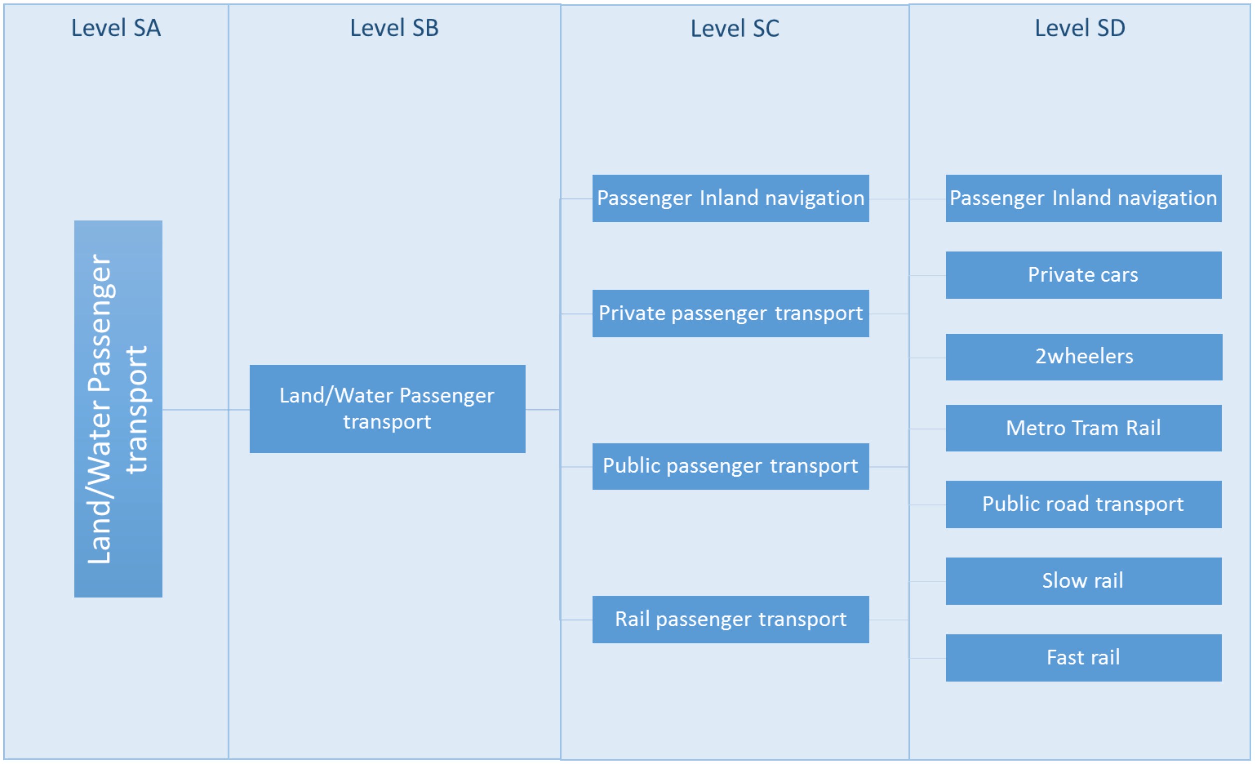


Figure 22 Structure of Land/Water Passenger Transport sector for levels SA to SD

- The last two levels of the nesting tree (5th and 6th level, corresponding to sets SE and SF respectively) no longer represent a further categorization of subsectors of level SD, but rather the *processes or uses* of every subsector that are meant to *provide the useful energy needed* to satisfy the energy demand for the calculated activity-useful energy of the 4th level SD, and are thus called ***supply processes***. ***Every process/use is considered to correspond to a relevant equipment category***. In the previous example, the processes/equipment of the 5th level that correspond to Private cars subsector of the 4th level are: Internal Combustion Engine (ICE) cars, Electric cars and Hydrogen-consuming cars. At the lowest level SF of the nesting tree, the most detailed categorization of processes/equipment is presented, e.g. ICE cars are comprised of Diesel, Gasoline and Gas consuming cars, as shown in Figure 23. To provide another example from the industrial sectors, the Basic Oxygen Furnace subsector of Iron & Steel is comprised of 4 processes/uses: horizontal energy uses, raw material preparation, thermal & electric processing and product finishing. The detailed structure of every demand sector is presented in Appendix II. The calculated activity-useful energy of the subsectors of level SD is translated into useful energy needed to be produced by the supply processes of level SE. Similarly, useful energy produced by the supply processes level SE defines the need for useful energy production from the supply processes of level SF.

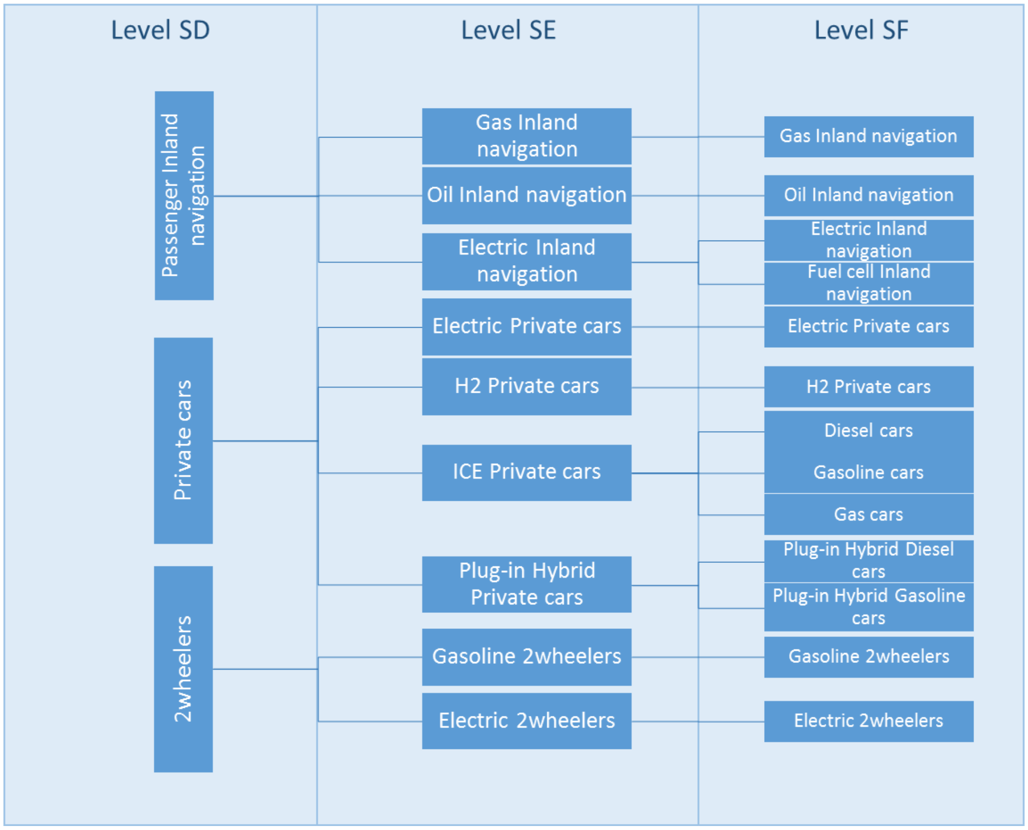


Figure 23 Supply processes/equipment of land/water passenger transport

- The final level SF of the nesting tree, is the level in which useful energy produced can be translated to final energy consumption, as this is the level of the most detailed equipment categorization. All technical characteristics of equipment, including specific energy consumption, utilization rates, investment/fixed costs etc. are defined for the equipment of level SF. At this level, the choices that have to be considered are of two categories:
    - Choice of the equipment type mix: the equipment type is defined by two parameters: the technology advancement level, as this has been described in Section 3.1.1. Definitions (ordinary, improved, advanced etc.), and the vintage of the equipment. Thus, in level SF, the combination of the equipment types that will operate needs to be defined.
    - Choice of the fuel mix: meaning the share of each fuel in the total final energy consumption of every equipment type.

Having defined the decomposition of demand sectors in subsectors and processes/equipment, the remaining problem to be solved is the calculation of the ***percentage*** to which every process/equipment or subsector of a lower level contributes to the satisfaction of the demand for activity-useful energy of the corresponding upper level process/equipment or subsector.

In economics, discrete choice models or qualitative choice models describe, explain and predict choices between two or more discrete alternatives, such as choosing between modes of transport, choosing amongst different processes or fuels, through the use of logit functions.

Consequently, in the CPS Demand Module the allocation of the activity of an upper level between the subsectors or processes of the lower level is defined through the use of ***logit functions***. The decisive variable that is inserted in the logit function in order to calculate the shares of the lower level subsectors or processes is the ***cost***. The logit function compares the costs of the available choices of the lower level subsectors or processes and defines the share of every subsector or process in the composition of the activity-useful energy of the upper level. Logit functions are applied also for the choice of the equipment type mix and fuel mix. The above description of the mathematical structure of the CPS Demand Module is summarized in Table 6.

Table 6 The nesting tree structure of the CPS Demand Module

Level	Description	Mathematical Formulation
SA	Top level of the nesting tree	-
SB	Conversion of macroeconomic driver to activity-useful energy of subsectors of level SB	Econometric function
SC	Allocation of activity-useful energy of subsectors of level SB to subsectors of level SC	Logit functions
SD	Allocation of activity-useful energy of subsectors of level SC to subsectors of level SD	Logit functions
SE	Allocation of activity-useful energy of subsectors of level SD to processes/equipment of level SE	Logit functions
SF	Allocation of useful energy of processes/equipment of level SE to processes/equipment of level SF	Logit functions
SF	Calculation of equipment type mix and fuel mix in a process SF	Logit functions

Before the extended review of the mathematical formulation of the Module it is useful to present the two types of economic behaviors of the representative decision-making agents considered in the Module: the short term behavior and the long term behavior. The notions of the two behaviors are presented in Table 7.

Table 7 Details on the modelling of long term and short term behavior

Long Term behavior	Short Term behavior
• Focuses on actions with a long-term effect	• Involves decision making related to the operation of existing equipment with fixed capital vintage
• Takes into account annuity payments	• Defines the fuel mix used in operating equipment
• Determines the volume of investments needed	• Does not take into account annuity payments
• Determines the technology type and fuel of investments	

Long term behavior is reflected in the calculation of long term marginal costs, while short term behavior is represented through short term marginal costs. For example, an industry may differentiate fuel usage (e.g. a cement industry may decide to use a combination of waste and coal as fuel, rather than 100% coal) by comparing short term marginal costs between the fuel options. On the other hand, the decision regarding the upgrade or renewal of equipment involves the consideration of capital costs embedded within. In this decision making process, the comparison of long term marginal costs will determine the technology type of the new investment, as well as the capacity of the new equipment and the fuel it will consume.

Equipment of levels SE and SF have both short and long term costs, as mentioned previously. In order to calculate the investments in new equipment, the model projects the **optimum** technology mix, via the use of long term costs **assuming no existing capacity of equipment** and calculates the capacity of new investments as:

- Capacity of new investments

$$Inv = max\big(0, (optimum\ technology\ mix - existing\ capacity)\big)$$

4.2.1.1 Calculation of sectoral activity of level SB

At the second level of nesting SB, activity is derived from macroeconomic drivers, such as GDP, income and population. The projection of macroeconomic drivers is exogenous to the model.

For the projection of second level activity-useful energy $ACT_{SB,t}$ an econometric-type equation is used, which involves elasticity $bact_{SB,t}$ regarding the macroeconomic drivers $macro_{SB,t}$. The elasticity $bact_{SB,t}$ is changing over time, depending on the distance of the macroeconomic driver of the previous period $macro_{SB,t-1}$ from the value of the macroeconomic driver at the inflection point $macro_{SB,t}^{ip}$, divided by the benchmark value of the macroeconomic driver $\overline{macro}_{SB,t}$. For the calculation of elasticity $bact_{SB,t}$ a logit function is used.

- The econometric equation for the calculation of sectoral activity

$$log\big(ACT_{SB,t}\big) = aact_{SB,t} + bact_{SB,t} \cdot log\big(macro_{SB,t}\big)$$

Where

$aact_{SB,t}$: Additive parameter of the econometric equation

- The logit function for elasticity $bact_{SB,t}$

$$bact_{SB,t} = \overline{bact}_{SB,t} + cal_{SB,t} \cdot \frac{bact_{SB}^{max} - \overline{bact}_{SB,t}}{1 + e^{bspeed_{SB,t} \cdot \left(\frac{macro_{SB,t-1} - macro_{SB,t}^{ip}}{\overline{macro}_{SB,t}}\right)}}$$

$$cal_{SB,t} := 1 + e^{-bspeed_{SB,t} \cdot \left(\frac{macro_{SB,t}^{ip}}{\overline{macro}_{SB,t}}\right)}$$

Where

t: Year

$bact_{SB}^{max}$: Maximum value of elasticity

$\overline{bact}_{SB,t}$: Benchmark value of elasticity

$bspeed_{SB,t}$: Speed of convergence

$macro_{SB,t}^{ip}$: Macroeconomic driver equal to activity level at the inflection point

$\overline{macro}_{SB,t}$: Benchamrk value of macroeconomic driver

4.2.1.2 Allocation of activity-useful energy along the subsectors' levels SB to SD

The allocation of activity-useful energy $ACT_{SU,t}$ of an upper level SU between the subsectors of a lower level SL is calculated through the use of two **generalized** logit functions: the Inertia Share and the Optimum Share logit function. The Inertia Share logit function $SH_{SU,SL,t}^{Inert}$ projects the shares of subsectors, as these would be defined influenced by the current observed preferences, while the Optimum Share logit function $SH_{SU,SL,t}^{Opt}$ projects the shares of subsectors defined solely by their costs, deprived of market preferences.

The mathematical formulations of the Inertia and Optimum share logit functions are:

- The Inertia Share logit function

$$SH_{SU,SL,t}^{Inert} = multi_{SU,t} \cdot \frac{\delta_{SU,SL,t} \cdot e^{-g_{SU,t} \cdot (p_{SL,t})}}{\sum_{SL} \delta_{SU,SL,t} \cdot e^{-g_{SU,t} \cdot (p_{SL,t})}}$$

- The Optimum Share logit function

$$SH_{SU,SL,t}^{Opt} = multi_{SU,t} \cdot \frac{\delta_{SU,SL,t}^{Opt} \cdot e^{-g_{SU,t}^{Opt} \cdot (p_{SL,t})}}{\sum_{SL} \delta_{SU,SL,t}^{Opt} \cdot e^{-g_{SU,t}^{Opt} \cdot (p_{SL,t})}}$$

Where
t: Year
$multi_{SU,t}$: Parameter distinguishing between substitutability and complementarity of subsectors SL (equal to 1 for substitutable subsectors or equal to the number of relevant choices of level SL for complementary subsectors)

$\delta_{SU,SL,t}$: Scale parameter of inertia logit function of level SL depicting preferences between subsectors

$g_{SU,t}$: Exponent of inertia logit function of level SU

$p_{SL,t}$: Cost per unit of activity of subsector SL

$\delta_{SU,SL,t}^{Opt}$: Scale parameter of optimum logit function of level SL (equal to the inverse of the number of relevant choices of level SL, used for scaling purposes)

$g_{SU,t}^{Opt}$: Exponent of optimum logit function of level SU

The above generalized logit functions have to the ability to represent both substitutability and complementarity cases in one compact formula. This is established via the application of proper values for the functions' parameters: $multi$ and g.

The share $SH_{SU,SL,t}$ of each subsector of level SL which belongs to a corresponding subsector of level SU, is calculated as the weighted average of the two generalized logit functions $SH_{SU,SL,t}^{Inert}$ and $SH_{SU,SL,t}^{Opt}$:

- The share of a subsector/process SL in the activity of level SU as the weighted average

$$SH_{SU,SL,t} = (1 - \theta_{SU}) \cdot SH_{SU,SL,t}^{Inert} + \theta_{SU} \cdot SH_{SU,SL,t}^{Opt}$$

- The generalized unit cost of level SU

$$p_{SU,t} = \sum_{SL} SH_{SU,SL,t} \cdot p_{SL,t}$$

- The activity-useful energy of lower level SL

$$ACT_{SL,t} = SH_{SU,SL,t} \cdot ACT_{SU,t}$$

Where

θ_{SU}: Parameter depicting the degree of tendency towards the optimum share of level SU

$p_{SU,t}$: Cost per unit of activity of subsector SU

$ACT_{SL,t}$: Activity of subsector SL

Through this mathematical mechanism, the exogenous macroeconomic drivers have now been translated to activity volumes per subsector of levels SC and SD.

The energy demand corresponding to the calculated activity of level SD must be satisfied by the production of useful energy by the supply processes of final levels SE and SF. Once more, the variable which defines the useful energy produced by each supply process is the cost/price. In order to depict the way the model calculates the cost of each supply process, a bottom-up approach will be used below for the description of the decision making included in the last two levels.

4.2.1.3 Choice of fuel mix

At the level of *each equipment type of a process* SF - *technology* te *and vintage* v - the model applies the same logit mechanism to select the fuel mix of *each* equipment type. For the choice of the fuel mix, the allocation of equipment types is considered known and only ***fuel-related short term costs*** ($STC_{SF,te,v,f,t}$) apply in the logit functions. At this level of decision making, *the goal is to minimize the operational/short* *term cost of each equipment type* ($STC_{SF,te,v,t}$). It should be noted that, at the point of the definition of the fuel mix, only fuels purchased from the market compete with each other. The share of heat recovery/energy savings in the fuel mix of a process SF is calculated separately, as described in Section 4.2.1.4 Modelling of heat recovery.

Some of the fuels may have a limited availability potential, e.g. biomass, waste, solar or geothermal, meaning a significant risk of exhaustion exists. The model applies asymptotic cost-supply curves of ascending slope to represent the cost impact of potential exhaustion ($MPot_{SD,f,t}$), through the use of a polynomial function of 6th degree. The amount of availability potential (maximum available volume of a fuel) relates to the nature of the use or process and *is defined at the last level of subsectors SD*. Promotion of renewable fuels ($RESvalue_{f,SF,t}$) and carbon pricing ($poprice_{po,SF,t}$ for ETS sectors and $povalue_{po,SF,t}$ for non-ETS sectors) are also inserted in the calculation of fuel-related short term costs and thus influence the choice of the fuel mix.

- Fuel related short term cost

$$
\begin{aligned}
STC_{SF,te,v,f,t} = h_{f,SF,te,v,t} \\
\cdot \Bigg(& pc_{SF,f,t} + \left[price_{SF,f,t}\right]_{[if\ f \in fmarket_f]} + \left[\sum_{SD\_SF(SD,SF)} MPot_{SD,f,t}\right]_{[if\ f \in fpot_{SD,f,t}]} \\
& - \left[RESvalue_{f,SF,t}\right]_{[if\ f \in fres_f]} + \left[\sum_{po} povalue_{po,SF,t} \cdot emf_{po,f,t}\right]_{[if\ SF\ \in\ non-ETS]} \\
& + \left[\sum_{po} poprice_{po,SF,t} \cdot emf_{po,f,t}\right]_{[if\ SF\ \in\ ETS]} \Bigg)
\end{aligned}
$$

- Cost impact of potential exhaustion

$$
Mpot_{SD,f,t} = \sum_{\mu=1}^{6} ap_{SD,f,t}^{\mu} \cdot \left(\frac{\sum_{SD\_SF(SD,SF)} FE_{SF,f,t}}{pot_{SD,f,t}} \right)^{\mu}
$$

Where

te: Technology advancement level

v: Vintage

f: Fuel

$h_{f,SF,te,v,t}$: Heatrate of fuel f, process SF, technology te and vintage v

$pc_{SF,f,t}$: Perceived cost of process SF and fuel f

$price_{SF,f,t}$: Market price of fuel f for process SF

$emf_{po,f,t}$: Emission factor of fuel f for pollutant po

μ: Degree of polynomial function

$ap^{\mu}_{SD,f,t}$: Coefficient of polynomial function (cost-supply curve of fuel f) of degree μ

$FE_{SF,f,t}$: Final energy consumption of process SF and fuel f

$pot_{SD,f,t}$: Availability potential of fuel in SD level

The share $SH_{SF,te,v,f,t}$ of each fuel f for an equipment type of a process SF, technology te and vintage v is calculated as the weighted average of the two generalized logit functions ($SH^{Inert}_{SF,te,v,f,t}$,$SH^{Opt}_{SF,te,v,f,t}$):

- The Inertia Share logit function

$$SH^{Inert}_{SF,te,v,f,t} = \frac{\delta_{SF,te,v,f,t} \cdot e^{-g_{SF,te,v,f,t} \cdot (STC_{SF,te,v,f,t})}}{\sum_f \delta_{SF,te,v,f,t} \cdot e^{-g_{SF,te,v,f,t} \cdot (STC_{SF,te,v,f,t})}}$$

- The Optimum Share logit function

$$SH^{Opt}_{SF,te,v,f,t} = \frac{e^{-g^{Opt}_{SF,te,v,f,t} \cdot (STC_{SF,te,v,f,t})}}{\sum_f e^{-g^{Opt}_{SF,te,v,f,t} \cdot (STC_{SF,te,v,f,t})}}$$

- The share of fuel f calculated as the weighted average

$$SH_{SF,te,v,f,t} = \left(1 - \theta_{SF,t}\right) \cdot SH^{Inert}_{SF,te,v,f,t} + \theta_{SF,t} \cdot SH^{Opt}_{SF,te,v,f,t}$$

Where

$\delta_{SF,te,v,f,t}$: Scale parameter of inertia logit function of fuel f, process SF, technology te and vintage v depicting preferences

$g_{SF,te,v,f,t}$: Exponent of inertia logit function of fuel f, process SF, technology te and vintage v

$g^{Opt}_{SF,te,v,f,t}$: Exponent of optimum logit function of fuel f, process SF, technology te and vintage v

$\theta_{SF,t}$: Parameter depicting the degree of tendency towards the optimum share for process SF

4.2.1.4 Modelling of heat recovery

This section addresses the specific topic of modelling heat recovery/energy savings. In industrial sectors, heat recovery represents the equipment that take advantage of waste heat derived from the industrial processes and redirect it back to the system in order to be reused. In buildings, investments concern renovation of structures using insulation and other materials, thus heat recovery investments aim at the reduction of heat losses in the building. Heat recovery can also derive from energy management and control systems.

The objective is to define the share of recovered heat in the final fuel consumption of a process SF. The share of heat recovered ($SH\_HER_{SF,te,v,t}$) in a process SF is calculated as the share of the previous year ($SH\_HER_{SF,te,v,t-1}$) plus the additional share ($SH\_HER\_AD_{SF,te,v,t}$) of the current year:

- Share of heat recovered

$$SH\_HER_{SF,te,v,t} = SH\_HER\_AD_{SF,te,v,t} + SH\_HER_{SF,te,v,t-1}$$

In order to assess the additional share of heat recovery for the current year, the model compares the long term cost of heat recovery (including heat recovery investments of current year) for a process SF, technology te and vintage v ($LTC\_HER_{SF,te,v,t}$) and the short term cost of the process SF, technology te and vintage v ($STC\_NoHER_{SF,te,v,t}$) ***assuming no new investments are made***.

- Additional share of heat recovery

$$SH\_HER\_AD_{SF,te,v,t} = \frac{e^{-g_{HER,SF,t}\cdot(LTC\_HER_{SF,te,v,t}+pc_{HER,SF,te,v,t})}}{e^{-g_{HER,SF,t}\cdot(LTC\_HER_{SF,te,v,t}+pc_{SF,te,v,t})} + e^{-g_{HER,SF,t}\cdot STC\_NoHER_{SF,te,v,t}}}$$

Where

$g_{HER,SF,t}$: Exponent of heat recovery for process SF

$pc_{HER,SF,te,v,t}$: Perceived cost of heat recovery for process SF, technology te and vintage v

For the calculation of the long term cost of heat recovery, the availability potential has to be taken into account. Availability potential of heat recovery, or energy savings, is limited ($SH\_HER\_Pot_{SF,t}$ represents maximum share of energy savings that can be achieved in a process SF). The model applies the same asymptotic curve of ascending slope to represent the cost impact of potential exhaustion ($M\_HER\_Pot_{SF,te,v,t}$), through the use of a polynomial function of 6th degree.

The capital cost of heat recovery investments ($capc_{HER,SF,t}$) is thus increased by the cost impact of potential exhaustion ($M\_HER\_Pot_{SF,te,v,t}$), which tends to infinity when the share of heat recovery approaches the maximum potential. The long term cost of heat recovery is calculated via:

- Long term cost of heat recovery

$$LTC\_HER_{SF,te,v,t} = \left(\frac{capc_{HER,SF,t}\cdot(1-subs_{HER,SF,t})\cdot annfactor_{HER,SF,t}}{util_{SF,t}\cdot 8760}\cdot(1+M\_HER\_Pot_{SF,te,v,t}) + \frac{omc_{HER,SF,t}}{util_{SF,t}\cdot 8760} - EEvalue_{HER,SF,t} \right)\cdot h_{HER,SF,te,v,t}$$

Where

$capc_{HER,SF,t}$: Capital cost of heat recovery equipment for process SF

$subs_{HER,SF,t}$: Subsidy for heat recovery equipment for process SF

$annfactor_{HER,SF,t}$: Annuity factor for heat recovery investments in equipment of process SF

$util_{SF,t}$: Utilization rate of equipment of process SF

$omc_{HER,SF,t}$: Operation and maintenance cost of heat recovery for process SF

$EEvalue_{HER,SF,t}$: Energy efficiency value of heat recovery for process SF

$h_{HER,SF,te,v,t}$: Heatrate of heat recovery equipment for process SF, technology te and vintage v

- Cost impact of the heat recovery potential exhaustion

$$M\_HER\_Pot_{SF,te,v,t} = \sum_{\mu=1}^{6} ap^{\mu}_{HER,SF,te,v,t} \left(\frac{SH\_HER\_AD_{SF,te,v,t} + SH\_HER_{SF,te,v,t-1}}{SH\_HER\_Pot_{SF,t}} \right)^{\mu}$$

Where

$ap^{\mu}_{HER,SF,te,v,t}$: Coefficient of polynomial function (cost-supply curve of heat recovery for process SF, technology te and vintage v) of degree μ

In case no investments in heat recovery equipment are made at the current year, the share of heat recovered remains the same as the previous year $(SH\_HER_{SF,te,v,t-1})$ and the short term cost of process SF, technology te and vintage v $(STC\_NoHER_{SF,te,v,t})$ is calculated as:

- Short term cost of process SF excluding new investments in heat recovery

$$STC\_NoHER_{SF,te,v,t} = \left(1 - SH\_HER_{SF,te,v,t-1}\right) \cdot \sum_{f} SH_{SF,te,v,f,t} \cdot STC_{SF,te,v,f,t}$$
$$+ vc_{SF,t} \cdot \bar{h}_{SF} + \frac{omc_{SF,t}}{\frac{util_{SF,t} \cdot 8760}{\bar{h}_{SF}}} \cdot \left(1 + omg_{SF,t}\right)^{v}$$

Where

$vc_{SF,t}$: Variable cost of process SF

$\bar{h}_{SF}$: Average heatrate of process SF

$omc_{SF,t}$: Operation & Maintenance cost of process SF

$omg_{SF,t}$: Growth rate of operation and maintenance cost of process SF

Investments in heat recovery are derived from the calculated additional share of heat recovered:

- Heat recovery investments

$$INV\_HER_{SF,te,v,t} = \frac{h_{SF,te,v,t} \cdot SH\_HER\_AD_{SF,te,v,t} \cdot UE_{SF,te,v,t}}{util_{SF,t} \cdot 8760}$$

Where

$INV\_HER_{SF,te,v,t}$: Investments in heat recovery equipment for process SF of technology te and vintage v

$h_{SF,te,v,t}$: Heatrate of process SF of technology te and vintage v

$UE_{SF,te,v,t}$: Useful energy of process SF, technology te and vintage v

Operational capacity of heat recovery equipment is derived from the capacity of the previous year ($CAP\_HER_{SF,te,v,t-1}$), multiplied by a probability of survival factor ($prob\_surv\_HER_{SF,te,v,t}$), and increased by the new investments ($INV\_HER_{SF,te,v,t}$):

- Operational capacity of heat recovery equipment

$$CAP\_HER_{SF,te,v,t} = CAP\_HER_{SF,te,v,t-1} \cdot prob\_surv\_HER_{SF,te,v,t} + INV\_HER_{SF,te,v,t}$$

4.2.1.5 Choice of equipment type mix

Having defined the fuel mix, as well as the share of recovered heat for each equipment type of process SF, technology te and vintage v, the next decision to be taken is the combination of equipment types, ***regarding both the operation of existing equipment, as well as investments in new equipment***.

Choice of existing equipment type mix in operation

The decision regarding which of the existing equipment will operate is made from a short term behavior perspective, taking into account short term marginal costs (operational costs). The short term cost $STC_{SF,te,v,t}$ of an equipment type of a process SF, technology te and vintage v is:

- Short term cost of equipment type

$$STC_{SF,te,v,t} = \left(1 - SH\_HER_{SF,te,v,t}\right) \cdot \sum_{f} SH_{SF,te,v,f,t} \cdot STC_{SF,te,v,f,t} + vc_{SF,t} \cdot \bar{h}_{SF} + \frac{MCAP_{SF,te,v,t}}{util_{SF,t} \cdot 8760}$$

Where:

$SH\_HER_{SF,te,v,t}$: Share of heat recovered in process SF, technology te and vintage v

$SH_{SF,te,v,f,t}$: Share of fuel f in fuel consumption of process SF, technology te and vintage v

$STC_{SF,te,v,f,t}$: Fuel-related short term cost of fuel f, process SF, technology te and vintage v

$vc_{SF,t}$: Variable cost of process SF (mentioned above)

$\bar{h}_{SF}$: Average heatrate of process SF

$MCAP_{SF,te,v,t}$: Marginal-shadow value of existing capacity constraints for process SF, technology te and vintage v

$util_{SF,t}$: Utilization rate or mileage of process SF

The share of heat recovered is subtracted from fuel cost as it represents the percentage of energy savings.

As mentioned in Section 3.1 Common Input Data, the model considers several equipment types for each use/process. The CPS Demand Module supports 7 levels of technology progress, shown in Table 1 of Section 3 Definitions, and 9 possible vintages: from 0 to 40 years of age, in 5-year steps.

The share ($SH_{SF,te,v,t}$) of an equipment type of a process SF, technology te and vintage v is calculated once more as the weighted average of two generalized logit functions ($SH^{Inert}_{SF,te,v,t}$,$SH^{Opt}_{SF,te,v,t}$). The marginal-shadow value of the capacity constraints ($MCAP_{SF,te,v,t}$) influences the choice of existing equipment in operation.

- The Inertia Share logit function

$$SH^{Inert}_{SF,te,v,t} = \frac{\delta_{SF,te,v,t} \cdot e^{-g_{SF,te,v,t} \cdot (STC_{SF,te,v,t})}}{\sum_f \delta_{SF,te,v,t} \cdot e^{-g_{SF,te,v,t} \cdot (STC_{SF,te,v,t})}}$$

- The Optimum Share logit function

$$SH^{Opt}_{SF,te,v,t} = \frac{e^{-g^{Opt}_{SF,te,v,t} \cdot (STC_{SF,te,v,t})}}{\sum_f e^{-g^{Opt}_{SF,te,v,t} \cdot (STC_{SF,te,v,t})}}$$

- The share of equipment type calculated as the weighted average

$$SH_{SF,te,v,t} = \left(1 - \theta_{SF,t}\right) \cdot SH^{Inert}_{SF,te,v,t} + \theta_{SF,t} \cdot SH^{Opt}_{SF,te,v,t}$$

Where

$\delta_{SF,te,v,t}$: Scale parameter of inertia logit function of process SF, technology te and vintage v

$g_{SF,te,v,t}$: Exponent of inertia logit function of process SF, technology te and vintage v

$g^{Opt}_{SF,te,v,t}$: Exponent of optimum logit function of process SF, technology te and vintage v

$\theta_{SF,t}$: Parameter depicting the degree of tendency towards the optimum share for process SF

After the calculation of the shares of each equipment type (te, v) in the equipment mix of process SF, *the short term unit cost of each process* is defined as:

- Short term unit cost of a process SF

$$STC_{SF,t} = \sum_{te,v} SH_{SF,te,v,t} \cdot STC_{SF,te,v,t}$$

Choice of equipment type mix in investments

Planning for investments in new equipment is made from a long term behavior perspective, taking into account long term costs. The long term cost $LTC_{SF,te,t}$ of an equipment type of a process SF and technology te is:

- Long term cost of equipment type

$$LTC_{SF,te,t} = \left(\frac{capc_{SF,te,t} \cdot (1 - subs_{SF,te,t}) \cdot annfactor_{SF,t}}{\frac{util_{SF,t} \cdot 8760}{\bar{h}_{SF}}} + (1 - SH\_HER_{SF,te,0,t}) \cdot \sum_{f} SH_{SF,te,0,f,t} \cdot STC_{SF,te,0,f,t} \cdot (1 + pc_{f,SF,t}) + vc_{SF,t} \cdot \bar{h}_{SF} + \frac{omc_{SF,t}}{\frac{util_{SF,t} \cdot 8760}{\bar{h}_{SF}}} \right) \cdot (1 + pc_{SF,te,t})$$

Where

$capc_{SF,te,t}$: Capital cost of equipment of process SF and technology te

$subs_{SF,te,t}$: Subsidy of equipment of process SF and technology te

$annfactor_{SF,t}$: Annuity factor of investment in equipment of process SF

$pc_{f,SF,t}$: Fuel related perceived/hidden costs of equipment of process SF and fuel f

$omc_{SF,t}$: Operation and maintenance cost of equipment of process SF

$pc_{SF,te,t}$: Technology related perceived/hidden costs of equipment of process SF and technology te

Vintage values in the above equation are set equal to zero, as investments in new equipment are only of vintage/age 0.

The long term share ($SH^{LT}_{SF,te,t}$) of an equipment type of a process SF and technology te in new investments is calculated in the same way as in the choice of existing equipment type mix, as the weighted average of the inertia and the optimum share, via the use of corresponding long term parameters and long terms costs.

After the calculation of the shares of each equipment type in the investments of process/equipment SF, *the long term unit cost of each process* is defined as:

- Long term unit cost of a process SF

$$LTC_{SF,t} = \sum_{te} SH^{LT}_{SF,te,t} \cdot LTC_{SF,te,t}$$

4.2.1.6 Allocation of activity-useful energy of level SE in level SF

Having defined the short term and long term unit cost of the lowest level SF, it is now possible to apply the same mathematical mechanism in order to calculate the extent/share to which each process SF contributes to the production of useful energy of the upper level SE, both in short term and long term decision making.

The short term share $SH_{SE,SF,t}$ of a process SF in the composition of the activity-useful energy of level SE is calculated via:

- The Inertia Share logit function

$$SH^{Inert}_{SE,SF,t} = multi_{SE,t} \cdot \frac{\delta_{SE,SF,t} \cdot e^{-g_{SE,t}\cdot(STC_{SF,t})}}{\sum_{SF} \delta_{SE,SF,t} \cdot e^{-g_{SE,t}\cdot(STC_{SF,t})}}$$

- The Optimum Share logit function

$$SH^{Opt}_{SE,SF,t} = multi_{SE,t} \cdot \frac{\delta^{Opt}_{SE,SF,t} \cdot e^{-g^{Opt}_{SE,t}\cdot(STC_{SF,t})}}{\sum_{SF} \delta^{Opt}_{SE,SF,t} \cdot e^{-g^{Opt}_{SE,t}\cdot(STC_{SF,t})}}$$

- The share of a process SF in the activity of level SE as the weighted average

$$SH_{SE,SF,t} = (1 - \theta_{SE}) \cdot SH^{Inert}_{SE,SF,t} + \theta_{SE} \cdot SH^{Opt}_{SE,SF,t}$$

Where

$multi_{SE,t}$: Parameter distinguishing between substitutability and complementarity of processes SF (equal to 1 for substitutable processes or equal to the number of relevant choices of processes SF for complementary processes)

The short term cost of a process of level SE is thus equal to:

- Short term unit cost of a process SE

$$STC_{SE,t} = \sum_{SF} SH_{SE,SF,t} \cdot STC_{SF,t}$$

The same equations apply also for the calculation of the long term share of a process SF.

For the levels SE and SF of the nesting tree, the calculated costs of processes/equipment and the consequential shares are differentiated between short and long term, as ***these levels have the notion of equipment***. *Thus, long term shares of equipment types in the investments' composition, defined by the long term costs, have a meaning only for levels* SE and SF. For the rest levels of the nesting tree SD to SB, the costs as well as the shares are not differentiated between short term and long term and only a generalized unit cost is calculated.

4.2.1.7 Agent heterogeneity

The logit functions represent heterogeneity of preferences of individual consumers. The CPS Demand Module involves further heterogeneity by distinguishing agents with different preferences in the choice of *private cars* and the choice of *space heating* for residential sector. There are five agent classes considered in the CPS Demand Module, shown in Table 8.

Table 8 Agent classes of CPS Demand Module

Agent classes (a)
High income or consumption class
Medium High intermediate income or consumption class
Medium income or consumption class
Low Medium intermediate income or consumption class
Low income or consumption class

Once more, agent heterogeneity exists only in the last two levels of processes/equipment SE and SF. An assumed histogram ($hist_{a,t}$) denotes the distribution of activity between the agent classes. Also, values for certain characteristics are differentiated across the agent classes such as: discount rate, utilization rate or mileage, perceived costs and parameters of the logit function. The generalized logit functions apply to each agent, with agent specific corresponding parameters, and then aggregate to the share $SH_{SU,SL,t}$:

- The Inertia Share logit function

$$SH^{Inert}_{a,SU,SL,t} = multi_{SU,t} \cdot \frac{\delta_{a,SU,SL,t} \cdot e^{-g_{a,SU,t} \cdot (p_{a,SL,t})}}{\sum_{SL} \delta_{a,SU,SL,t} \cdot e^{-g_{a,SU,t} \cdot (p_{a,SL,t})}}$$

- The Optimum Share logit function

$$SH^{Opt}_{a,SU,SL,t} = multi_{SU,t} \cdot \frac{\delta^{Opt}_{a,SU,SL,t} \cdot e^{-g^{Opt}_{a,SU,t} \cdot (p_{a,SL,t})}}{\sum_{SL} \delta^{Opt}_{a,SU,SL,t} \cdot e^{-g^{Opt}_{a,SU,t} \cdot (p_{a,SL,t})}}$$

- The share of a process SL in the activity/useful energy of level SU as the weighted average

$$SH_{a,SU,SL,t} = \left(1 - \theta_{a,SU}\right) \cdot SH^{Inert}_{a,SU,SL,t} + \theta_{a,SU} \cdot SH^{Opt}_{a,SU,SL,t}$$

$$SH_{SU,SL,t} = \sum_{a} hist_{a,t} \cdot SH_{a,SU,SL,t}$$

- The generalized unit cost of level SL for agent a

$$P_{a,SL,t} = f\left(C_{SL,t}, pc_{a,SF,t}, util_{a,SF,t}, r_{a,t}\right)$$

Where

$P_{a,SL,t}$: Generalized cost of process SL for agent a used for the decision

$C_{SL,t}$: Short term or long term cost of level SL

$pc_{a,SF,t}$: Perceived cost of process SF for agent a

$util_{a,SF,t}$: Utilization rate or mileage of process SF for agent a

$r_{a,t}$: Discount rate for agent a

4.2.1.8 Technology standards

At the point of choice for the equipment type mix in new investments – level SF – another policy instrument which influences the decision (apart from promotion of RES and carbon pricing mentioned above) is the technology standards. The technology standards/targets ($stn\_target_{Stn,SD,t}$) are carbon emissions and energy efficiency standards, *defined per unit of output in level* SD. These standards influence the decision for the equipment type mix in new investments, through the following mechanism:

- every equipment type has a label - nominal performance ($lbl_{Stn,SF,te,t}$) corresponding to a standard type (carbon emissions or energy efficiency)
- the model calculates the weighted average label (performance) of the equipment type mix of new investments at the last level of subsectors SD
- in case the weighted average performance of level SD is higher than the targeted value of the standard ($stn\_target_{Stn,SD,t}$) then a penalty ($Pstn_{SF,te,t}$) applies to the *non-compliant* equipment types
- hence the model modifies the equipment type mix until the average performance of level SD complies with the targeted value of the standard

➢ Technology Standards Constraint

$$stn\_target_{Stn,SD,t} \cdot \sum_{SD\_SF(SD,SF)} INV_{SF,te,t} \geq \sum_{SD\_SF(SD,SF)} lbl_{Stn,SF,te,t} \cdot INV_{SF,te,t} \perp M\_stn_{Stn,SD,t} \geq 0$$

➢ Penalty of non-compliance

$$Pstn_{SF,te,t} = M\_stn_{Stn,SD,t} \cdot \max\left(lbl_{Stn,SF,te,t} - stn\_target_{Stn,SD,t}, 0\right)$$

Where

Stn: Type of standard - carbon emissions or energy efficiency

$INV_{SF,te,t}$: Investments in equipment of process SF of technology te

$M\_stn_{Stn,SD,t}$: Marginal/shadow value of the technology standards constraint for standard Stn defined in level SD.

4.2.1.9 Cokery

In Iron & Steel sector specifically, fuels from the market, including purchased coke, compete with coke and derived gasses (DGS) produced from cokery. The fuel mix of the relevant processes is calculated by comparing the price of market fuels with the unit cost of coke or derived gasses production, via the use of inertia and optimum shares, as described in Section 4.2.1.3 Choice of fuel mix. Derived gasses are a by-product of coke production and thus have no real cost of production. However, in the CPS Demand Module, the unit cost of derived gasses is set equal to the marginal value of the constraint of DGS demand satisfaction.

Calculation of unit cost of coke production

In order to calculate the unit cost of coke production, the combination of fuels ***consumed*** in the production of coke (fuel mix of cokery) has to be defined. At the level of choice of cokery's fuel mix, the fuels' shares ($SH\_Coke_{te,v,f,t}$) are calculated through the same logit mechanism mentioned in Section 4.2.1.3 Choice of fuel mix.

The same mathematical method applies also for the choice of the equipment type mix that will be used both in short term - operation ($SH\_Coke_{te,t}$) and long term - planning ($SH\_Coke\_LT_{te,t}$) of cokery, as described in Section 4.2.1.5 Choice of equipment type mix.

Once the above shares are calculated, the costs of coke production are calculated as:

- Fuel-related short term cost of cokery for fuel f, technology te and vintage v

$$STC\_Coke_{te,v,f,t} = h_{Coke,f,te,v,t} \cdot \left(pc\_Coke_{f,t} + [price_{Coke,f,t}]_{[if\ f \in fmarket_f]} - [RESvalue_{Coke,f,t}]_{[if\ f \in fres_f]} + \left[\sum_{po} poprice\_Coke_{po,t} \cdot emf\_Coke_{po,f,t} \right]_{[if\ f \in pollprice_{SF,t}]} \right)$$

Where

$h_{Coke,f,te,v,t}$: Heatrate of cokery equipment for fuel f, technology te and vintage v

$pc\_Coke_{f,t}$: Fuel-related perceived cost of coke production for fuel f

$price_{Coke,f,t}$: Market price of fuel f for cokery

$RESvalue_{Coke,f,t}$: Renewable value of fuel f for cokery

$poprice\_Coke_{po,t}$: Price of pollutant po for cokery

$emf\_Coke_{po,f,t}$: Emission factor of cokery for fuel f and pollutant po,

- Short term cost of coke production for technology te and vintage v

$$STC\_Coke_{te,v,t} = \sum_{f} SH\_Coke_{te,v,f,t} \cdot STC\_Coke_{te,v,f,t} + vc\_Coke_t + MCAP_{Coke,te,v,t}$$

Where:

$SH\_Coke_{te,v,f,t}$: Share of fuel f in the fuel mix of coke production for technology te and vintage v

vc_Coke_t: Variable cost of cokery equipment

$MCAP_{Coke,te,v,t}$: Marginal-shadow value of existing equipment capacity constraint for technology te and vintage v

- Long term cost of coke production for technology te

$$\begin{aligned} LTC\_Coke_{te,t} = \Bigg(& \frac{capc\_Coke_{te,t} \cdot \left(1 - subs\_Coke_{te,t}\right) \cdot annfactor\_Coke_t}{util\_Coke_t \cdot 8760} \\ & + \sum_{f} SH\_Coke_{te,0,f,t} \cdot STC\_Coke_{te,0,f,t} \cdot \left(1 + pc\_Coke_{f,t}\right) + vc\_Coke_t \\ & \cdot + \frac{omc\_Coke_t}{util\_Coke_t \cdot 8760} \Bigg) \cdot \left(1 + pc\_Coke_{te,t}\right) \end{aligned}$$

Where

$capc\_Coke_{te,t}$: Capital cost of cokery equipment of technology te

$subs\_Coke_{te,t}$: Subsidy of cokery equipment of technology te

$annfactor\_Coke_t$: Annuity factor of cokery investments

$SH\_Coke_{te,0,f,t}$: Share of fuel f in the fuel mix of coke production for technology te and vintage 0

$STC\_Coke_{te,0,f,t}$: Fuel-related short term cost of coke production for fuel f, technology te and vintage 0

$pc_{Coke,f,t}$: Fuel-related perceived/hidden cost of cokery for fuel f

$util\_Coke_t$: Utilization rate of cokery equipment

omc_Coke_t: Operation and maintenance cost of cokery equipment

$pc\_Coke_{te,t}$: Technology-related perceived/hidden costs of cokery equipment for technology te

- Long term cost of coke production

$$LTC\_Coke_t = \sum_{te} SH\_Coke\_LT_{te,t} \cdot LTC\_Coke_{te,t}$$

Where

$SH\_Coke\_LT_{te,t}$: Long term share of technology te in coke production

Finally, the unit cost of self-produced coke ($UCauto_{Coke,t}$) is calculated as the long term cost of coke production (LTC_Coke_t), reduced by the opportunity cost ($OpCost_t$) – cost avoided due to not purchasing fuels from the market – plus the additional emissions cost (Ad_EmCost_t).

- Unit cost of self-produced coke

$$UCauto_{Coke,t} = LTC\_Coke_t - OpCost_t + Ad\_EmCost_t$$

- Opportunity cost of self-production of coke

$$OpCost_t = \frac{1}{outputratio_{Coke,DGS}} \cdot op\_ratio_{DGS,NGS} \cdot price_{NGS,t}$$

- Additional emissions cost of self-production of coke

$$Ad\_EmCost_t = \frac{1}{outputratio_{Coke,DGS}} \cdot \sum_{po} poprice_{po,t} \cdot (emf_{po,DGS,t} - emf_{po,NGS,t})$$

Where

$outputratio_{coke,DGS}$: Ratio of coke output over the derived gasses output in cokery

$op\_ratio_{DGS,NGS}$: Ratio denoting fraction of price of marketed natural gas not paid due to consumption of derived gasses from cokery

$price_{NGS,t}$: Market price of natural gas

Output fuels of cokery

The coke volume needed to be produced is derived by the total final consumption of coke for all demand processes:

- Coke output needed to be produced

$$Output\_Prim_{Coke,t} = \sum_{SF} FE_{Coke,SF,t}$$

Where

$FE_{Coke,SF,t}$: Final energy consumption of coke in process SF

During the production of coke, derived gasses are produced as a secondary output fuel. The volume of derived gasses ($Output\_Sec_{DGS,t}$) is directly linked to the volume of produced coke via the output ratio ($outputratio_{Coke,DGS}$):

- Output of derived gasses from self-production of coke

$$Output\_Sec_{DGS,t} = \frac{1}{outputratio_{Coke,DGS}} \cdot Output\_Prim_{Coke,t}$$

The produced volume of derived gasses from cokery ($Output\_Sec_{DGS,t}$) must be greater or equal to the final demand for derived gasses ($FE_{DGS,SF,t}$). The marginal-shadow value of this constraint is $M\_OUTSEC_{DGS,t}$, which is equal to zero when production of derived gasses from cokery is greater than demand for DGS and equal or greater than zero when the equality is met. The price of derived gasses $UCauto_{DGS,t}$ is set equal to $M\_OUTSEC_{DGS,t}$. In case of excess production of DGS, the remaining volume ($F_{DGS,t}^{EleSupply}$) is consumed by the power generation plants, in the Supply Module.

- Output of derived gasses constraint

$$Output\_Sec_{DGS,t} \geq \sum_{SF} FE_{DGS,SF,t} \quad \perp \; M\_OUTSEC_{DGS,t} \geq 0$$

- Remaining volume of derived gasses

$$FE_{DGS,t}^{EleSupply} = Output\_Sec_{DGS,t} - \sum_{SF} FE_{DGS,SF,t}$$

- Price of derived gasses

$$UCauto_{DGS,t} = M\_OUTSEC_{DGS,t}$$

Investments in cokery are calculated through the estimation of desired capacity, reduced by the survived capacity of each year, as in the case of investments in supply processes of demand.

Operational capacity of cokery ($CAP\_Coke_{te,v,t}$) is derived from the capacity of the previous year, multiplied by a probability of survival factor ($prob\_surv\_Coke_{te,v,t}$) and a probability of premature replacement factor ($1 - prob\_premr\_Coke_{te,v,t}$) and increased by the capacity of new investments ($INV\_Coke_{te,0,t}$).

- Operational capacity of cokery equipment

$$\begin{aligned} & CAP\_Coke_{te,v,t} \\ & = (CAP\_Coke_{te,v,t-1} \cdot prob\_surv\_Coke_{te,v,t}) \cdot (1 - prob\_premr\_Coke_{te,v,t}) + INV\_Coke_{te,0,t} \end{aligned}$$

4.2.2. Unknown variables

The unknown variables of the CPS Demand Module include at least the following:

- Activity-useful energy for subsectors/processes of all nesting levels apart from the top level (SA)
- Useful energy of each supply process SF by technology category te and vintage v
- Generalized unit cost for levels SB to SD

- Short term and long term unit cost for levels SE and SF (and per agent, where agent heterogeneity applies)
- Share of fuel f in final energy consumption of supply process SF by technology category te and vintage v
- Share of heat recovery in final energy consumption of supply process SF by technology category te and vintage v
- Final Energy Consumption of supply process SF by fuel f
- Short term and long term marginal cost of supply process SF by technology category te and vintage v (and per agent, where agent heterogeneity applies)
- Unit cost of self-produced coke
- Volume of self-produced coke and derived gasses from cokery
- Survived and operational capacity of supply process SF by technology category te and vintage v
- Investments in supply process SF by technology category te
- Investments in equipment for cokery by technology category te.

4.2.3. Exogenous Parameters

The parameters provided by the user include:

- Macroeconomic drivers/data for the calculation of activity
- Fuel prices for fuels purchased from the market
- Parameters for the calculation of elasticity $bact_{S,t}$: maximum value $bact_S^{max}$, minimum value $\overline{bact}_{S,t}$, speed of convergence $bspeed_{S,t}$
- Carbon price (ETS) and carbon value (non ETS)
- Renewable (RES) and Energy Efficiency (EE) value
- Carbon and efficiency Standards
- Parameters for the calculation of learning-by-doing index, floor cost, inflection year and speed of learning
- Technical characteristics of processes - specific energy consumption (SEC) of ordinary technology, lifetime, capacity factor (utilization rate), efficiency of technology category (normalized, efficiency of ordinary technology equal to 1), heat recovery potential, range of penalty, mileage, occupancy and specific electricity consumption for all processes of level SF
- Variable cost, operation & maintenance cost and growth rate of operation & maintenance cost of processes
- Investment cost of processes and subsidies
- Perceived costs
- Availability potential limitation of fuels
- Technical characteristics and costs for heat recovery - heat recovery potential, investment cost, perceived cost, subsidies, lifetime of equipment and operation & maintenance cost

- Technical characteristics and costs for cokery – heatrate, variable cost, operation & maintenance cost, growth rate of operation & maintenance cost, lifetime, capacity factor (utilization rate), investment cost, heatrate of technology category (normalized, efficiency of ordinary technology equal to 1), output ratio
- Agent specific characteristics, such as discount rate, utilization factor and population share
- Existing capacity of supply processes for year 2015
- Parameters for the calculation of probability of survival of equipment for each process
- Exogenous improvement of efficiency for ordinary technology of processes
- ETS parameters, such as percentage of free allocation of allowances and partial exemption of processes from the EU ETS.

The location of the above parameters in the demand-related input file is mentioned in Section 4.5 Explaining the demand-related scenario input file, and the way their values can be changed is explained in Section 4.5.16 Options for changing parameters' values exogenously.

4.3 Model features, considerations and assumptions

Apart from the attributes of the CPS Demand Module described in the previous sections, the Module includes also the following features:

- The model solves the short term (operation) and long term (investment) problems **simultaneously** and for each projection year **separately**, meaning there is no foresight in the decision of new investments
- The model keeps track of stock of equipment by technology type te and vintage v, by dynamically applying *rotating vintages*. This means that previous year's vintages become five years older in the next projection year, and all invested technologies of previous year aggregate to the "ordinary" technology category for the next year's run
- Probability of survival of equipment follows a Gompertz survival probability function. The Gompertz survival probability function uses 3 parameters which are defined exogenously and are:
    - the scale parameter of survival function of equipment
    - the survival rate of equipment at the end of lifetime
    - the survival rate of equipment at 80% of lifetime
- Premature replacement of equipment is possible for certain processes and is calculated endogenously. The processes for which premature replacement is allowed is defined by the user in the demand-related input excel file. During the Module run, premature replacement takes place when the operation costs of the existing equipment exceed the total cost of new equipment
- The technical-economic characteristics of equipment types are fixed over the entire projection horizon. However, the choice of the equipment mix is influenced by additional parameters representing perceived and hidden costs, as well as learning by doing factors. The latter parameters change over time and may vary by scenario

- Naturally, the choice of the equipment type mix influences the degree of energy efficiency improvement.

4.3.1. Sectoral coverage of the CPS Demand Module

This section describes the sectoral coverage of the CPS Demand Module.

4.3.1.1 Industrial Sector

Industry splits in 10 sectors: Iron & Steel, Non Ferrous, Chemicals, Building Materials, Paper & Pulp, Food, Drink &Tobacco, Engineering, Textiles, Other Industries and Non Energy. Sectors Iron & Steel, Non Ferrous, Chemicals, Building Materials are further split in two subsectors, as shown in Figure 24.

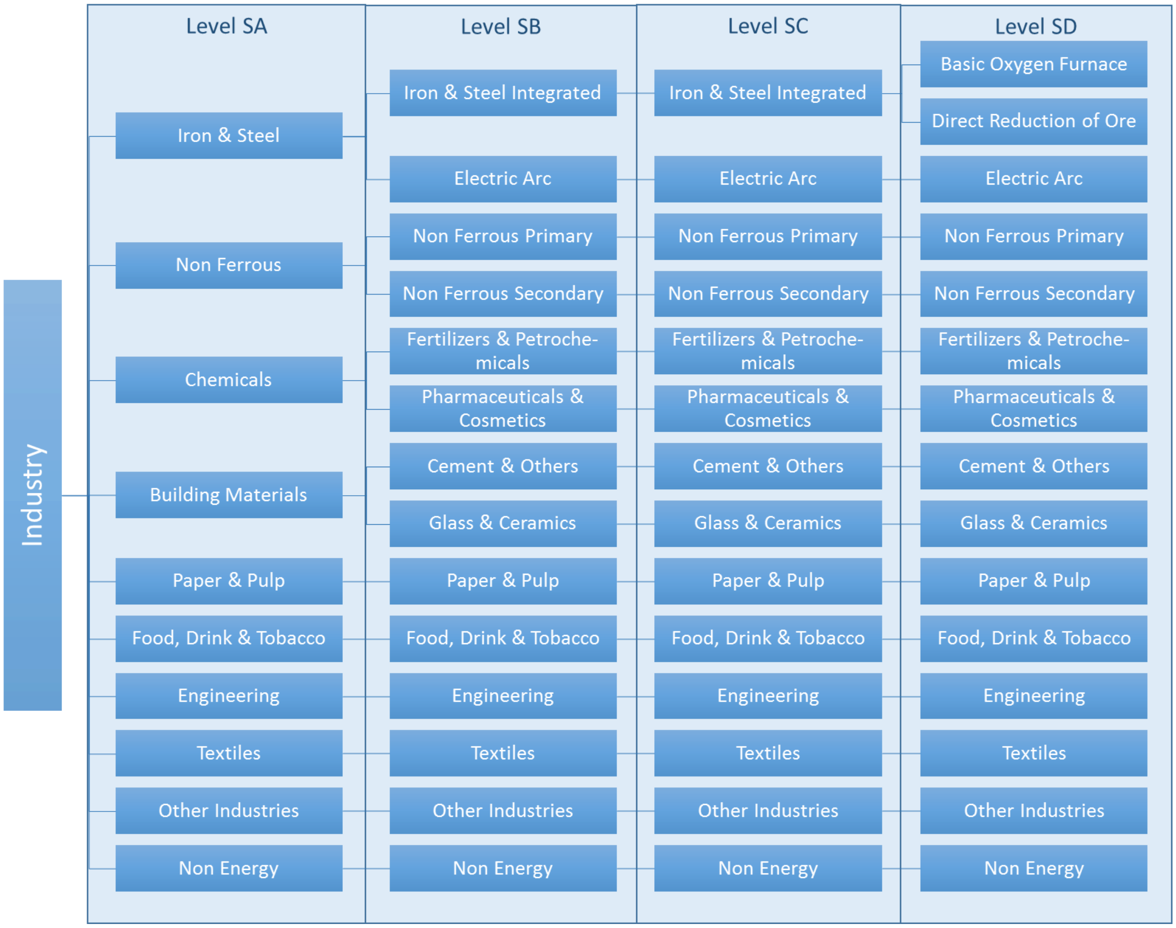


Figure 24 Industrial sectors' structure

The supply processes are sector-specific and include: heat uses, raw material preparation, thermal processing, product finishing, electric processing, blast furnace, electric arc, smelting, kilns and specific electricity uses. Figure 25 presents the processes of Iron & Steel sector.

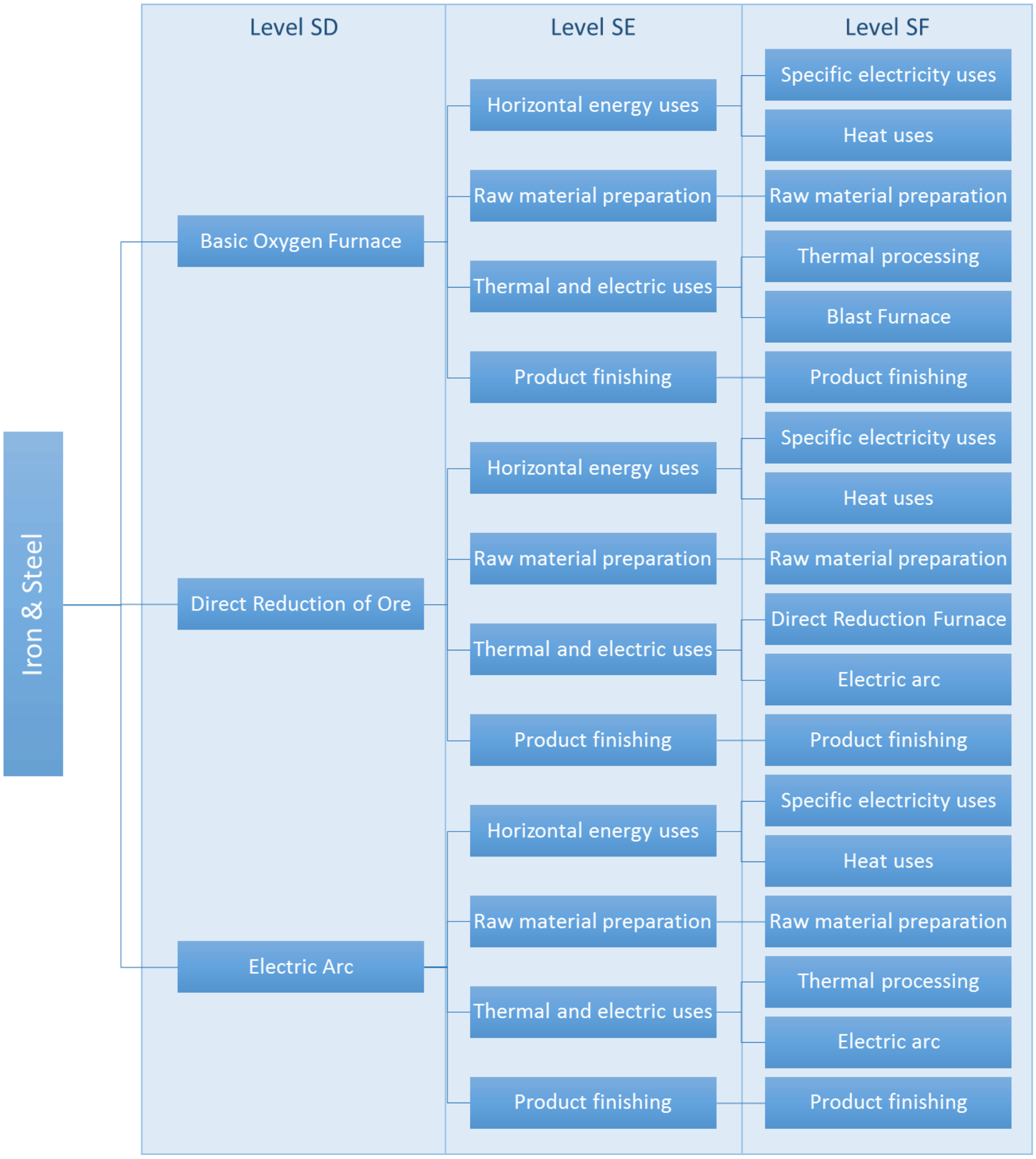


Figure 25 Iron & Steel supply processes

4.3.1.2 Residential Sector

Residential sector represents the energy demand in households. The energy services include thermal uses – space heating, air cooling, cooking and water heating – lighting and appliances, split in black and white appliances. White appliances include laundry equipment, refrigerators, freezers and dishwashers, while black appliances are ICT-related appliances. The equipment for space heating, water heating and cooking are distinguished by fuel type in: boilers (consuming LPG, gasoline or NGS), stoves (consuming solids including biomass), renewables (using solar and geothermal energy), electricity and district heating, as shown in Figure 26. For lighting and appliances there is no such distinction, as they both use solely electricity, thus processes of levels SE and SF are identical to the subsectors of level SD for these uses.

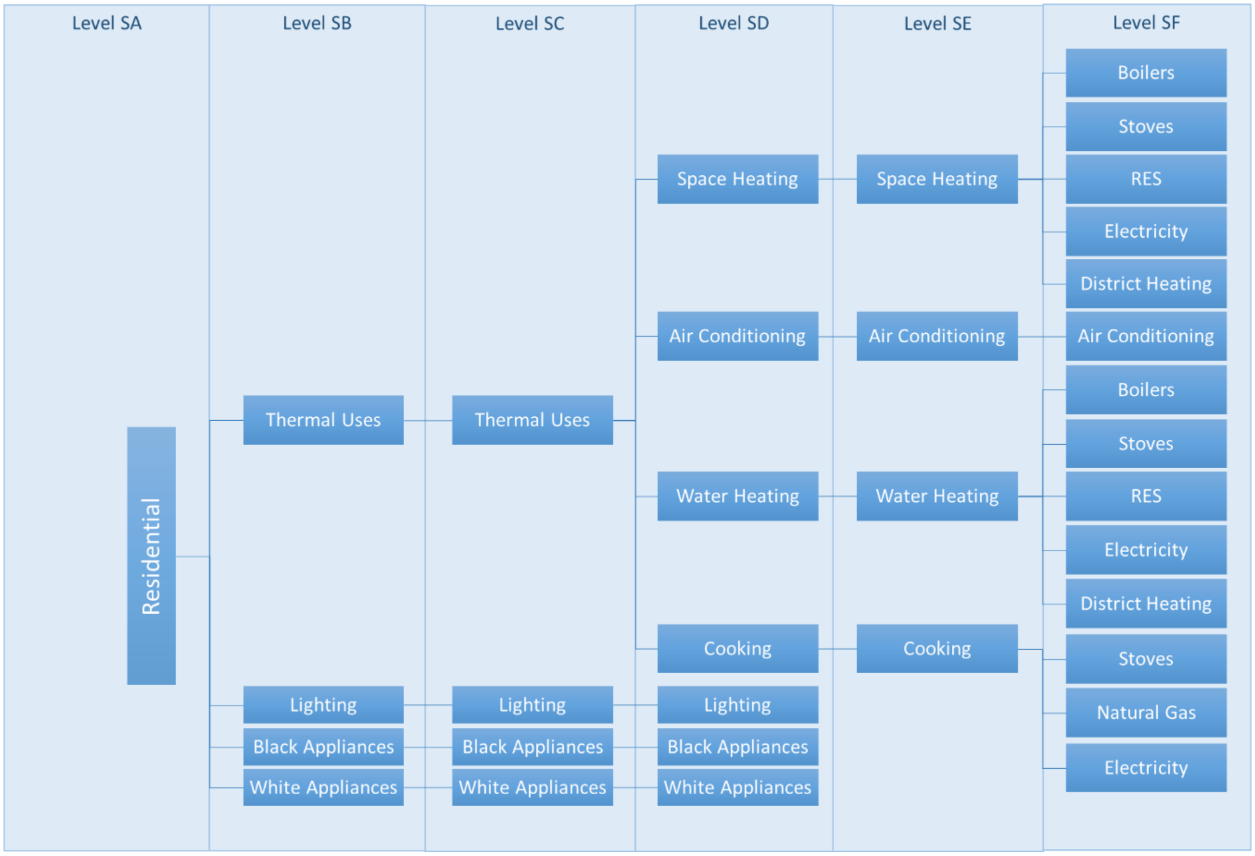


Figure 26 Residential sector structure and supply processes

4.3.1.3 Tertiary Sector

Tertiary sector splits in services and agriculture. The energy services include thermal uses – space heating, air cooling, cooking and water heating – lighting and pumping & motors for agriculture subsector. The equipment classification for space and water heating is the same as in the residential sector. Pumping & motors processes may consume diesel or electricity, while for lighting and electric uses there is no further distinction in level SF, as in the residential sector.

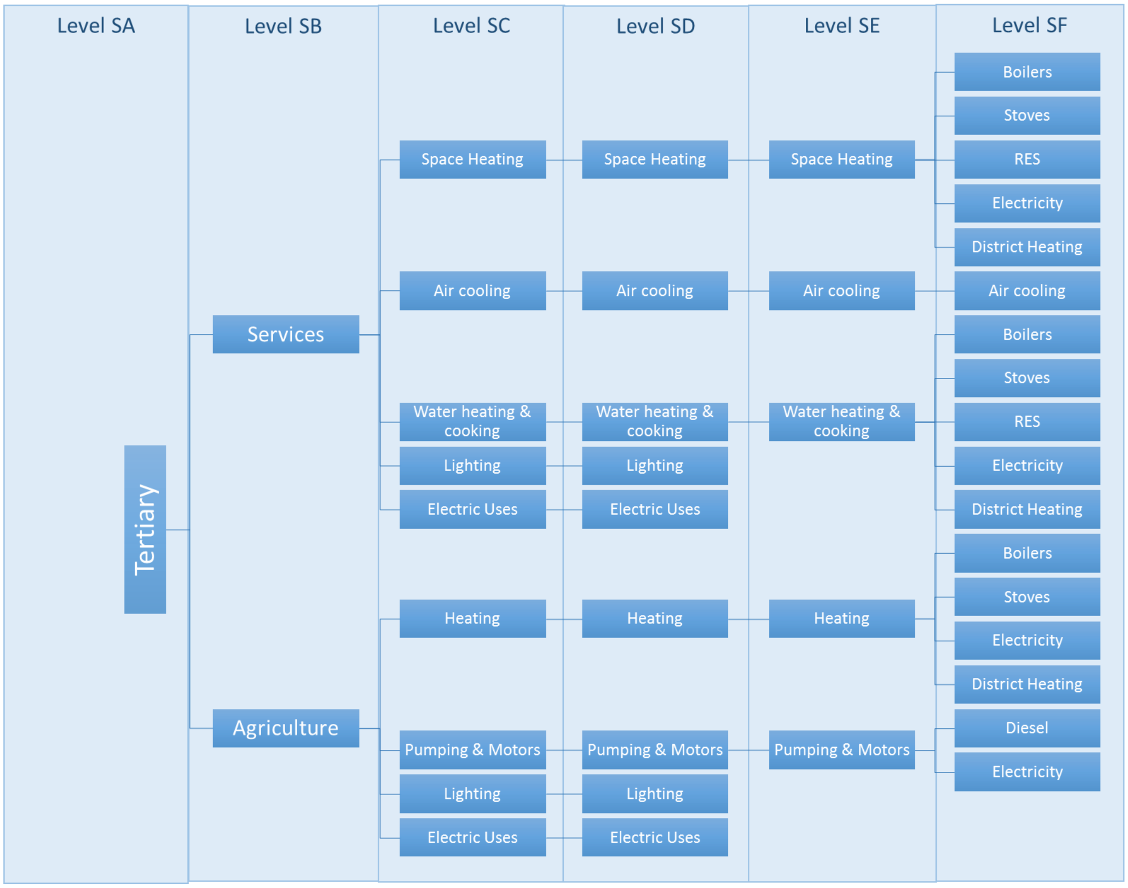


Figure 27 Tertiary sector energy structure and supply processes

4.3.1.4 Transport Sector

<u>The transport sector</u> is distinguished between Land/Water Passenger transport, Freight transport and Aviation. The modes for passenger and freight transport, such as public or private passenger transport, rail, inland navigation and road transport, are shown in Figure 28 and Figure 29 below.

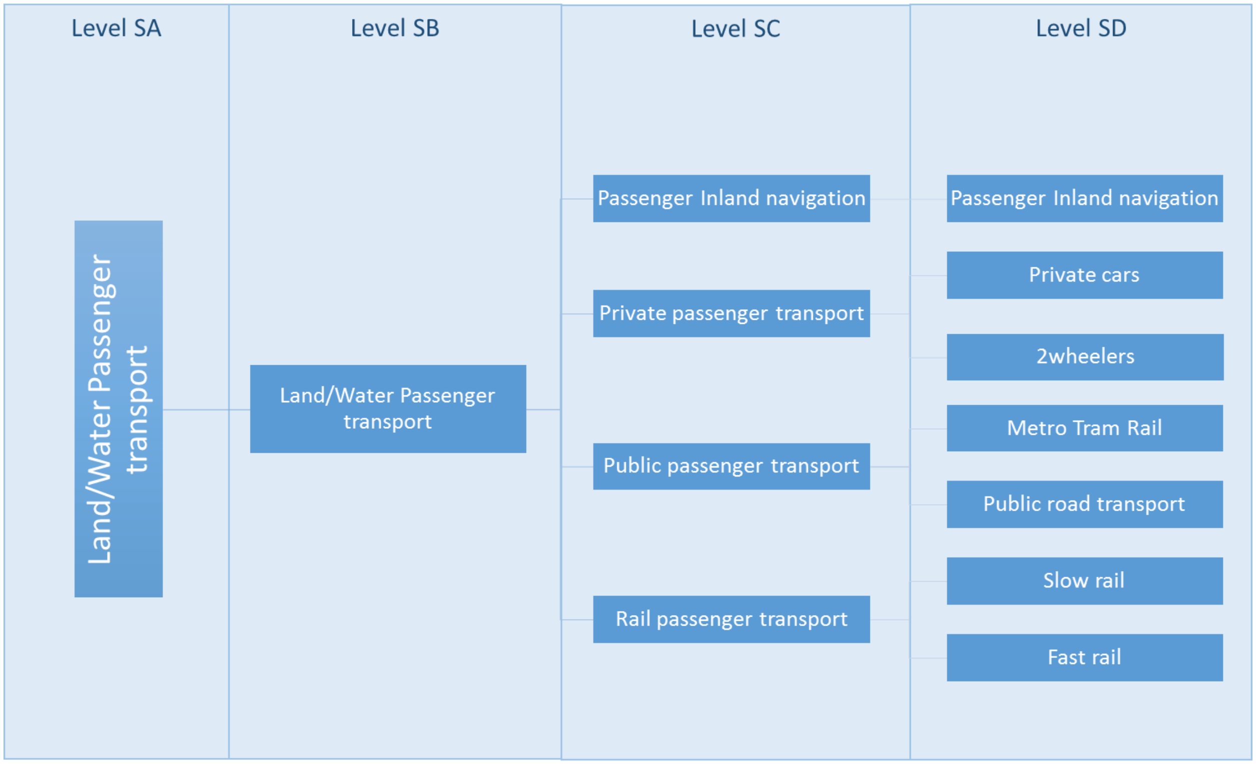


Figure 28 Land/Water passenger transport structure

Figure 29 Freight transport structure

Further classification of transport processes for levels SE and SF is based on the type of fuels consumed by each mode of transport. Figure 30 presents the structure of passenger inland navigation, private cars and 2 wheelers for levels SE and SF.

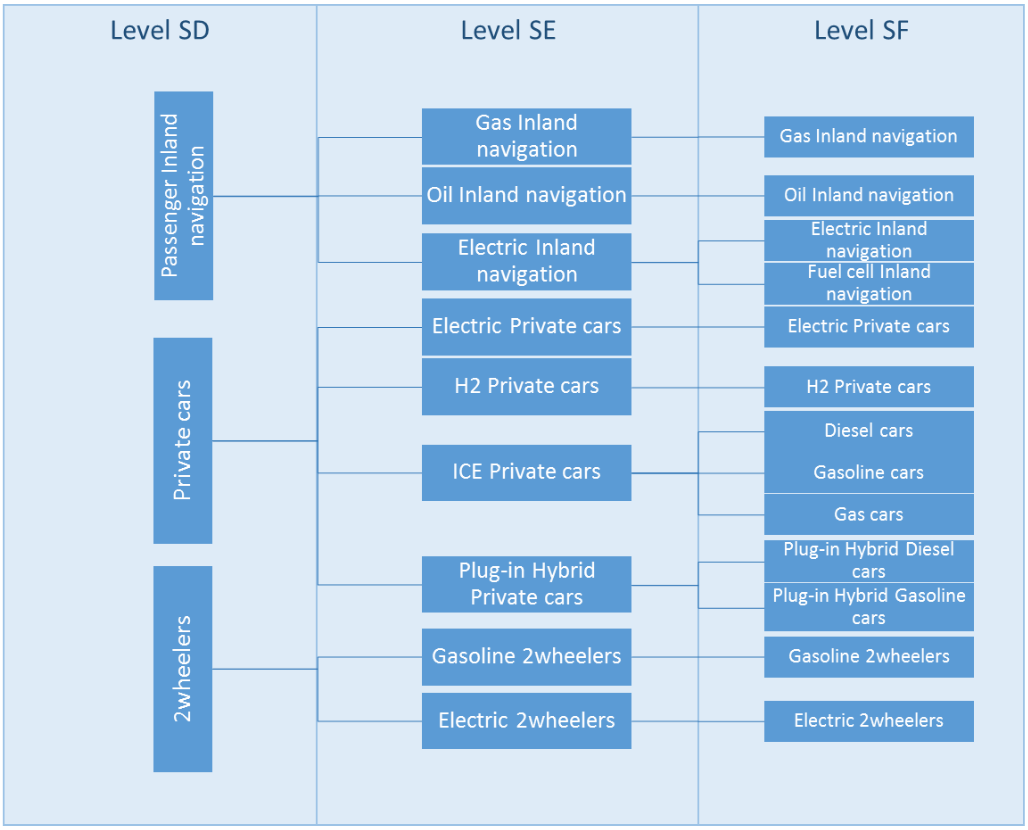


Figure 30 SD to SF structure of certain land/water passenger transport modes

4.4 Policy Focus – Demand

The CPS Demand Module has inherited PRIMES' rich representation of policy instruments and measures. All drivers are available in the input file as described in the next section and can be modified by the user.

This section outlines the variety of instruments and policy actions available in the Demand Module to meet specific targets set either by the EU or at national level. Table 9 relates policy instruments to the corresponding CPS drivers incorporated in the Demand Module.

Table 9 Policy Instruments and corresponding CSP drivers

Policy Instrument	CPS driver
EU ETS	Carbon price
Emissions taxation (non ETS)	Carbon value
Promotion of Renewables	RES value
Promotion of energy efficiency improvement	EE value
	Perceived costs

Removal of uncertainties and non-price barriers – Enabling Conditions	LBD index
	Optimum share coefficient
Taxes & Subsidies	Taxes & Subsidies
Discount rates	Discount rates
Promotion of fuel switch	Fuel potential
Fuel restrictions	Fuel ban in a certain use/process
Promotion of advanced biofuels in transport sector	Biofuel share
Technology Standards	Technology Standards/targets

4.4.1. Policy drivers of Demand Module

A detailed description of the Demand Module's drivers is presented below. All drivers are available in the demand-related input file and can be modified by the user, as described in Section 4.5.16 Options for changing parameters' values exogenously.

- *Carbon Price (EU ETS)*: The European Emissions Trading System is included in the model and affects all sectors included in the EU ETS. Users can specify the price of the European Union Allowances for each projected year. *Note that the ETS price is an important driver for the reduction of fossil fuels' consumption and RES deployment*
- *Carbon value (non ETS)*: Carbon value represents carbon emissions taxation and other emissions reduction policies and is taken into account to determine fuel mix, but is not finally paid. Carbon value applies to sectors not included in the EU ETS
- *RES value*: RES value is a sector-specific driver that represents non – identified policies aiming at the increase of RES use. In the model's formulation RES value reflects the shadow cost (marginal benefit) of the implicit RES target by sector. RES value is inserted in the calculation of short term (operation) costs with a negative sign, thus decreasing short term costs when the consumed fuel is RES. The lower short term costs for RES fuels enable RES penetration. RES value is a non-materialized benefit, meaning it does not represent subsidies for the use of renewables
- *EE value*: EE value is also defined by sector and represents non – identified energy efficiency promoting policies. EE value reflects the shadow value of an energy efficiency target per sector and is inserted in the calculation of long term costs of heat recovery equipment with a negative sign, thus decreasing the capital costs of heat recovery investments in industry. The same applies in the calculation of capital costs for renovation in buildings, regarding the residential and tertiary sectors. In this manner, EE value enhances investments in heat recovery and energy savings measures. Similar to RES value, EE value is a non-materialized benefit and does not represent subsidies for energy savings investments
- *Enabling Conditions:* Enabling conditions represent a set of policies aiming at the removal of uncertainties or non-price barriers associated with the use of new technologies or fuels. There are several drivers belonging in this category of drivers:
    - *Perceived costs*: Perceived or hidden costs are a main driver used in the CPS Demand Module to control the emergence of enabling conditions. Perceived costs can be associated with both processes – parameter AgentPerceivedCost – and fuels –

  parameter FuelPerceivedCost. AgentPerceivedCost parameter represents the perceived costs of equipment by process SF and agent and is used in the calculation of long term costs. FuelPerceivedCost parameter represents the perceived cost of a fuel's consumption and is inserted in the calculation of long term costs also. By reducing the perceived costs of equipment or fuels in time the user has the ability to promote investments in new technologies or the consumption of emerging fuels respectively.
  - *LBD index*: Learning-by-doing index represents the removal of uncertainties regarding the use of new technologies, via a learning-by-doing process. In CPS Demand Module, LBD parameter is directly multiplied with the capital cost of equipment, thus reducing investment costs and assisting the increase of investments in new technologies
  - *ThetaOptimum*: ThetaOptimum parameter is defined upon all nesting levels of the demand sectors and corresponds to the coefficient θ_i of the optimum share in the calculation of the final share:

    $$SH_{i,j,t} = (1-\theta_i) \cdot SH_{i,j,t}^{Inert} + \theta_i \cdot SH_{i,j,t}^{Opt}$$

    By increasing ThetaOptimum, optimum shares receive an increased weight, shifting final shares towards the optimum mix, as this is defined by marginal costs

- *Taxes & Subsidies*: Fuel taxes – excise tax and VAT – are exogenous in the CPS Model and follow the level of detail of regulations. The CPS Demand Module allows users to assess in detail the impact of taxation imposed on specific fuels and sectors
- *Discount rates*: The CPS Demand Module takes into account the level of the discount rate for investments. To reflect uncertainty surrounding a certain investment, the user can use the discount rate to introduce in the model a specific risk premium, which affects the weighted average cost of capital (WACC) of an investment. Discount rates are differentiated by sector and by agent, where agent heterogeneity exists
- *Potential*: Availability potential parameter represents the maximum potential of a fuel's consumption per year and can be used to assist fuel shifting towards biomass & waste fuels versus the consumption of fossil fuels
- *Doff_f*: Doff_f parameter is used in the CPS Model to represent the ban of a fuel in a certain process. If activated (value equal to 1) doff_f implies the restriction of a fuel's consumption in the corresponding process
- *BiofuelShare*: BiofuelShare parameter corresponds to the blend of conventional and advanced biofuels in transport sector. Increasing the share of advanced biofuels in this parameter results in the increase of advanced biofuel consumption versus conventional biofuels
- *Standards*: As mentioned in Section 4.2.1.8. Technology standards, technology standards, such as carbon emissions and efficiency targets, are included in the model in the form of constraints that have to be met by the equipment type mix in investments.

4.5 Explaining the demand-related scenario input file

To run alternative scenarios the user would need to modify accordingly the demand-related scenario input file located in the *Scenarios\”Scenario name”\Inputxlsx* folder (see section 2.4 The structure of the *Scenario name* subfolder) and named “*Scenario name*”_Input_Demand.xlsb.

The main sheets from where the user can affect parameters of the Demand Module and assess the impact of alternative policy options are:

1) **Macro_data**: The sheet includes macroeconomic input data such as population, GDP, GDP per Capita and Income per capita, used for the calculation of activity-useful energy of level SB. Also, *Macro_data* sheet includes activity values for years 2015 to 2050 for nesting levels SB to SF, as well as capacity of equipment/stock figures per process SF. Activity and stock values for 2015 are used for calibration purposes, while future years’ values are used for initialization purposes
2) **Vintages**: The sheet includes the distribution (shares) of vintages for the stock of equipment in 2015 per process SF
3) **Drivers_data**: This sheet includes several policy drivers such as the carbon price (for the ETS sectors) and carbon value (for the non-ETS sectors), renewable (RES) value and energy efficiency (EE) value and parameters for the calculation of the macroeconomic drivers’ elasticity
4) **Doff_f**: This sheet lists the values of the parameter doff_f which represents the ban of a fuel in a certain process (value 1 means the fuel is forbidden as input for the corresponding process)
5) **Prob_premat_poss**: This sheet allows the user to denote if premature replacement of equipment per process SF is allowed (value 1 for existing possibility, value 0 for no possibility of premature replacement)
6) **Prices_data**: This sheet includes pre-tax prices of imported or domestically produced fuels, transport costs, markups, additional costs for biomass and hydrogen, excise tax and VAT in %
7) **Techdata_sf**: This sheet summarises all technical characteristics of the CPS Demand Module processes, such as specific energy consumption (SEC) of ordinary technology, variable cost, operation & maintenance cost, growth rate of operation & maintenance cost, lifetime, capacity factor (utilization rate), investment cost, efficiency of technology category, heat recovery potential, range of penalty, mileage, occupancy and specific electricity consumption for all processes of the Module
8) **Techdata_ep**: This sheet summarises the specific technical characteristics of coal gasification units for the production of coke (cokery) – heatrate, variable cost, operation & maintenance cost, growth rate of operation & maintenance cost, lifetime, capacity factor (utilization rate), investment cost, heatrate per technology category, output ratio
9) **Policy_dem_data**: This sheet includes discount factors (rates), utilization factors and population shares per agent. It also includes carbon and efficiency standards for cars and freight duty vehicles and the elasticity parameter of deviation of the share of a subsector from the benchmark value

10) **Carbonpricing:** This sheet is related to the Emissions Trading Scheme. It includes the percentage of free allocation of allowances to the industrial sectors that participate in the EU ETS per process SF, as compensation for the risk of carbon leakage
11) **ETSsplit:** This sheet is also related to the Emissions Trading Scheme. Values between 0 and 1 denote the proportion of CO_2 emissions of a process SF that are not included in the EU ETS
12) **EquipmentSubsidy**: This sheet allows the user to include subsidies for equipment of processes per technology type
13) **EquipmentPerceivedCost**: This sheet includes the cokery perceived cost $pc\_Coke_{te,t}$ by technology te
14) **AgentPerceivedCost**: This sheet includes equipment perceived cost $pc_{SF,a,te,t}$ by process SF, agent a and technology te
15) **FuelPerceivedCost**: This sheet includes fuel perceived cost $pc_{SF,f,t}$ of fuel f per process SF
16) **Potential**: This sheet includes potential limitation of fuels for every projection year
17) **LBD**: This sheet includes the learning-by-doing parameters – floor cost, inflection year and speed of learning
18) **ThetaOptimum**: This sheet includes the coefficient θ_l of the optimum share, for all nesting levels, for both short term and long term operation and per agent, for processes where agent heterogeneity applies
19) **Exo_effi_ORD**: This sheet includes the trend of improvement of the efficiency of ordinary technology, which is defined exogenously. The value of Exo_effi_ORD is applied in all other technology categories in the Module during runtime
20) **HER_logit**: This sheet includes the parameters of heat recovery – coefficients ap_{HER}^{μ} of the polynomial function of heat recovery potential, investment cost, perceived cost, subsidies, lifetime of equipment and operation & maintenance cost
21) Sheets **dACTSBC_inert** to **dACTSEF_AG_ST_inert**: These sheets include the scale parameter $\delta_{SU,SL,t}$ of the inertia logit function
22) **dSW_F_inert_av**: The sheet includes the scale parameter $\delta_{SF,te,v,f,t}$ used for the calculation of the inertia share of fuel f in a process/equipment SF of technology te and vintage v
23) Sheets **da1_POT_SD to da6_POT_SD** include coefficients ap^{μ} of the polynomial function of the fuel potential

SVA: This sheet includes the Sectoral Value Added for Iron & Steel, Non Ferrous Metals, Chemicals, Building Materials, Paper & Pulp and Tertiary (split in Services and Agriculture) sectors. The specific sheet is used for reporting reasons only.

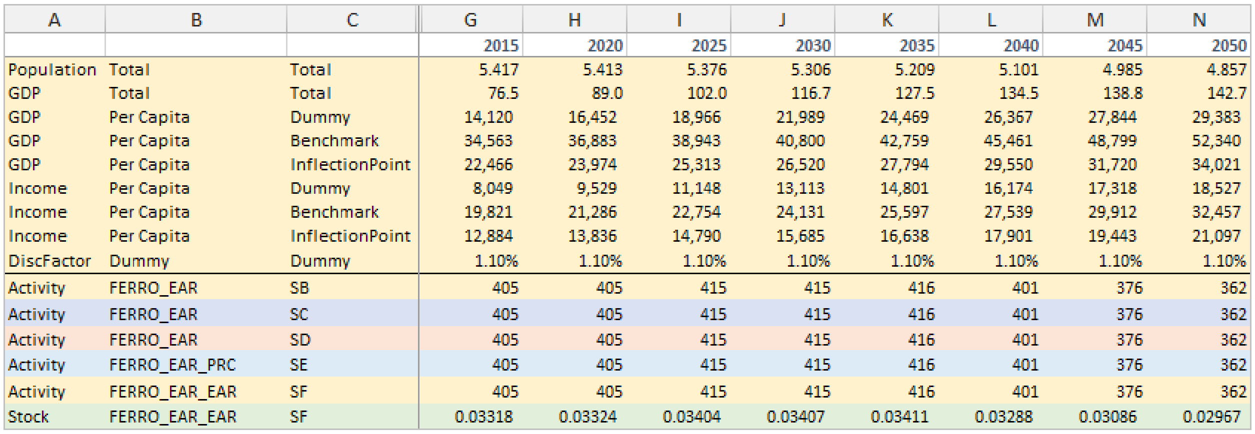
A more detailed presentation of the most important sheets is cited in the following paragraphs. For simplicity reasons, figures do not depict the real version of the corresponding sheet, but a selection of rows and columns.

4.5.1. Macro_data

- Population: Projection of population in million inhabitants
- GDP, Total: Projection of GDP in billion €'13
- GDP, Per Capita, Dummy: Projection of GDP per capita in €/capita
- GDP, Per Capita, Benchmark: Projection of GDP per capita benchmark value in €/capita
- GDP, Per Capita, Inflection Point: Projection of GDP per capita inflection point in €/capita
- Income, Per Capita, Dummy: Projection of Income per capita in €/capita
- Income, Per Capita, Benchmark: Projection of Income per capita benchmark value in €/capita
- Income, Per Capita, Inflection Point: Projection of Income per capita inflection point in €/capita
- Activity: Activity per nesting level SB to SF for calibration and initialization purposes, as described above. Units of activity differ from one sector to another, or between the uses of a sector, as shown in Table 10.
- Stock: Capacity per supply process SF in GW or thousand vehicles for transport sector – for calibration and initialization purposes, as described above.

Table 10 Units of activity per sector/process

Sector/Use	Unit of activity
Iron & Steel, Non Ferrous, Chemicals, Building Materials, Paper & Pulp	ktons product
Food, Drink & Tobacco, Engineering, Textiles and Other Industries	MEUR value added
Refineries	GWh throughput (crude oil refined)
Space heating, air cooling, water heating and electric uses	GWh useful energy
Lighting	lighting units
Black and white appliances	000 Appliances
Passenger transport	Mpkm
Freight transport	Mtkm

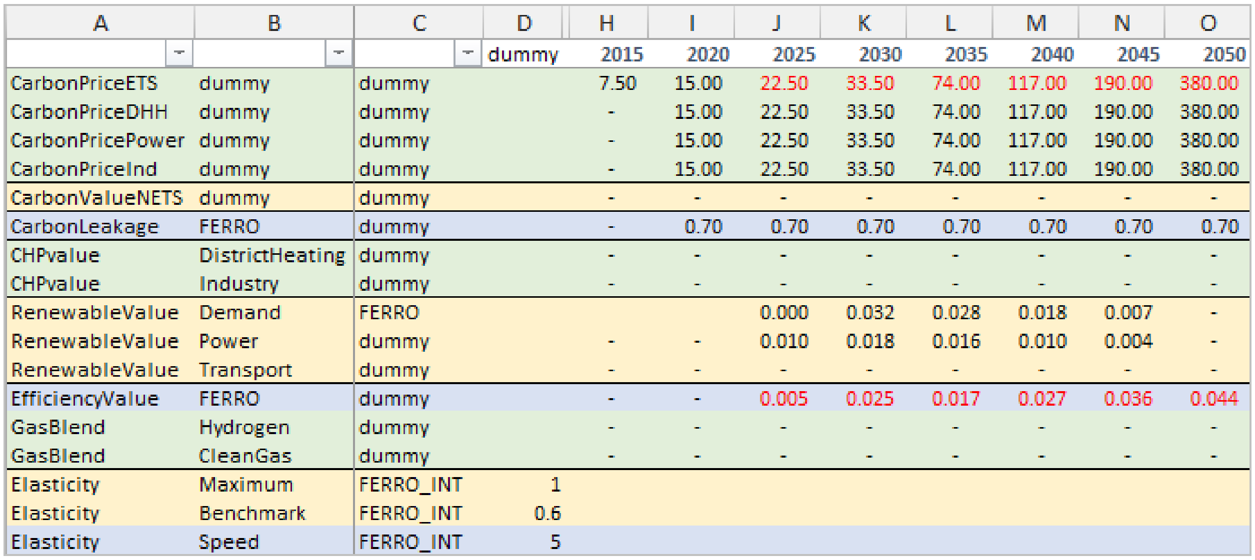


A	B	C	G	H	I	J	K	L	M	N
			2015	2020	2025	2030	2035	2040	2045	2050
Population	Total	Total	5.417	5.413	5.376	5.306	5.209	5.101	4.985	4.857
GDP	Total	Total	76.5	89.0	102.0	116.7	127.5	134.5	138.8	142.7
GDP	Per Capita	Dummy	14,120	16,452	18,966	21,989	24,469	26,367	27,844	29,383
GDP	Per Capita	Benchmark	34,563	36,883	38,943	40,800	42,759	45,461	48,799	52,340
GDP	Per Capita	InflectionPoint	22,466	23,974	25,313	26,520	27,794	29,550	31,720	34,021
Income	Per Capita	Dummy	8,049	9,529	11,148	13,113	14,801	16,174	17,318	18,527
Income	Per Capita	Benchmark	19,821	21,286	22,754	24,131	25,597	27,539	29,912	32,457
Income	Per Capita	InflectionPoint	12,884	13,836	14,790	15,685	16,638	17,901	19,443	21,097
DiscFactor	Dummy	Dummy	1.10%	1.10%	1.10%	1.10%	1.10%	1.10%	1.10%	1.10%
Activity	FERRO_EAR	SB	405	405	415	415	416	401	376	362
Activity	FERRO_EAR	SC	405	405	415	415	416	401	376	362
Activity	FERRO_EAR	SD	405	405	415	415	416	401	376	362
Activity	FERRO_EAR_PRC	SE	405	405	415	415	416	401	376	362
Activity	FERRO_EAR_EAR	SF	405	405	415	415	416	401	376	362
Stock	FERRO_EAR_EAR	SF	0.03318	0.03324	0.03404	0.03407	0.03411	0.03288	0.03086	0.02967

Figure 31 CPS demand input file: Macro_data sheet

4.5.2. Drivers_data

- CarbonPriceETS: Carbon price of EU ETS in €/tCO_2
- CarbonPriceDHH: Carbon price of EU ETS for District Heating in €/tCO_2
- CarbonPricePower: Carbon price of EU ETS for Power sector in €/tCO_2
- CarbonPriceInd: Carbon price of EU ETS for Industrial Sector in €/tCO_2
- CarbonValueNETS: Carbon value for non EU ETS sectors in €/tCO_2
- CarbonLeakage: Percentage of free allocation of allowances per industrial sector
- CHPValue: Virtual subsidy for investments in CHP plants used in the CPS Power Module in €/kWh_e
- RenewableValue, Demand: RES value per demand sector in €/kWh
- RenewableValue, Power: RES value for power sector in €/kWh
- RenewableValue, Transport: RES value for transport in €/kpkm
- EfficiencyValue: Efficiency value per demand sector in €/kWh
- GasBlend: Percentage of clean gas and hydrogen in distributed natural gas
- Elasticity, Maximum: Maximum possible value of income or GDP elasticity
- Elasticity, Benchmark: Income or GDP elasticity of a mature economy (lower than maximum)
- Elasticity, Speed: Speed of convergence of income or GDP elasticity to the benchmark



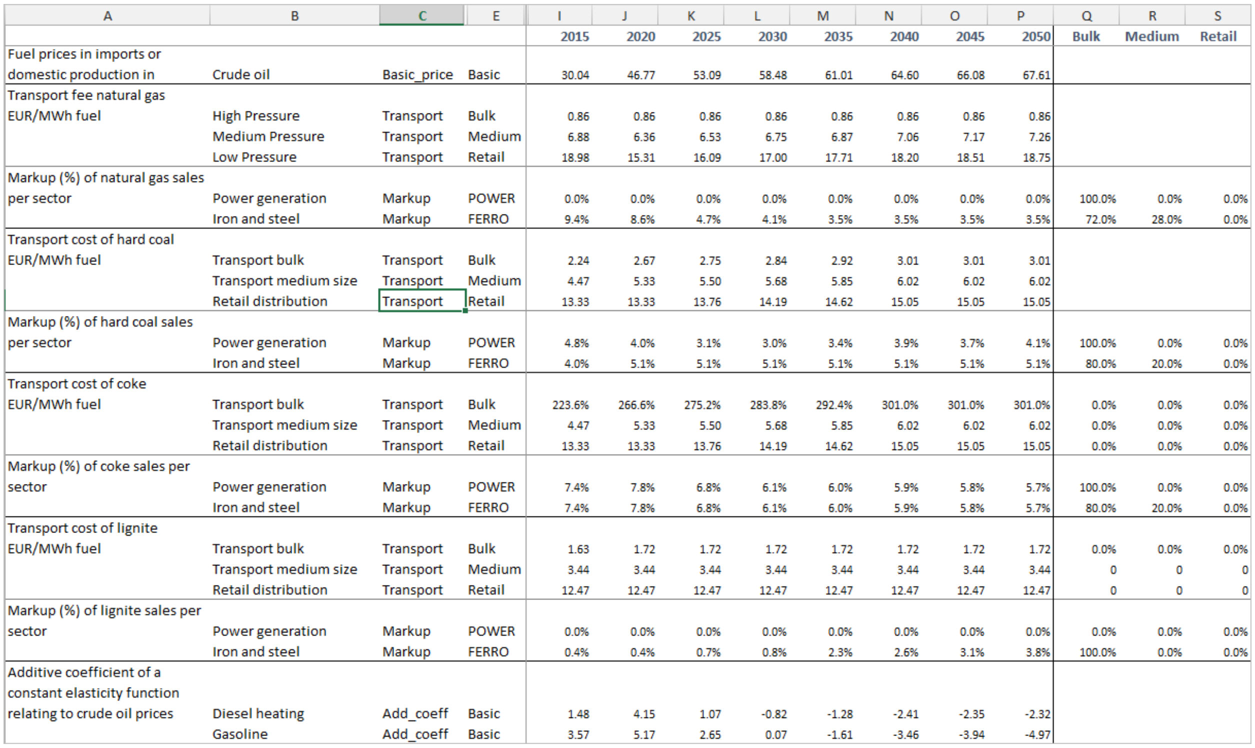
A	B	C	D	H	I	J	K	L	M	N	O
			dummy	2015	2020	2025	2030	2035	2040	2045	2050
CarbonPriceETS	dummy	dummy		7.50	15.00	22.50	33.50	74.00	117.00	190.00	380.00
CarbonPriceDHH	dummy	dummy		-	15.00	22.50	33.50	74.00	117.00	190.00	380.00
CarbonPricePower	dummy	dummy		-	15.00	22.50	33.50	74.00	117.00	190.00	380.00
CarbonPriceInd	dummy	dummy		-	15.00	22.50	33.50	74.00	117.00	190.00	380.00
CarbonValueNETS	dummy	dummy		-	-	-	-	-	-	-	-
CarbonLeakage	FERRO	dummy		-	0.70	0.70	0.70	0.70	0.70	0.70	0.70
CHPvalue	DistrictHeating	dummy		-	-	-	-	-	-	-	-
CHPvalue	Industry	dummy		-	-	-	-	-	-	-	-
RenewableValue	Demand	FERRO				0.000	0.032	0.028	0.018	0.007	-
RenewableValue	Power	dummy		-	-	0.010	0.018	0.016	0.010	0.004	-
RenewableValue	Transport	dummy		-	-	-	-	-	-	-	-
EfficiencyValue	FERRO	dummy		-	-	0.005	0.025	0.017	0.027	0.036	0.044
GasBlend	Hydrogen	dummy		-	-	-	-	-	-	-	-
GasBlend	CleanGas	dummy		-	-	-	-	-	-	-	-
Elasticity	Maximum	FERRO_INT	1								
Elasticity	Benchmark	FERRO_INT	0.6								
Elasticity	Speed	FERRO_INT	5								

Figure 32 CPS demand input file: Drivers_data sheet

4.5.3. Prices_data

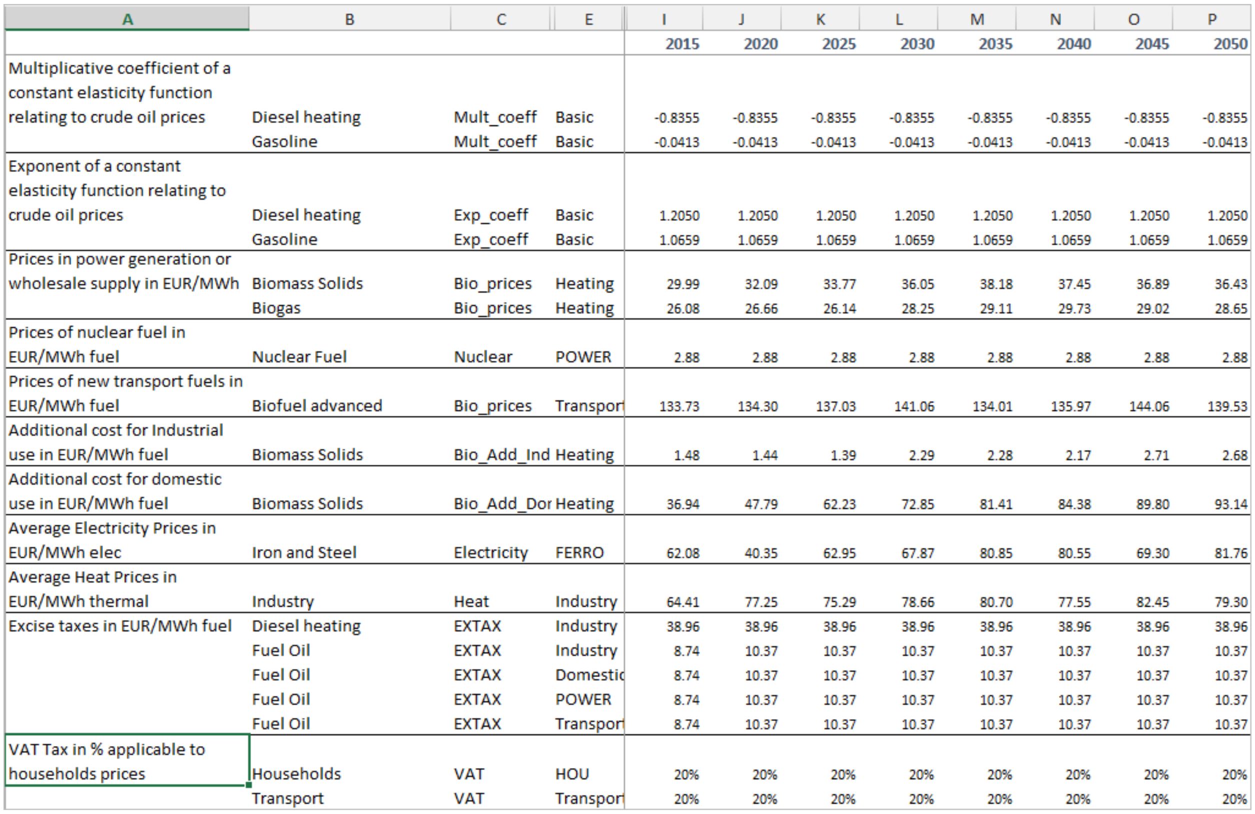
- Fuel prices for imports and domestic production for crude oil, natural gas, lignite, coke and hard coal in €/Mwh$_{\text{fuel}}$
- Transport fee for natural gas by high pressure, medium pressure and low pressure pipelines in €/Mwh$_{\text{fuel}}$
- Markup (%) of natural gas sales per sector
- Transport cost of hard coal for bulk transport, medium size transport and retail distribution in €/Mwh$_{\text{fuel}}$
- Markup (%) of hard coal sales per sector
- Transport cost of coke for bulk transport, medium size transport and retail distribution in €/Mwh$_{\text{fuel}}$
- Markup (%) of coke sales per sector
- Transport cost of lignite for bulk transport, medium size transport and retail distribution in €/Mwh$_{\text{fuel}}$
- Markup (%) of lignite sales per sector
- Additive coefficient of constant elasticity function relating to crude oil prices for diesel in heating, diesel in transport, gasoline, kerosene, fuel oil, LPG and naphtha
- Multiplicative coefficient of constant elasticity function relating to crude oil prices diesel in heating, diesel in transport, gasoline, kerosene, fuel oil, LPG and naphtha
- Exponent of constant elasticity function relating to crude oil prices for diesel in heating, diesel in transport, gasoline, kerosene, fuel oil, LPG and naphtha

- Prices in power generation or wholesale supply in €/Mwh$_{\text{fuel}}$ for biomass solids, biogas, waste solids, waste gas and H_2 used for heating
- Prices of nuclear fuel in €/Mwh$_{\text{fuel}}$ used in power generation
- Prices of new transport fuels in €/Mwh$_{\text{fuel}}$ for biofuel advanced, biofuel conventional, biogas, H_2 and biomass solids
- Additional cost for industrial use in €/Mwh$_{\text{fuel}}$ for biomass solids, biogas, waste solids, waste gas and H_2
- Additional cost for domestic use in €/Mwh$_{\text{fuel}}$ for biomass solids, biogas, waste solids, H_2 for heating and H_2 for transport
- Average Electricity Prices in €/Mwh$_{e}$ per demand sector
- Average Heat Prices in €/MWhth per aggregate demand sector: Industry, Households, Services and Agriculture
- Excise taxes in €/Mwh$_{\text{fuel}}$ per fuel and aggregate sector
- VAT Tax in % applicable to prices for Households and Transport



A	B	C	E	I	J	K	L	M	N	O	P	Q	R	S
				2015	2020	2025	2030	2035	2040	2045	2050	Bulk	Medium	Retail
Fuel prices in imports or domestic production in	Crude oil	Basic_price	Basic	30.04	46.77	53.09	58.48	61.01	64.60	66.08	67.61			
Transport fee natural gas EUR/MWh fuel	High Pressure	Transport	Bulk	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86			
	Medium Pressure	Transport	Medium	6.88	6.36	6.53	6.75	6.87	7.06	7.17	7.26			
	Low Pressure	Transport	Retail	18.98	15.31	16.09	17.00	17.71	18.20	18.51	18.75			
Markup (%) of natural gas sales per sector	Power generation	Markup	POWER	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
	Iron and steel	Markup	FERRO	9.4%	8.6%	4.7%	4.1%	3.5%	3.5%	3.5%	3.5%	72.0%	28.0%	0.0%
Transport cost of hard coal EUR/MWh fuel	Transport bulk	Transport	Bulk	2.24	2.67	2.75	2.84	2.92	3.01	3.01	3.01			
	Transport medium size	Transport	Medium	4.47	5.33	5.50	5.68	5.85	6.02	6.02	6.02			
	Retail distribution	Transport	Retail	13.33	13.33	13.76	14.19	14.62	15.05	15.05	15.05			
Markup (%) of hard coal sales per sector	Power generation	Markup	POWER	4.8%	4.0%	3.1%	3.0%	3.4%	3.9%	3.7%	4.1%	100.0%	0.0%	0.0%
	Iron and steel	Markup	FERRO	4.0%	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	80.0%	20.0%	0.0%
Transport cost of coke EUR/MWh fuel	Transport bulk	Transport	Bulk	223.6%	266.6%	275.2%	283.8%	292.4%	301.0%	301.0%	301.0%	0.0%	0.0%	0.0%
	Transport medium size	Transport	Medium	4.47	5.33	5.50	5.68	5.85	6.02	6.02	6.02	0.0%	0.0%	0.0%
	Retail distribution	Transport	Retail	13.33	13.33	13.76	14.19	14.62	15.05	15.05	15.05	0.0%	0.0%	0.0%
Markup (%) of coke sales per sector	Power generation	Markup	POWER	7.4%	7.8%	6.8%	6.1%	6.0%	5.9%	5.8%	5.7%	100.0%	0.0%	0.0%
	Iron and steel	Markup	FERRO	7.4%	7.8%	6.8%	6.1%	6.0%	5.9%	5.8%	5.7%	80.0%	20.0%	0.0%
Transport cost of lignite EUR/MWh fuel	Transport bulk	Transport	Bulk	1.63	1.72	1.72	1.72	1.72	1.72	1.72	1.72	0.0%	0.0%	0.0%
	Transport medium size	Transport	Medium	3.44	3.44	3.44	3.44	3.44	3.44	3.44	3.44	0	0	0
	Retail distribution	Transport	Retail	12.47	12.47	12.47	12.47	12.47	12.47	12.47	12.47	0	0	0
Markup (%) of lignite sales per sector	Power generation	Markup	POWER	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Iron and steel	Markup	FERRO	0.4%	0.4%	0.7%	0.8%	2.3%	2.6%	3.1%	3.8%	100.0%	0.0%	0.0%
Additive coefficient of a constant elasticity function relating to crude oil prices	Diesel heating	Add_coeff	Basic	1.48	4.15	1.07	-0.82	-1.28	-2.41	-2.35	-2.32			
	Gasoline	Add_coeff	Basic	3.57	5.17	2.65	0.07	-1.61	-3.46	-3.94	-4.97			

Figure 33 CPS demand input file: Prices_data sheet (first part)



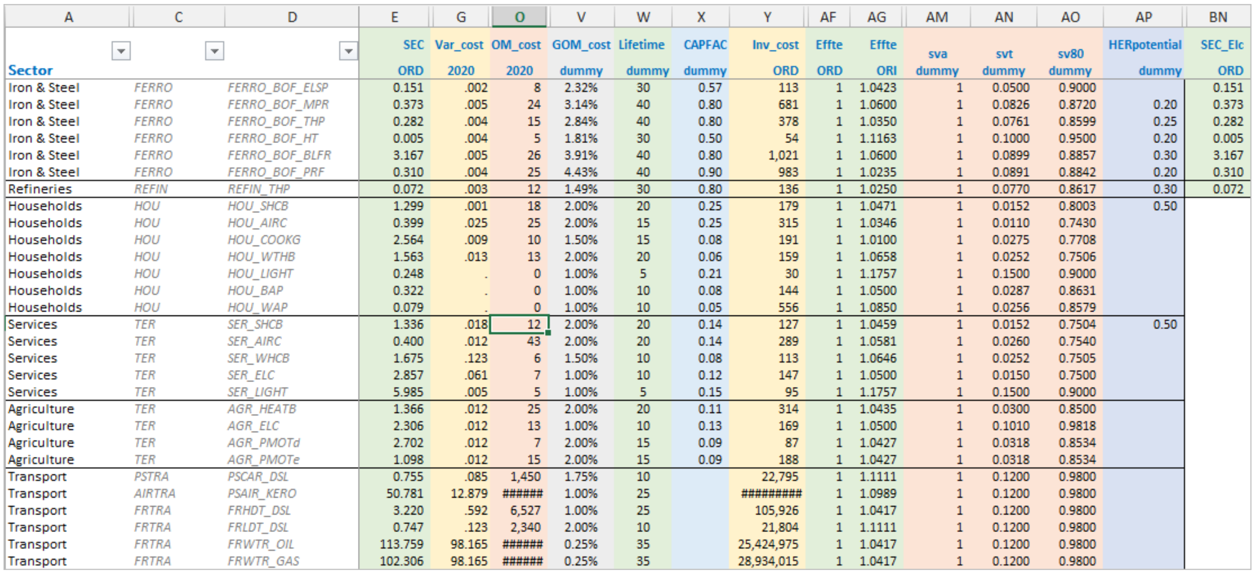
A	B	C	E	I	J	K	L	M	N	O	P
				2015	2020	2025	2030	2035	2040	2045	2050
Multiplicative coefficient of a constant elasticity function relating to crude oil prices	Diesel heating	Mult_coeff	Basic	-0.8355	-0.8355	-0.8355	-0.8355	-0.8355	-0.8355	-0.8355	-0.8355
	Gasoline	Mult_coeff	Basic	-0.0413	-0.0413	-0.0413	-0.0413	-0.0413	-0.0413	-0.0413	-0.0413
Exponent of a constant elasticity function relating to crude oil prices	Diesel heating	Exp_coeff	Basic	1.2050	1.2050	1.2050	1.2050	1.2050	1.2050	1.2050	1.2050
	Gasoline	Exp_coeff	Basic	1.0659	1.0659	1.0659	1.0659	1.0659	1.0659	1.0659	1.0659
Prices in power generation or wholesale supply in EUR/MWh	Biomass Solids	Bio_prices	Heating	29.99	32.09	33.77	36.05	38.18	37.45	36.89	36.43
	Biogas	Bio_prices	Heating	26.08	26.66	26.14	28.25	29.11	29.73	29.02	28.65
Prices of nuclear fuel in EUR/MWh fuel	Nuclear Fuel	Nuclear	POWER	2.88	2.88	2.88	2.88	2.88	2.88	2.88	2.88
Prices of new transport fuels in EUR/MWh fuel	Biofuel advanced	Bio_prices	Transpor	133.73	134.30	137.03	141.06	134.01	135.97	144.06	139.53
Additional cost for Industrial use in EUR/MWh fuel	Biomass Solids	Bio_Add_Ind	Heating	1.48	1.44	1.39	2.29	2.28	2.17	2.71	2.68
Additional cost for domestic use in EUR/MWh fuel	Biomass Solids	Bio_Add_Dor	Heating	36.94	47.79	62.23	72.85	81.41	84.38	89.80	93.14
Average Electricity Prices in EUR/MWh elec	Iron and Steel	Electricity	FERRO	62.08	40.35	62.95	67.87	80.85	80.55	69.30	81.76
Average Heat Prices in EUR/MWh thermal	Industry	Heat	Industry	64.41	77.25	75.29	78.66	80.70	77.55	82.45	79.30
Excise taxes in EUR/MWh fuel	Diesel heating	EXTAX	Industry	38.96	38.96	38.96	38.96	38.96	38.96	38.96	38.96
	Fuel Oil	EXTAX	Industry	8.74	10.37	10.37	10.37	10.37	10.37	10.37	10.37
	Fuel Oil	EXTAX	Domesti	8.74	10.37	10.37	10.37	10.37	10.37	10.37	10.37
	Fuel Oil	EXTAX	POWER	8.74	10.37	10.37	10.37	10.37	10.37	10.37	10.37
	Fuel Oil	EXTAX	Transpor	8.74	10.37	10.37	10.37	10.37	10.37	10.37	10.37
VAT Tax in % applicable to households prices	Households	VAT	HOU	20%	20%	20%	20%	20%	20%	20%	20%
	Transport	VAT	Transpor	20%	20%	20%	20%	20%	20%	20%	20%

Figure 34 CPS demand input file: Prices_data sheet (second part)

4.5.4. Techdata_sf

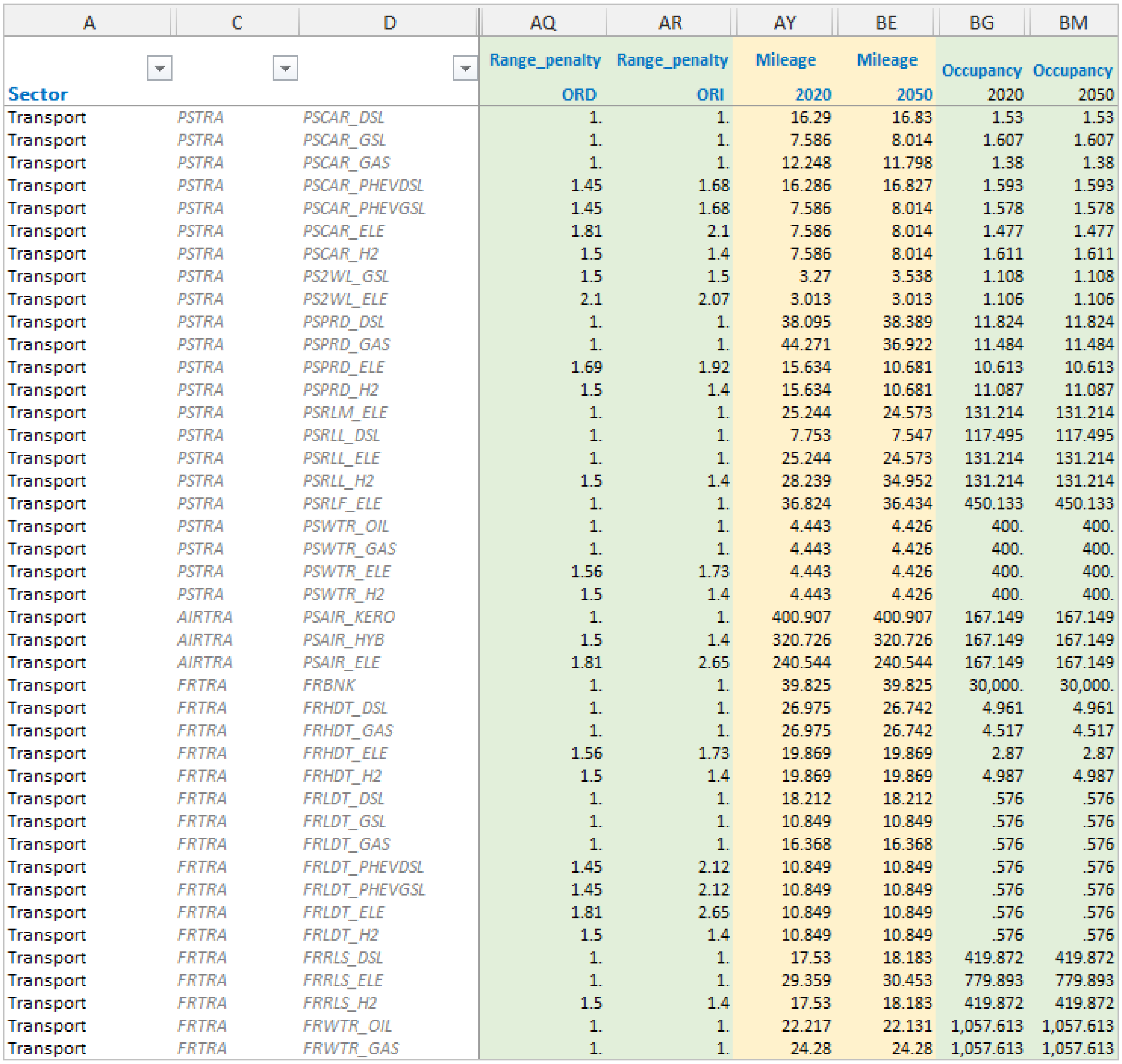
SEC:	Specific Energy consumption – heatrate in GWh per unit of activity
Var_cost:	Variable cost per in €/kW
OM_cost:	Operation & Maintenance cost in €/kW annually
GOM_cost:	Growth rate of operation & maintenance cost %
Lifetime:	Lifetime of equipment in years
CAPFAC:	Utilization rate of equipment
Inv_cost:	Investment cost of equipment in €/kW
Effte:	Normalized efficiency of technology categories (equal to 1 for ordinary technology)
Sva:	Scale parameter of survival function of equipment
Svt:	Survival rate of equipment at the end of lifetime
sv80:	Survival rate of equipment at 80% of lifetime
HERpotential:	Heat recovery potential of processes %

- Range_penalty: Penalty index per technology category, multiplied with capital cost of a vehicle due to range limitations (e.g. electric, hydrogen or plug-in hybrid vehicles)
- Mileage: Mileage per type of vehicle in thousand vehicle-km per year
- Occupancy: Occupancy per type of vehicle in persons or tons per vehicle-trip
- SEC_Elc: Specific electricity consumption – heatrate in GWh per unit of activity



A	C	D	E	G	O	V	W	X	Y	AF	AG	AM	AN	AO	AP	BN
			SEC	Var_cost	OM_cost	GOM_cost	Lifetime	CAPFAC	Inv_cost	Effte	Effte	sva	svt	sv80	HERpotential	SEC_Elc
Sector			ORD	2020	2020	dummy	dummy	dummy	ORD	ORD	ORI	dummy	dummy	dummy	dummy	ORD
Iron & Steel	FERRO	FERRO_BOF_ELSP	0.151	.002	8	2.32%	30	0.57	113	1	1.0423	1	0.0500	0.9000		0.151
Iron & Steel	FERRO	FERRO_BOF_MPR	0.373	.005	24	3.14%	40	0.80	681	1	1.0600	1	0.0826	0.8720	0.20	0.373
Iron & Steel	FERRO	FERRO_BOF_THP	0.282	.004	15	2.84%	40	0.80	378	1	1.0350	1	0.0761	0.8599	0.25	0.282
Iron & Steel	FERRO	FERRO_BOF_HT	0.005	.004	5	1.81%	30	0.50	54	1	1.1163	1	0.1000	0.9500	0.20	0.005
Iron & Steel	FERRO	FERRO_BOF_BLFR	3.167	.005	26	3.91%	40	0.80	1,021	1	1.0600	1	0.0899	0.8857	0.30	3.167
Iron & Steel	FERRO	FERRO_BOF_PRF	0.310	.004	25	4.43%	40	0.90	983	1	1.0235	1	0.0891	0.8842	0.20	0.310
Refineries	REFIN	REFIN_THP	0.072	.003	12	1.49%	30	0.80	136	1	1.0250	1	0.0770	0.8617	0.30	0.072
Households	HOU	HOU_SHCB	1.299	.001	18	2.00%	20	0.25	179	1	1.0471	1	0.0152	0.8003	0.50	
Households	HOU	HOU_AIRC	0.399	.025	25	2.00%	15	0.25	315	1	1.0346	1	0.0110	0.7430		
Households	HOU	HOU_COOKG	2.564	.009	10	1.50%	15	0.08	191	1	1.0100	1	0.0275	0.7708		
Households	HOU	HOU_WTHB	1.563	.013	13	2.00%	20	0.06	159	1	1.0658	1	0.0252	0.7506		
Households	HOU	HOU_LIGHT	0.248	.	0	1.00%	5	0.21	30	1	1.1757	1	0.1500	0.9000		
Households	HOU	HOU_BAP	0.322	.	0	1.00%	10	0.08	144	1	1.0500	1	0.0287	0.8631		
Households	HOU	HOU_WAP	0.079	.	0	1.00%	10	0.05	556	1	1.0850	1	0.0256	0.8579		
Services	TER	SER_SHCB	1.336	.018	12	2.00%	20	0.14	127	1	1.0459	1	0.0152	0.7504	0.50	
Services	TER	SER_AIRC	0.400	.012	43	2.00%	20	0.14	289	1	1.0581	1	0.0260	0.7540		
Services	TER	SER_WHCB	1.675	.123	6	1.50%	10	0.08	113	1	1.0646	1	0.0252	0.7505		
Services	TER	SER_ELC	2.857	.061	7	1.00%	10	0.12	147	1	1.0500	1	0.0150	0.7500		
Services	TER	SER_LIGHT	5.985	.005	5	1.00%	5	0.15	95	1	1.1757	1	0.1500	0.9000		
Agriculture	TER	AGR_HEATB	1.366	.012	25	2.00%	20	0.11	314	1	1.0435	1	0.0300	0.8500		
Agriculture	TER	AGR_ELC	2.306	.012	13	1.00%	10	0.13	169	1	1.0500	1	0.1010	0.9818		
Agriculture	TER	AGR_PMOTd	2.702	.012	7	2.00%	15	0.09	87	1	1.0427	1	0.0318	0.8534		
Agriculture	TER	AGR_PMOTe	1.098	.012	15	2.00%	15	0.09	188	1	1.0427	1	0.0318	0.8534		
Transport	PSTRA	PSCAR_DSL	0.755	.085	1,450	1.75%	10		22,795	1	1.1111	1	0.1200	0.9800		
Transport	AIRTRA	PSAIR_KERO	50.781	12.879	######	1.00%	25		#########	1	1.0989	1	0.1200	0.9800		
Transport	FRTRA	FRHDT_DSL	3.220	.592	6,527	1.00%	25		105,926	1	1.0417	1	0.1200	0.9800		
Transport	FRTRA	FRLDT_DSL	0.747	.123	2,340	2.00%	10		21,804	1	1.1111	1	0.1200	0.9800		
Transport	FRTRA	FRWTR_OIL	113.759	98.165	######	0.25%	35		25,424,975	1	1.0417	1	0.1200	0.9800		
Transport	FRTRA	FRWTR_GAS	102.306	98.165	######	0.25%	35		28,934,015	1	1.0417	1	0.1200	0.9800		

Figure 35 CPS demand input file: Techdata_sf sheet (first part)



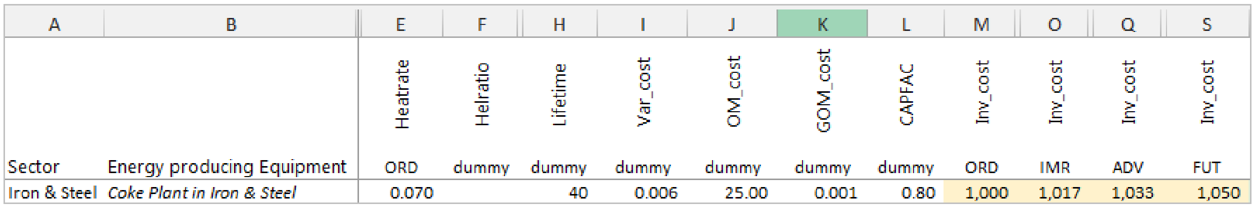
A	C	D	AQ	AR	AY	BE	BG	BM
Sector			Range_penalty ORD	Range_penalty ORI	Mileage 2020	Mileage 2050	Occupancy 2020	Occupancy 2050
Transport	PSTRA	PSCAR_DSL	1.	1.	16.29	16.83	1.53	1.53
Transport	PSTRA	PSCAR_GSL	1.	1.	7.586	8.014	1.607	1.607
Transport	PSTRA	PSCAR_GAS	1.	1.	12.248	11.798	1.38	1.38
Transport	PSTRA	PSCAR_PHEVDSL	1.45	1.68	16.286	16.827	1.593	1.593
Transport	PSTRA	PSCAR_PHEVGSL	1.45	1.68	7.586	8.014	1.578	1.578
Transport	PSTRA	PSCAR_ELE	1.81	2.1	7.586	8.014	1.477	1.477
Transport	PSTRA	PSCAR_H2	1.5	1.4	7.586	8.014	1.611	1.611
Transport	PSTRA	PS2WL_GSL	1.5	1.5	3.27	3.538	1.108	1.108
Transport	PSTRA	PS2WL_ELE	2.1	2.07	3.013	3.013	1.106	1.106
Transport	PSTRA	PSPRD_DSL	1.	1.	38.095	38.389	11.824	11.824
Transport	PSTRA	PSPRD_GAS	1.	1.	44.271	36.922	11.484	11.484
Transport	PSTRA	PSPRD_ELE	1.69	1.92	15.634	10.681	10.613	10.613
Transport	PSTRA	PSPRD_H2	1.5	1.4	15.634	10.681	11.087	11.087
Transport	PSTRA	PSRLM_ELE	1.	1.	25.244	24.573	131.214	131.214
Transport	PSTRA	PSRLL_DSL	1.	1.	7.753	7.547	117.495	117.495
Transport	PSTRA	PSRLL_ELE	1.	1.	25.244	24.573	131.214	131.214
Transport	PSTRA	PSRLL_H2	1.5	1.4	28.239	34.952	131.214	131.214
Transport	PSTRA	PSRLF_ELE	1.	1.	36.824	36.434	450.133	450.133
Transport	PSTRA	PSWTR_OIL	1.	1.	4.443	4.426	400.	400.
Transport	PSTRA	PSWTR_GAS	1.	1.	4.443	4.426	400.	400.
Transport	PSTRA	PSWTR_ELE	1.56	1.73	4.443	4.426	400.	400.
Transport	PSTRA	PSWTR_H2	1.5	1.4	4.443	4.426	400.	400.
Transport	AIRTRA	PSAIR_KERO	1.	1.	400.907	400.907	167.149	167.149
Transport	AIRTRA	PSAIR_HYB	1.5	1.4	320.726	320.726	167.149	167.149
Transport	AIRTRA	PSAIR_ELE	1.81	2.65	240.544	240.544	167.149	167.149
Transport	FRTRA	FRBNK	1.	1.	39.825	39.825	30,000.	30,000.
Transport	FRTRA	FRHDT_DSL	1.	1.	26.975	26.742	4.961	4.961
Transport	FRTRA	FRHDT_GAS	1.	1.	26.975	26.742	4.517	4.517
Transport	FRTRA	FRHDT_ELE	1.56	1.73	19.869	19.869	2.87	2.87
Transport	FRTRA	FRHDT_H2	1.5	1.4	19.869	19.869	4.987	4.987
Transport	FRTRA	FRLDT_DSL	1.	1.	18.212	18.212	.576	.576
Transport	FRTRA	FRLDT_GSL	1.	1.	10.849	10.849	.576	.576
Transport	FRTRA	FRLDT_GAS	1.	1.	16.368	16.368	.576	.576
Transport	FRTRA	FRLDT_PHEVDSL	1.45	2.12	10.849	10.849	.576	.576
Transport	FRTRA	FRLDT_PHEVGSL	1.45	2.12	10.849	10.849	.576	.576
Transport	FRTRA	FRLDT_ELE	1.81	2.65	10.849	10.849	.576	.576
Transport	FRTRA	FRLDT_H2	1.5	1.4	10.849	10.849	.576	.576
Transport	FRTRA	FRRLS_DSL	1.	1.	17.53	18.183	419.872	419.872
Transport	FRTRA	FRRLS_ELE	1.	1.	29.359	30.453	779.893	779.893
Transport	FRTRA	FRRLS_H2	1.5	1.4	17.53	18.183	419.872	419.872
Transport	FRTRA	FRWTR_OIL	1.	1.	22.217	22.131	1,057.613	1,057.613
Transport	FRTRA	FRWTR_GAS	1.	1.	24.28	24.28	1,057.613	1,057.613

Figure 36 CPS demand input file: Techdata_sf sheet (second part)

4.5.5. Techdata_ep

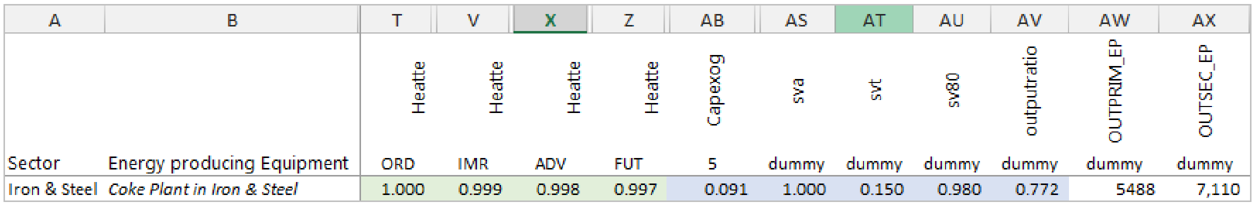
- Heatrate: Heatrate of cokery equipment (GWh consumed per GWh output)
- Helratio: Heat to electricity ratio of cokery equipment
- Lifetime: Lifetime of cokery equipment in years
- Var_cost: Variable cost of cokery equipment in €/kW

- OM_cost: Operation & maintenance cost of cokery equipment in €/kW annually
- GOM_cost: Growth rate of O&M cost of cokery equipment
- CAPFAC: Utilization rate of cokery equipment
- Inv_cost: Investment cost of cokery equipment in €/kW
- Heatte: Normalized heatrate of technology categories (equal to 1 for ordinary technology)
- Capexog: Capacity of cokery equipment per vintage for year 2015 in GW
- Sva: Scale parameter of survival function of cokery equipment
- Svt: Survival rate of cokery equipment at the end of lifetime
- Sv80: Survival rate of cokery equipment in 80% of lifetime
- Outputratio: Ratio of coke output over DGS output
- OUTPRIM_EP: Coke output of cokery for 2015 in GWh
- OUTSEC_EP: DGS output of cokery for 2015 in GWh



A	B	E	F	H	I	J	K	L	M	O	Q	S
		Heatrate	Helratio	Lifetime	Var_cost	OM_cost	GOM_cost	CAPFAC	Inv_cost	Inv_cost	Inv_cost	Inv_cost
Sector	Energy producing Equipment	ORD	dummy	dummy	dummy	dummy	dummy	dummy	ORD	IMR	ADV	FUT
Iron & Steel	*Coke Plant in Iron & Steel*	0.070		40	0.006	25.00	0.001	0.80	1,000	1,017	1,033	1,050

Figure 37 CPS demand input file: Techdata_ep sheet (first part)



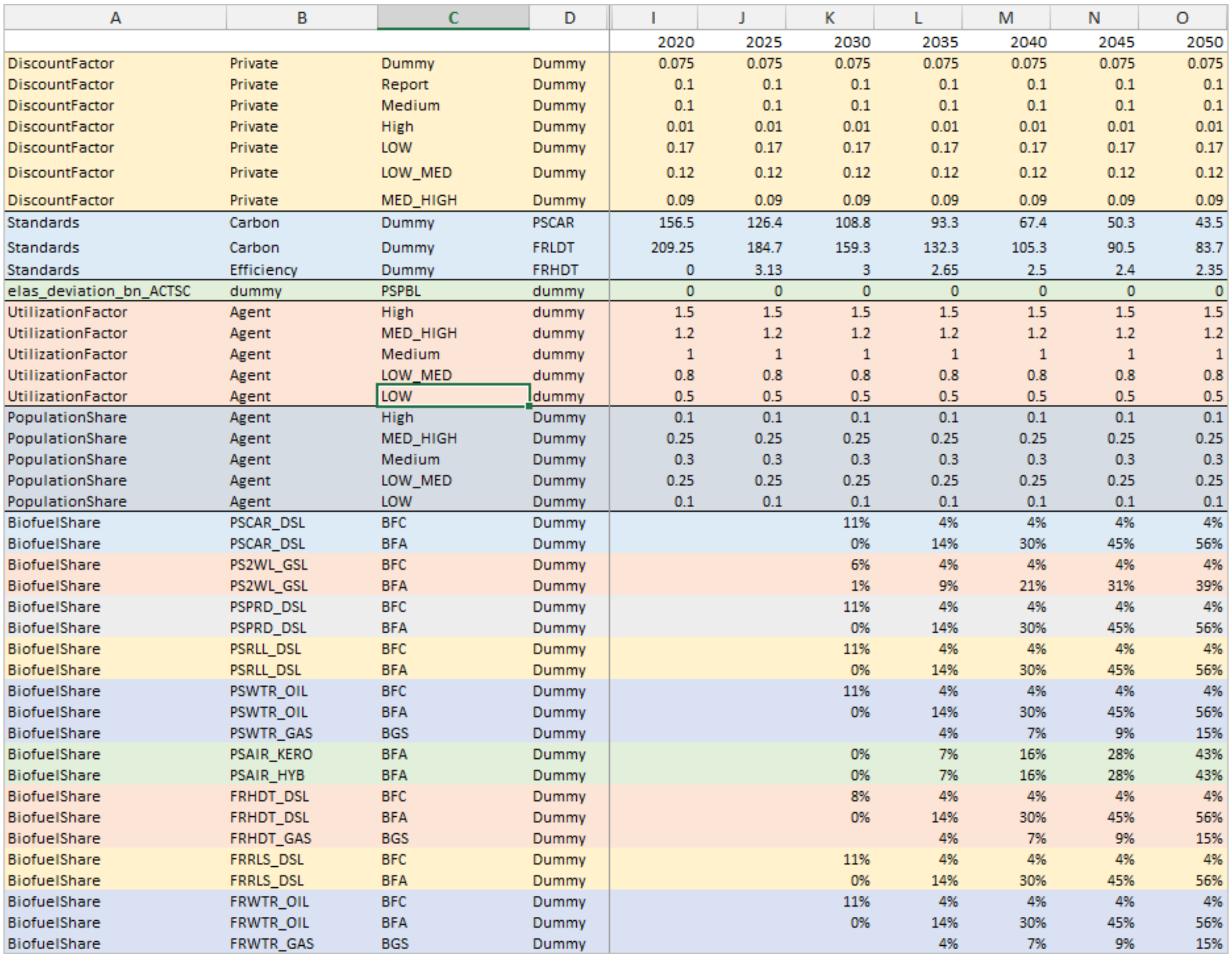
A	B	T	V	X	Z	AB	AS	AT	AU	AV	AW	AX
		Heatte	Heatte	Heatte	Heatte	Capexog	sva	svt	sv80	outputratio	OUTPRIM_EP	OUTSEC_EP
Sector	Energy producing Equipment	ORD	IMR	ADV	FUT	5	dummy	dummy	dummy	dummy	dummy	dummy
Iron & Steel	*Coke Plant in Iron & Steel*	1.000	0.999	0.998	0.997	0.091	1.000	0.150	0.980	0.772	5488	7,110

Figure 38 CPS Demand input file: Techdata_ep sheet (second part)

4.5.6. Policy_dem_data

- Discountfactor: Discount rates per agent class, as well as the uniform discount rate used for cost reporting
- Standards: Technology standards (targets) for efficiency and carbon emissions of vehicles in grCO$_2$/km
- elas_deviation_bn_ACTSC: Elasticity parameter of deviation of the share of a subsector from the benchmark value
- UtilizationFactor: Utilization rate by agent class. In the CPS Demand Module this factor is multiplied with the capacity factor of each process

- PopulationShare: Population share of each agent class
- BiofuelShare: Shares (%) of conventional and advanced biofuels in transport sector

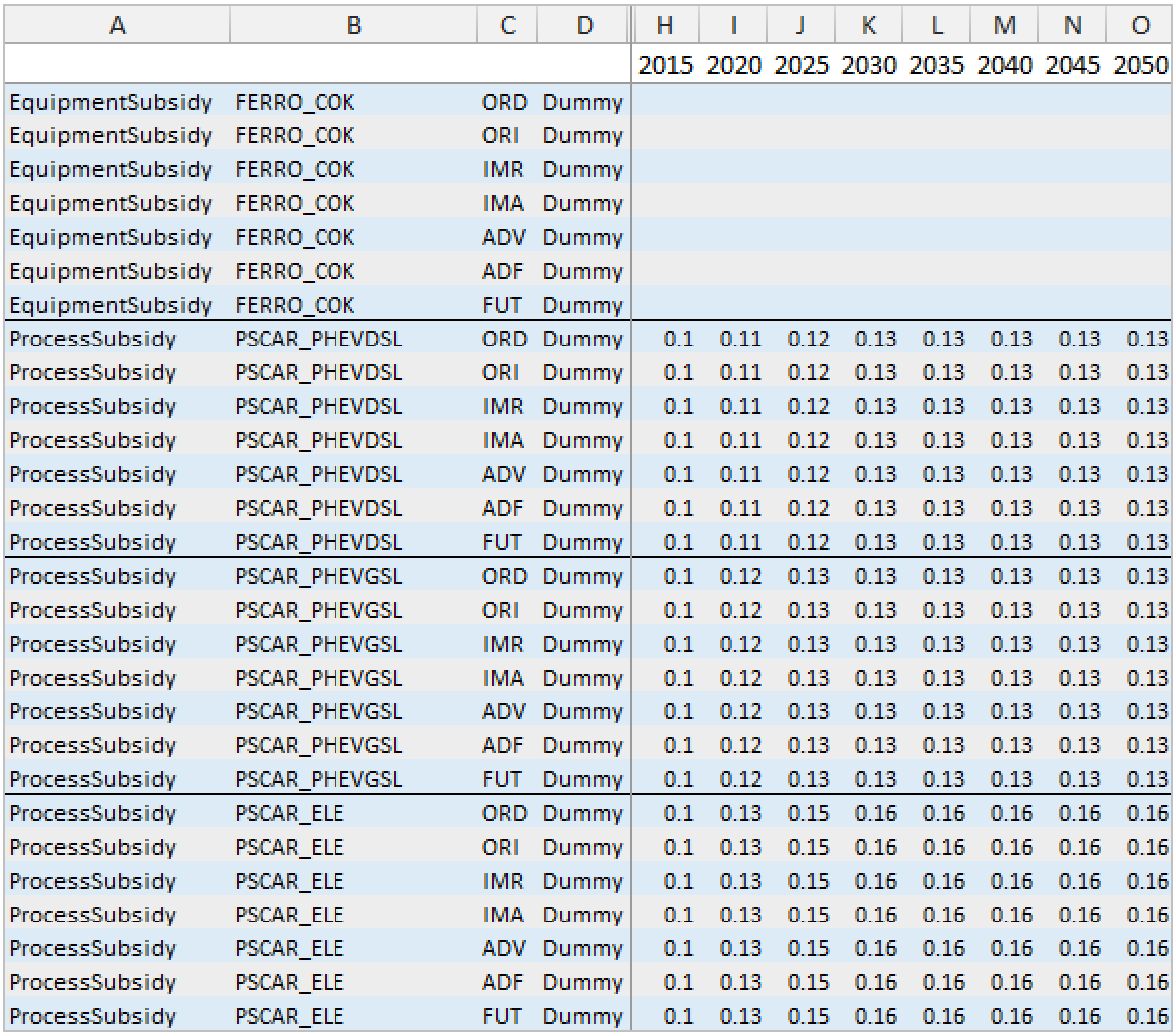


A	B	C	D	I	J	K	L	M	N	O
				2020	2025	2030	2035	2040	2045	2050
DiscountFactor	Private	Dummy	Dummy	0.075	0.075	0.075	0.075	0.075	0.075	0.075
DiscountFactor	Private	Report	Dummy	0.1	0.1	0.1	0.1	0.1	0.1	0.1
DiscountFactor	Private	Medium	Dummy	0.1	0.1	0.1	0.1	0.1	0.1	0.1
DiscountFactor	Private	High	Dummy	0.01	0.01	0.01	0.01	0.01	0.01	0.01
DiscountFactor	Private	LOW	Dummy	0.17	0.17	0.17	0.17	0.17	0.17	0.17
DiscountFactor	Private	LOW_MED	Dummy	0.12	0.12	0.12	0.12	0.12	0.12	0.12
DiscountFactor	Private	MED_HIGH	Dummy	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Standards	Carbon	Dummy	PSCAR	156.5	126.4	108.8	93.3	67.4	50.3	43.5
Standards	Carbon	Dummy	FRLDT	209.25	184.7	159.3	132.3	105.3	90.5	83.7
Standards	Efficiency	Dummy	FRHDT	0	3.13	3	2.65	2.5	2.4	2.35
elas_deviation_bn_ACTSC	dummy	PSPBL	dummy	0	0	0	0	0	0	0
UtilizationFactor	Agent	High	dummy	1.5	1.5	1.5	1.5	1.5	1.5	1.5
UtilizationFactor	Agent	MED_HIGH	dummy	1.2	1.2	1.2	1.2	1.2	1.2	1.2
UtilizationFactor	Agent	Medium	dummy	1	1	1	1	1	1	1
UtilizationFactor	Agent	LOW_MED	dummy	0.8	0.8	0.8	0.8	0.8	0.8	0.8
UtilizationFactor	Agent	LOW	dummy	0.5	0.5	0.5	0.5	0.5	0.5	0.5
PopulationShare	Agent	High	Dummy	0.1	0.1	0.1	0.1	0.1	0.1	0.1
PopulationShare	Agent	MED_HIGH	Dummy	0.25	0.25	0.25	0.25	0.25	0.25	0.25
PopulationShare	Agent	Medium	Dummy	0.3	0.3	0.3	0.3	0.3	0.3	0.3
PopulationShare	Agent	LOW_MED	Dummy	0.25	0.25	0.25	0.25	0.25	0.25	0.25
PopulationShare	Agent	LOW	Dummy	0.1	0.1	0.1	0.1	0.1	0.1	0.1
BiofuelShare	PSCAR_DSL	BFC	Dummy			11%	4%	4%	4%	4%
BiofuelShare	PSCAR_DSL	BFA	Dummy			0%	14%	30%	45%	56%
BiofuelShare	PS2WL_GSL	BFC	Dummy			6%	4%	4%	4%	4%
BiofuelShare	PS2WL_GSL	BFA	Dummy			1%	9%	21%	31%	39%
BiofuelShare	PSPRD_DSL	BFC	Dummy			11%	4%	4%	4%	4%
BiofuelShare	PSPRD_DSL	BFA	Dummy			0%	14%	30%	45%	56%
BiofuelShare	PSRLL_DSL	BFC	Dummy			11%	4%	4%	4%	4%
BiofuelShare	PSRLL_DSL	BFA	Dummy			0%	14%	30%	45%	56%
BiofuelShare	PSWTR_OIL	BFC	Dummy			11%	4%	4%	4%	4%
BiofuelShare	PSWTR_OIL	BFA	Dummy			0%	14%	30%	45%	56%
BiofuelShare	PSWTR_GAS	BGS	Dummy				4%	7%	9%	15%
BiofuelShare	PSAIR_KERO	BFA	Dummy			0%	7%	16%	28%	43%
BiofuelShare	PSAIR_HYB	BFA	Dummy			0%	7%	16%	28%	43%
BiofuelShare	FRHDT_DSL	BFC	Dummy			8%	4%	4%	4%	4%
BiofuelShare	FRHDT_DSL	BFA	Dummy			0%	14%	30%	45%	56%
BiofuelShare	FRHDT_GAS	BGS	Dummy				4%	7%	9%	15%
BiofuelShare	FRRLS_DSL	BFC	Dummy			11%	4%	4%	4%	4%
BiofuelShare	FRRLS_DSL	BFA	Dummy			0%	14%	30%	45%	56%
BiofuelShare	FRWTR_OIL	BFC	Dummy			11%	4%	4%	4%	4%
BiofuelShare	FRWTR_OIL	BFA	Dummy			0%	14%	30%	45%	56%
BiofuelShare	FRWTR_GAS	BGS	Dummy				4%	7%	9%	15%

Figure 39 CPS Demand input file: Policy_dem_data sheet

4.5.7. EquipmentSubsidy

- EquipmentSubsidy: Subsidy for the purchase of equipment of cokery per technology category as percentage (%) of the investment cost
- ProcessSubsidy: Subsidy for the purchase of equipment per process and technology category as percentage (%) of the investment cost

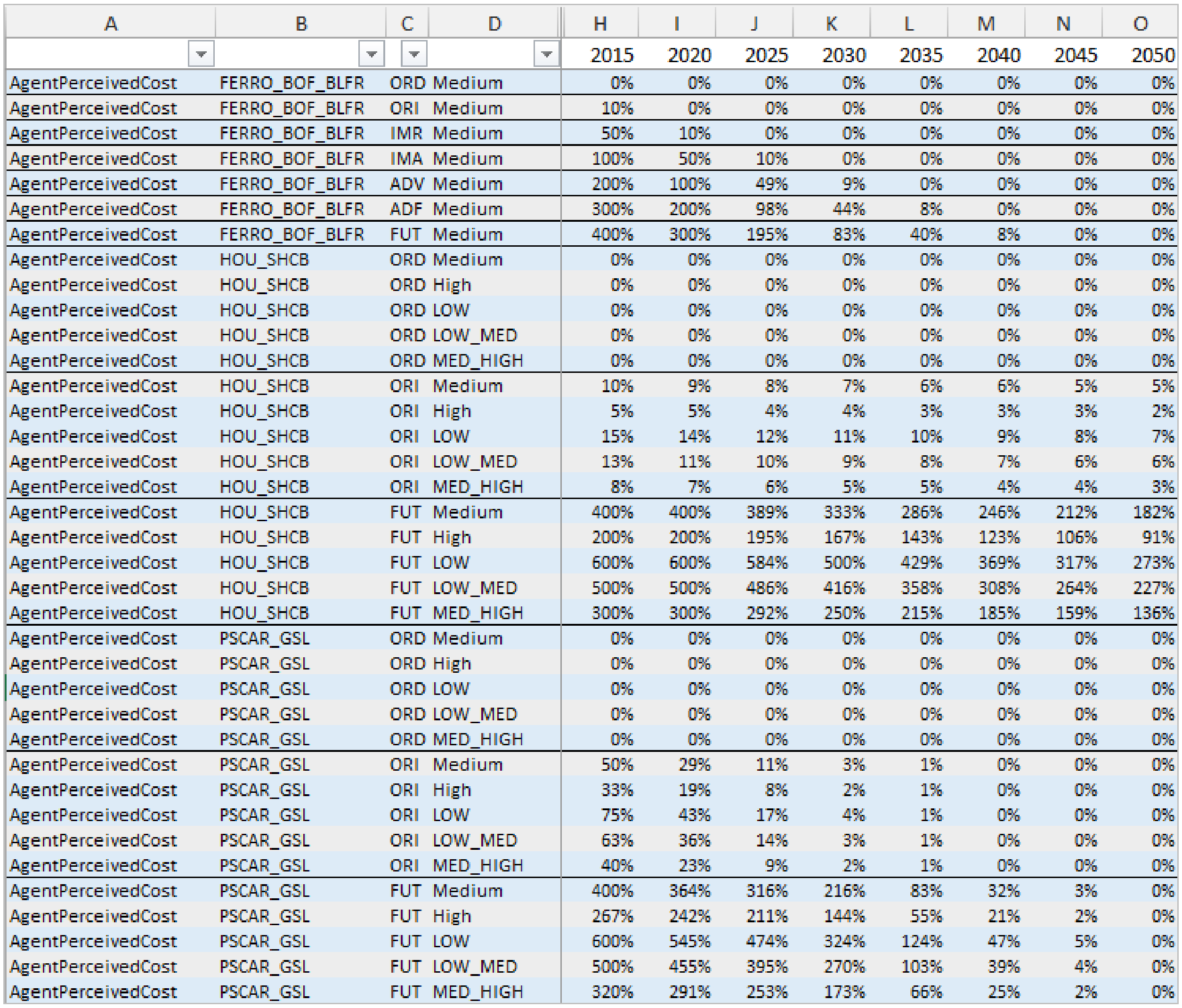


A	B	C	D	H	I	J	K	L	M	N	O
				2015	2020	2025	2030	2035	2040	2045	2050
EquipmentSubsidy	FERRO_COK	ORD	Dummy								
EquipmentSubsidy	FERRO_COK	ORI	Dummy								
EquipmentSubsidy	FERRO_COK	IMR	Dummy								
EquipmentSubsidy	FERRO_COK	IMA	Dummy								
EquipmentSubsidy	FERRO_COK	ADV	Dummy								
EquipmentSubsidy	FERRO_COK	ADF	Dummy								
EquipmentSubsidy	FERRO_COK	FUT	Dummy								
ProcessSubsidy	PSCAR_PHEVDSL	ORD	Dummy	0.1	0.11	0.12	0.13	0.13	0.13	0.13	0.13
ProcessSubsidy	PSCAR_PHEVDSL	ORI	Dummy	0.1	0.11	0.12	0.13	0.13	0.13	0.13	0.13
ProcessSubsidy	PSCAR_PHEVDSL	IMR	Dummy	0.1	0.11	0.12	0.13	0.13	0.13	0.13	0.13
ProcessSubsidy	PSCAR_PHEVDSL	IMA	Dummy	0.1	0.11	0.12	0.13	0.13	0.13	0.13	0.13
ProcessSubsidy	PSCAR_PHEVDSL	ADV	Dummy	0.1	0.11	0.12	0.13	0.13	0.13	0.13	0.13
ProcessSubsidy	PSCAR_PHEVDSL	ADF	Dummy	0.1	0.11	0.12	0.13	0.13	0.13	0.13	0.13
ProcessSubsidy	PSCAR_PHEVDSL	FUT	Dummy	0.1	0.11	0.12	0.13	0.13	0.13	0.13	0.13
ProcessSubsidy	PSCAR_PHEVGSL	ORD	Dummy	0.1	0.12	0.13	0.13	0.13	0.13	0.13	0.13
ProcessSubsidy	PSCAR_PHEVGSL	ORI	Dummy	0.1	0.12	0.13	0.13	0.13	0.13	0.13	0.13
ProcessSubsidy	PSCAR_PHEVGSL	IMR	Dummy	0.1	0.12	0.13	0.13	0.13	0.13	0.13	0.13
ProcessSubsidy	PSCAR_PHEVGSL	IMA	Dummy	0.1	0.12	0.13	0.13	0.13	0.13	0.13	0.13
ProcessSubsidy	PSCAR_PHEVGSL	ADV	Dummy	0.1	0.12	0.13	0.13	0.13	0.13	0.13	0.13
ProcessSubsidy	PSCAR_PHEVGSL	ADF	Dummy	0.1	0.12	0.13	0.13	0.13	0.13	0.13	0.13
ProcessSubsidy	PSCAR_PHEVGSL	FUT	Dummy	0.1	0.12	0.13	0.13	0.13	0.13	0.13	0.13
ProcessSubsidy	PSCAR_ELE	ORD	Dummy	0.1	0.13	0.15	0.16	0.16	0.16	0.16	0.16
ProcessSubsidy	PSCAR_ELE	ORI	Dummy	0.1	0.13	0.15	0.16	0.16	0.16	0.16	0.16
ProcessSubsidy	PSCAR_ELE	IMR	Dummy	0.1	0.13	0.15	0.16	0.16	0.16	0.16	0.16
ProcessSubsidy	PSCAR_ELE	IMA	Dummy	0.1	0.13	0.15	0.16	0.16	0.16	0.16	0.16
ProcessSubsidy	PSCAR_ELE	ADV	Dummy	0.1	0.13	0.15	0.16	0.16	0.16	0.16	0.16
ProcessSubsidy	PSCAR_ELE	ADF	Dummy	0.1	0.13	0.15	0.16	0.16	0.16	0.16	0.16
ProcessSubsidy	PSCAR_ELE	FUT	Dummy	0.1	0.13	0.15	0.16	0.16	0.16	0.16	0.16

Figure 40 CPS Demand input file: EquipmentSubsidy sheet

4.5.8. Perceived Costs sheets

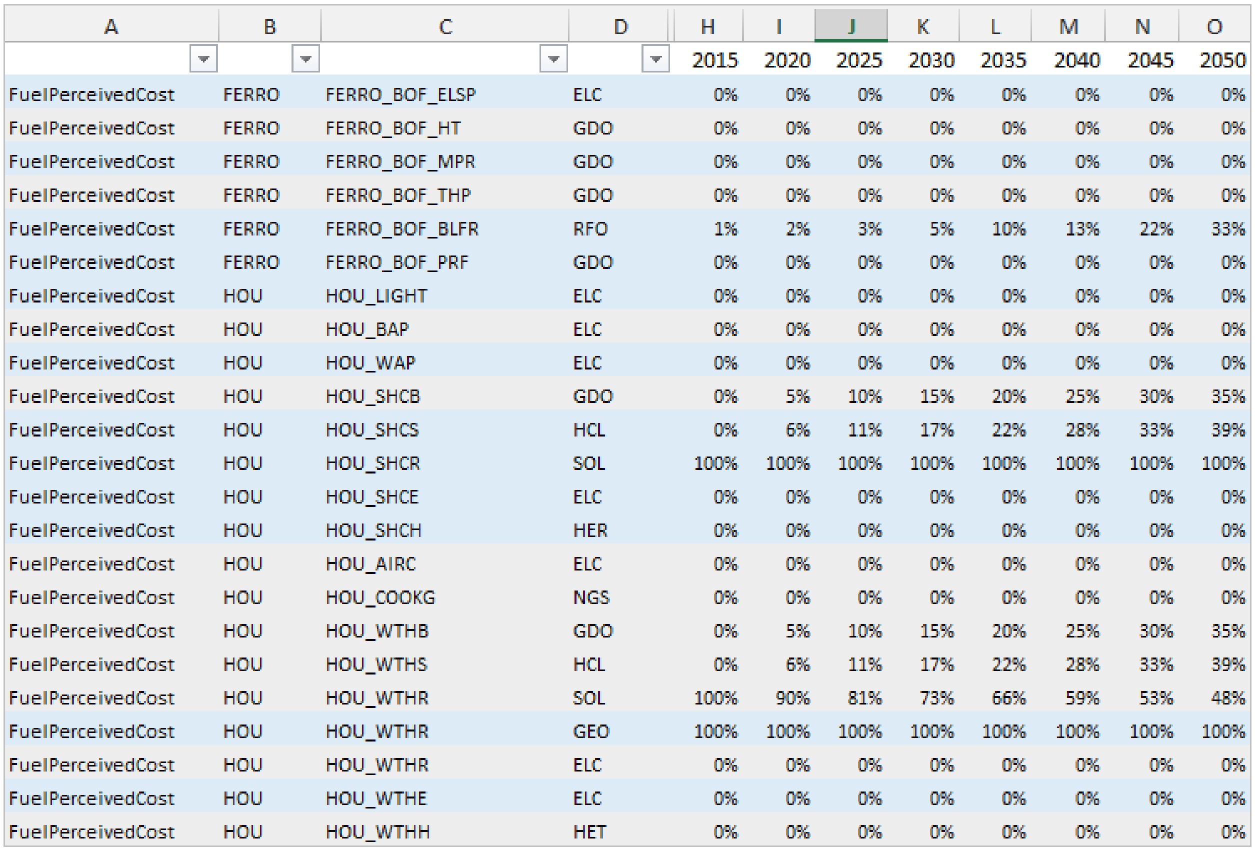
- AgentPerceivedCost: Perceived cost (%) of process per technology category and agent class



A	B	C	D	H	I	J	K	L	M	N	O
				2015	2020	2025	2030	2035	2040	2045	2050
AgentPerceivedCost	FERRO_BOF_BLFR	ORD	Medium	0%	0%	0%	0%	0%	0%	0%	0%
AgentPerceivedCost	FERRO_BOF_BLFR	ORI	Medium	10%	0%	0%	0%	0%	0%	0%	0%
AgentPerceivedCost	FERRO_BOF_BLFR	IMR	Medium	50%	10%	0%	0%	0%	0%	0%	0%
AgentPerceivedCost	FERRO_BOF_BLFR	IMA	Medium	100%	50%	10%	0%	0%	0%	0%	0%
AgentPerceivedCost	FERRO_BOF_BLFR	ADV	Medium	200%	100%	49%	9%	0%	0%	0%	0%
AgentPerceivedCost	FERRO_BOF_BLFR	ADF	Medium	300%	200%	98%	44%	8%	0%	0%	0%
AgentPerceivedCost	FERRO_BOF_BLFR	FUT	Medium	400%	300%	195%	83%	40%	8%	0%	0%
AgentPerceivedCost	HOU_SHCB	ORD	Medium	0%	0%	0%	0%	0%	0%	0%	0%
AgentPerceivedCost	HOU_SHCB	ORD	High	0%	0%	0%	0%	0%	0%	0%	0%
AgentPerceivedCost	HOU_SHCB	ORD	LOW	0%	0%	0%	0%	0%	0%	0%	0%
AgentPerceivedCost	HOU_SHCB	ORD	LOW_MED	0%	0%	0%	0%	0%	0%	0%	0%
AgentPerceivedCost	HOU_SHCB	ORD	MED_HIGH	0%	0%	0%	0%	0%	0%	0%	0%
AgentPerceivedCost	HOU_SHCB	ORI	Medium	10%	9%	8%	7%	6%	6%	5%	5%
AgentPerceivedCost	HOU_SHCB	ORI	High	5%	5%	4%	4%	3%	3%	3%	2%
AgentPerceivedCost	HOU_SHCB	ORI	LOW	15%	14%	12%	11%	10%	9%	8%	7%
AgentPerceivedCost	HOU_SHCB	ORI	LOW_MED	13%	11%	10%	9%	8%	7%	6%	6%
AgentPerceivedCost	HOU_SHCB	ORI	MED_HIGH	8%	7%	6%	5%	5%	4%	4%	3%
AgentPerceivedCost	HOU_SHCB	FUT	Medium	400%	400%	389%	333%	286%	246%	212%	182%
AgentPerceivedCost	HOU_SHCB	FUT	High	200%	200%	195%	167%	143%	123%	106%	91%
AgentPerceivedCost	HOU_SHCB	FUT	LOW	600%	600%	584%	500%	429%	369%	317%	273%
AgentPerceivedCost	HOU_SHCB	FUT	LOW_MED	500%	500%	486%	416%	358%	308%	264%	227%
AgentPerceivedCost	HOU_SHCB	FUT	MED_HIGH	300%	300%	292%	250%	215%	185%	159%	136%
AgentPerceivedCost	PSCAR_GSL	ORD	Medium	0%	0%	0%	0%	0%	0%	0%	0%
AgentPerceivedCost	PSCAR_GSL	ORD	High	0%	0%	0%	0%	0%	0%	0%	0%
AgentPerceivedCost	PSCAR_GSL	ORD	LOW	0%	0%	0%	0%	0%	0%	0%	0%
AgentPerceivedCost	PSCAR_GSL	ORD	LOW_MED	0%	0%	0%	0%	0%	0%	0%	0%
AgentPerceivedCost	PSCAR_GSL	ORD	MED_HIGH	0%	0%	0%	0%	0%	0%	0%	0%
AgentPerceivedCost	PSCAR_GSL	ORI	Medium	50%	29%	11%	3%	1%	0%	0%	0%
AgentPerceivedCost	PSCAR_GSL	ORI	High	33%	19%	8%	2%	1%	0%	0%	0%
AgentPerceivedCost	PSCAR_GSL	ORI	LOW	75%	43%	17%	4%	1%	0%	0%	0%
AgentPerceivedCost	PSCAR_GSL	ORI	LOW_MED	63%	36%	14%	3%	1%	0%	0%	0%
AgentPerceivedCost	PSCAR_GSL	ORI	MED_HIGH	40%	23%	9%	2%	1%	0%	0%	0%
AgentPerceivedCost	PSCAR_GSL	FUT	Medium	400%	364%	316%	216%	83%	32%	3%	0%
AgentPerceivedCost	PSCAR_GSL	FUT	High	267%	242%	211%	144%	55%	21%	2%	0%
AgentPerceivedCost	PSCAR_GSL	FUT	LOW	600%	545%	474%	324%	124%	47%	5%	0%
AgentPerceivedCost	PSCAR_GSL	FUT	LOW_MED	500%	455%	395%	270%	103%	39%	4%	0%
AgentPerceivedCost	PSCAR_GSL	FUT	MED_HIGH	320%	291%	253%	173%	66%	25%	2%	0%

Figure 41 CPS Demand input file: AgentPerceivedCost sheet

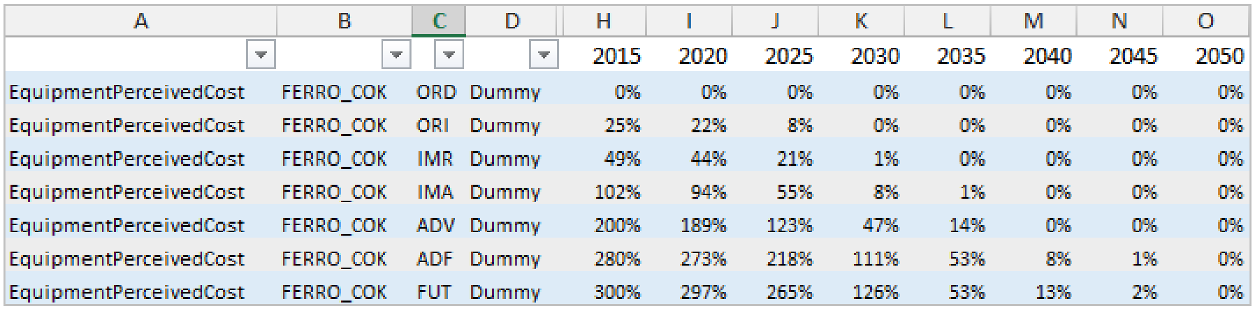
- FuelPerceivedCost: Perceived cost (%) of fuel per process



A	B	C	D	H	I	J	K	L	M	N	O
				2015	2020	2025	2030	2035	2040	2045	2050
FuelPerceivedCost	FERRO	FERRO_BOF_ELSP	ELC	0%	0%	0%	0%	0%	0%	0%	0%
FuelPerceivedCost	FERRO	FERRO_BOF_HT	GDO	0%	0%	0%	0%	0%	0%	0%	0%
FuelPerceivedCost	FERRO	FERRO_BOF_MPR	GDO	0%	0%	0%	0%	0%	0%	0%	0%
FuelPerceivedCost	FERRO	FERRO_BOF_THP	GDO	0%	0%	0%	0%	0%	0%	0%	0%
FuelPerceivedCost	FERRO	FERRO_BOF_BLFR	RFO	1%	2%	3%	5%	10%	13%	22%	33%
FuelPerceivedCost	FERRO	FERRO_BOF_PRF	GDO	0%	0%	0%	0%	0%	0%	0%	0%
FuelPerceivedCost	HOU	HOU_LIGHT	ELC	0%	0%	0%	0%	0%	0%	0%	0%
FuelPerceivedCost	HOU	HOU_BAP	ELC	0%	0%	0%	0%	0%	0%	0%	0%
FuelPerceivedCost	HOU	HOU_WAP	ELC	0%	0%	0%	0%	0%	0%	0%	0%
FuelPerceivedCost	HOU	HOU_SHCB	GDO	0%	5%	10%	15%	20%	25%	30%	35%
FuelPerceivedCost	HOU	HOU_SHCS	HCL	0%	6%	11%	17%	22%	28%	33%	39%
FuelPerceivedCost	HOU	HOU_SHCR	SOL	100%	100%	100%	100%	100%	100%	100%	100%
FuelPerceivedCost	HOU	HOU_SHCE	ELC	0%	0%	0%	0%	0%	0%	0%	0%
FuelPerceivedCost	HOU	HOU_SHCH	HER	0%	0%	0%	0%	0%	0%	0%	0%
FuelPerceivedCost	HOU	HOU_AIRC	ELC	0%	0%	0%	0%	0%	0%	0%	0%
FuelPerceivedCost	HOU	HOU_COOKG	NGS	0%	0%	0%	0%	0%	0%	0%	0%
FuelPerceivedCost	HOU	HOU_WTHB	GDO	0%	5%	10%	15%	20%	25%	30%	35%
FuelPerceivedCost	HOU	HOU_WTHS	HCL	0%	6%	11%	17%	22%	28%	33%	39%
FuelPerceivedCost	HOU	HOU_WTHR	SOL	100%	90%	81%	73%	66%	59%	53%	48%
FuelPerceivedCost	HOU	HOU_WTHR	GEO	100%	100%	100%	100%	100%	100%	100%	100%
FuelPerceivedCost	HOU	HOU_WTHR	ELC	0%	0%	0%	0%	0%	0%	0%	0%
FuelPerceivedCost	HOU	HOU_WTHE	ELC	0%	0%	0%	0%	0%	0%	0%	0%
FuelPerceivedCost	HOU	HOU_WTHH	HET	0%	0%	0%	0%	0%	0%	0%	0%

Figure 42 CPS Demand input file: FuelPerceivedCost sheet

- EquipmentPerceivedCost: Perceived cost (%) of cokery equipment per technology category

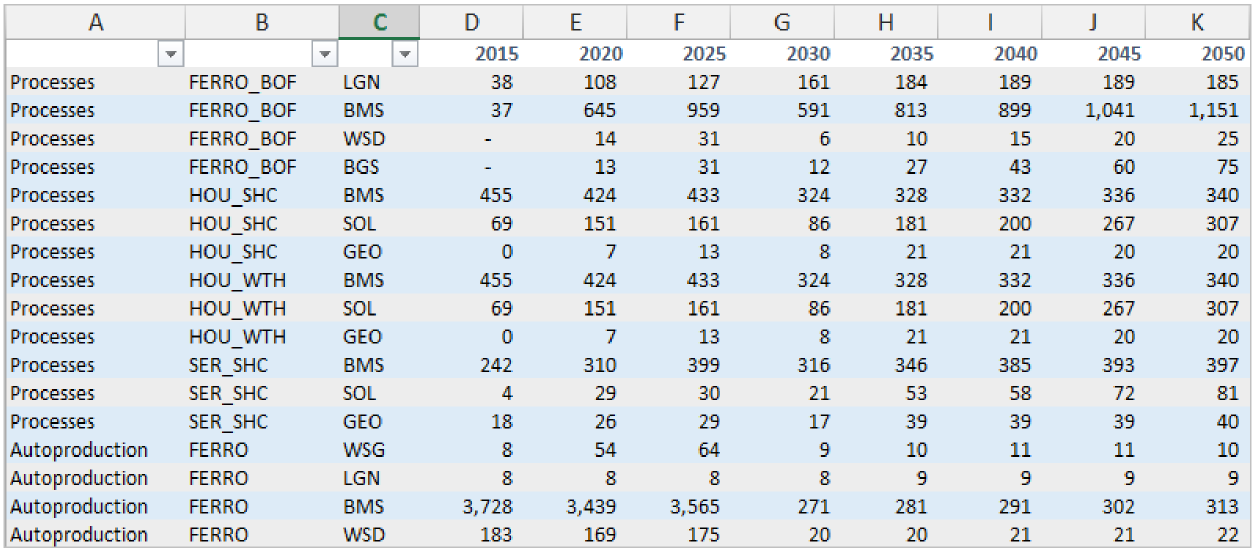


A	B	C	D	H	I	J	K	L	M	N	O
				2015	2020	2025	2030	2035	2040	2045	2050
EquipmentPerceivedCost	FERRO_COK	ORD	Dummy	0%	0%	0%	0%	0%	0%	0%	0%
EquipmentPerceivedCost	FERRO_COK	ORI	Dummy	25%	22%	8%	0%	0%	0%	0%	0%
EquipmentPerceivedCost	FERRO_COK	IMR	Dummy	49%	44%	21%	1%	0%	0%	0%	0%
EquipmentPerceivedCost	FERRO_COK	IMA	Dummy	102%	94%	55%	8%	1%	0%	0%	0%
EquipmentPerceivedCost	FERRO_COK	ADV	Dummy	200%	189%	123%	47%	14%	0%	0%	0%
EquipmentPerceivedCost	FERRO_COK	ADF	Dummy	280%	273%	218%	111%	53%	8%	1%	0%
EquipmentPerceivedCost	FERRO_COK	FUT	Dummy	300%	297%	265%	126%	53%	13%	2%	0%

Figure 43 CPS Demand input file: EquipmentPerceivedCost sheet

4.5.9. Potential

- Potential: Potential limitation of fuels per subsector SD and year in Gwh$_{\text{fuel}}$

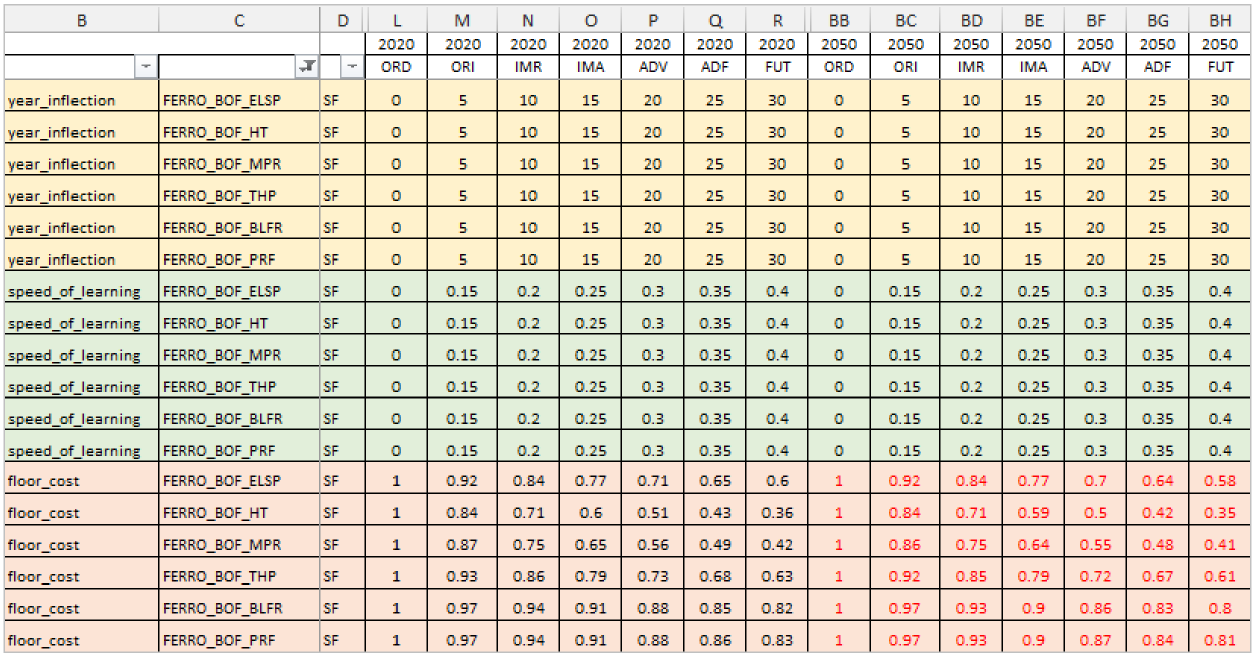


A	B	C	D	E	F	G	H	I	J	K
			2015	2020	2025	2030	2035	2040	2045	2050
Processes	FERRO_BOF	LGN	38	108	127	161	184	189	189	185
Processes	FERRO_BOF	BMS	37	645	959	591	813	899	1,041	1,151
Processes	FERRO_BOF	WSD	-	14	31	6	10	15	20	25
Processes	FERRO_BOF	BGS	-	13	31	12	27	43	60	75
Processes	HOU_SHC	BMS	455	424	433	324	328	332	336	340
Processes	HOU_SHC	SOL	69	151	161	86	181	200	267	307
Processes	HOU_SHC	GEO	0	7	13	8	21	21	20	20
Processes	HOU_WTH	BMS	455	424	433	324	328	332	336	340
Processes	HOU_WTH	SOL	69	151	161	86	181	200	267	307
Processes	HOU_WTH	GEO	0	7	13	8	21	21	20	20
Processes	SER_SHC	BMS	242	310	399	316	346	385	393	397
Processes	SER_SHC	SOL	4	29	30	21	53	58	72	81
Processes	SER_SHC	GEO	18	26	29	17	39	39	39	40
Autoproduction	FERRO	WSG	8	54	64	9	10	11	11	10
Autoproduction	FERRO	LGN	8	8	8	8	9	9	9	9
Autoproduction	FERRO	BMS	3,728	3,439	3,565	271	281	291	302	313
Autoproduction	FERRO	WSD	183	169	175	20	20	21	21	22

Figure 44 CPS Demand input file: Potential sheet

4.5.10. LBD

- year_inflection: Number of years after 2015 required to reach the inflection point of the LBD logistic curve per process, technology category and year
- floor_cost: Floor value of the LBD (lowest possible reduction of capital cost relative to the ordinary technology, considered as a technology potential) per process, technology category and year
- speed_of_learning: Parameter denoting speed of LBD towards the floor value per process, technology category and year

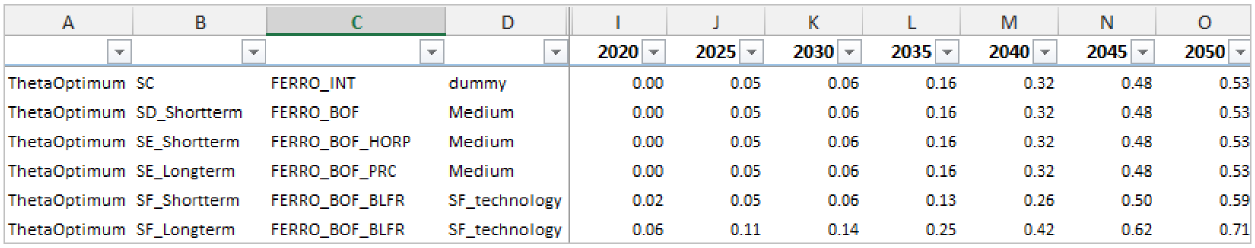


B	C	D	L	M	N	O	P	Q	R	BB	BC	BD	BE	BF	BG	BH
			2020	2020	2020	2020	2020	2020	2020	2050	2050	2050	2050	2050	2050	2050
			ORD	ORI	IMR	IMA	ADV	ADF	FUT	ORD	ORI	IMR	IMA	ADV	ADF	FUT
year_inflection	FERRO_BOF_ELSP	SF	0	5	10	15	20	25	30	0	5	10	15	20	25	30
year_inflection	FERRO_BOF_HT	SF	0	5	10	15	20	25	30	0	5	10	15	20	25	30
year_inflection	FERRO_BOF_MPR	SF	0	5	10	15	20	25	30	0	5	10	15	20	25	30
year_inflection	FERRO_BOF_THP	SF	0	5	10	15	20	25	30	0	5	10	15	20	25	30
year_inflection	FERRO_BOF_BLFR	SF	0	5	10	15	20	25	30	0	5	10	15	20	25	30
year_inflection	FERRO_BOF_PRF	SF	0	5	10	15	20	25	30	0	5	10	15	20	25	30
speed_of_learning	FERRO_BOF_ELSP	SF	0	0.15	0.2	0.25	0.3	0.35	0.4	0	0.15	0.2	0.25	0.3	0.35	0.4
speed_of_learning	FERRO_BOF_HT	SF	0	0.15	0.2	0.25	0.3	0.35	0.4	0	0.15	0.2	0.25	0.3	0.35	0.4
speed_of_learning	FERRO_BOF_MPR	SF	0	0.15	0.2	0.25	0.3	0.35	0.4	0	0.15	0.2	0.25	0.3	0.35	0.4
speed_of_learning	FERRO_BOF_THP	SF	0	0.15	0.2	0.25	0.3	0.35	0.4	0	0.15	0.2	0.25	0.3	0.35	0.4
speed_of_learning	FERRO_BOF_BLFR	SF	0	0.15	0.2	0.25	0.3	0.35	0.4	0	0.15	0.2	0.25	0.3	0.35	0.4
speed_of_learning	FERRO_BOF_PRF	SF	0	0.15	0.2	0.25	0.3	0.35	0.4	0	0.15	0.2	0.25	0.3	0.35	0.4
floor_cost	FERRO_BOF_ELSP	SF	1	0.92	0.84	0.77	0.71	0.65	0.6	1	0.92	0.84	0.77	0.7	0.64	0.58
floor_cost	FERRO_BOF_HT	SF	1	0.84	0.71	0.6	0.51	0.43	0.36	1	0.84	0.71	0.59	0.5	0.42	0.35
floor_cost	FERRO_BOF_MPR	SF	1	0.87	0.75	0.65	0.56	0.49	0.42	1	0.86	0.75	0.64	0.55	0.48	0.41
floor_cost	FERRO_BOF_THP	SF	1	0.93	0.86	0.79	0.73	0.68	0.63	1	0.92	0.85	0.79	0.72	0.67	0.61
floor_cost	FERRO_BOF_BLFR	SF	1	0.97	0.94	0.91	0.88	0.85	0.82	1	0.97	0.93	0.9	0.86	0.83	0.8
floor_cost	FERRO_BOF_PRF	SF	1	0.97	0.94	0.91	0.88	0.86	0.83	1	0.97	0.93	0.9	0.87	0.84	0.81

Figure 45 CPS Demand input file: LBD sheet

4.5.11. ThetaOptimum

- ThetaOptimum: ThetaOptimum parameter per nesting, per short term and long term operation and per agent class

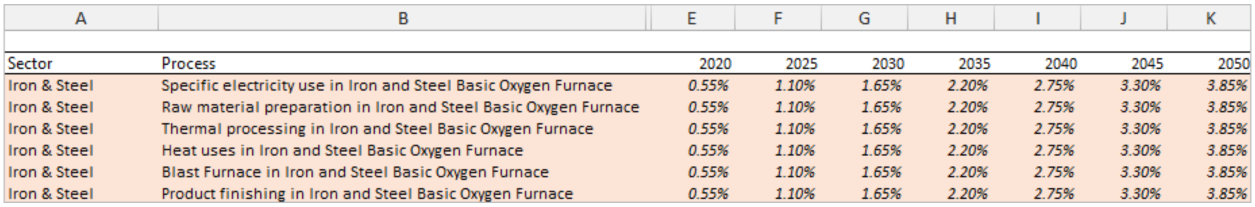


A	B	C	D	I	J	K	L	M	N	O
				2020	2025	2030	2035	2040	2045	2050
ThetaOptimum	SC	FERRO_INT	dummy	0.00	0.05	0.06	0.16	0.32	0.48	0.53
ThetaOptimum	SD_Shortterm	FERRO_BOF	Medium	0.00	0.05	0.06	0.16	0.32	0.48	0.53
ThetaOptimum	SE_Shortterm	FERRO_BOF_HORP	Medium	0.00	0.05	0.06	0.16	0.32	0.48	0.53
ThetaOptimum	SE_Longterm	FERRO_BOF_PRC	Medium	0.00	0.05	0.06	0.16	0.32	0.48	0.53
ThetaOptimum	SF_Shortterm	FERRO_BOF_BLFR	SF_technology	0.02	0.05	0.06	0.13	0.26	0.50	0.59
ThetaOptimum	SF_Longterm	FERRO_BOF_BLFR	SF_technology	0.06	0.11	0.14	0.25	0.42	0.62	0.71

Figure 46 CPS Demand input file: ThetaOptimum sheet

4.5.12. Exo_effi_ORD

- Exo_effi_ORD: Exogenous improvement of efficiency (%) for ordinary technology per process and year. The percentage of efficiency improvement is applied in the Demand Module during runtime in all technology categories

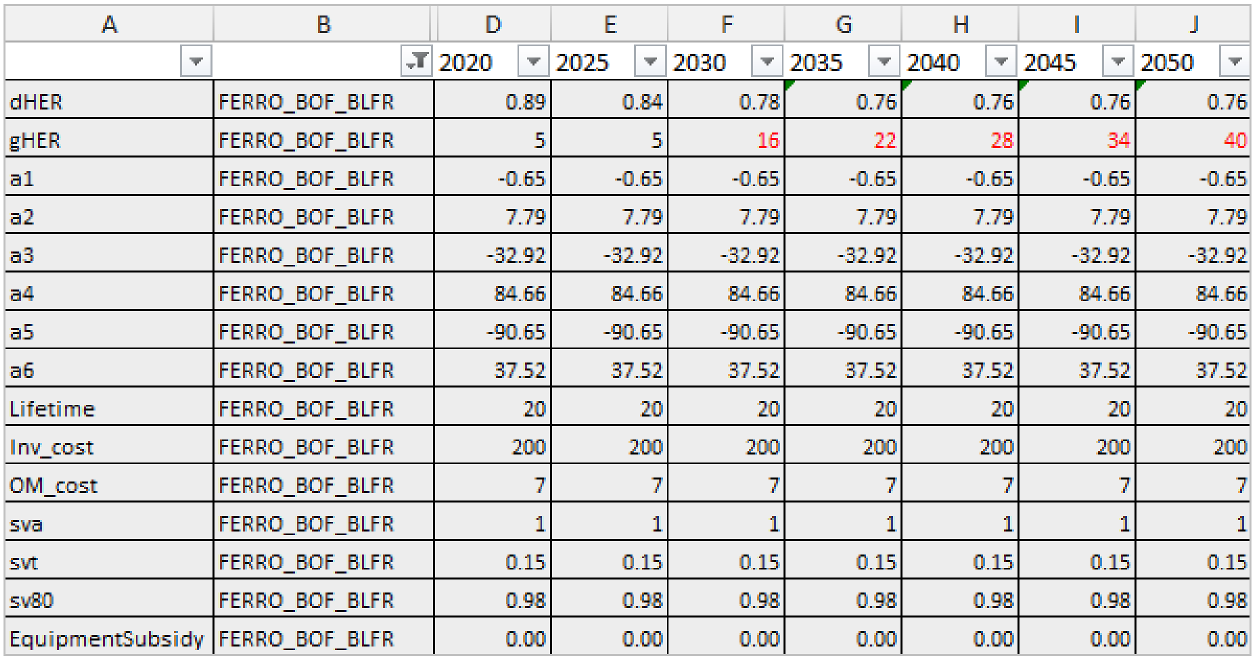


A	B	E	F	G	H	I	J	K
Sector	Process	2020	2025	2030	2035	2040	2045	2050
Iron & Steel	Specific electricity use in Iron and Steel Basic Oxygen Furnace	0.55%	1.10%	1.65%	2.20%	2.75%	3.30%	3.85%
Iron & Steel	Raw material preparation in Iron and Steel Basic Oxygen Furnace	0.55%	1.10%	1.65%	2.20%	2.75%	3.30%	3.85%
Iron & Steel	Thermal processing in Iron and Steel Basic Oxygen Furnace	0.55%	1.10%	1.65%	2.20%	2.75%	3.30%	3.85%
Iron & Steel	Heat uses in Iron and Steel Basic Oxygen Furnace	0.55%	1.10%	1.65%	2.20%	2.75%	3.30%	3.85%
Iron & Steel	Blast Furnace in Iron and Steel Basic Oxygen Furnace	0.55%	1.10%	1.65%	2.20%	2.75%	3.30%	3.85%
Iron & Steel	Product finishing in Iron and Steel Basic Oxygen Furnace	0.55%	1.10%	1.65%	2.20%	2.75%	3.30%	3.85%

Figure 47 CPS Demand input file: Exo_effi_ORD sheet

4.5.13. HER_logit

dHER:	Perceived cost of heat recovery equipment in €/kW
gHER:	Exponent of logit function for choice of heat recovery
a1:	Coefficient of first degree of the polynomial function of heat recovery potential
a2:	Coefficient of second degree of the polynomial function of heat recovery potential
a3:	Coefficient of third degree of the polynomial function of heat recovery potential
a4:	Coefficient of fourth degree of the polynomial function of heat recovery potential
a5:	Coefficient of fifth degree of the polynomial function of heat recovery potential
a6:	Coefficient of sixth degree of the polynomial function of heat recovery potential
Lifetime:	Lifetime of heat recovery equipment in years
Inv_cost:	Investment cost of heat recovery equipment in €/kW
OM_cost:	Operation & maintenance cost of heat recovery equipment in €/kW annually
Sva:	Scale parameter of survival function of heat recovery equipment
Svt:	Survival rate of heat recovery equipment at the end of lifetime
sv80:	Survival rate of heat recovery equipment at 80% of lifetime
EquipmentSubsidy:	Subsidies for equipment of heat recovery, as percentage (%) of investment cost

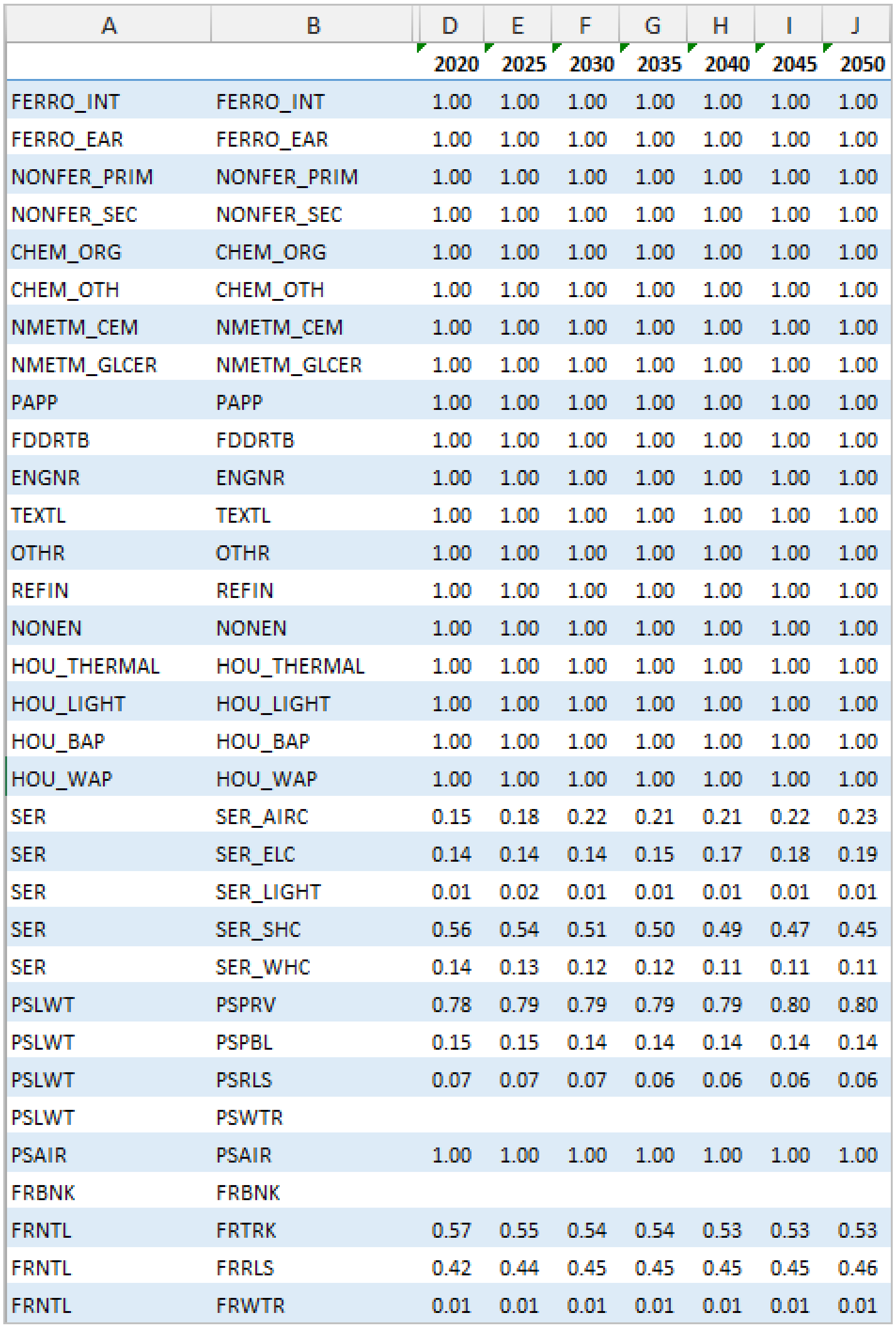


A	B	D	E	F	G	H	I	J
		2020	2025	2030	2035	2040	2045	2050
dHER	FERRO_BOF_BLFR	0.89	0.84	0.78	0.76	0.76	0.76	0.76
gHER	FERRO_BOF_BLFR	5	5	16	22	28	34	40
a1	FERRO_BOF_BLFR	-0.65	-0.65	-0.65	-0.65	-0.65	-0.65	-0.65
a2	FERRO_BOF_BLFR	7.79	7.79	7.79	7.79	7.79	7.79	7.79
a3	FERRO_BOF_BLFR	-32.92	-32.92	-32.92	-32.92	-32.92	-32.92	-32.92
a4	FERRO_BOF_BLFR	84.66	84.66	84.66	84.66	84.66	84.66	84.66
a5	FERRO_BOF_BLFR	-90.65	-90.65	-90.65	-90.65	-90.65	-90.65	-90.65
a6	FERRO_BOF_BLFR	37.52	37.52	37.52	37.52	37.52	37.52	37.52
Lifetime	FERRO_BOF_BLFR	20	20	20	20	20	20	20
Inv_cost	FERRO_BOF_BLFR	200	200	200	200	200	200	200
OM_cost	FERRO_BOF_BLFR	7	7	7	7	7	7	7
sva	FERRO_BOF_BLFR	1	1	1	1	1	1	1
svt	FERRO_BOF_BLFR	0.15	0.15	0.15	0.15	0.15	0.15	0.15
sv80	FERRO_BOF_BLFR	0.98	0.98	0.98	0.98	0.98	0.98	0.98
EquipmentSubsidy	FERRO_BOF_BLFR	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 48 CPS Demand input file: HER_logit sheet

4.5.14. Sheets dACTSBC_inert to dACTSEF_AG_ST_inert

- dACTSBC_inert: Scale parameter of the inertia logit function for the calculation of the inertia share of lower nesting level (set SC) in the activity of the upper nesting level (set SB). This parameter is defined upon the sets (SB,SC,$year\_all$)
- dACTSCD_inert: Scale parameter of the inertia logit function for the calculation of the inertia share of lower nesting level (set SD) in the activity of the upper nesting level (set SC). This parameter is defined upon the sets (SC,SD,$year\_all$)
- dACTSEF_AG_LT_inert: Scale parameter of the inertia logit function for the calculation of the choice of equipment type mix of level SF in the aggregate supply processes of level SE, used for decision making of investments. The latter meaning that this parameter is used in the logit function of unit levelized total costs (long term costs). This parameter is agent-specific, and thus defined upon the sets (AG, SE,SF,$year\_all$)
- dACTSEF_AG_ST_inert: Scale parameter of the inertia logit function for the calculation of the choice of equipment type mix in operation of level SF in the aggregate supply processes of level SE. The latter meaning that this parameter is used in the logit function of short-term marginal operation costs. This parameter is also agent-specific, and thus defined upon the sets (AG, SE,SF,$year\_all$)

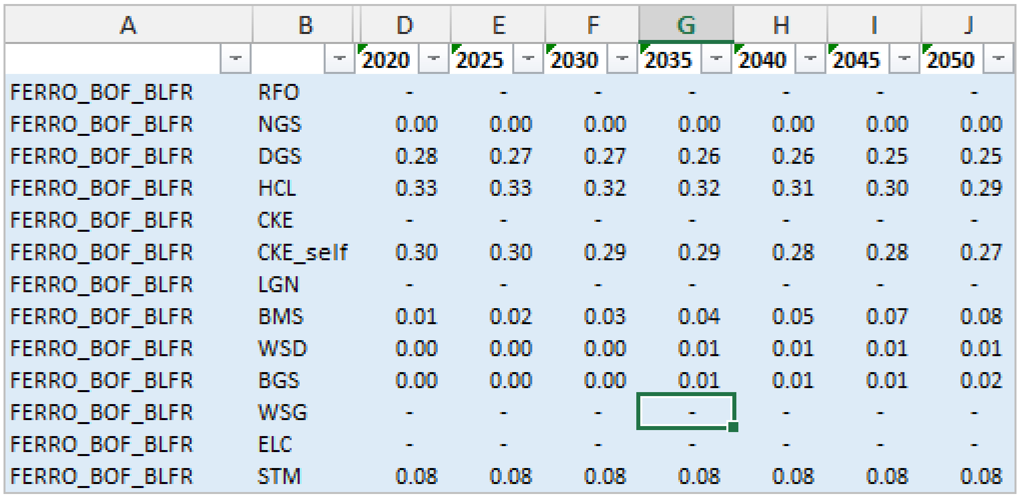


A	B	D	E	F	G	H	I	J
		2020	2025	2030	2035	2040	2045	2050
FERRO_INT	FERRO_INT	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FERRO_EAR	FERRO_EAR	1.00	1.00	1.00	1.00	1.00	1.00	1.00
NONFER_PRIM	NONFER_PRIM	1.00	1.00	1.00	1.00	1.00	1.00	1.00
NONFER_SEC	NONFER_SEC	1.00	1.00	1.00	1.00	1.00	1.00	1.00
CHEM_ORG	CHEM_ORG	1.00	1.00	1.00	1.00	1.00	1.00	1.00
CHEM_OTH	CHEM_OTH	1.00	1.00	1.00	1.00	1.00	1.00	1.00
NMETM_CEM	NMETM_CEM	1.00	1.00	1.00	1.00	1.00	1.00	1.00
NMETM_GLCER	NMETM_GLCER	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PAPP	PAPP	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FDDRTB	FDDRTB	1.00	1.00	1.00	1.00	1.00	1.00	1.00
ENGNR	ENGNR	1.00	1.00	1.00	1.00	1.00	1.00	1.00
TEXTL	TEXTL	1.00	1.00	1.00	1.00	1.00	1.00	1.00
OTHR	OTHR	1.00	1.00	1.00	1.00	1.00	1.00	1.00
REFIN	REFIN	1.00	1.00	1.00	1.00	1.00	1.00	1.00
NONEN	NONEN	1.00	1.00	1.00	1.00	1.00	1.00	1.00
HOU_THERMAL	HOU_THERMAL	1.00	1.00	1.00	1.00	1.00	1.00	1.00
HOU_LIGHT	HOU_LIGHT	1.00	1.00	1.00	1.00	1.00	1.00	1.00
HOU_BAP	HOU_BAP	1.00	1.00	1.00	1.00	1.00	1.00	1.00
HOU_WAP	HOU_WAP	1.00	1.00	1.00	1.00	1.00	1.00	1.00
SER	SER_AIRC	0.15	0.18	0.22	0.21	0.21	0.22	0.23
SER	SER_ELC	0.14	0.14	0.14	0.15	0.17	0.18	0.19
SER	SER_LIGHT	0.01	0.02	0.01	0.01	0.01	0.01	0.01
SER	SER_SHC	0.56	0.54	0.51	0.50	0.49	0.47	0.45
SER	SER_WHC	0.14	0.13	0.12	0.12	0.11	0.11	0.11
PSLWT	PSPRV	0.78	0.79	0.79	0.79	0.79	0.80	0.80
PSLWT	PSPBL	0.15	0.15	0.14	0.14	0.14	0.14	0.14
PSLWT	PSRLS	0.07	0.07	0.07	0.06	0.06	0.06	0.06
PSLWT	PSWTR							
PSAIR	PSAIR	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRBNK	FRBNK							
FRNTL	FRTRK	0.57	0.55	0.54	0.54	0.53	0.53	0.53
FRNTL	FRRLS	0.42	0.44	0.45	0.45	0.45	0.45	0.46
FRNTL	FRWTR	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Figure 49 CPS Demand input file: dACTSBC_inert sheet

4.5.15. dSW_F_inert_av

- dSW_F_inert_av: Scale parameter of the inertia logit function for a fuel's share per process and year, applied to all technology categories and vintages.



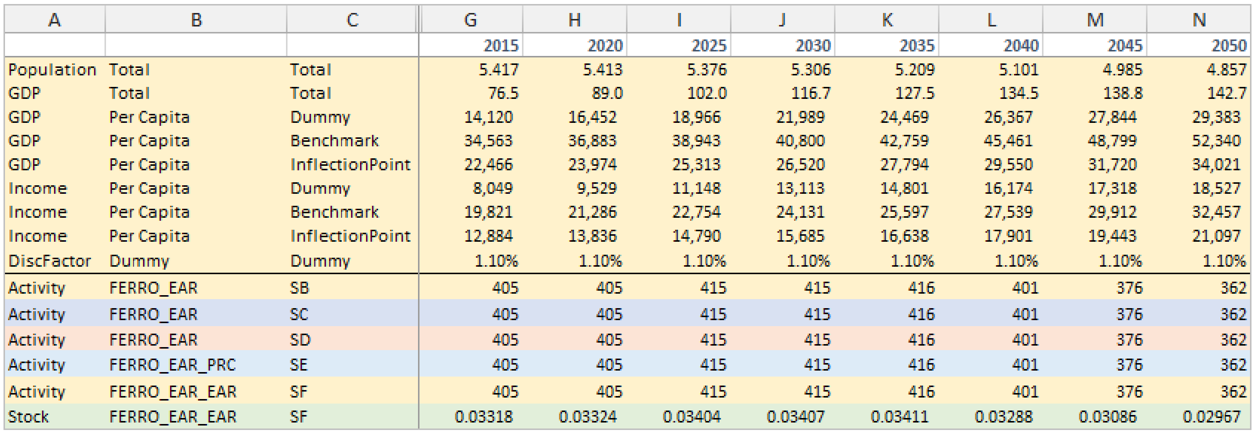
A	B	D	E	F	G	H	I	J
		2020	2025	2030	2035	2040	2045	2050
FERRO_BOF_BLFR	RFO	-	-	-	-	-	-	-
FERRO_BOF_BLFR	NGS	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FERRO_BOF_BLFR	DGS	0.28	0.27	0.27	0.26	0.26	0.25	0.25
FERRO_BOF_BLFR	HCL	0.33	0.33	0.32	0.32	0.31	0.30	0.29
FERRO_BOF_BLFR	CKE	-	-	-	-	-	-	-
FERRO_BOF_BLFR	CKE_self	0.30	0.30	0.29	0.29	0.28	0.28	0.27
FERRO_BOF_BLFR	LGN	-	-	-	-	-	-	-
FERRO_BOF_BLFR	BMS	0.01	0.02	0.03	0.04	0.05	0.07	0.08
FERRO_BOF_BLFR	WSD	0.00	0.00	0.00	0.01	0.01	0.01	0.01
FERRO_BOF_BLFR	BGS	0.00	0.00	0.00	0.01	0.01	0.01	0.02
FERRO_BOF_BLFR	WSG	-	-	-	-	-	-	-
FERRO_BOF_BLFR	ELC	-	-	-	-	-	-	-
FERRO_BOF_BLFR	STM	0.08	0.08	0.08	0.08	0.08	0.08	0.08

Figure 50 CPS Demand input file: dSW_F_inert_av sheet

4.5.16. Options for changing parameters' values exogenously

1) How to change the macroeconomic drivers – **Macro_data sheet**

The user has the ability to change the macroeconomic drivers such as GDP per capita and income per capita, by changing the content of the relevant cells in columns G to N, as shown in Figure 51.

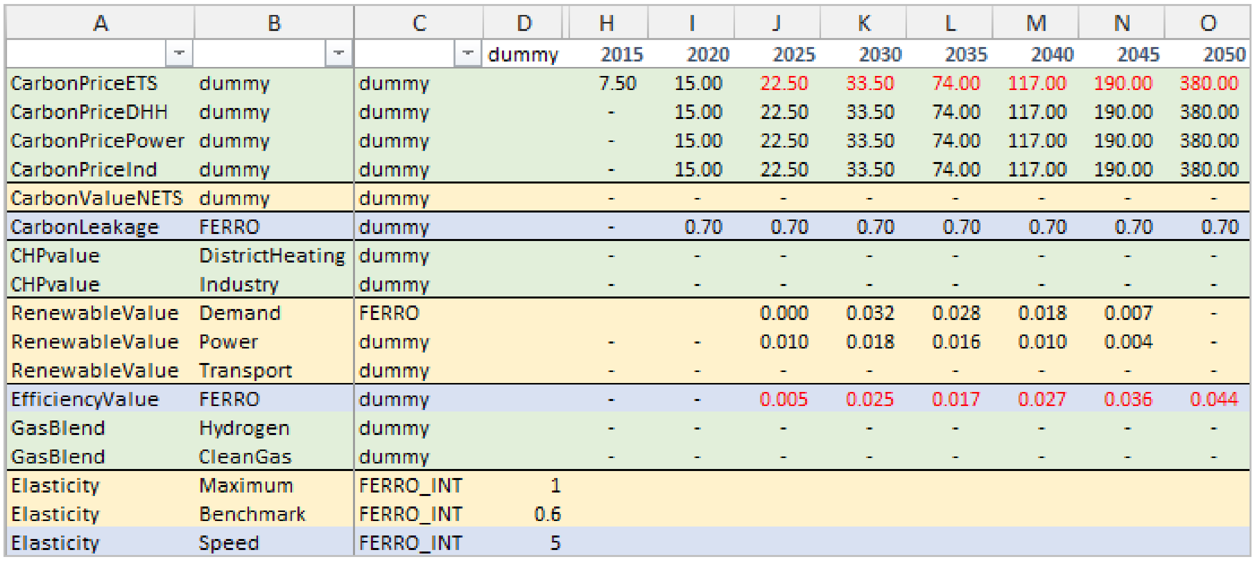


A	B	C	G	H	I	J	K	L	M	N
			2015	2020	2025	2030	2035	2040	2045	2050
Population	Total	Total	5.417	5.413	5.376	5.306	5.209	5.101	4.985	4.857
GDP	Total	Total	76.5	89.0	102.0	116.7	127.5	134.5	138.8	142.7
GDP	Per Capita	Dummy	14,120	16,452	18,966	21,989	24,469	26,367	27,844	29,383
GDP	Per Capita	Benchmark	34,563	36,883	38,943	40,800	42,759	45,461	48,799	52,340
GDP	Per Capita	InflectionPoint	22,466	23,974	25,313	26,520	27,794	29,550	31,720	34,021
Income	Per Capita	Dummy	8,049	9,529	11,148	13,113	14,801	16,174	17,318	18,527
Income	Per Capita	Benchmark	19,821	21,286	22,754	24,131	25,597	27,539	29,912	32,457
Income	Per Capita	InflectionPoint	12,884	13,836	14,790	15,685	16,638	17,901	19,443	21,097
DiscFactor	Dummy	Dummy	1.10%	1.10%	1.10%	1.10%	1.10%	1.10%	1.10%	1.10%
Activity	FERRO_EAR	SB	405	405	415	415	416	401	376	362
Activity	FERRO_EAR	SC	405	405	415	415	416	401	376	362
Activity	FERRO_EAR	SD	405	405	415	415	416	401	376	362
Activity	FERRO_EAR_PRC	SE	405	405	415	415	416	401	376	362
Activity	FERRO_EAR_EAR	SF	405	405	415	415	416	401	376	362
Stock	FERRO_EAR_EAR	SF	0.03318	0.03324	0.03404	0.03407	0.03411	0.03288	0.03086	0.02967

Figure 51 How to change the macroeconomic drivers

2) How to change the policy drivers – **Drivers_data sheet**

The user may alter the values of the policy drivers such as Carbon price, Carbon value, RES value, and EE value, by changing the content of the corresponding cells in columns H to O, as shown in Figure 52.



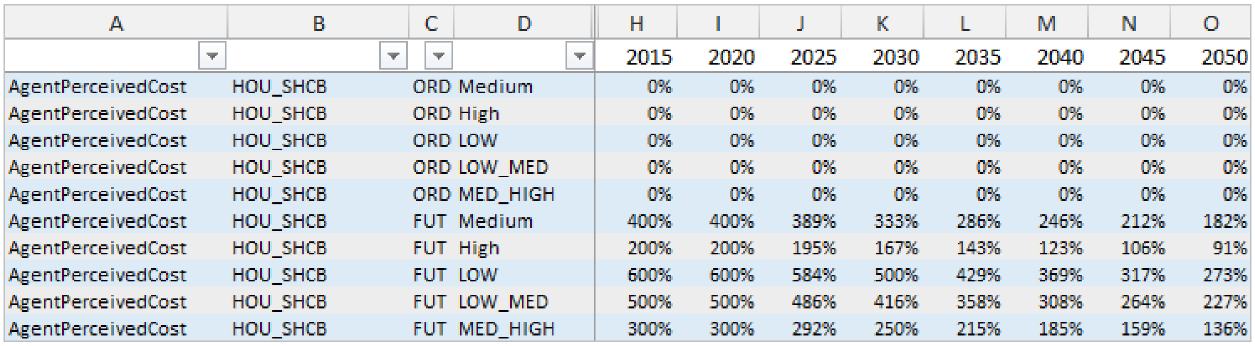
A	B	C	D	H	I	J	K	L	M	N	O
			dummy	2015	2020	2025	2030	2035	2040	2045	2050
CarbonPriceETS	dummy	dummy		7.50	15.00	22.50	33.50	74.00	117.00	190.00	380.00
CarbonPriceDHH	dummy	dummy		-	15.00	22.50	33.50	74.00	117.00	190.00	380.00
CarbonPricePower	dummy	dummy		-	15.00	22.50	33.50	74.00	117.00	190.00	380.00
CarbonPriceInd	dummy	dummy		-	15.00	22.50	33.50	74.00	117.00	190.00	380.00
CarbonValueNETS	dummy	dummy		-	-	-	-	-	-	-	-
CarbonLeakage	FERRO	dummy		-	0.70	0.70	0.70	0.70	0.70	0.70	0.70
CHPvalue	DistrictHeating	dummy		-	-	-	-	-	-	-	-
CHPvalue	Industry	dummy		-	-	-	-	-	-	-	-
RenewableValue	Demand	FERRO				0.000	0.032	0.028	0.018	0.007	-
RenewableValue	Power	dummy		-	-	0.010	0.018	0.016	0.010	0.004	-
RenewableValue	Transport	dummy		-	-	-	-	-	-	-	-
EfficiencyValue	FERRO	dummy		-	-	0.005	0.025	0.017	0.027	0.036	0.044
GasBlend	Hydrogen	dummy		-	-	-	-	-	-	-	-
GasBlend	CleanGas	dummy		-	-	-	-	-	-	-	-
Elasticity	Maximum	FERRO_INT	1								
Elasticity	Benchmark	FERRO_INT	0.6								
Elasticity	Speed	FERRO_INT	5								

Figure 52 How to change the policy drivers

3) How to change perceived costs – **Sheets AgentPerceivedCost, FuelPerceivedCost & EquipmentPerceivedCost**

The user has the ability to control the level of perceived costs:

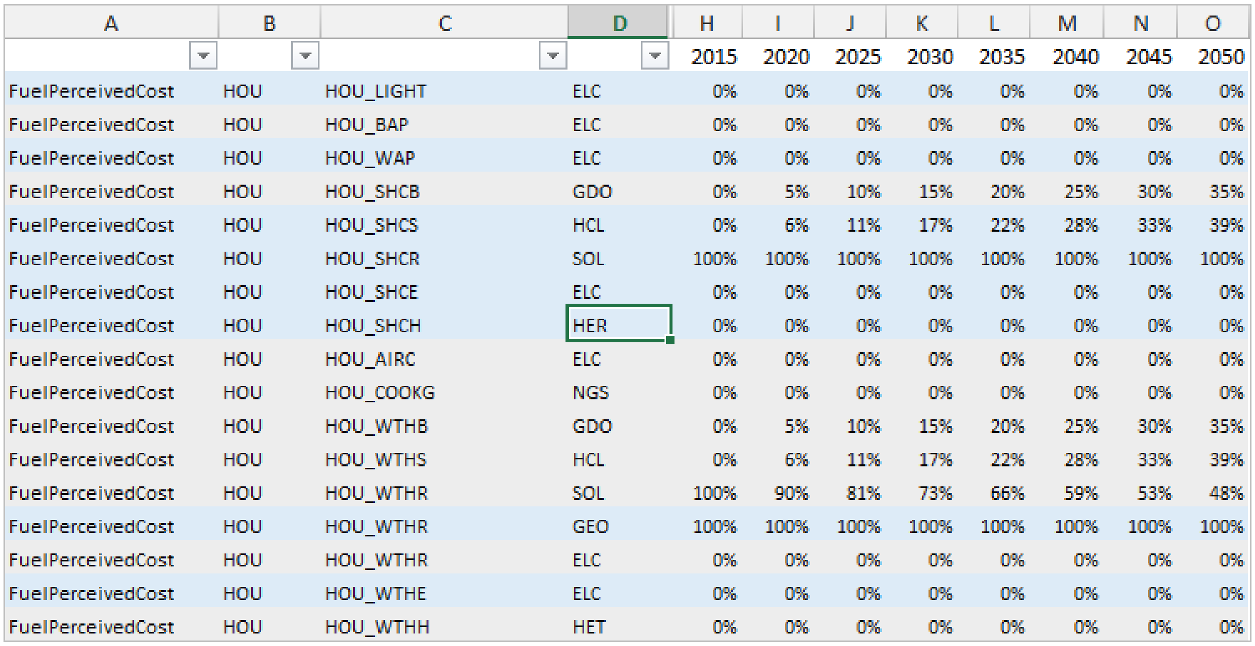
- AgentPerceivedCost: In order to change the perceived cost of a process per technology category (column C) and agent class (column D), the user needs to access the corresponding cells in columns H to O, as shown in Figure 53.



A	B	C	D	H	I	J	K	L	M	N	O
				2015	2020	2025	2030	2035	2040	2045	2050
AgentPerceivedCost	HOU_SHCB	ORD	Medium	0%	0%	0%	0%	0%	0%	0%	0%
AgentPerceivedCost	HOU_SHCB	ORD	High	0%	0%	0%	0%	0%	0%	0%	0%
AgentPerceivedCost	HOU_SHCB	ORD	LOW	0%	0%	0%	0%	0%	0%	0%	0%
AgentPerceivedCost	HOU_SHCB	ORD	LOW_MED	0%	0%	0%	0%	0%	0%	0%	0%
AgentPerceivedCost	HOU_SHCB	ORD	MED_HIGH	0%	0%	0%	0%	0%	0%	0%	0%
AgentPerceivedCost	HOU_SHCB	FUT	Medium	400%	400%	389%	333%	286%	246%	212%	182%
AgentPerceivedCost	HOU_SHCB	FUT	High	200%	200%	195%	167%	143%	123%	106%	91%
AgentPerceivedCost	HOU_SHCB	FUT	LOW	600%	600%	584%	500%	429%	369%	317%	273%
AgentPerceivedCost	HOU_SHCB	FUT	LOW_MED	500%	500%	486%	416%	358%	308%	264%	227%
AgentPerceivedCost	HOU_SHCB	FUT	MED_HIGH	300%	300%	292%	250%	215%	185%	159%	136%

Figure 53 How to change the agent specific perceived cost

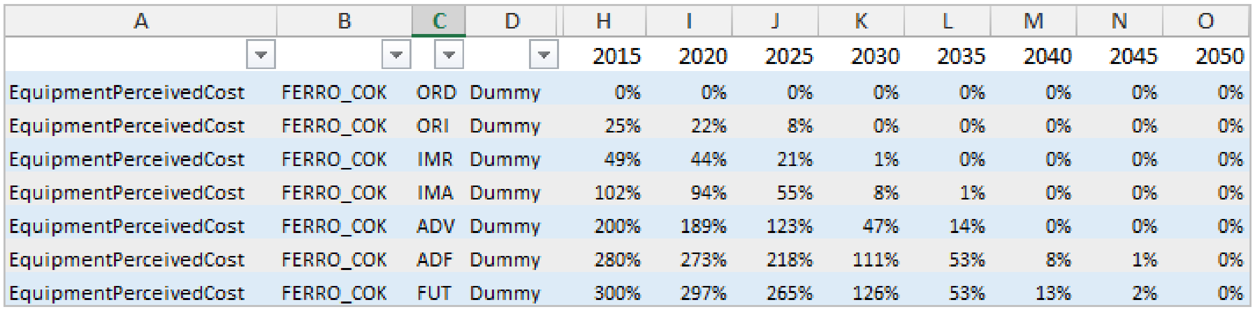
- FuelPerceivedCost: In order to change the perceived cost of a fuel (column D) per process (column C), the user needs to access the corresponding cells in columns H to O, as shown in Figure 54.



A	B	C	D	H	I	J	K	L	M	N	O
				2015	2020	2025	2030	2035	2040	2045	2050
FuelPerceivedCost	HOU	HOU_LIGHT	ELC	0%	0%	0%	0%	0%	0%	0%	0%
FuelPerceivedCost	HOU	HOU_BAP	ELC	0%	0%	0%	0%	0%	0%	0%	0%
FuelPerceivedCost	HOU	HOU_WAP	ELC	0%	0%	0%	0%	0%	0%	0%	0%
FuelPerceivedCost	HOU	HOU_SHCB	GDO	0%	5%	10%	15%	20%	25%	30%	35%
FuelPerceivedCost	HOU	HOU_SHCS	HCL	0%	6%	11%	17%	22%	28%	33%	39%
FuelPerceivedCost	HOU	HOU_SHCR	SOL	100%	100%	100%	100%	100%	100%	100%	100%
FuelPerceivedCost	HOU	HOU_SHCE	ELC	0%	0%	0%	0%	0%	0%	0%	0%
FuelPerceivedCost	HOU	HOU_SHCH	HER	0%	0%	0%	0%	0%	0%	0%	0%
FuelPerceivedCost	HOU	HOU_AIRC	ELC	0%	0%	0%	0%	0%	0%	0%	0%
FuelPerceivedCost	HOU	HOU_COOKG	NGS	0%	0%	0%	0%	0%	0%	0%	0%
FuelPerceivedCost	HOU	HOU_WTHB	GDO	0%	5%	10%	15%	20%	25%	30%	35%
FuelPerceivedCost	HOU	HOU_WTHS	HCL	0%	6%	11%	17%	22%	28%	33%	39%
FuelPerceivedCost	HOU	HOU_WTHR	SOL	100%	90%	81%	73%	66%	59%	53%	48%
FuelPerceivedCost	HOU	HOU_WTHR	GEO	100%	100%	100%	100%	100%	100%	100%	100%
FuelPerceivedCost	HOU	HOU_WTHR	ELC	0%	0%	0%	0%	0%	0%	0%	0%
FuelPerceivedCost	HOU	HOU_WTHE	ELC	0%	0%	0%	0%	0%	0%	0%	0%
FuelPerceivedCost	HOU	HOU_WTHH	HET	0%	0%	0%	0%	0%	0%	0%	0%

Figure 54 How to change the fuel specific perceived cost

- EquipmentPerceivedCost: In order to change the perceived cost of cokery equipment per technology category (column C), the user needs to access the corresponding cells in columns H to O, as shown in Figure 55.

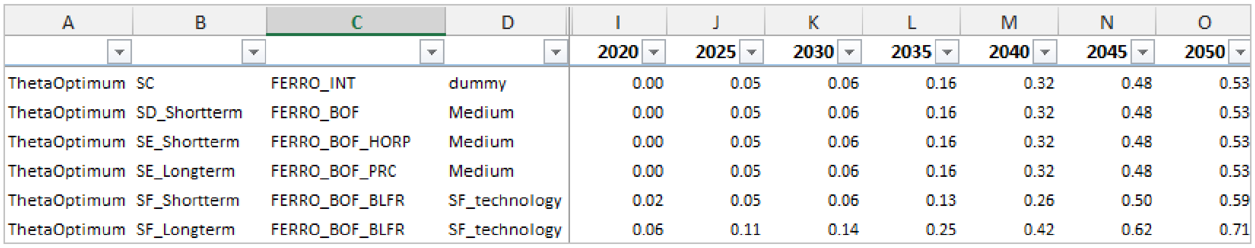


A	B	C	D	H	I	J	K	L	M	N	O
				2015	2020	2025	2030	2035	2040	2045	2050
EquipmentPerceivedCost	FERRO_COK	ORD	Dummy	0%	0%	0%	0%	0%	0%	0%	0%
EquipmentPerceivedCost	FERRO_COK	ORI	Dummy	25%	22%	8%	0%	0%	0%	0%	0%
EquipmentPerceivedCost	FERRO_COK	IMR	Dummy	49%	44%	21%	1%	0%	0%	0%	0%
EquipmentPerceivedCost	FERRO_COK	IMA	Dummy	102%	94%	55%	8%	1%	0%	0%	0%
EquipmentPerceivedCost	FERRO_COK	ADV	Dummy	200%	189%	123%	47%	14%	0%	0%	0%
EquipmentPerceivedCost	FERRO_COK	ADF	Dummy	280%	273%	218%	111%	53%	8%	1%	0%
EquipmentPerceivedCost	FERRO_COK	FUT	Dummy	300%	297%	265%	126%	53%	13%	2%	0%

Figure 55 How to change the cokery equipment perceived cost

4) How to change the theta parameter – **ThetaOptimum sheet**

The user has the ability to change the theta parameter per nesting level (column B), per short term and long term operation (column B) and per agent class (column D), by changing the content of the relevant cells in columns I to O, as shown in Figure 56.

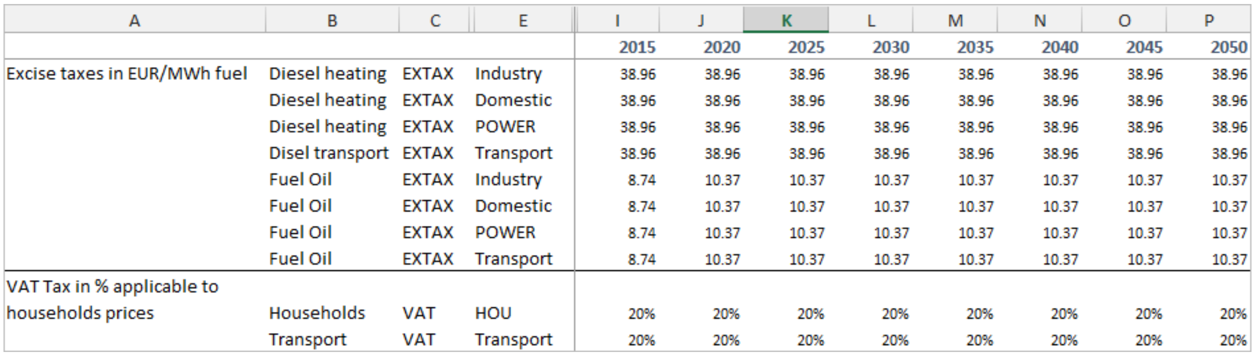


A	B	C	D	I	J	K	L	M	N	O
				2020	2025	2030	2035	2040	2045	2050
ThetaOptimum	SC	FERRO_INT	dummy	0.00	0.05	0.06	0.16	0.32	0.48	0.53
ThetaOptimum	SD_Shortterm	FERRO_BOF	Medium	0.00	0.05	0.06	0.16	0.32	0.48	0.53
ThetaOptimum	SE_Shortterm	FERRO_BOF_HORP	Medium	0.00	0.05	0.06	0.16	0.32	0.48	0.53
ThetaOptimum	SE_Longterm	FERRO_BOF_PRC	Medium	0.00	0.05	0.06	0.16	0.32	0.48	0.53
ThetaOptimum	SF_Shortterm	FERRO_BOF_BLFR	SF_technology	0.02	0.05	0.06	0.13	0.26	0.50	0.59
ThetaOptimum	SF_Longterm	FERRO_BOF_BLFR	SF_technology	0.06	0.11	0.14	0.25	0.42	0.62	0.71

Figure 56 How to change the theta parameter

5) How to change taxes' values – **Prices_data sheet**

The user has the ability to change the excise tax per fuel (column B) and sector (column E), as well as the VAT value for households and transport (column B & E), by changing the content of the relevant cells in columns I to P, as shown in Figure 57.

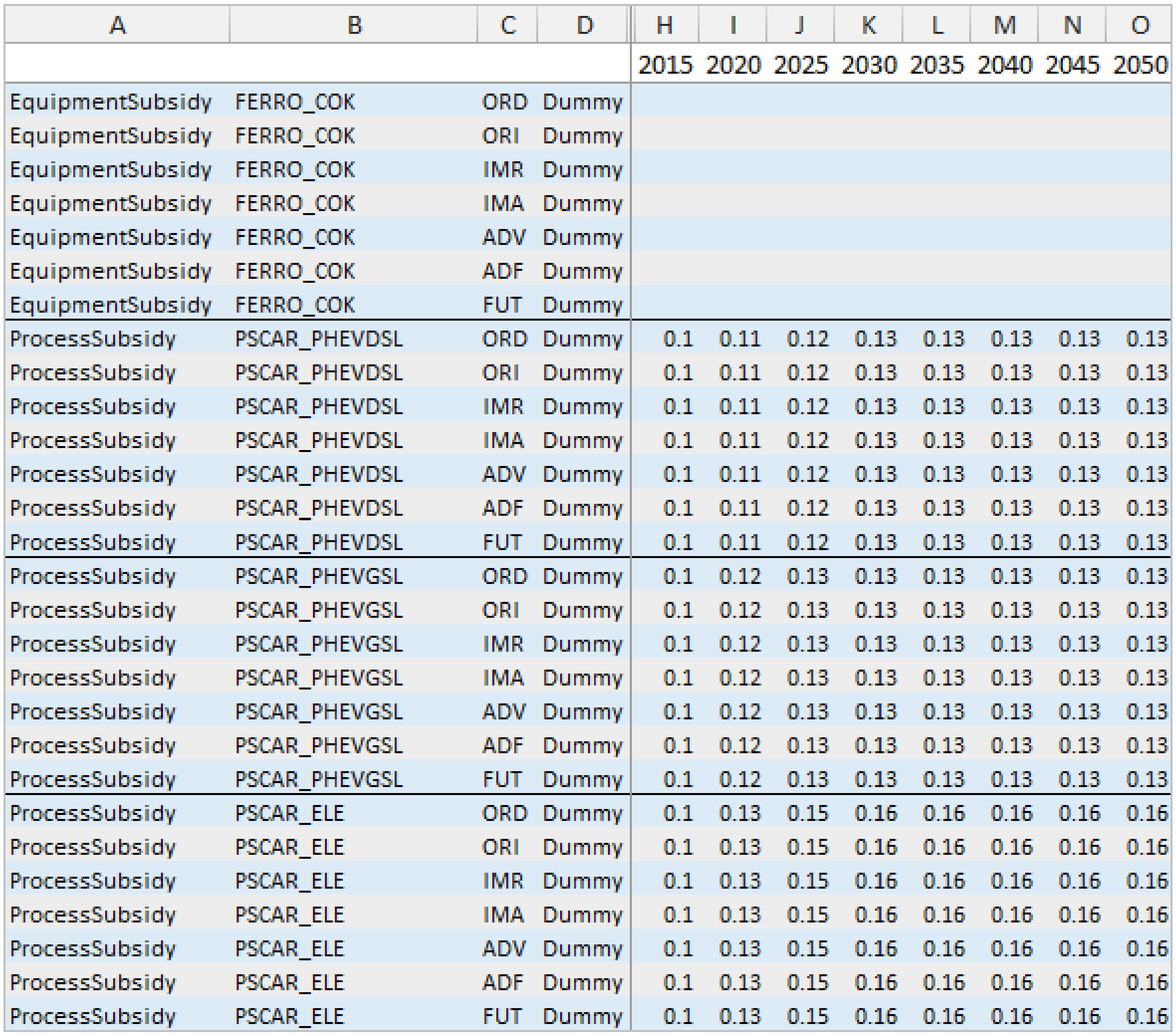


A	B	C	E	I	J	K	L	M	N	O	P
				2015	2020	2025	2030	2035	2040	2045	2050
Excise taxes in EUR/MWh fuel	Diesel heating	EXTAX	Industry	38.96	38.96	38.96	38.96	38.96	38.96	38.96	38.96
	Diesel heating	EXTAX	Domestic	38.96	38.96	38.96	38.96	38.96	38.96	38.96	38.96
	Diesel heating	EXTAX	POWER	38.96	38.96	38.96	38.96	38.96	38.96	38.96	38.96
	Disel transport	EXTAX	Transport	38.96	38.96	38.96	38.96	38.96	38.96	38.96	38.96
	Fuel Oil	EXTAX	Industry	8.74	10.37	10.37	10.37	10.37	10.37	10.37	10.37
	Fuel Oil	EXTAX	Domestic	8.74	10.37	10.37	10.37	10.37	10.37	10.37	10.37
	Fuel Oil	EXTAX	POWER	8.74	10.37	10.37	10.37	10.37	10.37	10.37	10.37
	Fuel Oil	EXTAX	Transport	8.74	10.37	10.37	10.37	10.37	10.37	10.37	10.37
VAT Tax in % applicable to households prices	Households	VAT	HOU	20%	20%	20%	20%	20%	20%	20%	20%
	Transport	VAT	Transport	20%	20%	20%	20%	20%	20%	20%	20%

Figure 57 How to change the excise and VAT taxes

6) How to change subsidies' values – **EquipmentSubsidy sheet**

The user has the ability to change the subsidy for the purchase of cokery equipment (FERRO_COK) per technology category (column C), as well as subsidies for the purchase of equipment per supply process (column B) and technology category (column C), by changing the content of the relevant cells in columns H to O, as shown in Figure 58.

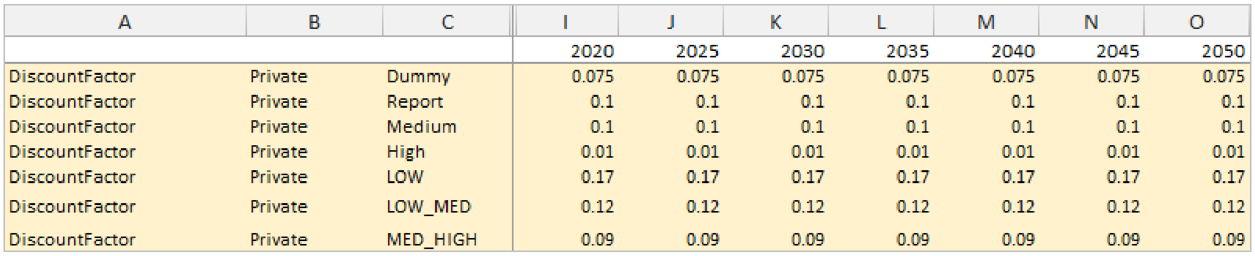


A	B	C	D	H	I	J	K	L	M	N	O
				2015	2020	2025	2030	2035	2040	2045	2050
EquipmentSubsidy	FERRO_COK	ORD	Dummy								
EquipmentSubsidy	FERRO_COK	ORI	Dummy								
EquipmentSubsidy	FERRO_COK	IMR	Dummy								
EquipmentSubsidy	FERRO_COK	IMA	Dummy								
EquipmentSubsidy	FERRO_COK	ADV	Dummy								
EquipmentSubsidy	FERRO_COK	ADF	Dummy								
EquipmentSubsidy	FERRO_COK	FUT	Dummy								
ProcessSubsidy	PSCAR_PHEVDSL	ORD	Dummy	0.1	0.11	0.12	0.13	0.13	0.13	0.13	0.13
ProcessSubsidy	PSCAR_PHEVDSL	ORI	Dummy	0.1	0.11	0.12	0.13	0.13	0.13	0.13	0.13
ProcessSubsidy	PSCAR_PHEVDSL	IMR	Dummy	0.1	0.11	0.12	0.13	0.13	0.13	0.13	0.13
ProcessSubsidy	PSCAR_PHEVDSL	IMA	Dummy	0.1	0.11	0.12	0.13	0.13	0.13	0.13	0.13
ProcessSubsidy	PSCAR_PHEVDSL	ADV	Dummy	0.1	0.11	0.12	0.13	0.13	0.13	0.13	0.13
ProcessSubsidy	PSCAR_PHEVDSL	ADF	Dummy	0.1	0.11	0.12	0.13	0.13	0.13	0.13	0.13
ProcessSubsidy	PSCAR_PHEVDSL	FUT	Dummy	0.1	0.11	0.12	0.13	0.13	0.13	0.13	0.13
ProcessSubsidy	PSCAR_PHEVGSL	ORD	Dummy	0.1	0.12	0.13	0.13	0.13	0.13	0.13	0.13
ProcessSubsidy	PSCAR_PHEVGSL	ORI	Dummy	0.1	0.12	0.13	0.13	0.13	0.13	0.13	0.13
ProcessSubsidy	PSCAR_PHEVGSL	IMR	Dummy	0.1	0.12	0.13	0.13	0.13	0.13	0.13	0.13
ProcessSubsidy	PSCAR_PHEVGSL	IMA	Dummy	0.1	0.12	0.13	0.13	0.13	0.13	0.13	0.13
ProcessSubsidy	PSCAR_PHEVGSL	ADV	Dummy	0.1	0.12	0.13	0.13	0.13	0.13	0.13	0.13
ProcessSubsidy	PSCAR_PHEVGSL	ADF	Dummy	0.1	0.12	0.13	0.13	0.13	0.13	0.13	0.13
ProcessSubsidy	PSCAR_PHEVGSL	FUT	Dummy	0.1	0.12	0.13	0.13	0.13	0.13	0.13	0.13
ProcessSubsidy	PSCAR_ELE	ORD	Dummy	0.1	0.13	0.15	0.16	0.16	0.16	0.16	0.16
ProcessSubsidy	PSCAR_ELE	ORI	Dummy	0.1	0.13	0.15	0.16	0.16	0.16	0.16	0.16
ProcessSubsidy	PSCAR_ELE	IMR	Dummy	0.1	0.13	0.15	0.16	0.16	0.16	0.16	0.16
ProcessSubsidy	PSCAR_ELE	IMA	Dummy	0.1	0.13	0.15	0.16	0.16	0.16	0.16	0.16
ProcessSubsidy	PSCAR_ELE	ADV	Dummy	0.1	0.13	0.15	0.16	0.16	0.16	0.16	0.16
ProcessSubsidy	PSCAR_ELE	ADF	Dummy	0.1	0.13	0.15	0.16	0.16	0.16	0.16	0.16
ProcessSubsidy	PSCAR_ELE	FUT	Dummy	0.1	0.13	0.15	0.16	0.16	0.16	0.16	0.16

Figure 58 How to change the cokery and process equipment subsidies

7) How to change the discount rates – **Policy_dem_data sheet**

The user has the ability to change the discount rate per agent class (column C), by changing the content of the relevant cells in columns I to O, as shown in Figure 59.

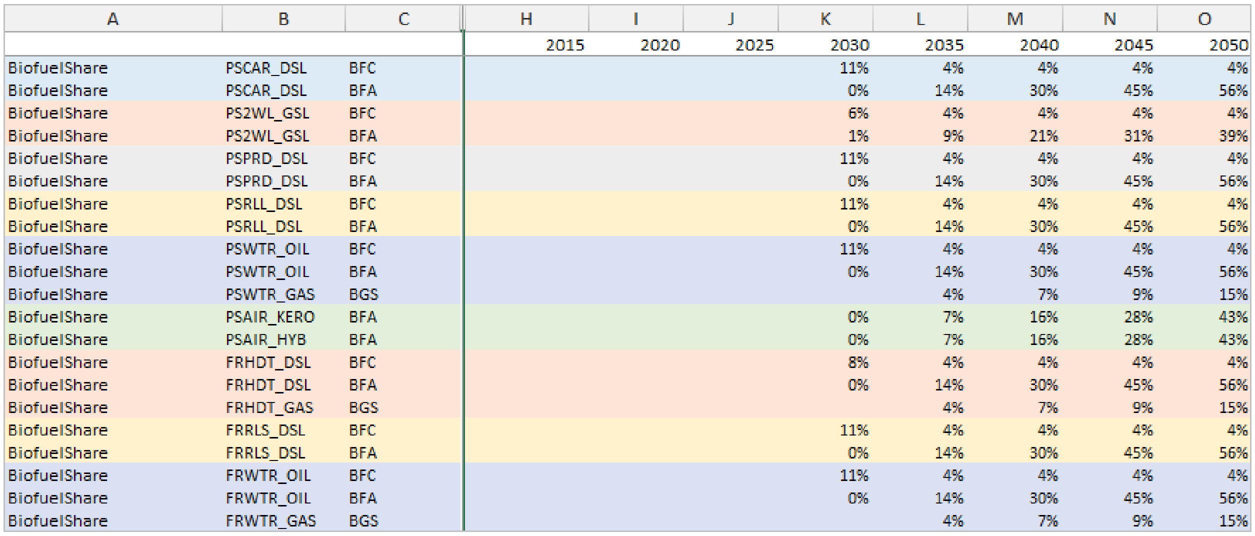


A	B	C	I	J	K	L	M	N	O
			2020	2025	2030	2035	2040	2045	2050
DiscountFactor	Private	Dummy	0.075	0.075	0.075	0.075	0.075	0.075	0.075
DiscountFactor	Private	Report	0.1	0.1	0.1	0.1	0.1	0.1	0.1
DiscountFactor	Private	Medium	0.1	0.1	0.1	0.1	0.1	0.1	0.1
DiscountFactor	Private	High	0.01	0.01	0.01	0.01	0.01	0.01	0.01
DiscountFactor	Private	LOW	0.17	0.17	0.17	0.17	0.17	0.17	0.17
DiscountFactor	Private	LOW_MED	0.12	0.12	0.12	0.12	0.12	0.12	0.12
DiscountFactor	Private	MED_HIGH	0.09	0.09	0.09	0.09	0.09	0.09	0.09

Figure 59 How to change the discount rate

8) How to change biofuel shares – **Policy_dem_data sheet**

The user has the ability to change the share of conventional and advanced biofuels (column C) in transport processes/vehicles (column B), by changing the content of the relevant cells in columns H to O, as shown Figure 60.

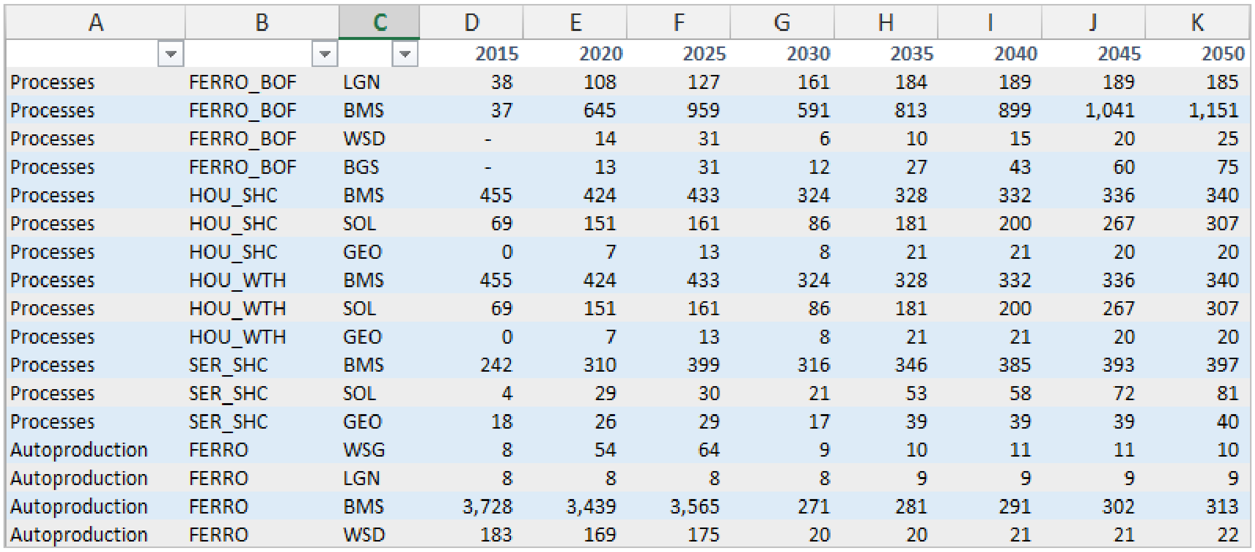


A	B	C	H	I	J	K	L	M	N	O
			2015	2020	2025	2030	2035	2040	2045	2050
BiofuelShare	PSCAR_DSL	BFC				11%	4%	4%	4%	4%
BiofuelShare	PSCAR_DSL	BFA				0%	14%	30%	45%	56%
BiofuelShare	PS2WL_GSL	BFC				6%	4%	4%	4%	4%
BiofuelShare	PS2WL_GSL	BFA				1%	9%	21%	31%	39%
BiofuelShare	PSPRD_DSL	BFC				11%	4%	4%	4%	4%
BiofuelShare	PSPRD_DSL	BFA				0%	14%	30%	45%	56%
BiofuelShare	PSRLL_DSL	BFC				11%	4%	4%	4%	4%
BiofuelShare	PSRLL_DSL	BFA				0%	14%	30%	45%	56%
BiofuelShare	PSWTR_OIL	BFC				11%	4%	4%	4%	4%
BiofuelShare	PSWTR_OIL	BFA				0%	14%	30%	45%	56%
BiofuelShare	PSWTR_GAS	BGS					4%	7%	9%	15%
BiofuelShare	PSAIR_KERO	BFA				0%	7%	16%	28%	43%
BiofuelShare	PSAIR_HYB	BFA				0%	7%	16%	28%	43%
BiofuelShare	FRHDT_DSL	BFC				8%	4%	4%	4%	4%
BiofuelShare	FRHDT_DSL	BFA				0%	14%	30%	45%	56%
BiofuelShare	FRHDT_GAS	BGS					4%	7%	9%	15%
BiofuelShare	FRRLS_DSL	BFC				11%	4%	4%	4%	4%
BiofuelShare	FRRLS_DSL	BFA				0%	14%	30%	45%	56%
BiofuelShare	FRWTR_OIL	BFC				11%	4%	4%	4%	4%
BiofuelShare	FRWTR_OIL	BFA				0%	14%	30%	45%	56%
BiofuelShare	FRWTR_GAS	BGS					4%	7%	9%	15%

Figure 60 How to change the biofuel shares

9) How to change the availability potential – **Potential sheet**

The user has the ability to change the potential limitation per fuel (column C) and subsector SD (column B), by changing the content of the relevant cells in columns D to K, as shown in Figure 61.



A	B	C	D	E	F	G	H	I	J	K
			2015	2020	2025	2030	2035	2040	2045	2050
Processes	FERRO_BOF	LGN	38	108	127	161	184	189	189	185
Processes	FERRO_BOF	BMS	37	645	959	591	813	899	1,041	1,151
Processes	FERRO_BOF	WSD	-	14	31	6	10	15	20	25
Processes	FERRO_BOF	BGS	-	13	31	12	27	43	60	75
Processes	HOU_SHC	BMS	455	424	433	324	328	332	336	340
Processes	HOU_SHC	SOL	69	151	161	86	181	200	267	307
Processes	HOU_SHC	GEO	0	7	13	8	21	21	20	20
Processes	HOU_WTH	BMS	455	424	433	324	328	332	336	340
Processes	HOU_WTH	SOL	69	151	161	86	181	200	267	307
Processes	HOU_WTH	GEO	0	7	13	8	21	21	20	20
Processes	SER_SHC	BMS	242	310	399	316	346	385	393	397
Processes	SER_SHC	SOL	4	29	30	21	53	58	72	81
Processes	SER_SHC	GEO	18	26	29	17	39	39	39	40
Autoproduction	FERRO	WSG	8	54	64	9	10	11	11	10
Autoproduction	FERRO	LGN	8	8	8	8	9	9	9	9
Autoproduction	FERRO	BMS	3,728	3,439	3,565	271	281	291	302	313
Autoproduction	FERRO	WSD	183	169	175	20	20	21	21	22

Figure 61 How to change the availability potential

5. Overview of the CPS Power Module

This chapter provides an overview of the main principles of the CPS Power Module.

- Section 5.1: Basic concepts in the CPS Power Module
- Section 5.2: Mathematical Structure, unknown variables and exogenous parameters
- Section 5.3: Model features, considerations and assumptions
- Section 5.4: Principles of the pricing model
- Section 5.5: Policy Focus - Power
- Section 5.6: Explaining the supply-related scenario input file

5.1 Basic concepts in the CPS Power Module

The CPS Power Module includes all necessary mathematical formulations for projecting energy supply with distinct representations for the power system, district heating and CHP, both utilities and industrial. The reader is referred to Section 5.3.1 Representation of Plants for a detailed analysis regarding the representation of plants.

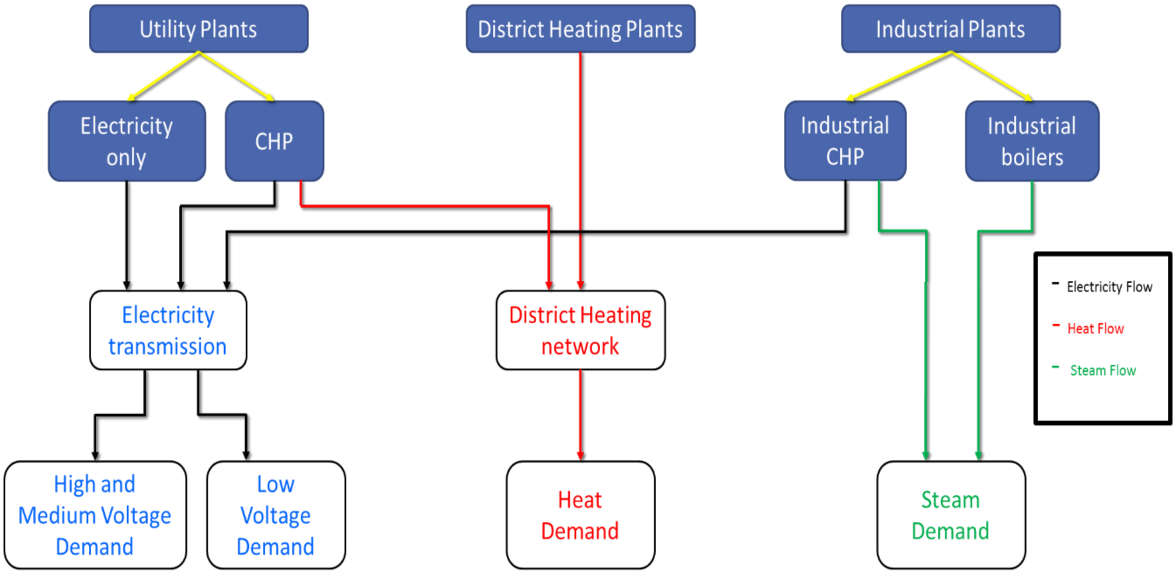


Figure 62 Overview of the CPS Power Module showing how the model accounts for electricity, steam and heat demand and serves electricity demand in High/Medium and Low Voltages

The power and heat/steam production model solves ***simultaneously*** the optimum capacity expansion of power plants, district heating units and industrial plants, as further described below, along with the dispatching of plants (Unit Commitment Dispatching Algorithm), simulating a wholesale market. The simultaneous simulation of power market along with the steam/heat simulation enables the capture of trade-offs between the choice of investing in cogeneration and boilers and between CHP and pure-electric plants. The choice of investing in new plants is endogenous in the model, while the optimisation is inter-temporal (perfect foresight). Thus, investments are driven by the long term marginal costs, subject to operational constraints, fuel limitations and demand for energy and ancillary services.

The co – optimisation of the system takes into account the hourly profiles of demand, for electricity, heat and steam decomposed by sector and energy use of origin, and similarly the hourly production possibilities of resources that are variable such as the renewables. The CPS model distinguishes between heat consumed in residential, services and agriculture sectors via the district heating network, and steam consumed in the industrial sectors and the refineries. The model also treats distinctly steam production and demand by industrial sector.

The production of heat and steam is possible from cogeneration power plants, boilers and heat pumps. The calibration data assume that the cogeneration plants operated by power utilities supply heat to the district heating sector and that industrial cogeneration plants specified by industrial sector produce the industrial steam. The latter are specific to the sectors and are not operated by utilities. Similarly, the boilers for heat are operated by the district heating and the boilers for steam distinct by sector are operated by the industries. In other words, the cogeneration plants and the industrial boilers are located on the industrial sites and can only supply steam to the industrial sector they belong. The model does not consider trading of steam among the industrial sectors. The model considers endogenously the possibility of industries to purchase electricity from the grid or to self-generate. In the former case, the industry may enjoy low supply tariffs but in the latter case the industry reduces total energy costs by cogenerating industrial steam together with the self-produced electricity. In some sectors, there is also possibility to use industrial by-products, such as gases in iron and steel, refinery gas in refineries or waste in pulp industry, which are not tradable commodities.

Also, a variety of electricity storage facilities are represented in the model, including hydroelectric pumping, batteries, and power-to-hydrogen, power-to-gas and power-to liquid technologies. The power-to-X technologies are providing the so-called chemical storage of electricity, endogenously in the model, as they can produce electricity when the resources are in excess of demand and use the outputs of power-to-X to produce electricity when demand is in excess of resources. In addition, the power-to-X facilities can produce endogenously in the model methane, hydrogen and liquid hydrocarbons from a synthesis of CO_2 and hydrogen to supply demand for such fuels, which may arise in the final demand sectors. Such a demand may emerge in the context of scenarios, which aim at replacing fossil fuels with synthetic fuels to reduce greenhouse gas emissions or to achieve petroleum or natural gas independence. The unit commitment sub-model performs a high hourly resolution optimization of system operation, taking into account all kinds of ancillary services and reserve, which ensure power supply reliability. The CPS model simulates the operation and expansion of power plants on an individual plant basis and takes into account the eventual technical operating restrictions, such as the minimum stable power generation, ramp rates, minimum up and down times and resource constraints. The latter applies to hydroelectric plants with reservoir, which are subject to water availability and storage limitations.

Once the system is optimally operated and expanded in the future, the model calculates costs and on this basis it calculates the tariffs of electricity per sector of final demand, as well as the tariffs for synthetically produced fuels. The tariffs distinguish between energy supply and the provision of grid services, the latter being under a regulated monopoly regime. The model calculates tariffs also for industrial steam by sector and for district heating. All these prices by sector feed the closed loop of the entire model and return to the demand sectors for further adjustment of demand in the next model iteration. Thus, the demand for electricity is price-elastic, as the model performs adjustment of demand driven by electricity prices per sector. After the optimization two additional steps are included in the model, pricing and reporting as shown Figure 63.

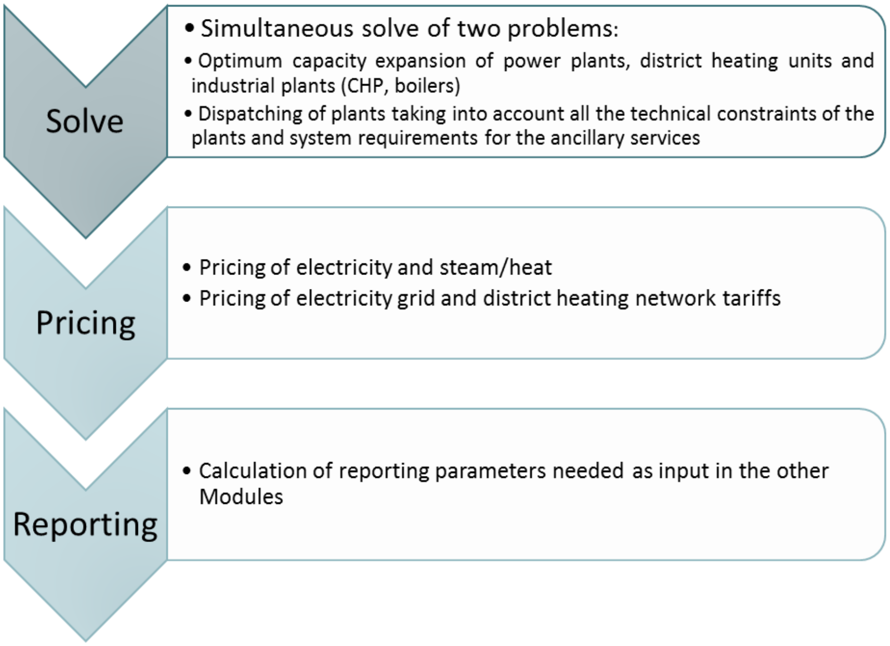


Figure 63 Sequence of CPS Power Module

Through pricing, the Power Module is linked to the Demand Module (Chapter 4 Overview of the CPS Demand Module) and solved as a mixed complementarity problem that concatenates the individual problems of energy consumers and producers via endogenous calculation of energy prices. CPS simulates a well-functioning market, where total costs (capital and operating) are recovered, including also possible stranded investment costs. The pricing of electricity commodity is explicit and is based on the Ramsey-Boiteux methodology. Marginal cost pricing is used, so as to calculate the price in a virtual wholesale market; then a fixed mark-up is added according to Ramsey pricing, allocating the not yet allocated system costs using the marginal cost pricing. A detailed description of the pricing model is included in the Section 5.4 Principles of the pricing model.

Table 11 Overview of the CPS Power Module

Optimisation Considerations	The system minimizes total generation costs including annualized capital cost of new investment and all variable and fixed costs of generation to meet given demand increased by distribution losses
	Demand is price-elastic, i.e. it responds to electricity/heat prices
	The optimization is subject to constraints regarding capacity expansion and potential limitations by plant type.
	Total generation costs include fuel costs and other variable costs. Therefore, the optimisation of capacity expansion includes the estimation of the merit order dispatching and takes account in full the provision of system reserves
Detailed representation of the system and plant characteristics	The integration of a Unit Commitment Problem (UC) allows for a detailed representation of the system operation taking into account also the use of parts of the capacities of plants to meet the system reserves (ancillary services)
	The CPS Power Module takes into account the technical restrictions of plant operation and system services and simulates the operation of the Slovakian power system on an hourly basis (Unit-Commitment Problem)
Investment decision	RES investments are decided under a separate support mechanism
	Old plants are decommissioned due to their age
	The user can define exogenously the extension of lifetime for each existing power plant, as well as fuel switching and fuel blending
	Capacity expansion to meet system reserve requirements is part of the optimization, considering given levels of reserves
Clean Energy Policies	EU and national policies may impose a system-wide clean energy obligation (e.g. RES obligation) or an emissions reduction obligation or an energy efficiency saving obligation. These obligations are also taken into account by the CPS Power Module in the determination of the endogenous capacity expansion

5.2 Mathematical Structure, unknown variables and exogenous parameters

5.2.1. Mathematical Structure

The mathematical structure of the CPS Power Module is a mixed integer linear problem (MILP), the optimisation is inter-temporal (perfect foresight) and solves simultaneously:

- A capacity expansion problem and
- A unit commitment-dispatching algorithm

The model determines the optimal capacity mix and dispatching schedule of plants, so as to meet the demand for electricity and heat/steam, subject to several constraints, aiming to minimize the total system costs. The total system costs include:

- Annualized capital costs of new investments based on WACC for discounting over time
- Fixed costs (Operation and Maintenance)
- Variable (non-fuel) costs
- Fuel costs and
- Taxes and environmental policies costs/subsidies (e.g. ETS costs, FIT equivalent policies).

Optimisation constraints can be grouped under the following categories:

1) Energy equilibrium constraints (electricity, heat, steam)
2) System – related technical constraints (reserve requirements)
3) Investment constraints (limited potential of investing in some plant types, i.e. nuclear plants, RES)
4) Plant – related technical constraints (e.g. max capacity, minimum power level, ramp up and ramp down constraints etc.)
5) Fuel Consumption and resource availability constraints
6) Storage and Power-to-X constraints (e.g. capacity of storage facilities, maximum daily stored energy, balance of stored energy etc.)
7) CCS – related constraints
8) Policies and Emissions constraints
9) Additional Constraints for heat and steam supply

Figure 64 depicts the Optimisation constraints of the CPS Power Module.

The next paragraphs provide further details in relation to the mathematical representation of each constraint in the CPS Power Module.

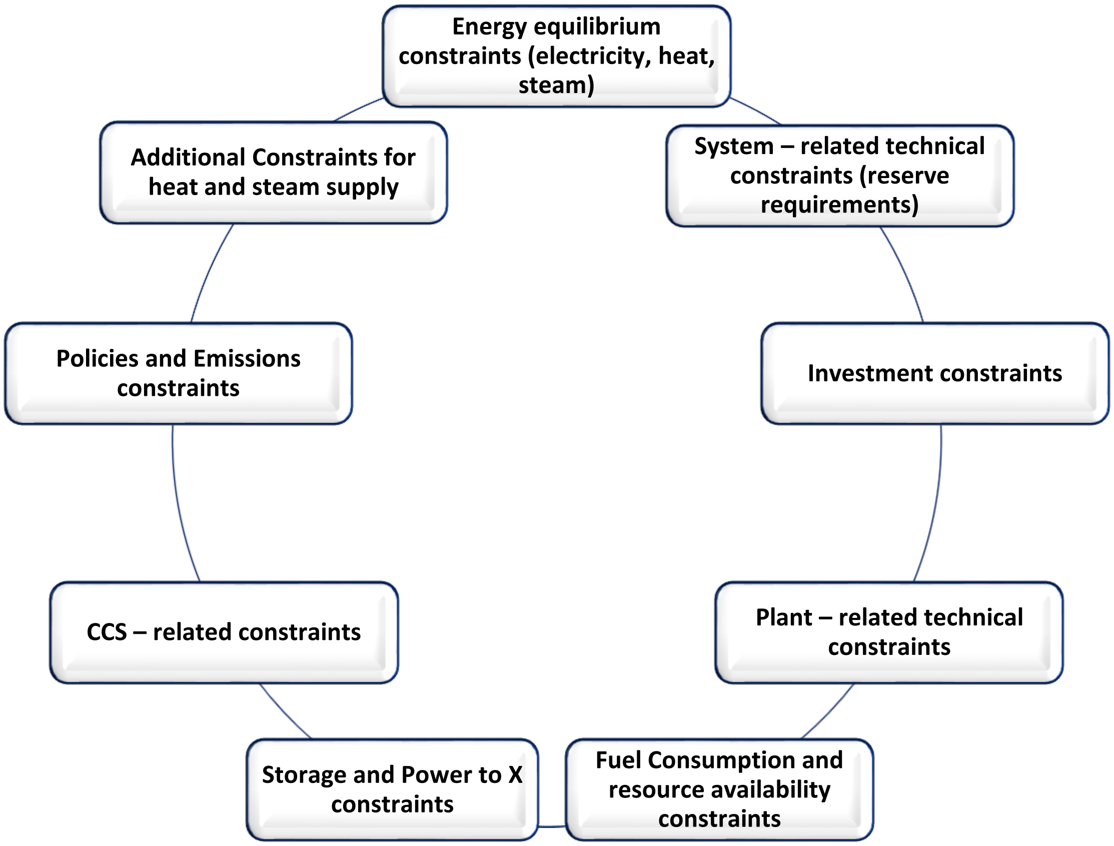


Figure 64 Optimisation Constraints

5.2.1.1 Energy Equilibrium constraints

The energy equilibrium constraints ensure that the given demand[4] for each form of energy is met by the supply. The energy forms simulated in the CPS Power Module are electricity, heat, steam and hydrogen. Although heat and steam are the same form of energy, we have chosen to include both in the CPS Power Module as in principle households and tertiary sectors use heat for heating purposes, while industrial sectors use steam as input to several industrial processes. The energy equilibrium constraints are included in the model as following:

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[4] The demand for electricity, steam/heat and clean fuels is endogenous within the CPS model. The CPS Power Module is linked with the CPS Demand Module via prices for each energy form, representing a perfect equilibrium.

- Energy equilibrium constraint

$$\sum_{p} G_{p,h,ef,t} + \begin{cases} \sum_{sto} STOout_{sto,h,t} + Imports_{h,t}, if\ ef \in elec \\ 0, \quad if\ ef \in (heat \cup steam) \end{cases} = \sum_{s} D_{s,h,ef,t} + \begin{cases} \sum_{sto} STOin_{sto,h,t} + \sum_{p2x} P2Xin_{p2x,h,t} + Exports_{h,t}, if\ ef \in elec \\ 0, \quad if\ ef \in (heat \cup steam) \end{cases}, \forall\ ef, h, t$$

Where

p: Plant

h: Typical hour

t: Year

$elec$: Electricity

s: Demand sector

ef: Energy form

sto: Storage facility

$p2x$: Type of power to X facility

$G_{p,h,ef,t}$: Generated power for plant p, typical hour h, energy form ef and year t

$D_{s,h,ef,t}$: Demand of power for demand sector s, typical hour h, energy form ef and year t

$STOin_{sto,h,t}$: Charge of storage facility sto via electricity for typical hour h and year t

$STOout_{sto,h,t}$: Discharge of storage facility sto via electricity for typical hour h and year t

$P2Xin_{p2x,h,t}$: Input of type of power to X facility $p2x$ for typical hour h

$Imports_{h,t}$: Imports of electricity to Slovakia for typical hour h and year t

$Exports_{h,t}$: Exports of electricity from Slovakia for typical hour h and year t

Energy demand is calculated by the CPS Demand Module annually and for each sector. The Power Module receives energy demand results from the Demand Module and calculates an hourly demand load curve via the use of individual load patterns decomposed by demand sector. The hourly patterns of each demand sector and the aggregated hourly demand load curve have been calibrated in the base year (2015), so as to reproduce the demand load curve based on the ENTSO – E data.

Electricity demand is increased by transmission and distribution losses, for each voltage type, while heat demand is increased due to losses in the district heating network. For steam demand no losses are assumed, as the generation of steam is met by industrial onsite plants. The reader is referred to Section 5.3.1.2 Network grids for a more detailed description of the network assumptions.

- *It must be noted that since the CPS is a single-country model, possible network constraints are not accounted for.* $Imports$ *and* $Exports$ *are input parameters, applicable only to electricity.*

5.2.1.2 System-related technical constraints

The system-related technical constraints refer to the minimum hourly quantities of operating reserves. The CPS Power Module includes all three types of reserves, as defined by the pan-European harmonized terminology of ENTSO-E[5]:

1) FCR: Frequency Containment Reserve
2) aFRR: automatic Frequency Restoration Reserve (upwards and downwards)
3) mFRR/RR: manual Frequency Restoration Reserve and Replacement Reserve

The following mathematical formulation describes the inclusion of the system-related technical constraints in the CPS Power Module:

- System-related technical constraint

$$\sum_{p} R_{p,r,h,t} \geq SysReq_{r,t}, \forall\, r, h, t$$

Where

r: Reserve type (FCR, aFRR or mFRR/RR),

$R_{p,r,h,t}$: Delivery of plant p of reserve type r for typical hour h

$SysReq_{r,t}$: System reserve requirements of reserve type r

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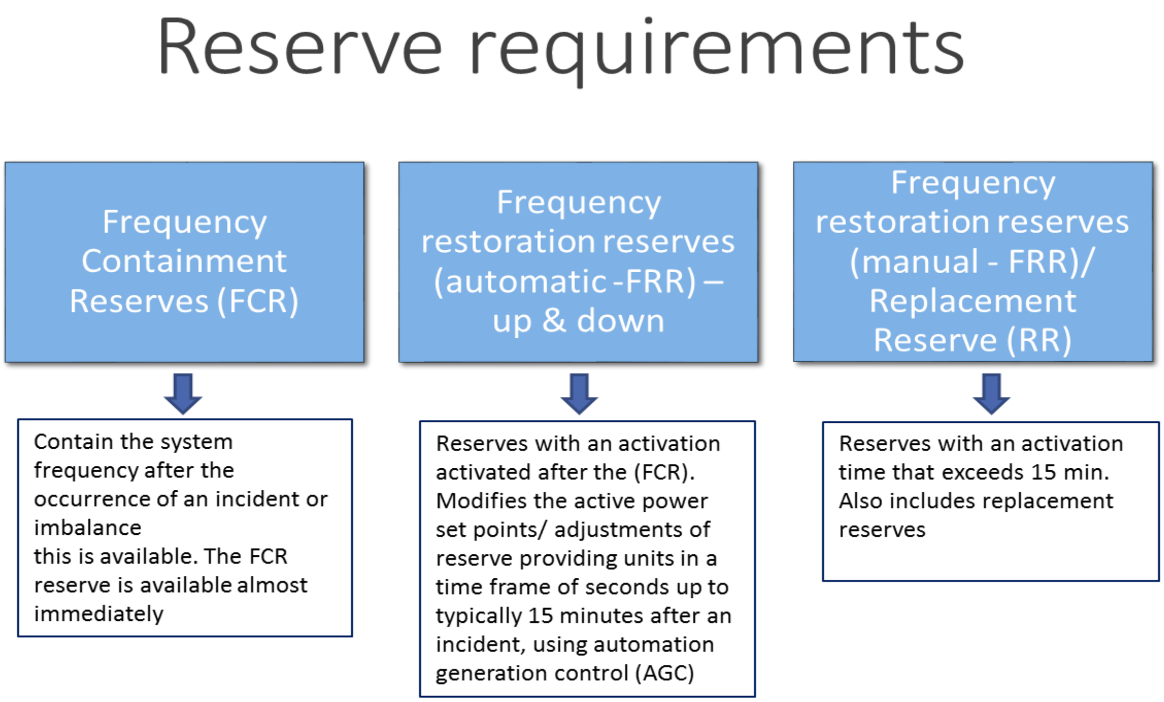
[5] https://ec.europa.eu/energy/sites/ener/files/documents/SystemOperationGuideline%20final%28provisional%2904052016.pdf



Reserve requirements

Frequency Containment Reserves (FCR)

Contain the system frequency after the occurrence of an incident or imbalance
this is available. The FCR reserve is available almost immediately

Frequency restoration reserves (automatic -FRR) – up & down

Reserves with an activation activated after the (FCR). Modifies the active power set points/ adjustments of reserve providing units in a time frame of seconds up to typically 15 minutes after an incident, using automation generation control (AGC)

Frequency restoration reserves (manual - FRR)/ Replacement Reserve (RR)

Reserves with an activation time that exceeds 15 min. Also includes replacement reserves

Figure 65 Specific constraints for reserves

- *It must be noted that since CPS is a single country model, no sharing of reserves is taken into account. This means that in the CPS Power Module's approach the TSO cannot access reserve capacity in another synchronous area to fulfill its' reserve requirements. Thus reserve requirements are solely met by providers located in the same balancing area (i.e. in Slovakia).*

5.2.1.3 Investment Constraints

Investment constraints reflect a possibly limited potential of investing in some plant types (i.e. nuclear plants, RES). Investment constraints are exogenous to the model and the user can change the maximum potential level. The investment constraint is the following:

- Investment constraint

$$\sum_{p} Pmax_p * INST_{p,t} \leq maxpot_{p,t} \,, \qquad \forall\, p,t$$

Where

$Pmax_p$: Maximum installed capacity of plant p

$INST_{p,t}$: Number of installed units of plant p

$maxpot_{p,t}$: Maximum potential of installed units of plant p

Investment constraints also include the non-linear cost supply curves with ascending slope (stepwise linearized), representing potential resource exhaustion. The user is referred to Section 5.3.1.5 Non-linear cost curves for a detailed description.

5.2.1.4 Plant-related technical constraints

A unit commitment algorithm (UC) has been incorporated into the CPS Power Module. The UC approach allows for detailed representation of technical constraints for plants.

The following mathematical formulations describe the plant-related technical constraints included in the CPS Power Module:

- Maximum installed capacity

$$G_{p,h,elec,t} + \sum_{r \in up} R_{p,r,h,t} \leq Pmax_p * UC_{p,h,t}\, , \forall\, p, h, t$$

Where

$UC_{p,h,t}$: Number of committed units of plant p for typical hour h

- Minimum stable power generation level

$$G_{p,h,elec,t} - \sum_{r \in down} R_{p,r,h,t} \geq Pmin_p \ * UC_{p,h,t}\, , \forall\, p, h, t$$

Where

$Pmin_p$: Minimum generation level (capacity) of plant p

- Minimum up time

$$UC_{p,h,t} \geq \sum_{h' \in [(h' \leq h) \cap (h - minuptime_p \leq hh)]} SU_{p,h',t}\, , \forall\, p, h, t$$

Where

$SU_{p,h',t}$: Number of starting up units of plant p for typical hour h'

- Minimum down time

$$INST_{p,t} - \ UC_{p,h,t} \geq \sum_{h' \in [(h' \leq h) \cap (h - mindowntime_p \leq hh)]} SD_{p,h',t}\, , \forall\, p, h, t$$

Where

$SD_{p,h',t}$: Number of shutting down units of plant p for typical hour h'

- Maximum upward ramping rates

$$G_{p,h,elec,t} - G_{p,h-1,elec,t} \leq UC_{p,h-1,t} * rampup_p * 60 + SU_{p,h,t} * Pmax_p\, , \forall\, p, h, t$$

Where

$rampup_p$: Upward ramping rate of plant p

- Maximum downward ramping rates (up & down)

$$G_{p,h-1,elec,t} - G_{p,h,elec,t} \leq UC_{p,h-1,t} * rampdn_p * 60 + SD_{p,h,t} * Pmax_p \ , \forall\ p,h,t$$

Where

$rampdown_p$: Downward ramping rate of plant p

- Maximum operating hours

$$\sum_h G_{p,h,elec,t} * freq_h \leq maxoper_p * Pmax_p * INST_{p,t} \ \ , \forall\ p,t$$

Where
$freq_h$: Annual frequency of typical hour h
$maxoper_p$: Maximum operating hours of plant p

- Maximum contribution to each type of reserve per plant

$$R_{p,r,h,t} \leq maxres_{p,r} \ , \forall\ p,r,h,t$$

Where

$maxres_{p,r}$: Maximum contribution of plant p of reserve type r

- CHP – related constraints

$$G_{p,h,elec,t} + slope_p * G_{p,h,steam,t} \leq Pmax_p * UC_{p,h,t} \ , \forall\ p \in chp,h,t$$

$$S_{p,h,t} \leq helratio_p * G_{p,h,el,t} \ , \forall\ p \in chp,h,t$$

Where

$slope_p$: Iso-fuel curve of CHP plant p

$G_{p,h,steam,t}$: Steam generation of plant p for typical hour h

$S_{p,h,t}$: Steam generation of plant p for typical hour h

$helratio_p$: Heat to electricity ratio of plant p

5.2.1.5 Fuel Consumption and resource availability constraints

Fuel Consumption in each power plant is a linear function of the electricity generation, depending on a heatrate value defined exogenously by fuel and plant type. The choice of fuels derives from the simultaneous optimisation of investments and operation, performed inter-temporally.

The following mathematical formulations describe the fuel consumption and resource availability constraints included in the CPS Power Module:

- Fuel Consumption Constraint

$$FC_{p,f,t} = heatrate_p * \sum_{h} freq_h * \begin{cases} G_{p,h,el,t}\,, & \forall\, p \notin chp, t \\ G_{p,h,el,t} + slope_p * G_{p,h,steam,t}, & \forall\, p \in chp, t \end{cases}$$

Where

f: Fuel consumed

chp: CHP power plants

$FC_{p,f,t}$: Fuel consumption of plant p and fuel f

- Fuel blending Constraint

$$blend_{p,f} * FC_{p,f,t} = \sum_{f'} FC_{p,f',t}\,, \forall\, p, f, t$$

Where

$blend_{p,f}$: Blending ratio of plant p for fuel f, denoting the ratio of each fuel to the total fuel consumption

- Maximum resource availability constraint

$$\sum_{p} FC_{p,f,t} \leq maxresource_{f,t}\,, \forall\, f, t$$

$maxresource_{f,t}$: Maximum available energy of fuel f

5.2.1.6 Storage and Power to X constraints

The CPS Power Module determines charging and discharging of the storage units endogenously. Typically, storage units are charged during times of low marginal cost and discharge electricity at times of high marginal cost. The investment and operation of the various storage and Power to X options are determined simultaneously with the capacity expansion and dispatching of the power system.

The following mathematical formulations describe the Storage and Power to X constraints included in the CPS Power Module:

- Capacity constraint of storage

$$STOin_{sto,h,t} + STOout_{sto,h,t} \leq Psto_{sto,t}, \forall\, sto, h, t$$

Where

$Psto_{sto}$: Capacity of storage facility sto

- Maximum daily stored energy

$$\sum_{h \in day} STOout_{sto,h,t} \leq dstor_{sto} * Psto_{sto}, \qquad \forall\, sto, day, t$$

Where

day: Typical day

$dstor_{sto}$: Maximum daily storage capability of storage facility sto

- Balance of stored energy

$$\sum_{h \in day} STOin_{sto,h,t} = heatrate_{sto} * \sum_{h \in day} STOout_{sto,h,t}\ , \forall\ sto\ , day, t$$

Where

$heatrate_{sto}$: Heatrate of storage facility sto

- Capacity constraint for clean fuel production

$$P2Xout_{p2x,h,t} \leq PP2X_{p2x,t}, \forall\, p2x, t$$

Where

$P2Xout_{p2x,h,t}$: Output of type of power to X facility $p2x$ for typical hour h

$PP2X_{p2x,t}$: Capacity of type of power to X facility $p2x$

- Balance constraint for clean fuel

$$\sum_{h \in day} P2Xin_{p2x,h,t} = heatrate_{p2x} * \sum_{h \in day} P2Xout_{p2x,h,t}\ , \forall\, p2x, h, t$$

Where

$heatrate_{p2x}$: Heatrate of power to X facility $p2x$

- Balance constraint for demand and supply of clean fuels

$$\sum_{h} freq_h * P2Xout_{p2x,h,t} = Dclf_{p2x,t}\ , \forall\, p2x, t$$

Where

$Dclf_{p2x,t}$: Demand of clean fuel of type of power to X facility $p2x$

The reader is referred to Section 5.3.1.1 Representation of Plants for a more detailed explanation of the modelling approach used for storage and power to x facilities.

5.2.1.7 CCS – related constraints

Power plants with the technology option of Carbon Capture and Storage (CCS) are among the list of plant types incorporated in the CPS Power Module. In a CCS power plant system, part of the emitted CO_2 is captured, transported and deposited to a storage site (a geological underground formation), instead of being released in the atmosphere, as in the case of conventional plants.

The cost of underground storage of CO_2 is taken into account through a cost-supply curve (defined exogenously), representing cost versus potential of storage. The cost of underground CO_2 storage is included as a cost item in the total cost of CCS power plants.

The following mathematical formulations describe the CCS – related constraints included in the CPS Power Module:

- Annually captured CO_2 in CCS power plants

$$\sum_{p\in ccs,f} emfstor_p * FC_{p,f,t} = CO_2capt_t, \qquad \forall\, t$$

Where

$emfstor_p$: Fraction of emissions of plant p that is being stored

CO_2capt_t: Captured CO_2 emissions from CCS power plants

- Cumulatively maximum quantity for captured CO_2 in CCS power plants

$$\sum_{t'\leq t} CO_2capt_{t'} \leq maxCO_2capt_t, \qquad \forall\, t$$

Where

$maxCO_2capt_t$: Maximum possible cumulative CO_2 stored

5.2.1.8 Policies and Emission constraints

Promotion of renewables is represented in the form of an equivalent feed-in-tariff. The equivalent feed-in-tariff is a virtual subsidy that is taken into account by the CPS Power Module when deciding on investments. The equivalent feed-in-tariff for each type of renewable technology and the total budget available for the support of RES are exogenous.

The CPS Power Module has been designed so as to allow the user to include additional support mechanisms which are made available under a given budget.

The following mathematical formulations describe the Policies and Emission constraints included in the CPS Power Module:

- Annual maximum budget for Feed-In-Tariff equivalent policies

$$\sum_{p,h} freq_h * G_{p,h,elec,t} * FITeq_{p,t} \leq fitbudget_t\ , \forall\, t$$

Where

$FITeq_{p,t}$: Equivalent feed-in-tariff for plant p

$fitbudget_t$: Maximum budget available for the implementation of a RES FIT support policy

- Additional promoting policies

$$\sum_{p.h} freq_h * \ G_{p,h,f,t} * policy_{p,f,t} = Psupport_t \ , \forall \ t$$

Where

$policy_{p,f,t}$: Additional policy tariff for plant p and fuel f

$Psupport_t$: Maximum budget available for the implementation of the additional policy

- Emissions constraint

$$\sum_{p,f} emf_{p,f} * FC_{p,f,t} = EMIS_t \ , \forall \ t$$

Where

$emf_{p,f}$: CO_2 emission factor of plant p for fuel f

$EMIS_t$: Total system's emissions

5.2.2. Unknown variables

The unknown variables of the CPS Power Module include the following:

- Capacity additions by plant type (several types of capacity investment)
- Electricity generation by plant
- Steam or heat generation by plant
- Fuel consumption by type of fuel and plant
- CO_2 emissions
- Storage and Power to X plants: injection or extraction from storage facilities and investments in storage equipment
- Capacity reserved for the provision of upward and downward ancillary services by plant
- Curtailment of renewable generation

The **integer** variables included in the CPS Power Module are the following:

- Number of installed plants
- Number of plant in operation in typical hour h

- Number of plant shut down in typical hour h
- Number of plant started up in typical hour h

It must be noted that the integer variables apply only for the power plants that are assumed to have technical limitations (i.e. nuclear, solids – fired, CCGT, large biomass plants).

The reader is referred to Section 5.3.1 Representation of Plants for a detailed analysis regarding the representation of plants.

5.2.3. Exogenous Parameters

The parameters provided by the user are:

- Installed capacity of existing plants in the beginning of the projection period
- Decommissioning plans related to the existing plants (if any)
- Capacities of plants under construction in the beginning of the projection period
- Grid loss rates
- Technical characteristics of plants by technology (commissioning/decommissioning year, technical lifetime, size, heatrate, self-consumption rate, technical minimum output, ramping rates, maximum contribution to each type of reserve, minimum up and down time, heat to electricity ratio and the slope of the iso-fuel curve for CHP plants)
- Economic characteristics of plants by technology (capital, fixed O&M and variable cost, economic lifetime, growth factor of fixed costs, capital cost incurred for extending the lifetime of plant, for fuel blending and for fuel switching, additional capital and fixed cost for CHP plants)
- Fuel prices
- Taxes & subsidies
- Carbon price in the context of the EU Emissions Trading System - EU ETS (i.e. the price of the European Union Allowance)
- Feed-in tariffs and other support schemes for RES (FIT equivalent)
- Costs and availability potential parameters for transportation and storage of captured CO_2
- Costs and availability potential parameters of storage technologies
- Parameters reflecting policy instruments and restrictions (nuclear, CCS, environmental, efficiency, CHP, etc.)
- Parameters used in the non-linear cost-supply curves
- Transmission grid, distribution grid and district heating network tariffs for the basis year

5.3 Model features, considerations and assumptions

This section presents the main features of the CPS Power Module, comprised of the following subsections:

- Representation of Plants: this section describes the different types of plants considered by the model (Utility, District Heating, electricity/steam production by the industrial sector, storage and power to X plants). This description includes detailed information on technologies, technical characteristics and main assumptions included in the CPS Power Module
- Fuels and Fuel Consumption: this section outlines the basic considerations in relation to fuel consumption
- Network Grids: this section discusses the CPS Power Module approach in relation to the power grid
- Imports and Exports: this section presents the modelling approach to electricity imports and exports to and from Slovakia
- Time resolution: the model represents demand variability for electricity and steam/heat by introducing an hourly fluctuation of load in typical days. This section describes the main principles of this approach
- Non-linear cost curves: including detailed description of cost optimization, taking into account current and future exploitation of resources and technological progress (including learning by doing)
- Investment decisions: this section outlines the basic considerations for the promotion of investments in specific technologies (e.g. RES, nuclear, CHP etc.)
- CHP operation: this section provides information on the modelling approach used for the simulation of CHP operation
- CCS and CO_2 capture: this section outlines the basic considerations of the CPS Power Module for the modelling of plants with the availability of carbon capture and storage (CCS)

5.3.1. Representation of Plants

The CPS Power Module includes all plants currently installed in Slovakia providing electricity and steam/heat for district heating or industrial purposes. It also provides for a wide range of technologies that may be installed in the future.

For the sake of simplicity, as well as to ensure a speedy execution, small existing plants have been grouped into larger plants (hereinafter Plant Groupings). Plant Grouping has been done by fuel type, technology (including CHP) and use (utility or industrial)[6]. The main categorization of the plants as taken into account by the CPS Power Module is summarized in Figure 66 and described below:

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[6] See for example all plants referred to as Small_CHP_Waste, Small_CHP_Biomass, Small_CHP_Coal, Small_IC_1, Small_IC_2, Small_IC_3, in the input data file under the Techdata_plants SHEET.

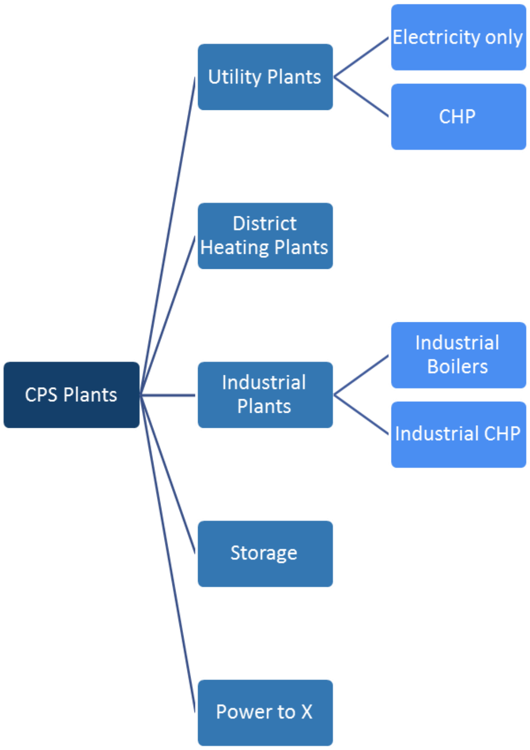

Figure 66 CPS Plant types

1) *Utility power plants*:
    a. Electricity only: power plants generating only electricity
    b. Cogeneration utility power plants: CHP power plants with main purpose of generating electricity, or CHP power plants used for district heating purposes (i.e. connected to district heating network or individual tertiary facilities)

The following paragraphs highlight the CPS Power Module approach on the treatment of Utility power plants. Attention is drawn on special topics, such as new capacity, cogeneration, decommissioning and retrofitting. Note that in the below paragraphs, the phrase “plant type” refers to different technologies.

- *The model treats **existing power plants (including Plant Groupings) individually***

- *New Capacity*

    - *The model **projects investment in individual new power plants at a fixed (standardized) capacity per plant type,** by the use of **integer variable** for the operation of all power plants (existing and new) and the investments in new units. As some plant types entail severe technical limitations*[7]*, only specific technologies are considered to have a fixed size in the CPS*

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[7] Plant types considered to have strict technical limitations are the following: nuclear, solids-fired, gas-fired steam turbines, CCS, CCGT and biomass-fired steam turbine

Power Module. For example, the fixed size of an investment in CCGT is 422MW. The variable of investment can take an integer value (e.g. 1,2 etc.) denoting the number of units that are being commissioned; if the investment variable takes the value of two, this mean that 2 x 422MW CCGT are being invested.

  - *Investments in the rest of technologies (i.e. RES, gas turbines, peak devices using gas, oil, biogas etc.) do not have a fixed size per plant type and are represented as a continuous variable.*

- *Cogeneration (CHP)*
  - *The user indicates which of the existing plants have a cogeneration possibility.*
  - *For new investments, different plant types (electricity only or CHP plants) are eligible. The model chooses endogenously the most cost-effective plant type.*
- *Decommissioning and retrofitting*
  - *Decommissioning or retrofitting (i.e. the extension of a power plant's lifetime) is exogenously defined by the user, while the **decisions regarding the investment in new power plant are fully endogenous.***
- *Ancillary services*
  - *Since the Power Module **co-optimizes the fulfillment of electricity and ancillary services demand**, the **power reserved for ancillary services in each power plant is an endogenous decision**; thus some power plants result in withdrawing a part of their capacity from energy production, so as to provide ancillary services.*

As summarized in Table 12, the following technologies are available for utility power plants: coal-firing (conventional) plants, coal-firing plants with carbon capture and storage (CCS), lignite-firing (conventional) plants, lignite-firing plants with carbon capture and storage (CCS), open cycle oil fired gas turbines and oil fired steam cycles, open cycle gas fired gas turbines, combined cycle gas turbines (CCGT, gas fired), nuclear plants, CCS-gas, biomass-firing, waste-firing, solar photovoltaic, wind onshore and geothermal.

The model represents hydro (in run river and lakes), and includes storage systems such as hydro-pumping, batteries and chemical storage (production of hydrogen and clean gas from renewables).

A power plant is characterized by the following attributes:

- Thermal (fuel and fuel consumption)
- Operational (gross and net capacity, ramping rates, technical minimum, minimum up and down time, maximum contribution to each type of ancillary service)
- Age (commissioning date, date of planned decommissioning)
- Cost (capital cost, fixed O&M cost, variable operating cost)
- Environmental (emissions).

These characteristics are known for plants already existing in the beginning of the projection period, as well as for plants under construction and for which the commissioning date is known. The user may change these data, as explained in Section 5.6.6 Options for changing parameters' values exogenously.

Regarding future plants, to be endogenously decided by the CPS Power Module, the respective characteristics have been drawn from our experience with PRIMES and many other projection data by various stakeholders. Also for these plants the user may change their data.

Table 12 Available plant technologies for utility power plants

Utility Plants types	
Nuclear	PPs firing biosolid CCS (Electricity only or CHP)
Coal (Electricity only or CHP)	PPs firing waste
Lignite (Electricity only or CHP)	PPs firing biogas (Electricity only or CHP)
Gas open cycle (Electricity only or CHP)	Hydro power plants - Run of river
Combined cycle gas turbines (CCGT) (Electricity only or CHP)	Hydro power plants - With Dam
Gas Turbines or ICE	Solar Photovoltaic
Coal CCS (Electricity only or CHP)	Wind turbines (Onshore and Offshore)
Lignite CCS (Electricity only or CHP)	Geothermal power
CCGT CCS (Electricity only or CHP)	Solar thermal
PPs firing biosolids (Electricity only or CHP)	

2) *District Heating plants*: heating only plants providing heat in the residential and tertiary sectors via the use of district heating network.

The model tracks DH units in vintages both for existing and new plants and includes exogenous technical and economic characteristics per vintage. These characteristics may improve in the future for technologies candidate for investment due to technical progress. The user may change these assumptions, as explained in Section 5.6.6 Options for changing parameters' values exogenously. Table 13 presents the DH technologies that are available in the CPS Power Module:

Table 13 Available plant technologies for District Heating plants

District Heating Plants types
Biomass Fired District Heating Plants
Gas Fired District Heating Plants
Solids (Coal/Lignite) District Heating Heat Plants
Oil Fired District Heating Plants
Geothermal District Heating Plants
Solar Thermal District Heating Boilers
Electric District Heating Boilers

3) *Industrial plants*: these plants are specific for each industrial sector and can be distinguished to:
    a. Industrial CHP plants: CHP plants providing electricity and steam, located onsite the corresponding industry with main purpose to provide steam for the industrial processes
    b. Industrial boilers: providing only steam and located onsite the corresponding industry

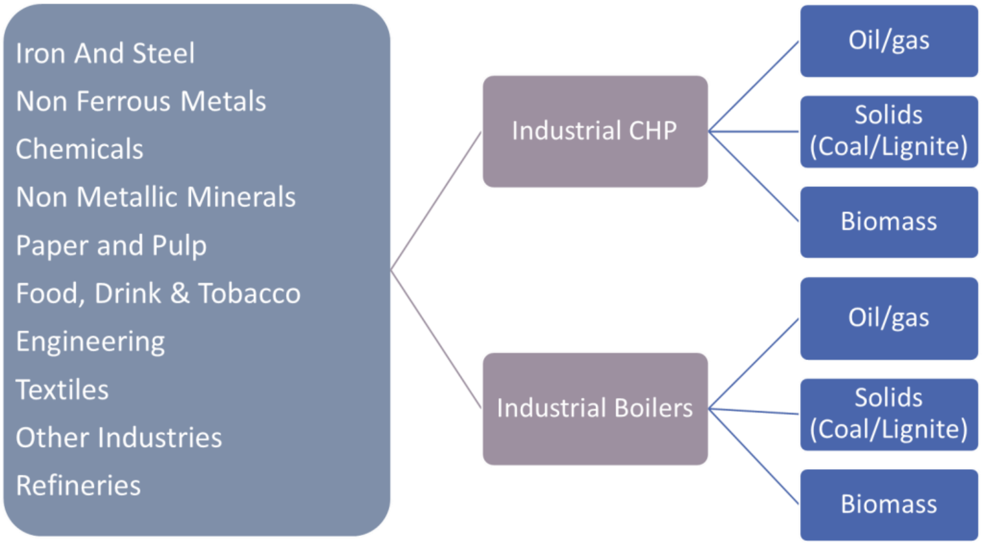

Figure 67 Industrial Plants types

The main purpose of industrial plants is the auto-production of steam to meet the requirements of various industrial processes. Steam is produced either by CHP or boilers. The CPS Power Module accounts for the fact that cogeneration plants produce electricity. Auto-produced electricity reduces the electricity that the industrial sectors would otherwise need to purchase from the market.

- *In the CPS model it is assumed that each industrial sector is never an overall net seller of electricity or steam. This means that the amounts of electricity and steam produced by the industrial plants of the corresponding industrial sector has as an upper bound the electricity and steam demand of the sector.*

4) *Storage plants*:
   The following types of storage plants are included in the CPS Power Module:
   a. Pure pumped storage plants
   b. Batteries
   c. Demand Response: demand response acts as demand shifting and not as demand shedding (e.g. shifting the use of washing machines from late afternoon to late at night, so as to smooth the daily peak)

The model determines the investment and operation of the various storage options simultaneously with the capacity expansion and operation of power and heat plants. The operation of storage plants is the charging times, when the storage unit consumes electricity thus increase the electricity demand; and discharging times, when the storage unit provides electricity to the grid. Typically the storage units charge at low marginal cost times and discharge at high marginal cost times of the system. The balancing cycle of storage is daily for hydro-pumping and batteries. The balancing involves loss of electricity with a different rate for each storage option. Also, demand response is included in the model and treated as a daily balancing storage. The demand response has a linear stepwise cost function with ascending slope and a fixed potential.

5) *Power to X plants*:

The following types of Power to X plants are included in the CPS Power Module:

a. Power to Hydrogen: plants performing electrolysis, using electricity as input, so as to produce hydrogen as output
b. Power to Clean Gas: plants performing a series of processes such as electrolysis, methanation and capture of CO_2 from air, so as to transform electricity (input) to synthetic gas (clean gas)
c. Power to Synthetic Liquids: plants performing a series of processes, so as to transform electricity (input) to synthetic liquids

The power-to-X plants produce indistinguishably fuels addressing demand of other sectors, taken as given from the projections of the rest of modules, and fuels used to perform chemical storage within the power system. To perform chemical storage, the power-to-X fuels are used to produce electricity (discharging) and use electricity produced (charging) at different times. The balancing cycle for the power-to-X technologies is seasonal.

5.3.1.1 Fuels and Fuel Consumption

The CPS includes a wide variety of fuel used as input to the plants. A detailed list of fuels taken into account in CPS is shown in Table 3. The choice of fuels derives from simultaneous optimisation of operation and investment, performed intertemporally. For the fuels purchased from the market[8], the sectors are price takers, meaning they cannot affect the fuel costs. The costs of the fuels may include carbon pricing, subsidies and hidden costs. All of these can be determined exogenously by the user. All fuels that are being produced in the power sector[9] have endogenous pricing mechanisms, reflecting production costs.

For all plants, fuel consumption is endogenously calculated in the CPS Power Module; it is represented as a linear variable, depending on an exogenous heatrate value different for each plant category.

The CPS Power Module assumes that each utility power plant may use as input one or more fuels. The new utility plants use only one fuel (e.g. CCGT_2020 uses natural gas, Nuclear_2020 uses nuclear fuel), while for the existing plants the possibility of fuel switch or fuel blend exists. The user may choose, whether an existing plant will switch its input fuel or whether this plant blends more than one fuels (e.g. Vojany coal plant co – blends coal and biomass) and to what extent (co-blending rates). These two mechanisms have been designed for the purposes of the CPS Power Module, so that users can assess the economics of potential fuel switching policies. Such assessments are well relevant given the current European trend where solids-fired plants are being converted to biomass plants. The reader is referred to Section 5.6 Explaining the supply-related scenario input file for more information.

Industrial onsite CHP and heat plants are represented in a more aggregate approach, compared to utility plants; thus it is assumed that multiple fuels are used as input. For the existing fleet the co – blending shares are fixed, meaning that they are not endogenously decided and are a result of the calibration to

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[8] The fuels that are not purchased from the market, are being auto-produced within the CPS Power Module. These fuels are electricity, clean fuels (e.g. clean gas, hydrogen) and heat/steam.

[9] These fuels are electricity, heat/steam, hydrogen and clean gas from Power to X technologies

the data of past years. For the new investments in industrial CHP and heat plants, the co – blending of fuels is an endogenous option of the CPS model. For example, plant "FERRO_BOIOILGAS_2020" represents an industrial boiler in the Iron & Steel industry, built in 2020 and has the option of using either natural gas or oil.

5.3.1.2 Network grids

Power Grid

After consultation with the Slovakian experts, two types of power grid are considered to CPS. The first is the transmission grid (high voltage) and the second is the distribution grid (Medium/Low voltage). Each demand sector (customer) is connected to the high or/and medium/low voltage either fully or partially (e.g. some small industries are connected to the medium voltage). For each type of power grid a power grid loss rate is applied aiming to represent the electricity losses. The user is able to change these loss rates, as explained in Section 5.6.6 Options for changing parameters' values exogenously.

District Heating Network

The CPS Power Module distinguishes between heat consumed in residential, services and agriculture sectors via the district heating network, and steam consumed in the industrial sectors and the refineries. Grid losses for the district heating network are considered in the modelling, while for the steam generation no grid losses apply as the production of steam is assumed to be located onsite the industry.

5.3.1.3 Imports and Exports

The CPS Model is a single country model and cannot handle the simulation of the EU electricity internal market endogenously. The imports and exports of electricity are exogenous parameters, which are specific to each scenario depending on the development of the power mix in Slovakia and the relative cost of power generation. Possible network constraints are ignored, as the whole country is represented as a single node. Nevertheless, the level of imports and exports are modelled in the form of bilateral contracts, accompanied with a load profile (i.e. base, medium, high). The user may choose the quantity of imports and exports for every load profile.

The reader is referred to Section 5.6.6 Options for changing parameters' values exogenously for a detailed explanation on how to affect import/export quantities and profiles.

5.3.1.4 Time resolution

The model represents demand variability for electricity and steam/heat by introducing an hourly fluctuation of load in typical days. The operation of power plants and the use of energy input resources are also calculated on an hourly basis for each typical day (load segments). Hourly profiles of intermittent renewable sources are further considered and load segment synchronisation also applies for electricity and steam/heat. The latter is important for capturing the operation of CHP plants and competition between cogeneration, boilers and distribution of heat.

For a better representation of the system's operation, each year (8760 hours) is represented by 4 typical days covering the following periods:

- From 1st of November to 30th of April, considering only working days
- From 1st of November to 30th of April, considering only holidays
- From 1st of May to 30th of October, considering only working days
- From 1st of May to 30th of October, considering only holidays

Each day is represented by 24 hours, thus each year is represented by 96 segments.

Note that the load profile is endogenously calculated in the model as a result of a bottom-up accounting of load profiles of individual energy uses in the various sectors. The latter are provided by the CPS Demand Module.

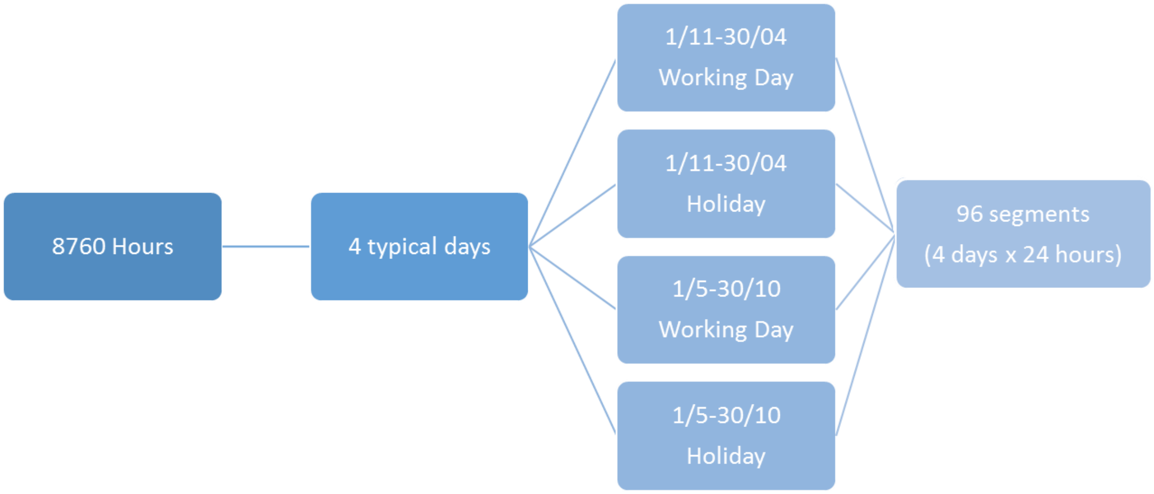

Figure 68 Time resolution of the CPS Power Module

5.3.1.5 Non-linear cost curves

(a) Increased cost due to resource exploitation

The CPS Power Module is using an elegant approach to account for the relative difficulty in developing incremental capacity due to potential fuel exhaustion, site availability restrictions and RES limitations, due to resource exploitation. This difficulty is modelled through non-linear cost-quantity curves representing the cost-supply locus of a resource (fuel supply, renewable potentials and limitations on development of new power plant sites, where applicable e.g. nuclear plant sites, wind sites, etc.). Cost-supply curves are numerically estimated functions with increasing slopes serving to capture take-or-pay contracts for fuels, possible promotion of domestically produced fuels, fuel supply response (increasing prices) to increased fuel demand by the power sector, exhaustion of renewable energy potential, difficulties to develop CO_2 storage areas, acceptability and policies regarding nuclear site development, etc. The non-linear cost-supply curves are a unique feature of the PRIMES Model and have been fully included in the power investment and plant operation optimisation of the CPS Power Module[10].

Box 3 An example of increased cost due to resource exploitation

To better understand this feature of the model consider the following example. Assume that a certain capacity of biomass plants has already been built. To build a new plant this would require for the investor to acquire a new site that may potentially be far away from the fuel resource. The cost of building a new plant in a new site is naturally increased e.g. due to the increased cost of site preparation and fuel transportation.

(b) Reduced cost due to technological maturity

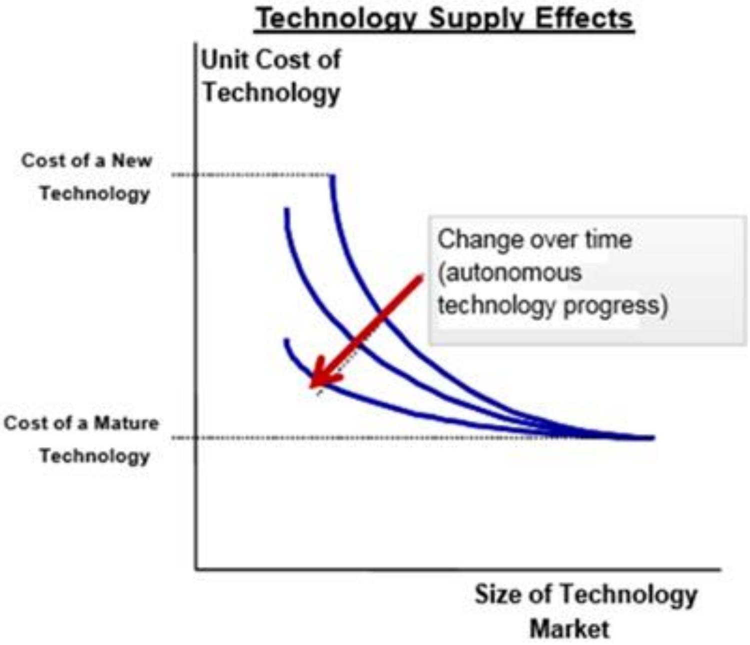

Figure 69 Cost reduction of new technologies driven by technology progress

The technical-economic characteristics of technologies are assumed to change over time (as a result of R&D and eventually economies of scale in mass production). The model evaluates consistently the potential of new technologies, by considering endogenous technology learning and commercial maturity, so that the unit cost of a technology decreases over time and also due to economies of scale, as shown in Figure 69.

The rate of change of technical-economic characteristics over time is an assumption of the modelling which may be altered depending on the scenario. For more information on how the user can specify

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[10] Data on potentials from various sources including: ECN (Admire-Rebus database), DLR (database), Green-X, RES-2020, Observer, national sources, various studies and a special data collection for biomass resources.

technological maturity as an input to the model see Section 5.6.6 Options for changing parameters' values exogenously.

5.3.1.6 Investment decisions

Targets for renewables, cogeneration of heat and power, and emissions are reflected as shadow values, influencing dispatching and choices in investment decision making[11].

(a) Investment in RES and storages

- In case of large development of variable RES, the model determines investment in low capital-intensive thermal power plants (back-up) in order to meet reliability and reserve power constraints. Flexibility of the power system to balance fluctuating RES is endogenously built and reflected on investments, as ramping possibilities differ by plant technology. As a result, costs increase and the competitiveness of variable RES decreases.
- The hydro resources are considered dispatchable but constrained by yearly available water flows: the model shows that they are used at peak hours until the water constraint is met. Large-scale storage is endogenous in the model (hydro-based pumped storage, power to X). Depending on economics, storage smooths load fluctuations and accommodates transfer of RES energy from times when RES availability exceeds load to times when RES production is scarce.
- Investment in RES is projected on economic grounds as for any other technology. The relative competitiveness of RES depends on technology progress (change of technical-economic characteristics over time, as discussed in the context of Figure 69) and on policies supporting RES directly or indirectly.
- Table 14 summarizes the mechanisms available in the CPS Power Module to directly affect RES penetration. As stated above, RES penetration may also be increased by modifying the non-linear cost curves reflecting increased cost due to resource exploitation and reduced cost due to technological maturity. Nevertheless caution is needed when changing the values of the non-

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[11] Shadow values are essentially dual variables that are calculated endogenously in the model so as to meet certain constraints (e.g. RES share or emissions reduction). These values should influence all energy-related decisions of energy system actors, i.e. power producers, individual consumers, manufacturers, and technology and infrastructure providers. The introduction of "shadow values" (carbon values, Efficiency values and RES values) increases the perceived costs of energy consumers, while ETS prices incur direct carbon payments for power plants and heavy industries; thus as climate constraints become more ambitious they influence decisions of energy consumers and producers away from fossil fuels and towards low-carbon energy forms and energy efficiency improvements. The consistent calculation of "shadow values" requires a simultaneous solution of the overall model taking into account the complex interactions via the whole energy system (including operation of the power system) and the costs of all energy sources so as to determine simultaneous market equilibrium of demand and supply in all energy markets, while at the same time meeting overall system-wide constraints (e.g. on energy savings). This is the reason we propose to use this modelling framework instead of simply increasing costs with increasing RES shares.

linear curves so that these remain realistic and are supported by literature or well substantiated data.

Table 14 Mechanisms to increase RES penetration

Mechanism	Description	Details
Equivalent RES Feed-in tariffs	Equivalent RES Feed-in tariffs reflect power purchase agreements between producers and suppliers (or the TSO/Market operator) obliged to absorb RES produced electricity.	The RES supporting schemes are represented in the model as equivalent feed-in tariff schemes (FiT), although in reality the adopted mechanism may be different (e.g. feed in premiums). Note that a scheme of feed-in premium which uses a strike price to define the premium relative to average wholesale market prices can be approximately modelled as an equivalent contract for difference (CfD) with the same strike price. In terms of modelling this does not differ from an equivalent FiT.
Other RES facilitation policies	These are reflected as unknown renewable support schemes and also by introducing modifications in the non-linear curves	Unknown support schemes may include other schemes to mitigate risks (in addition or in replacement of the equivalent FiT). Such schemes may for example include sovereign guarantees on investment or other types of subsidies. Scenario-specific policies, which may increase RES potential and make cheaper the access to potential can also be reflected in the parameters of the cost-potential curves.
Renewable values	These are reflected as unknown renewable support schemes by introducing a virtual subsidy of renewable generation.	Policy measures regarding the penetration of renewable energy sources are modelled via the use of renewable values. Renewable values are shadow values of a virtual RES constraint considered by the actors as a virtual subsidy. However this subsidy is not provided neither in reality nor in the model. The renewable values reflect policies facilitating renewables, as for example legislation and infrastructure easing site access and connections, quicker licensing and other.

(b) Investments in nuclear plants and other conventional plants using fossil fuels

Investments in nuclear power and other plants using fossil fuels are treated as economic decisions. Deployment depends on electricity demand, load profiles, economic features of competing technologies and the cost of the European Union Allowance (EUA) in the context of the EU ETS emissions trading system. Actually, the cost of the EUA (referred herein as carbon price, as already mentioned in the overview of the CPS Demand Module) is an important driver to investment decisions in nuclear, RES and conventional technologies. Investment decisions fit within the least cost capacity expansion to a long-term horizon (under perfect foresight).

Regulations such as the Integrated Pollution Prevention and Control Directive (2010/75/EC) Directive, other emission performance standards, as well as the best available techniques standards are fully supported by the CPS Power Module and can be easily introduced. Also note that the CPS Power Module supports CCS fitted solid and gas fired plants, as discussed in Section 5.2.1.7 CCS – related constraints.

Box 4 Introducing the requirements of Directive 2010/75/EC in the CPS

Directive 2010/75/EC foresees that, during the period from 1 January 2016 to 31 December 2023, combustion plants with operation hours less than 17,500 during the aforementioned period may be exempted from compliance with the emission limit values set by the same Directive. To include such a provision in the CPS Power Module, the user simply needs to set a maximum threshold in the plants' operating hours (set through the input file, see Section 5.6 Explaining the supply-related scenario input file). A fully compliant plant may be introduced in the CPS through e.g. an increase in the capital cost to reflect plant modernization and the addition of anti-pollution technologies (e.g. DeNOx and DeSOx devices and particle filters).

5.3.1.7 CHP Operation – balancing electricity and heat/steam production

The choice of CHP technologies and the operation mode (mix of electricity and heat/steam production) are endogenous in the CPS Power Module. The operation possibilities are constrained by the heat/steam requirements. The operation possibilities are constrained by the feasible combination of electricity and heat output. Each plant technology has a different feasible combination, which is illustrated in Figure 70. The CHP operational constraints delimit maximum electric power and minimum steam combinations as a locus of an iso – fuel line.

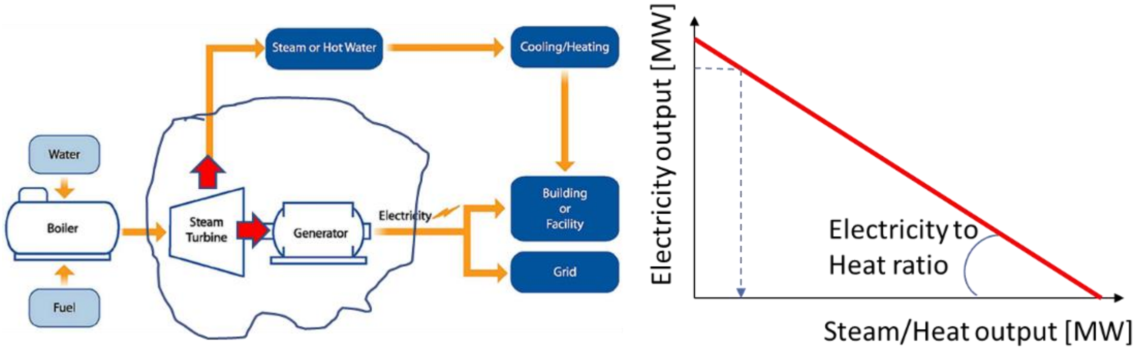

Figure 70 Basic concept of cogeneration of electricity and heat. The figure shows as an example the realisation of CHP through a conventional combustor/boiler/steam turbine and electricity generator.

The above mentioned approach is the one used for the utility CHP power plants providing heat to the demand sectors, while for the industrial onsite CHP power plants a different approach has been used. The demand for steam is the large majority of industry, mostly the most energy intensive, follows a base load, and thus steam generation follows the same pattern. As the main purpose of these plants is to provide steam to industry, they generate at stable level steam and electricity. Thus the electricity to steam ratio is considered as constant (fixed) and has been exogenously calculated based on several statistics and studies. The user is able to change all the technical characteristics for the CHP plants, as explained in Section 5.6.6 Options for changing parameters' values exogenously.

Also, the reader is referred to Appendix IV for the analytical mathematical formulations.

5.3.1.8 CCS and CO_2 capture

CPS model includes eight plant types with the carbon capture and storage (CCS) add – on, as candidate options for investment. The model takes into account the costs transportation and underground storage of the captured CO_2 and the stored CO_2 emissions are represented with the use of linear variables. The user may choose is each scenario, whether the underground storage of CO_2 emissions is permitted. In cases, where the carbon dioxide storage is prohibited, no CCS investments will take place. The reader is referred to Section 5.6.6 Options for changing parameters' values exogenously, for an illustrative example on how to affect the policies regarding CCS.

5.4 Principles of the pricing model

Once the system is optimally operated and expanded in the future, the model calculates costs and on this basis it calculates the tariffs of electricity per sector of final demand, as well as the tariffs for synthetically produced fuels. The tariffs distinguish between energy supply and the provision of grid services, the latter being under a regulated monopoly regime. The model calculates tariffs also for industrial steam by sector and for district heating. All these prices by sector feed the closed loop of the entire model and return to the demand sectors for further adjustment of demand in the next model iteration. Thus, the demand for electricity is price-elastic, as the model performs adjustment of demand driven by electricity prices per sector. After the optimization two additional steps are included in the model, pricing and reporting as shown in Figure 63.

Through pricing the Power Module is linked to the Demand Module and solved as a mixed complementarity problem that concatenates the individual problems of energy consumers and producers via endogenous calculation of energy prices. CPS simulates a well-functioning market, where total costs (capital and operating) are recovered, including also possible stranded investment costs. The pricing of electricity commodity is explicit and is based on the Ramsey-Boiteux methodology. Marginal cost pricing is used, so as to calculate the price in a virtual wholesale market; then a fixed mark-up is added according to Ramsey pricing, allocating the not yet allocated system costs using the marginal cost pricing.

Electricity prices in the CPS Power Module (as in the PRIMES model) are calculated in order to recuperate all system costs. These costs are the following:

- Capital investment costs: annuity payments of installed power plants (and also possible stranded investment costs)
- Fixed costs: fixed costs of installed plants
- Variable costs: variable operating, fixed maintenance, fuel costs and payments for fuel taxes
- Emission costs: emission taxes and ETS auction payments.
- Costs related to schemes supporting renewables: feed-in tariffs equivalent scheme for renewable plants
- Grid costs, separately by grid type, calculated according to a regulated asset basis methodology, which includes capital costs of old infrastructure, cost of new investment and operating/maintenance costs (this calculation is essentially the output of the CPEX/UC problems)

- Costs/Revenues from cross border trade (applicable only for electricity prices): electricity imports and exports are priced using the System Marginal Price (SMP), as this is the current pricing method in all market coupling power exchanges.

Electricity (and steam/heat) prices are determined by category of customer (sectors and sub-sectors of demand). Each customer type has a load profile, which is calculated in the CPS Demand Module (the model also provides for self-supply). The aim is to allocate variable, fixed, and capital costs as well as grid and other costs to each category of customers as would be the case in a well-functioning market in which suppliers would conclude efficient and stable bilateral contracts with each customer category, based on the specific load profile of the customer. To do this, the following calculation steps are performed:

a) The tariffs per consumer type are calculated to reflect the marginal costs of the generation system for the corresponding load profile (this is the Boiteux part of the tariffs)

b) As the revenues based on marginal costs do not recover the entire generation budget, all fixed and capital costs, fees and levies (e.g. RES support recovery and others) also need to be included. Thus at a second stage, the non-recovered part (mainly fixed and non-recovered capital costs) are allocated to consumer types using the reverse of consumer's price elasticity (this is the Ramsey part of the tariffs)

c) The resulting electricity tariffs recover the entire generation cost.

Grid tariffs are also included in the generation costs. Tariffs for the base year are exogenous to the Module, see Section 5.2.3 Exogenous Parameters. Any tariff modifications due to new investments are endogenous to the model and are calculated based on current regulatory practices across Europe:

a) Firstly, the regulated asset base (RAB) is determined as inclusive of capital costs and new investment costs of the grids (by voltage type), including possible investment for smart systems, recharging networks, etc.

b) Secondly, a regulated weight average cost of capital is used to calculate annualized asset basis.

c) Thirdly, the RAB is equally distributed to the consumer types depending on the voltage type by which they are served.

d) Regulated tariffs are applied for recovering grid costs.

Note that overall, consumer prices are derived from wholesale market prices and grid tariffs as described above, as well as taxation, including carbon emission pricing.

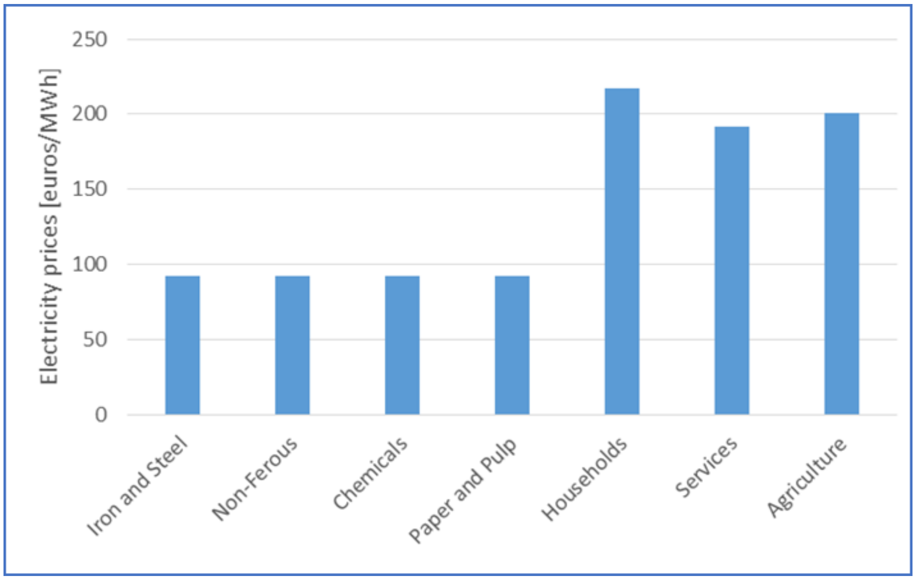

Figure 71 Illustrative example for electricity prices by consumer category

As noted above, the electricity prices differ per consumer category. This difference is related to the load profile of each category; most industrial sectors are associated with an almost continuous annual operation, without demand peaks. On the other hand, households, services and agriculture are associated with a less smooth load profile with occasional peaks. Demand of the former (industrial sector) is met by the (cheaper) power plants operating at base load while the demand of the remaining sectors may be met by a combination of load and peaking (more expensive) plants.

5.5 Policy Focus – Power

The CPS Power Module has inherited PRIMES' rich representation of policy instruments and measures.

Based on the long experience of our group with developing and using PRIMES in major policy analysis and impact assessment studies of the European Commission, national governments and industrial institutions, extensive detailed mechanisms have been built in the CPS Power Module to represent a large variety of policy measures and regulations.

5.5.1. Targets

It is important to understand that targets such as specific reductions in CO_2 emissions, penetration level of renewable energy sources and energy efficiency savings as prescribed in existing and future European policy (e.g. the 20-20-20 targets of the EU 2020 package and the 40-32-32.5 reflected in the 2016 winter package, as updated through the 2018 negotiations[12]) can be met through certain policy actions. For

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[12] https://ec.europa.eu/energy/en/news/commission-proposes-new-rules-consumer-centred-clean-energy-transition , Energy Efficiency target update see http://europa.eu/rapid/press-release_STATEMENT-18-3997_en.htm, RES target update see http://europa.eu/rapid/press-release_STATEMENT-18-4155_en.htm

example, RES targets can be achieved by application of favourable support schemes or increased carbon pricing in the European Emissions Trading system.
The CPS Power Module has been designed so that the user can assess, through multiple scenarios, the effect of alternative or complementary policy actions to meet one or more policy targets. Note that policy targets are not necessarily (or exclusively) related to the EU targets outlined above, but can also be additional or supplementary actions, under consideration by Slovakian policy makers at national level. For example, a policy in this direction can well be a strategic decision for non-coal generation from 2025 or 2030.

For users to achieve and assess the effect of a certain level of reduction in CO_2 emissions or increased penetration in RES or increase in EE, a trial-and-error process of multiple runs of the CPS Model is required, introducing consecutive changes (new and/or additional to previous runs) in order to reach a specified target.

5.5.2. Policy drivers of the CPS Power Module

Table 15 provides a summary of the various drivers available in the CPS Power Module that can be employed by users to either investigate the effect of certain policies or to achieve a certain pathway towards a predetermined target (e.g. a possible national contribution towards the proposed EU 2030 targets).

Table 15 Drivers available in the CPS Power Module for the impact assessment of climate and environmental policies

Policy/Mechanism	CPS driver
Taxation	Taxes
Feed-in-Tariff (FiT)	Feed-in-Tariff equivalent
Other non-specified forms of support	Support for power to X, Support for electricity storage, Support for electricity generation
Emissions Trading System (EU ETS)	Carbon price
Environmental Policies for airborne emissions and permitting policies	Maximum operating hours, possibility of CCS investments, maximum capacity of new investments per plant type
Policies related to lifetime extension of plants, retrofitting and early retirement	Extension of lifetime of plants
Technology progress and market failures	Non-linear curves

A detailed description of the CPS Power Module drivers is presented below. All drivers are available in the supply-related input file and can be modified by the user, as described Section 5.6.6 Options for changing parameters’ values exogenously.

- *Taxation*: Taxation is exogenous and follows the level of detail of regulations. The CPS Power Module allows users to assess in detail the impact of taxation imposed on specific for fuels and sectors.

- *Feed-in-Tariff (FiT), other forms of RES support*: Feed-in tariffs and other renewable support schemes are treated in great detail in the CPS Power Module. Users can specify FiT levels per technology and year. The module also allows for other (additional type of support) to be also included (parameter named “unknown renewable support schemes in EUR/kWh“). See also Table 14.
- *Carbon Price (EU ETS)*: The CPS Power Module takes into account the European emissions trading system. Users can specify the price of the European Union Allowance for each projected year, referred to as carbon price in the CPS. Note that the ETS price is an important driver to RES deployment and the reduction of coal/lignite plant operation.
- *Environmental Policies for airborne emissions and permitting policies*: The CPS Power Module accounts for Best Available Technology regulations, energy performance standards and the provisions of Directive 2010/75/EC, which imposes conditions that plants not satisfying certain emission levels are obliged to shut down after reaching a certain amount of hours of operation per year. As already described in Box 3, it is comparatively straight forward to impose limits in the operating hours of any plant, here due to environmental issues. Policies regarding the permission of investments in certain power plant technologies at national level, for example regarding nuclear, CCS etc., or including constraints applicable to new site development or expansion in existing sites are also supported by the module.
- *Policies related to lifetime extension of plants, retrofitting and early retirement*: The CPS Power Module has been designed to account for policies allowing for the lifetime extension of power plants (e.g. nuclear) and retrofitting (e.g. to comply with a certain emission regulation and early retirement due to increased operating/maintenance costs), see section 5.3.1.1 Representation of Plants.
- *Technology progress and market failures*: The CPS Power Module can further account for regulations and policies that address market failures and/or enable tapping on positive externalities (e.g. technology progress) which induce reduction of cost elements (technology costs) and improve the perception of consumers, leading to lower subjective cost components. Expansion to remote areas for RES development purposes, and different options about management and allocation of capacities can also be taken into account through the Cost Curves described in the previous sections.

5.6 Explaining the supply-related scenario input file

To run alternative scenarios the user would need to modify accordingly the supply-related scenario input file located in the Scenarios\”Scenario name”\Inputxlsx\ folder (see section 2.4 The structure of the *Scenario name* subfolder).

The main sheets from where you can affect the CPS Power Module are:

1) **Techdata_plants**: This sheet includes the full techno-economic data of existing and new plants (the latter to be decided endogenously by the CPS Power Module)
2) **Fuelswitch**: This sheet includes the data regarding fuel switching of existing power plants
3) **Fuelblend**: This sheet includes data related to fuel blending of existing power plants

4) **Policy_power_data**: This sheet allows the user to modify various parameters in order to assess the effect of policies, as discussed in the previous session
5) **Level_struct**: This sheet includes the non-linear cost curves for each investment type and fuel, as per Section 5.3.1.5 Non-linear cost curves.

Sheets **Techdata_bio** and **Policy_biofuels** include parameters of the CPS Biomass Module and will be described in Section 6.4 Explaining the biomass-related scenario input sheets.

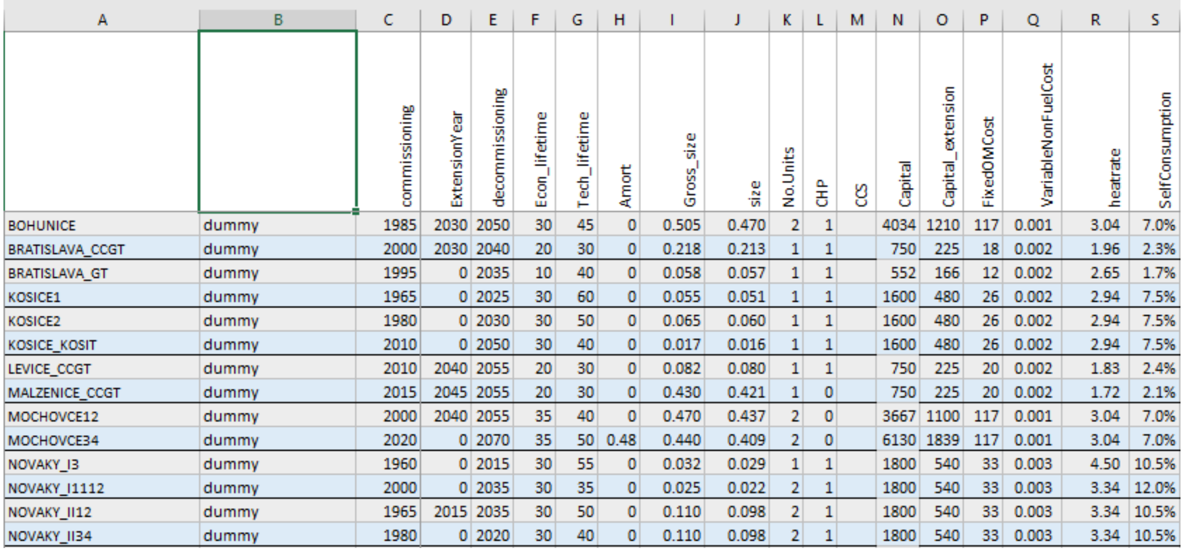
5.6.1. Techdata_plants

As shown in Figure 72 and Figure 73, the techdata_plants sheet includes the following data for both existing and new plants across columns C-AL:

- Commissioning: Commissioning year of each plant
- Extension Year: Year of life extension of each plant
- Decommissioning: Decommissioning year of each plant (in this year the plant will not operate)
- Econ_lifetime: Economic lifetime in years
- Tech_lifetime: Technical lifetime in years
- Amort: Share of capital costs that have already been recuperated
- Gross_size: Gross installed capacity (including self-consumption) in GW
- Size: Net installed capacity (excluding self-consumption) in GW
- No.Units: Number of units
- CHP: Indicator of CHP [1 if plant is CHP, 0 else]
- CCS: Indicator of CCS [1 if plant is CCS, 0 else]
- Capital: Overnight capital cost in €/kW
- Capital_extension: Capital cost incurred for extending the lifetime of plant in €/kW
- FixedOMCost: Fixed operation and maintenance costs in €/kW
- VariableNonFuelCost: Variable non fuel cost in €/kWh
- Heatrate: Heatrate
- SelfConsumption: Self-consumption
- Slope1_CHP: Iso-fuel curve for CHP
- Helratio_CHP: Heat to electricity ratio for CHP
- Minheatrate_CHP: Minimum heatrate for CHP
- Techn_min: Technical minimum output level at which a plant can operate in GW
- Ramp_up: Ramp up rate in GW/min
- Ramp_down: Ramp down rate in GW/min
- Uptime: Minimum uptime – minimum hours for which a plant has to operate above technical minimum after a start-up in hours

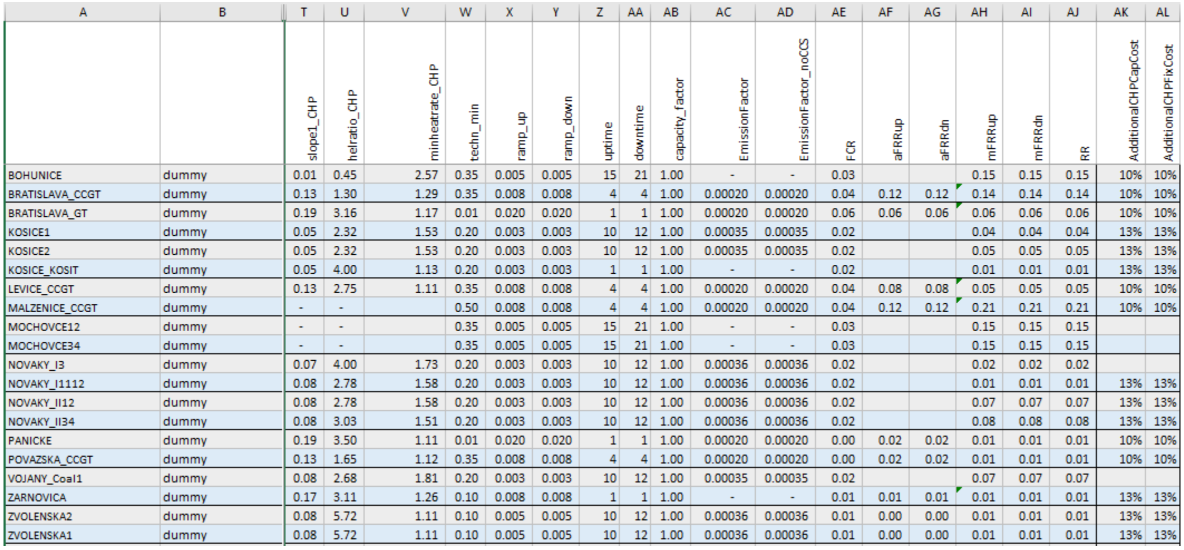
- Downtime: Minimum downtime – minimum hours for which a plant has remain offline after a shut-down in hours
- Capacity_factor: Capacity factor % of installed capacity
- EmissionFactor: Emission factor in Mtn CO_2/GWh_{fuel}
- EmissionFactor_noCCS: Emission factor for non CCS power plants in Mtn CO_2/GWh_{fuel}
- FCR: Maximum contribution of each plant to frequency containment reserve in GW per hour
- aFRRup: Maximum contribution of each plant to automatic frequency restoration reserve up in GW per hour
- aFRRdn: Maximum contribution of each plant to automatic frequency restoration reserve down in GW per hour
- mFRRup: Maximum contribution of each plant to manual frequency restoration reserve up in GW per hour
- mFRRdn: Maximum contribution of each plant to manual frequency restoration reserve down in GW per hour
- RR: Maximum contribution to replacement reserve in GW per hour
- AdditionalCHPCapCost: Additional capital cost in case a unit is CHP % of capital cost
- AdditionalCHPFixCost: Additional fixed cost in case a unit is CHP % of fixed cost

The user is able to change the above mentioned list of techno – economic characteristic for all plants considered in the CPS, both existing and new plants.



A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
		commissioning	ExtensionYear	decommissioning	Econ_lifetime	Tech_lifetime	Amort	Gross_size	size	No.Units	CHP	CCS	Capital	Capital_extension	FixedOMCost	VariableNonFuelCost	heatrate	SelfConsumption
BOHUNICE	dummy	1985	2030	2050	30	45	0	0.505	0.470	2	1		4034	1210	117	0.001	3.04	7.0%
BRATISLAVA_CCGT	dummy	2000	2030	2040	20	30	0	0.218	0.213	1	1		750	225	18	0.002	1.96	2.3%
BRATISLAVA_GT	dummy	1995	0	2035	10	40	0	0.058	0.057	1	1		552	166	12	0.002	2.65	1.7%
KOSICE1	dummy	1965	0	2025	30	60	0	0.055	0.051	1	1		1600	480	26	0.002	2.94	7.5%
KOSICE2	dummy	1980	0	2030	30	50	0	0.065	0.060	1	1		1600	480	26	0.002	2.94	7.5%
KOSICE_KOSIT	dummy	2010	0	2050	30	40	0	0.017	0.016	1	1		1600	480	26	0.002	2.94	7.5%
LEVICE_CCGT	dummy	2010	2040	2055	20	30	0	0.082	0.080	1	1		750	225	20	0.002	1.83	2.4%
MALZENICE_CCGT	dummy	2015	2045	2055	20	30	0	0.430	0.421	1	0		750	225	20	0.002	1.72	2.1%
MOCHOVCE12	dummy	2000	2040	2055	35	40	0	0.470	0.437	2	0		3667	1100	117	0.001	3.04	7.0%
MOCHOVCE34	dummy	2020	0	2070	35	50	0.48	0.440	0.409	2	0		6130	1839	117	0.001	3.04	7.0%
NOVAKY_I3	dummy	1960	0	2015	30	55	0	0.032	0.029	1	1		1800	540	33	0.003	4.50	10.5%
NOVAKY_I1112	dummy	2000	0	2035	30	35	0	0.025	0.022	2	1		1800	540	33	0.003	3.34	12.0%
NOVAKY_II12	dummy	1965	2015	2035	30	50	0	0.110	0.098	2	1		1800	540	33	0.003	3.34	10.5%
NOVAKY_II34	dummy	1980	0	2020	30	40	0	0.110	0.098	2	1		1800	540	33	0.003	3.34	10.5%

Figure 72 CPS supply input file: techdata_plants sheet (first part)



A	B	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL
		slope1_CHP	helratio_CHP	minheatrate_CHP	techn_min	ramp_up	ramp_down	uptime	downtime	capacity_factor	EmissionFactor	EmissionFactor_noCCS	FCR	aFRRup	aFRRdn	mFRRup	mFRRdn	RR	AdditionalCHPCapCost	AdditionalCHPFixCost
BOHUNICE	dummy	0.01	0.45	2.57	0.35	0.005	0.005	15	21	1.00	-	-	0.03			0.15	0.15	0.15	10%	10%
BRATISLAVA_CCGT	dummy	0.13	1.30	1.29	0.35	0.008	0.008	4	4	1.00	0.00020	0.00020	0.04	0.12	0.12	0.14	0.14	0.14	10%	10%
BRATISLAVA_GT	dummy	0.19	3.16	1.17	0.01	0.020	0.020	1	1	1.00	0.00020	0.00020	0.06	0.06	0.06	0.06	0.06	0.06	10%	10%
KOSICE1	dummy	0.05	2.32	1.53	0.20	0.003	0.003	10	12	1.00	0.00035	0.00035	0.02			0.04	0.04	0.04	13%	13%
KOSICE2	dummy	0.05	2.32	1.53	0.20	0.003	0.003	10	12	1.00	0.00035	0.00035	0.02			0.05	0.05	0.05	13%	13%
KOSICE_KOSIT	dummy	0.05	4.00	1.13	0.20	0.003	0.003	1	1	1.00	-	-	0.02			0.01	0.01	0.01	13%	13%
LEVICE_CCGT	dummy	0.13	2.75	1.11	0.35	0.008	0.008	4	4	1.00	0.00020	0.00020	0.04	0.08	0.08	0.05	0.05	0.05	10%	10%
MALZENICE_CCGT	dummy	-	-		0.50	0.008	0.008	4	4	1.00	0.00020	0.00020	0.04	0.12	0.12	0.21	0.21	0.21	10%	10%
MOCHOVCE12	dummy	-	-		0.35	0.005	0.005	15	21	1.00	-	-	0.03			0.15	0.15	0.15		
MOCHOVCE34	dummy	-	-		0.35	0.005	0.005	15	21	1.00	-	-	0.03			0.15	0.15	0.15		
NOVAKY_I3	dummy	0.07	4.00	1.73	0.20	0.003	0.003	10	12	1.00	0.00036	0.00036	0.02			0.02	0.02	0.02		
NOVAKY_I1112	dummy	0.08	2.78	1.58	0.20	0.003	0.003	10	12	1.00	0.00036	0.00036	0.02			0.01	0.01	0.01	13%	13%
NOVAKY_II12	dummy	0.08	2.78	1.58	0.20	0.003	0.003	10	12	1.00	0.00036	0.00036	0.02			0.07	0.07	0.07	13%	13%
NOVAKY_II34	dummy	0.08	3.03	1.51	0.20	0.003	0.003	10	12	1.00	0.00036	0.00036	0.02			0.08	0.08	0.08	13%	13%
PANICKE	dummy	0.19	3.50	1.11	0.01	0.020	0.020	1	1	1.00	0.00020	0.00020	0.00	0.02	0.02	0.01	0.01	0.01	10%	10%
POVAZSKA_CCGT	dummy	0.13	1.65	1.12	0.35	0.008	0.008	4	4	1.00	0.00020	0.00020	0.00	0.02	0.02	0.01	0.01	0.01	10%	10%
VOJANY_Coal1	dummy	0.08	2.68	1.81	0.20	0.003	0.003	10	12	1.00	0.00035	0.00035	0.02			0.07	0.07	0.07		
ZARNOVICA	dummy	0.17	3.11	1.26	0.10	0.008	0.008	1	1	1.00	-	-	0.01	0.01	0.01	0.01	0.01	0.01	13%	13%
ZVOLENSKA2	dummy	0.08	5.72	1.11	0.10	0.005	0.005	10	12	1.00	0.00036	0.00036	0.01	0.00	0.00	0.01	0.01	0.01	13%	13%
ZVOLENSKA1	dummy	0.08	5.72	1.11	0.10	0.005	0.005	10	12	1.00	0.00036	0.00036	0.01	0.00	0.00	0.01	0.01	0.01	13%	13%

Figure 73 CPS supply input file: techdata_plants sheet (second part)

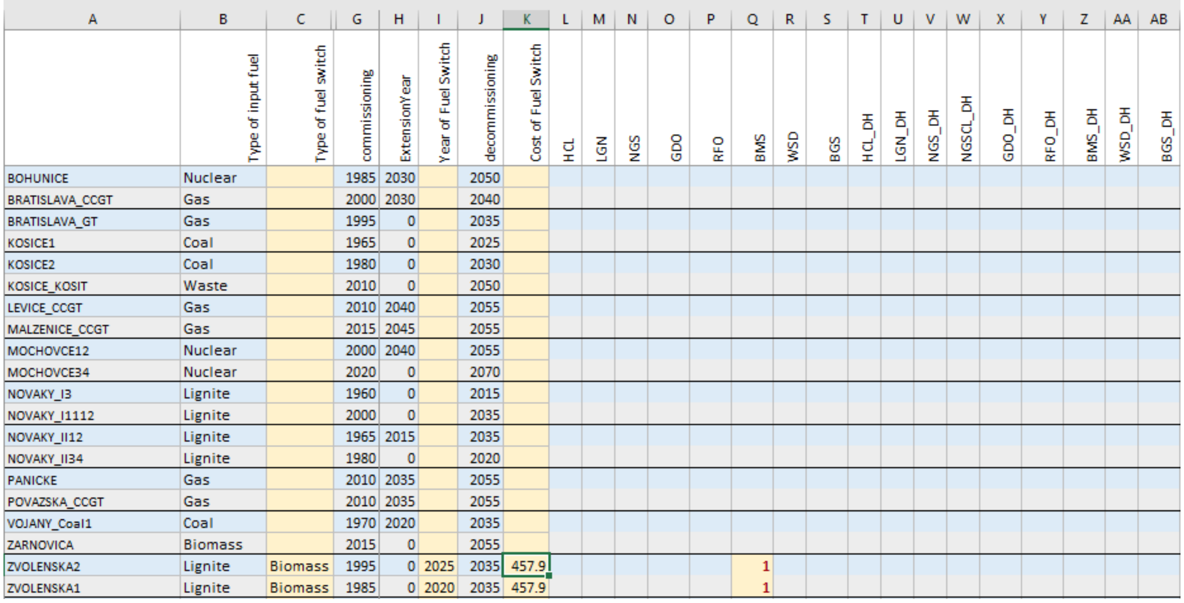
5.6.2. Fuelswitch

In “Fuelswitch” sheet, the user can exogenously define which existing plants have the possibility of fuel switching. This mechanism has been designed for the purposes of the CPS Power Module, so that the user can assess the economics of potential fuel switching policies. Such assessments are well relevant given the current European trend where solids-fired plants are being converted to biomass plants.

The columns B – AC of the fuelswitch sheet are explained below:

- Type of input fuel: Type of original fuel
- Type of fuel switch: Type of fuel switch
- Commissioning: Year of power plant commissioning
- ExtensionYear: Year of life extension of the power plant
- Year of Fuel Switch: Year of fuel switch
- Decommissioning: Year of power plant decommissioning
- Cost of Fuel Switch: Cost of fuel switch in €/kW
- HCL: Hard Coal
- LGN: Lignite
- NGS: Natural Gas
- GDO: Diesel
- RFO: Fuel Oil
- BMS: Biomass solids
- WSD: Waste solids
- BGS: Biogas
- HCL_DH: Hard Coal District-Heating

- LGN_DH: Lignite District Heating
- NGS_DH: Natural Gas District Heating
- NGSCL_DH: Clean Gas District Heating
- GDO_DH: Diesel District Heating
- RFO_DH: Fuel Oil District Heating
- BMS_DH: Biomass District Heating
- WSD_DH: Waste Solids District Heating
- BGS_DH: Biogas District Heating



A	B	C	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB
	Type of input fuel	Type of fuel switch	commissioning	ExtensionYear	Year of Fuel Switch	decommissioning	Cost of Fuel Switch	HCL	LGN	NGS	GDO	RFO	BMS	WSD	BGS	HCL_DH	LGN_DH	NGS_DH	NGSCL_DH	GDO_DH	RFO_DH	BMS_DH	WSD_DH	BGS_DH
BOHUNICE	Nuclear		1985	2030		2050																		
BRATISLAVA_CCGT	Gas		2000	2030		2040																		
BRATISLAVA_GT	Gas		1995	0		2035																		
KOSICE1	Coal		1965	0		2025																		
KOSICE2	Coal		1980	0		2030																		
KOSICE_KOSIT	Waste		2010	0		2050																		
LEVICE_CCGT	Gas		2010	2040		2055																		
MALZENICE_CCGT	Gas		2015	2045		2055																		
MOCHOVCE12	Nuclear		2000	2040		2055																		
MOCHOVCE34	Nuclear		2020	0		2070																		
NOVAKY_I3	Lignite		1960	0		2015																		
NOVAKY_I1112	Lignite		2000	0		2035																		
NOVAKY_II12	Lignite		1965	2015		2035																		
NOVAKY_II34	Lignite		1980	0		2020																		
PANICKE	Gas		2010	2035		2055																		
POVAZSKA_CCGT	Gas		2010	2035		2055																		
VOJANY_Coal1	Coal		1970	2020		2035																		
ZARNOVICA	Biomass		2015	0		2055																		
ZVOLENSKA2	Lignite	Biomass	1995	0	2025	2035	457.9						1											
ZVOLENSKA1	Lignite	Biomass	1985	0	2020	2035	457.9						1											

Figure 74 CPS supply input file: Fuelswitch sheet

The reader is referred to Section 5.6.6 Options for changing parameters’ values exogenously, for a detailed description on how to affect policies regarding fuel switching in power plants.

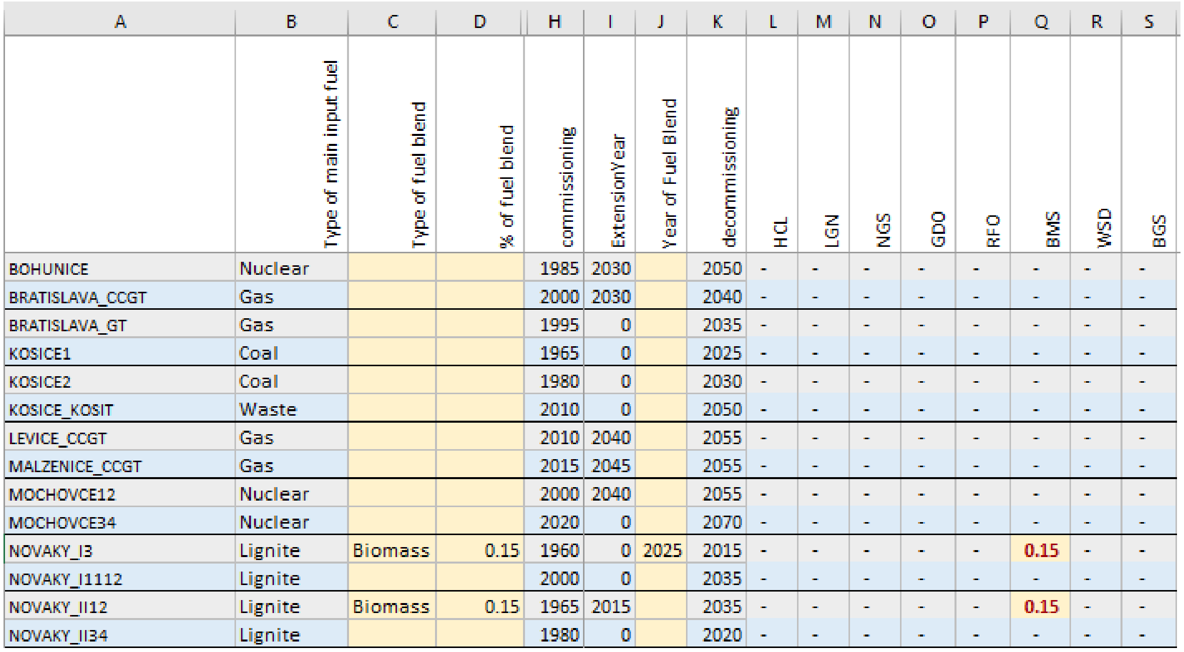
5.6.3. Fuelblend

In “Fuelblend” sheet, the user can exogenously define the existing plants which have a fuel blending opportunity (e.g. cofiring coal/biomass plants).

The columns B – S of the fuelblend sheet are explained below:

- Type of main input fuel: Type of main input fuel
- Type of fuel blend: Type of fuel blend
- % of fuel blend: Percentage of fuel blend
- Commissioning: Year of commissioning of the power plant
- ExtensionYear: Year of life extension of the power plant

- Year of Fuel Blend: Year of fuel blend
- Decommissioning: Year of decommissioning of the power plant
- HCL: Hard Coal
- LGN: Lignite
- NGS: Natural Gas
- GDO: Diesel
- RFO: Fuel Oil
- BMS: Biomass Solids
- WSD: Waste solids
- BGS: Biogas



A	B	C	D	H	I	J	K	L	M	N	O	P	Q	R	S
	Type of main input fuel	Type of fuel blend	% of fuel blend	commissioning	ExtensionYear	Year of Fuel Blend	decommissioning	HCL	LGN	NGS	GDO	RFO	BMS	WSD	BGS
BOHUNICE	Nuclear			1985	2030		2050	-	-	-	-	-	-	-	-
BRATISLAVA_CCGT	Gas			2000	2030		2040	-	-	-	-	-	-	-	-
BRATISLAVA_GT	Gas			1995	0		2035	-	-	-	-	-	-	-	-
KOSICE1	Coal			1965	0		2025	-	-	-	-	-	-	-	-
KOSICE2	Coal			1980	0		2030	-	-	-	-	-	-	-	-
KOSICE_KOSIT	Waste			2010	0		2050	-	-	-	-	-	-	-	-
LEVICE_CCGT	Gas			2010	2040		2055	-	-	-	-	-	-	-	-
MALZENICE_CCGT	Gas			2015	2045		2055	-	-	-	-	-	-	-	-
MOCHOVCE12	Nuclear			2000	2040		2055	-	-	-	-	-	-	-	-
MOCHOVCE34	Nuclear			2020	0		2070	-	-	-	-	-	-	-	-
NOVAKY_I3	Lignite	Biomass	0.15	1960	0	2025	2015	-	-	-	-	-	0.15	-	-
NOVAKY_I1112	Lignite			2000	0		2035	-	-	-	-	-	-	-	-
NOVAKY_II12	Lignite	Biomass	0.15	1965	2015		2035	-	-	-	-	-	0.15	-	-
NOVAKY_II34	Lignite			1980	0		2020	-	-	-	-	-	-	-	-

Figure 75 CPS supply input file: Fuelblend sheet

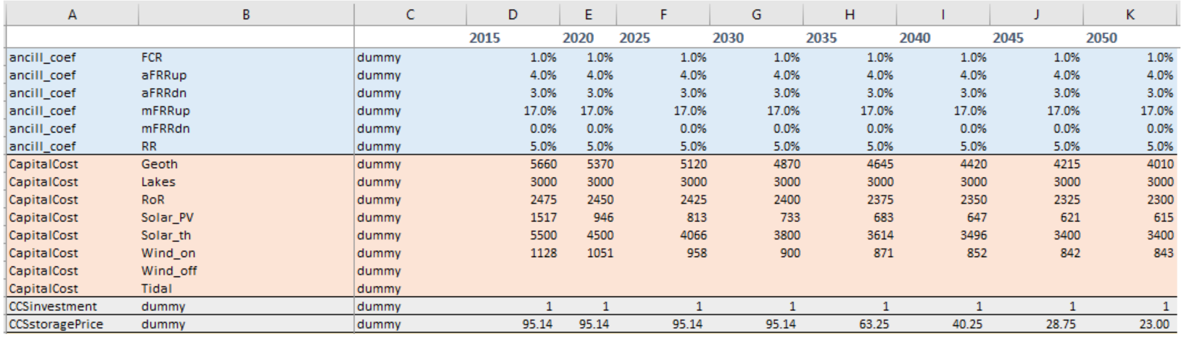
5.6.4. Policy_power_data

In the policy_power_data sheet, the user can exogenously change different parameters to simulate various policies. These parameters are:

- Ancil_coef: Level of each type of reserve % of demand
- Capitalcost: Overnight capital cost by plant type in €/kW
- CCSinvestment: Indicator of whether CCS is permitted [0,1]
- CCSstoragePrice: Price of CCS storage in €/tnCO$_2$ captured
- CurtailmentCost: Curtailment cost in €/kWh$_{elec}$
- Daily: Maximum charging hours per day for storage power plants in hours

- DHHGeneration, Max: Maximum District Heating Generation %
- DHHGeneration, Min: Minimum District Heating Generation %
- DHHGenTypeMax: District Heating max generation per plant type %
- DHHGenTypeMin: District Heating min generation per plant type %
- INDCHPGeneration, Max: Maximum share of steam generation from Industrial CHP plants %
- INDCHPGeneration, Min: Minimum share of steam generation from Industrial CHP plants %
- FITsupport, MaxBudget: Maximum budget of FiT support in M€
- FITsupport: Indicator of FIT existence [0,1]
- FITtariff: Feed-in-Tariff price in €/kWh$_{elec}$
- FITyears: Duration of FIT in years
- Max_fuel: Maximum quantity of fuel in GWh$_{fuel}$
- Max_resource: Maximum water resource for hydro in GWh$_{elec}$ per year
- Max_new_capacity: Maximum capacity of new investments per plant type in GW
- Max_oper: Maximum operational hours per power plant type in hours
- MaxCO$_2$capt: Maximum quantity of CO$_2$ captured in Mtn CO$_2$
- NetImports: Net imports per type of load (Base, medium, high and Annual) in GWh
- Imports: Imports per type of load (Base, medium, high) in GWh
- Exports: Exports per type of load (Base, medium, high) in GWh
- PtoXaddSupport: Support for power to X in €/kWh$_{elec}$
- SocialDiscount: Social discount rate %
- PrivateDiscount: Private discount rate %
- StorageaddSupport: Support for electricity storage in €/kWh$_{elec}$
- Losses: Grid losses % final demand
- AddCapitalCost: Additional capital cost per plant type in €/kW
- MinimumCHPheat: Minimum heat output for CHP power plants %
- HeatShare: Heat share % total heat demand
- LoadFactor: Load factor %
- Elec_elasticity: Electricity elasticity [#]
- ProfitRate: Profit rate %
- Expected_OpHours: Expected operational hours in hours
- Transmission Grid, Benchmark Tariff: Benchmark Tariff of transmission grid in €/kWh$_{elec}$
- Transmission Grid, Replacement: Percentage of the transmission grid that needs to be replaced % of installed GW$_{elec}$
- Transmission Grid, Extension: Extension of the transmission grid % of installed GW$_{elec}$
- Transmission Grid, Exogenous Investment: Exogenous Investment in transmission grid infrastructure % of installed GW$_{elec}$
- Distribution Grid, Benchmark Tariff: Benchmark Tariff of distribution grid in €/kWh$_{elec}$

- Distribution Grid, Replacement: Percentage of the distribution grid that needs to be replaced % of installed GW_{elec}
- Distribution Grid, Extension: Extension of the distribution grid % of installed GW_{elec}
- Distribution Grid, Exogenous Investment: Exogenous Investment in distribution grid infrastructure % of installed GW_{elec}
- DH Network, Benchmark Tariff: Benchmark Tariff of district heating network in €/kWh_{th}
- DH Network, Replacement : Percentage of the district heating network that needs to be replaced % of installed GW_{th}
- DH Network, Extension: Extension of the district heating network % of installed GW_{th}
- DH Network, Exogenous Investment: Exogenous Investment in district heating network % of installed GW_{th}
- ElecAddSupport: Support for electricity generation in €/kWh_{elec}
- CleanFuel, Storage: Use of clean fuel production as an energy storage mean [0,1]



A	B	C	D	E	F	G	H	I	J	K
			2015	2020	2025	2030	2035	2040	2045	2050
ancill_coef	FCR	dummy	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%
ancill_coef	aFRRup	dummy	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%
ancill_coef	aFRRdn	dummy	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%
ancill_coef	mFRRup	dummy	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%
ancill_coef	mFRRdn	dummy	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ancill_coef	RR	dummy	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%
CapitalCost	Geoth	dummy	5660	5370	5120	4870	4645	4420	4215	4010
CapitalCost	Lakes	dummy	3000	3000	3000	3000	3000	3000	3000	3000
CapitalCost	RoR	dummy	2475	2450	2425	2400	2375	2350	2325	2300
CapitalCost	Solar_PV	dummy	1517	946	813	733	683	647	621	615
CapitalCost	Solar_th	dummy	5500	4500	4066	3800	3614	3496	3400	3400
CapitalCost	Wind_on	dummy	1128	1051	958	900	871	852	842	843
CapitalCost	Wind_off	dummy								
CapitalCost	Tidal	dummy								
CCSinvestment	dummy	dummy	1	1	1	1	1	1	1	1
CCSstoragePrice	dummy	dummy	95.14	95.14	95.14	95.14	63.25	40.25	28.75	23.00

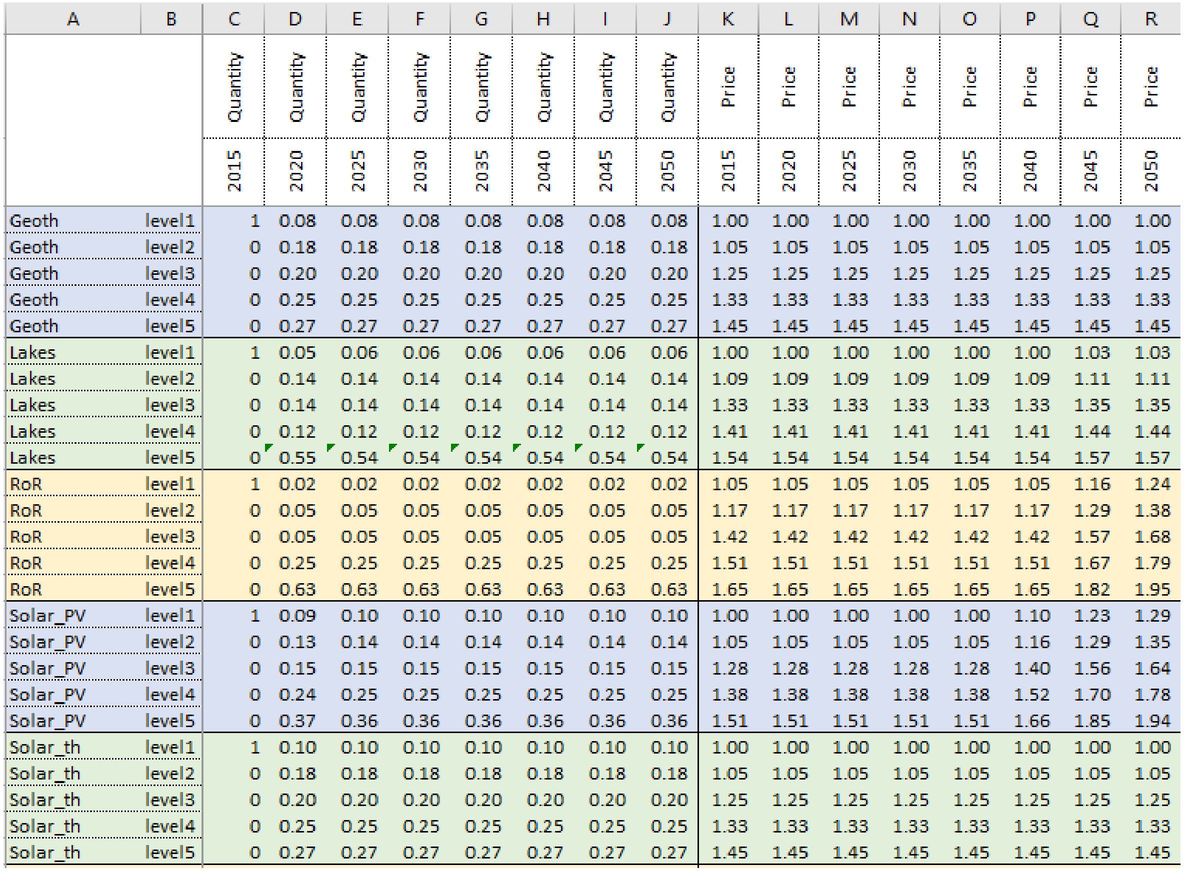
Figure 76 CPS supply input file: Sample of the Policy_Power_data sheet

The reader is referred to Section 5.6.6. Options for changing parameters' values exogenously for detailed examples on the use of this sheet.

5.6.5. Level_struct (non – linear curves)

As mentioned in Section 5.3.1.5 Non-linear cost curves, the CPS Power Module is using an elegant approach to account for the relative difficulty in developing incremental capacity due to potential fuel exhaustion, site availability restrictions and RES limitations, due to resource exploitation. This difficulty is modelled through non-linear cost-quantity curves representing the cost-supply locus of a resource (fuel supply, renewable potentials and limitations on development of new power plant sites, where applicable e.g. nuclear plant sites, wind sites, etc.).

This sheet includes these non – linear cost curves. The columns C-J represent the quantity, while column K-R the price at each level (step) of the stepwise linearized curve. The values regarding quantity are shares over the total potential of each resource (capacity for the investments and fuel quantity for fuels). The values regarding price are multiplier of the price. For example, as shown in the figure below, the first step of the curve for geothermal investment reflect that 8% of the potential investment can be realized with an investment cost multiplied by the factor of 1, at the second step an additional 18% of the geothermal investment has higher costs (multiplied by factor 1.05). The user is able to change these curves, so as to facilitate or creating difficulties due to resource exploitation or other reasons for the renewable investment. Similarly, this mechanisms applies to fuel resources.



A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
		Quantity	Quantity	Quantity	Quantity	Quantity	Quantity	Quantity	Quantity	Price	Price	Price	Price	Price	Price	Price	Price
		2015	2020	2025	2030	2035	2040	2045	2050	2015	2020	2025	2030	2035	2040	2045	2050
Geoth	level1	1	0.08	0.08	0.08	0.08	0.08	0.08	0.08	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Geoth	level2	0	0.18	0.18	0.18	0.18	0.18	0.18	0.18	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Geoth	level3	0	0.20	0.20	0.20	0.20	0.20	0.20	0.20	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Geoth	level4	0	0.25	0.25	0.25	0.25	0.25	0.25	0.25	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33
Geoth	level5	0	0.27	0.27	0.27	0.27	0.27	0.27	0.27	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45
Lakes	level1	1	0.05	0.06	0.06	0.06	0.06	0.06	0.06	1.00	1.00	1.00	1.00	1.00	1.00	1.03	1.03
Lakes	level2	0	0.14	0.14	0.14	0.14	0.14	0.14	0.14	1.09	1.09	1.09	1.09	1.09	1.09	1.11	1.11
Lakes	level3	0	0.14	0.14	0.14	0.14	0.14	0.14	0.14	1.33	1.33	1.33	1.33	1.33	1.33	1.35	1.35
Lakes	level4	0	0.12	0.12	0.12	0.12	0.12	0.12	0.12	1.41	1.41	1.41	1.41	1.41	1.41	1.44	1.44
Lakes	level5	0	0.55	0.54	0.54	0.54	0.54	0.54	0.54	1.54	1.54	1.54	1.54	1.54	1.54	1.57	1.57
RoR	level1	1	0.02	0.02	0.02	0.02	0.02	0.02	0.02	1.05	1.05	1.05	1.05	1.05	1.05	1.16	1.24
RoR	level2	0	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.17	1.17	1.17	1.17	1.17	1.17	1.29	1.38
RoR	level3	0	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.42	1.42	1.42	1.42	1.42	1.42	1.57	1.68
RoR	level4	0	0.25	0.25	0.25	0.25	0.25	0.25	0.25	1.51	1.51	1.51	1.51	1.51	1.51	1.67	1.79
RoR	level5	0	0.63	0.63	0.63	0.63	0.63	0.63	0.63	1.65	1.65	1.65	1.65	1.65	1.65	1.82	1.95
Solar_PV	level1	1	0.09	0.10	0.10	0.10	0.10	0.10	0.10	1.00	1.00	1.00	1.00	1.00	1.10	1.23	1.29
Solar_PV	level2	0	0.13	0.14	0.14	0.14	0.14	0.14	0.14	1.05	1.05	1.05	1.05	1.05	1.16	1.29	1.35
Solar_PV	level3	0	0.15	0.15	0.15	0.15	0.15	0.15	0.15	1.28	1.28	1.28	1.28	1.28	1.40	1.56	1.64
Solar_PV	level4	0	0.24	0.25	0.25	0.25	0.25	0.25	0.25	1.38	1.38	1.38	1.38	1.38	1.52	1.70	1.78
Solar_PV	level5	0	0.37	0.36	0.36	0.36	0.36	0.36	0.36	1.51	1.51	1.51	1.51	1.51	1.66	1.85	1.94
Solar_th	level1	1	0.10	0.10	0.10	0.10	0.10	0.10	0.10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Solar_th	level2	0	0.18	0.18	0.18	0.18	0.18	0.18	0.18	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Solar_th	level3	0	0.20	0.20	0.20	0.20	0.20	0.20	0.20	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Solar_th	level4	0	0.25	0.25	0.25	0.25	0.25	0.25	0.25	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33
Solar_th	level5	0	0.27	0.27	0.27	0.27	0.27	0.27	0.27	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45

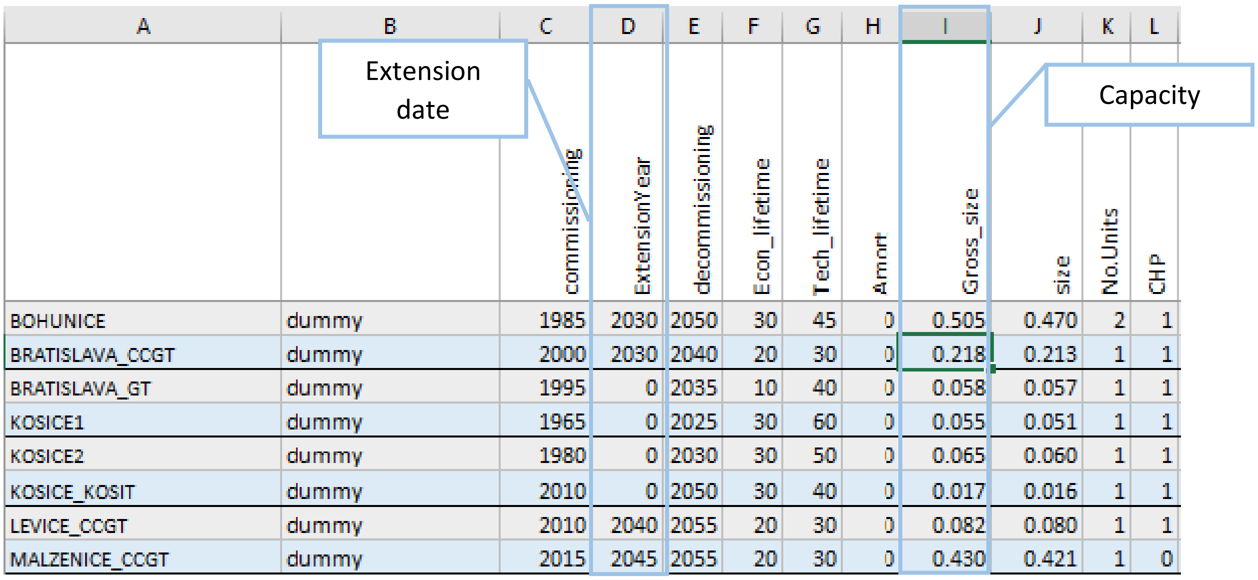
Figure 77 CPS supply input file: Level_struct sheet

5.6.6. Options for changing parameters' values exogenously

The input file gives the user the ability to change a wide variety of parameters in order to represent different policy assumptions across different scenarios. The reader may find below some of the main options.

1) How to change of the capacity of an existing plant or the fixed (standardized) size of a new investment - **Techdata_plants sheet**

The user has the ability to change the capacity of a power plant (both existing as well as future plants) exogenously, by changing the content of the cells in column I as shown in Figure 78.

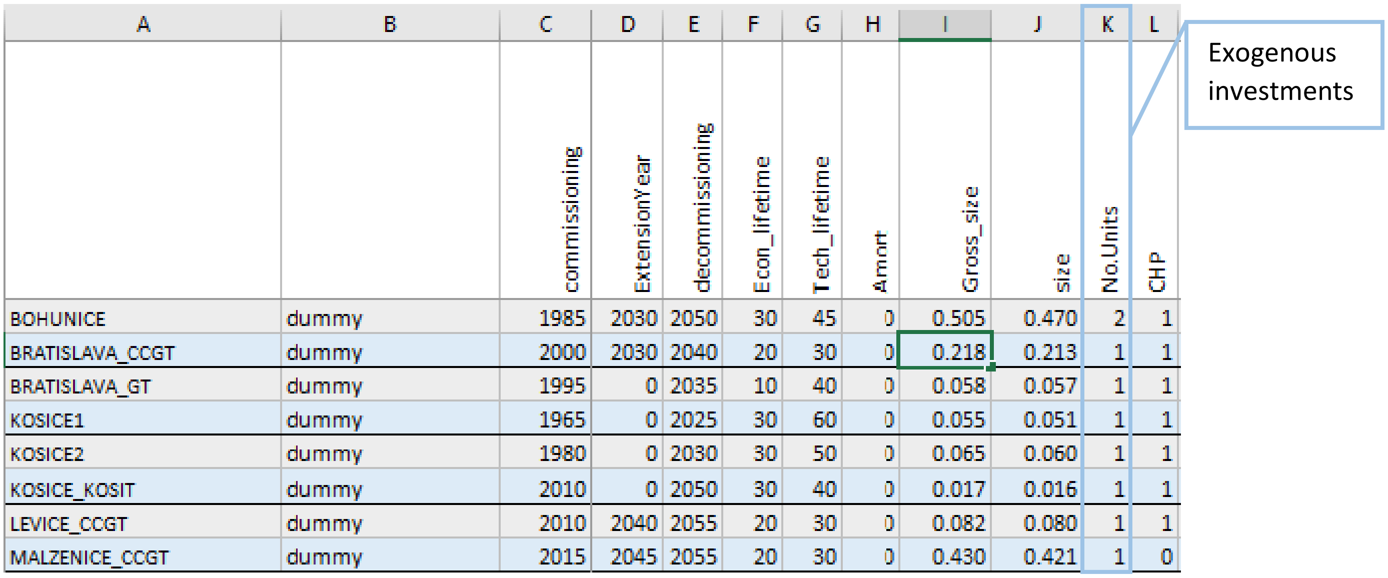


A	B	C	D	E	F	G	H	I	J	K	L
		commissioning	ExtensionYear	decommissioning	Econ_lifetime	Tech_lifetime	Amort	Gross_size	size	No.Units	CHP
BOHUNICE	dummy	1985	2030	2050	30	45	0	0.505	0.470	2	1
BRATISLAVA_CCGT	dummy	2000	2030	2040	20	30	0	0.218	0.213	1	1
BRATISLAVA_GT	dummy	1995	0	2035	10	40	0	0.058	0.057	1	1
KOSICE1	dummy	1965	0	2025	30	60	0	0.055	0.051	1	1
KOSICE2	dummy	1980	0	2030	30	50	0	0.065	0.060	1	1
KOSICE_KOSIT	dummy	2010	0	2050	30	40	0	0.017	0.016	1	1
LEVICE_CCGT	dummy	2010	2040	2055	20	30	0	0.082	0.080	1	1
MALZENICE_CCGT	dummy	2015	2045	2055	20	30	0	0.430	0.421	1	0

Figure 78 How to change capacity and extension date exogenously

2) How to introduce an exogenous investment - **Techdata_plants sheet**

In case a project is known, the user can introduce this investment exogenously in the CPS. Column K represent the number of installed units for each plant type. For new investments this column is blank. For example: if a CHP coal plant of 334MW is expected to be commissioned in 2020, the user has to apply the value of 1 to column K and the corresponding row; in case two coal plants are expected to be commissioned the value of 2 etc. It must be noted that the user must fill column K, if needed, only with integer values.



A	B	C	D	E	F	G	H	I	J	K	L
		commissioning	ExtensionYear	decommissioning	Econ_lifetime	Tech_lifetime	Amort	Gross_size	size	No.Units	CHP
BOHUNICE	dummy	1985	2030	2050	30	45	0	0.505	0.470	2	1
BRATISLAVA_CCGT	dummy	2000	2030	2040	20	30	0	0.218	0.213	1	1
BRATISLAVA_GT	dummy	1995	0	2035	10	40	0	0.058	0.057	1	1
KOSICE1	dummy	1965	0	2025	30	60	0	0.055	0.051	1	1
KOSICE2	dummy	1980	0	2030	30	50	0	0.065	0.060	1	1
KOSICE_KOSIT	dummy	2010	0	2050	30	40	0	0.017	0.016	1	1
LEVICE_CCGT	dummy	2010	2040	2055	20	30	0	0.082	0.080	1	1
MALZENICE_CCGT	dummy	2015	2045	2055	20	30	0	0.430	0.421	1	0

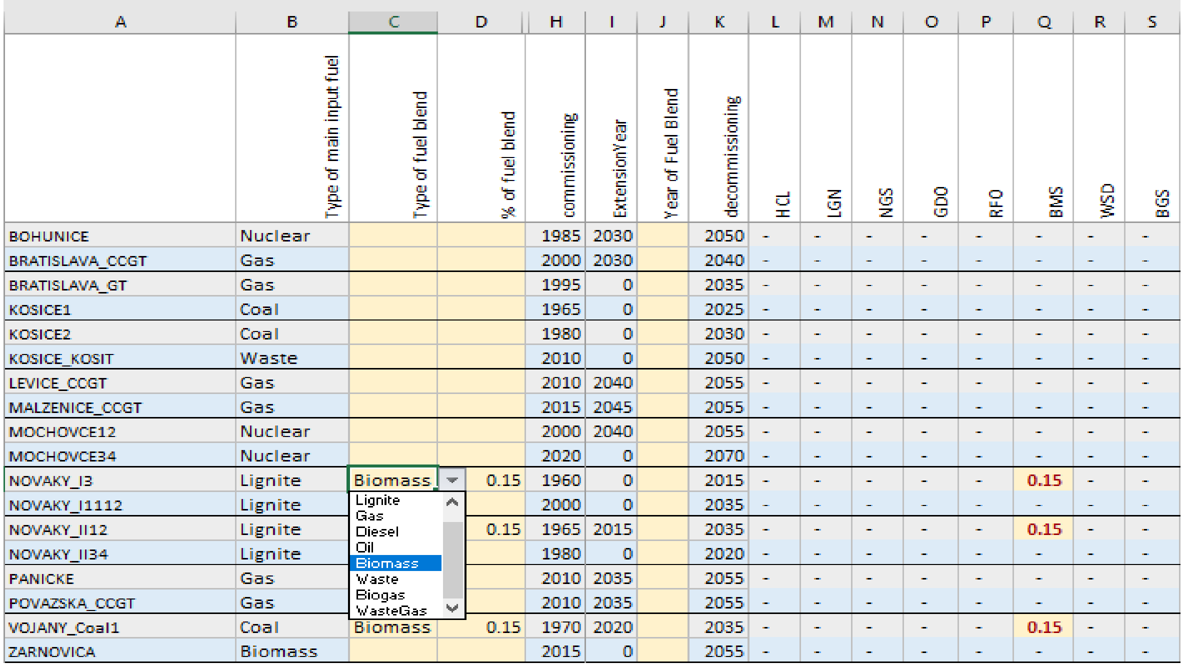
Figure 79 How to introduce an exogenous investment

3) How to change the year of lifetime extension for a power plant - **Techdata_plants sheet**

The user has the ability to change the extension date of a power plant exogenously, by changing the content of the cells in column D as shown in Figure 78.

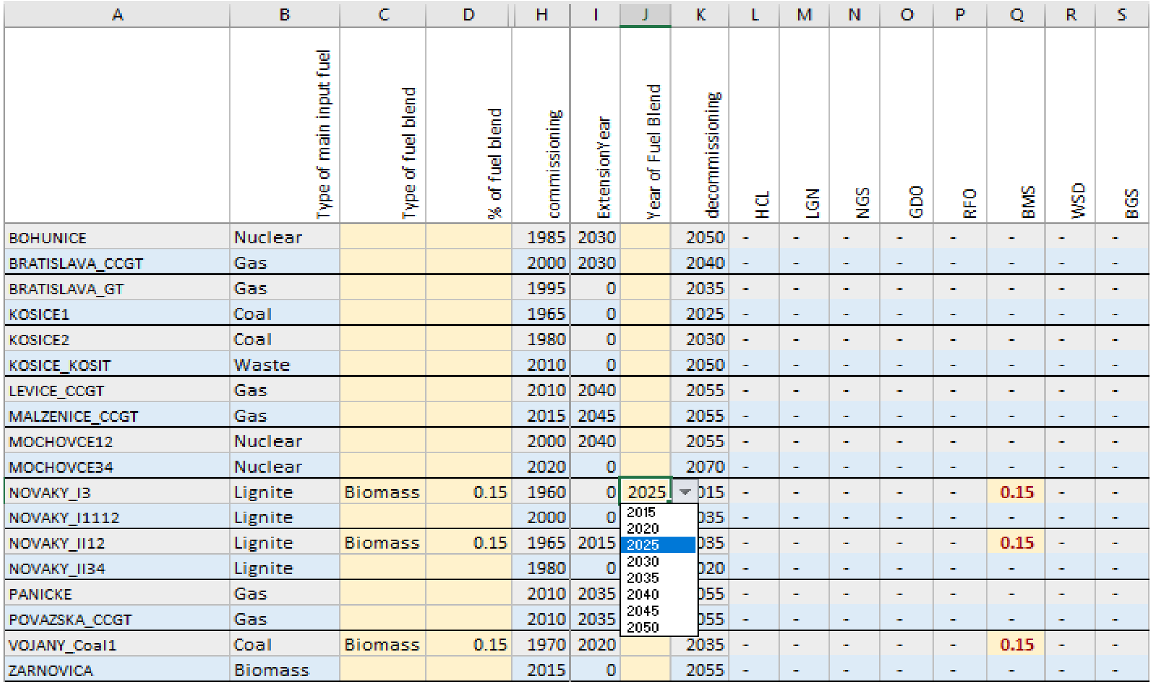
4) How to introduce fuel blend for a power plant– **Fuelblend sheet**

The user can choose the type and the year of fuel blend from the dropdown lists of columns C and J as shown in Figure 80 and Figure 81. The user can also decide the share of the fuel blend (column D).



A	B	C	D	H	I	J	K	L	M	N	O	P	Q	R	S
	Type of main input fuel	Type of fuel blend	% of fuel blend	commissioning	ExtensionYear	Year of Fuel Blend	decommissioning	HCL	LGN	NGS	GDO	RFO	BMS	WSD	BGS
BOHUNICE	Nuclear			1985	2030		2050	-	-	-	-	-	-	-	-
BRATISLAVA_CCGT	Gas			2000	2030		2040	-	-	-	-	-	-	-	-
BRATISLAVA_GT	Gas			1995	0		2035	-	-	-	-	-	-	-	-
KOSICE1	Coal			1965	0		2025	-	-	-	-	-	-	-	-
KOSICE2	Coal			1980	0		2030	-	-	-	-	-	-	-	-
KOSICE_KOSIT	Waste			2010	0		2050	-	-	-	-	-	-	-	-
LEVICE_CCGT	Gas			2010	2040		2055	-	-	-	-	-	-	-	-
MALZENICE_CCGT	Gas			2015	2045		2055	-	-	-	-	-	-	-	-
MOCHOVCE12	Nuclear			2000	2040		2055	-	-	-	-	-	-	-	-
MOCHOVCE34	Nuclear			2020	0		2070	-	-	-	-	-	-	-	-
NOVAKY_I3	Lignite	Biomass	0.15	1960	0		2015	-	-	-	-	-	0.15	-	-
NOVAKY_I1112	Lignite			2000	0		2035	-	-	-	-	-	-	-	-
NOVAKY_II12	Lignite		0.15	1965	2015		2035	-	-	-	-	-	0.15	-	-
NOVAKY_II34	Lignite			1980	0		2020	-	-	-	-	-	-	-	-
PANICKE	Gas			2010	2035		2055	-	-	-	-	-	-	-	-
POVAZSKA_CCGT	Gas			2010	2035		2055	-	-	-	-	-	-	-	-
VOJANY_Coal1	Coal	Biomass	0.15	1970	2020		2035	-	-	-	-	-	0.15	-	-
ZARNOVICA	Biomass			2015	0		2055	-	-	-	-	-	-	-	-

Figure 80 How to change type of fuel

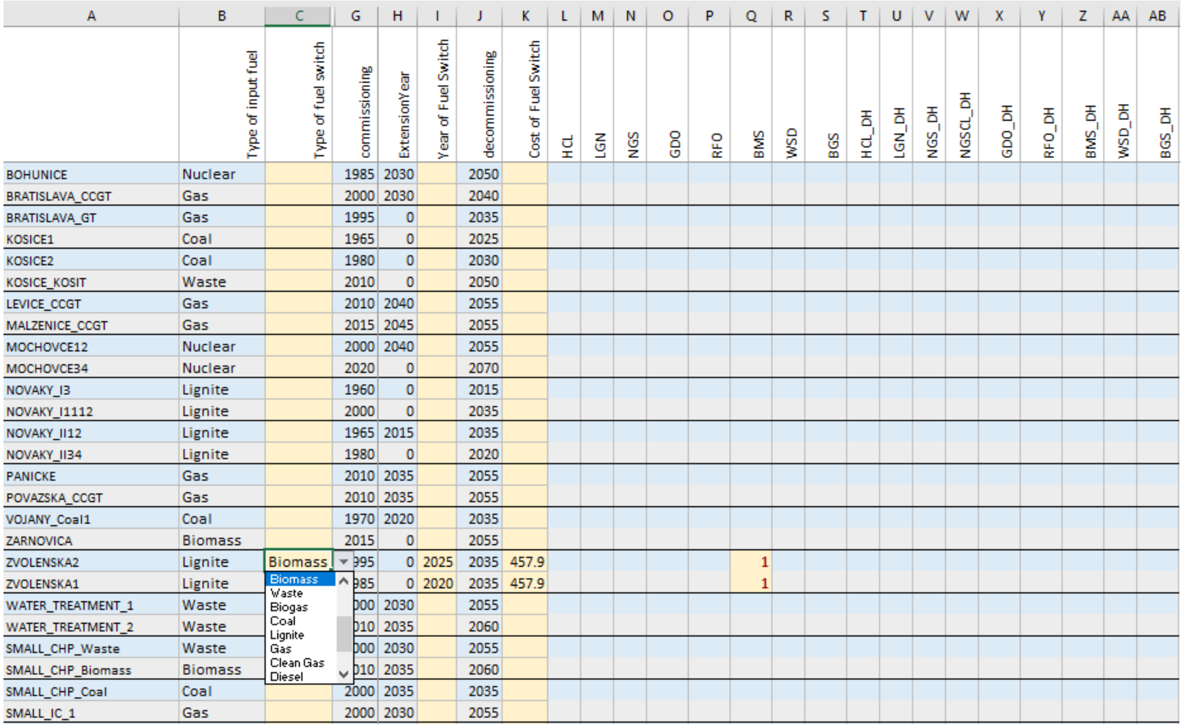


A	B	C	D	H	I	J	K	L	M	N	O	P	Q	R	S
	Type of main input fuel	Type of fuel blend	% of fuel blend	commissioning	ExtensionYear	Year of Fuel Blend	decommissioning	HCL	LGN	NGS	GDO	RFO	BMS	WSD	BGS
BOHUNICE	Nuclear			1985	2030		2050	-	-	-	-	-	-	-	-
BRATISLAVA_CCGT	Gas			2000	2030		2040	-	-	-	-	-	-	-	-
BRATISLAVA_GT	Gas			1995	0		2035	-	-	-	-	-	-	-	-
KOSICE1	Coal			1965	0		2025	-	-	-	-	-	-	-	-
KOSICE2	Coal			1980	0		2030	-	-	-	-	-	-	-	-
KOSICE_KOSIT	Waste			2010	0		2050	-	-	-	-	-	-	-	-
LEVICE_CCGT	Gas			2010	2040		2055	-	-	-	-	-	-	-	-
MALZENICE_CCGT	Gas			2015	2045		2055	-	-	-	-	-	-	-	-
MOCHOVCE12	Nuclear			2000	2040		2055	-	-	-	-	-	-	-	-
MOCHOVCE34	Nuclear			2020	0		2070	-	-	-	-	-	-	-	-
NOVAKY_I3	Lignite	Biomass	0.15	1960	0	2025	015	-	-	-	-	-	0.15	-	-
NOVAKY_I1112	Lignite			2000	0		035	-	-	-	-	-	-	-	-
NOVAKY_II12	Lignite	Biomass	0.15	1965	2015		035	-	-	-	-	-	0.15	-	-
NOVAKY_II34	Lignite			1980	0		020	-	-	-	-	-	-	-	-
PANICKE	Gas			2010	2035		055	-	-	-	-	-	-	-	-
POVAZSKA_CCGT	Gas			2010	2035		055	-	-	-	-	-	-	-	-
VOJANY_Coal1	Coal	Biomass	0.15	1970	2020		2035	-	-	-	-	-	0.15	-	-
ZARNOVICA	Biomass			2015	0		2055	-	-	-	-	-	-	-	-

Figure 81 How to change year of fuel blend

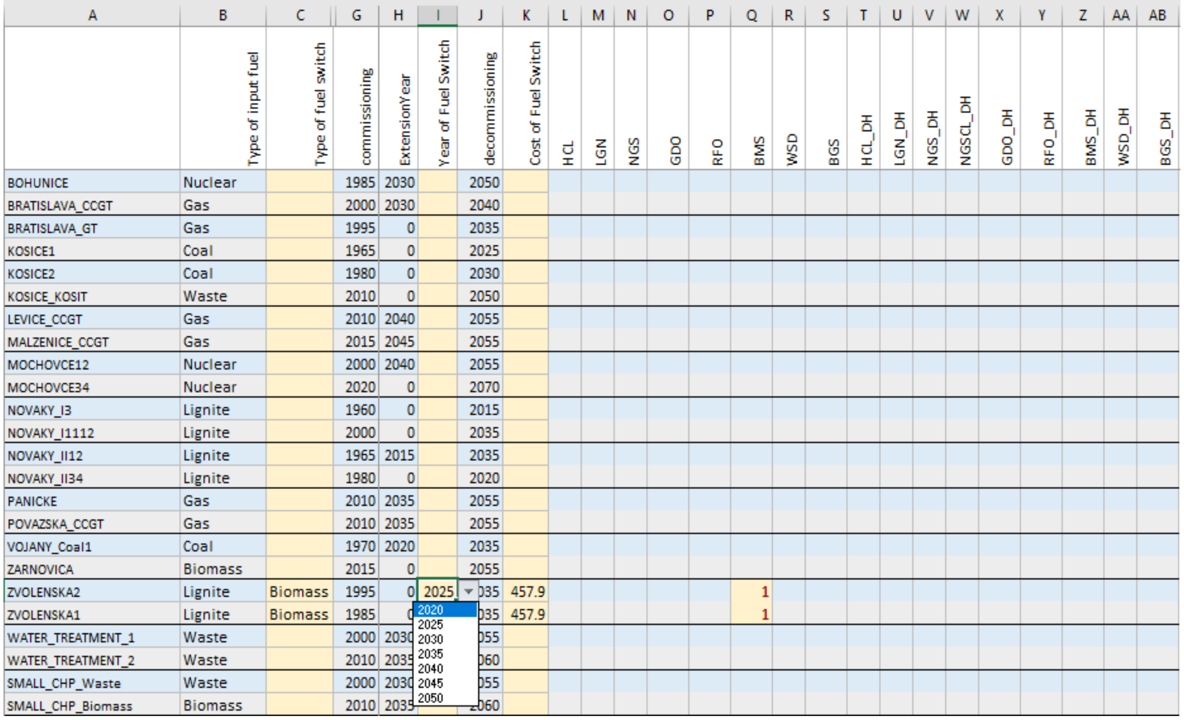
5) How to introduce fuel switching for a power plant - **Fuelswitch sheet**

As shown in Figure 82, the user can choose the type of the fuel switch from the dropdown list of column C. After choosing the type of fuel switch, the cell indicating the fuel type (columns L to AB) is automatically filled with 1. The user can also choose the year of the fuel switch from the dropdown list of column I as shown in Figure 83.



A	B	C	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB
	Type of input fuel	Type of fuel switch	commissioning	ExtensionYear	Year of Fuel Switch	decommissioning	Cost of Fuel Switch	HCL	LGN	NGS	GDO	RFO	BMS	WSD	BGS	HCL_DH	LGN_DH	NGS_DH	NGSCL_DH	GDO_DH	RFO_DH	BMS_DH	WSD_DH	BGS_DH
BOHUNICE	Nuclear		1985	2030		2050																		
BRATISLAVA_CCGT	Gas		2000	2030		2040																		
BRATISLAVA_GT	Gas		1995	0		2035																		
KOSICE1	Coal		1965	0		2025																		
KOSICE2	Coal		1980	0		2030																		
KOSICE_KOSIT	Waste		2010	0		2050																		
LEVICE_CCGT	Gas		2010	2040		2055																		
MALZENICE_CCGT	Gas		2015	2045		2055																		
MOCHOVCE12	Nuclear		2000	2040		2055																		
MOCHOVCE34	Nuclear		2020	0		2070																		
NOVAKY_I3	Lignite		1960	0		2015																		
NOVAKY_I1112	Lignite		2000	0		2035																		
NOVAKY_II12	Lignite		1965	2015		2035																		
NOVAKY_II34	Lignite		1980	0		2020																		
PANICKE	Gas		2010	2035		2055																		
POVAZSKA_CCGT	Gas		2010	2035		2055																		
VOJANY_Coal1	Coal		1970	2020		2035																		
ZARNOVICA	Biomass		2015	0		2055																		
ZVOLENSKA2	Lignite	Biomass	995	0	2025	2035	457.9						1											
ZVOLENSKA1	Lignite		985	0	2020	2035	457.9						1											
WATER_TREATMENT_1	Waste		000	2030		2055																		
WATER_TREATMENT_2	Waste		010	2035		2060																		
SMALL_CHP_Waste	Waste		000	2030		2055																		
SMALL_CHP_Biomass	Biomass		010	2035		2060																		
SMALL_CHP_Coal	Coal		2000	2035		2035																		
SMALL_IC_1	Gas		2000	2030		2055																		

Figure 82 How to change type of fuel switch



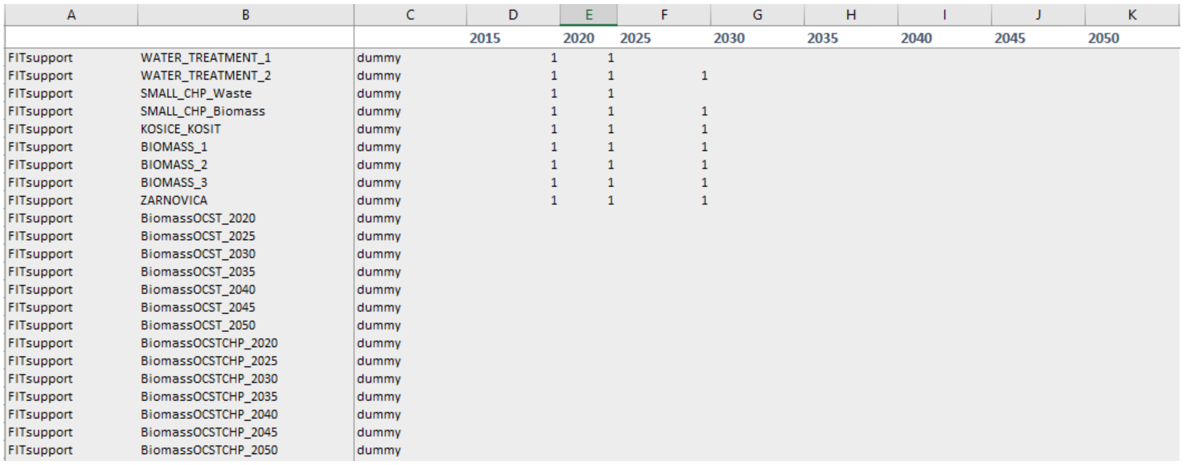
A	B	C	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB
	Type of input fuel	Type of fuel switch	commissioning	ExtensionYear	Year of Fuel Switch	decommissioning	Cost of Fuel Switch	HCL	LGN	NGS	GDO	RFO	BMS	WSD	BGS	HCL_DH	LGN_DH	NGS_DH	NGSCL_DH	GDO_DH	RFO_DH	BMS_DH	WSD_DH	BGS_DH
BOHUNICE	Nuclear		1985	2030		2050																		
BRATISLAVA_CCGT	Gas		2000	2030		2040																		
BRATISLAVA_GT	Gas		1995	0		2035																		
KOSICE1	Coal		1965	0		2025																		
KOSICE2	Coal		1980	0		2030																		
KOSICE_KOSIT	Waste		2010	0		2050																		
LEVICE_CCGT	Gas		2010	2040		2055																		
MALZENICE_CCGT	Gas		2015	2045		2055																		
MOCHOVCE12	Nuclear		2000	2040		2055																		
MOCHOVCE34	Nuclear		2020	0		2070																		
NOVAKY_I3	Lignite		1960	0		2015																		
NOVAKY_I1112	Lignite		2000	0		2035																		
NOVAKY_II12	Lignite		1965	2015		2035																		
NOVAKY_II34	Lignite		1980	0		2020																		
PANICKE	Gas		2010	2035		2055																		
POVAZSKA_CCGT	Gas		2010	2035		2055																		
VOJANY_Coal1	Coal		1970	2020		2035																		
ZARNOVICA	Biomass		2015	0		2055																		
ZVOLENSKA2	Lignite	Biomass	1995	0	2025	035	457.9						1											
ZVOLENSKA1	Lignite	Biomass	1985	0		035	457.9						1											
WATER_TREATMENT_1	Waste		2000	2030		055																		
WATER_TREATMENT_2	Waste		2010	2035		060																		
SMALL_CHP_Waste	Waste		2000	2030		055																		
SMALL_CHP_Biomass	Biomass		2010	2035		060																		

Figure 83 How to change year of fuel switch

6) How to introduce a Feed-In-Tariff equivalent policy - **Policy_power_data sheet**

In order to add FIT mechanism the user has to follow the next steps:

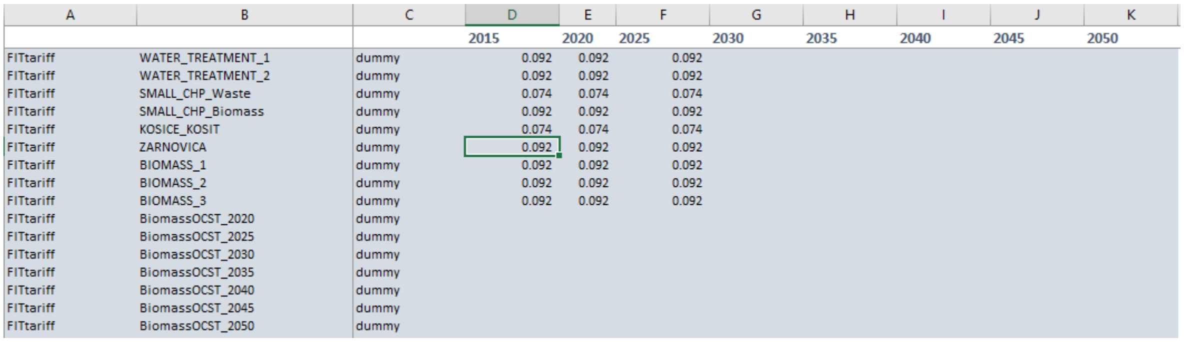
- Step 1: At **Policy_power_data** sheet, rows 127-211, select the types of plant eligible for FIT and fill the cells with 1 for the period (years), during which the FIT mechanism will exist.



A	B	C	D	E	F	G	H	I	J	K
			2015	2020	2025	2030	2035	2040	2045	2050
FITsupport	WATER_TREATMENT_1	dummy	1	1						
FITsupport	WATER_TREATMENT_2	dummy	1	1	1					
FITsupport	SMALL_CHP_Waste	dummy	1	1						
FITsupport	SMALL_CHP_Biomass	dummy	1	1	1					
FITsupport	KOSICE_KOSIT	dummy	1	1	1					
FITsupport	BIOMASS_1	dummy	1	1	1					
FITsupport	BIOMASS_2	dummy	1	1	1					
FITsupport	BIOMASS_3	dummy	1	1	1					
FITsupport	ZARNOVICA	dummy	1	1	1					
FITsupport	BiomassOCST_2020	dummy								
FITsupport	BiomassOCST_2025	dummy								
FITsupport	BiomassOCST_2030	dummy								
FITsupport	BiomassOCST_2035	dummy								
FITsupport	BiomassOCST_2040	dummy								
FITsupport	BiomassOCST_2045	dummy								
FITsupport	BiomassOCST_2050	dummy								
FITsupport	BiomassOCSTCHP_2020	dummy								
FITsupport	BiomassOCSTCHP_2025	dummy								
FITsupport	BiomassOCSTCHP_2030	dummy								
FITsupport	BiomassOCSTCHP_2035	dummy								
FITsupport	BiomassOCSTCHP_2040	dummy								
FITsupport	BiomassOCSTCHP_2045	dummy								
FITsupport	BiomassOCSTCHP_2050	dummy								

Figure 84 Add FIT support

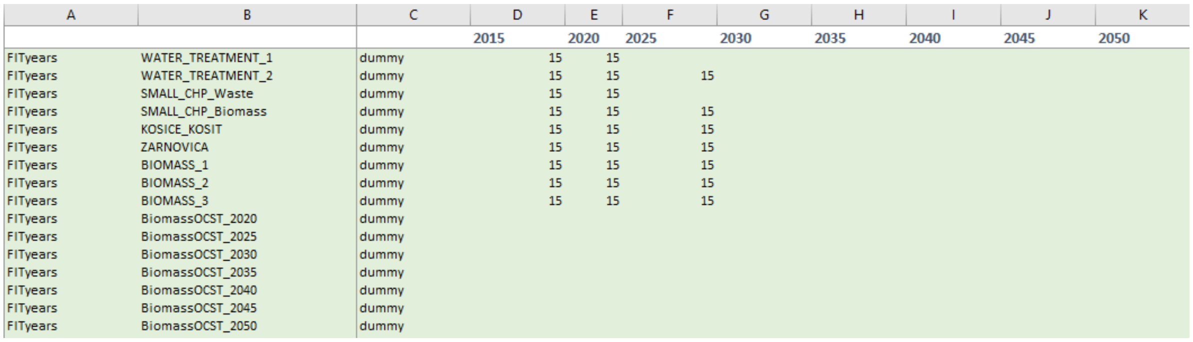
- Step 2: At **Policy_power_data** sheet, rows 212-295, fill the cells with the FIT price for the type of generation and the years that the FIT mechanism will exist.



A	B	C	D	E	F	G	H	I	J	K
			2015	2020	2025	2030	2035	2040	2045	2050
FITtariff	WATER_TREATMENT_1	dummy	0.092	0.092	0.092					
FITtariff	WATER_TREATMENT_2	dummy	0.092	0.092	0.092					
FITtariff	SMALL_CHP_Waste	dummy	0.074	0.074	0.074					
FITtariff	SMALL_CHP_Biomass	dummy	0.092	0.092	0.092					
FITtariff	KOSICE_KOSIT	dummy	0.074	0.074	0.074					
FITtariff	ZARNOVICA	dummy	0.092	0.092	0.092					
FITtariff	BIOMASS_1	dummy	0.092	0.092	0.092					
FITtariff	BIOMASS_2	dummy	0.092	0.092	0.092					
FITtariff	BIOMASS_3	dummy	0.092	0.092	0.092					
FITtariff	BiomassOCST_2020	dummy								
FITtariff	BiomassOCST_2025	dummy								
FITtariff	BiomassOCST_2030	dummy								
FITtariff	BiomassOCST_2035	dummy								
FITtariff	BiomassOCST_2040	dummy								
FITtariff	BiomassOCST_2045	dummy								
FITtariff	BiomassOCST_2050	dummy								

Figure 85 Add FIT tariff

- Step 3: At **Policy_power_data**, rows 296-379, fill the cells with the duration of the FIT years for the type of generation and the years that the FIT mechanism will exist.

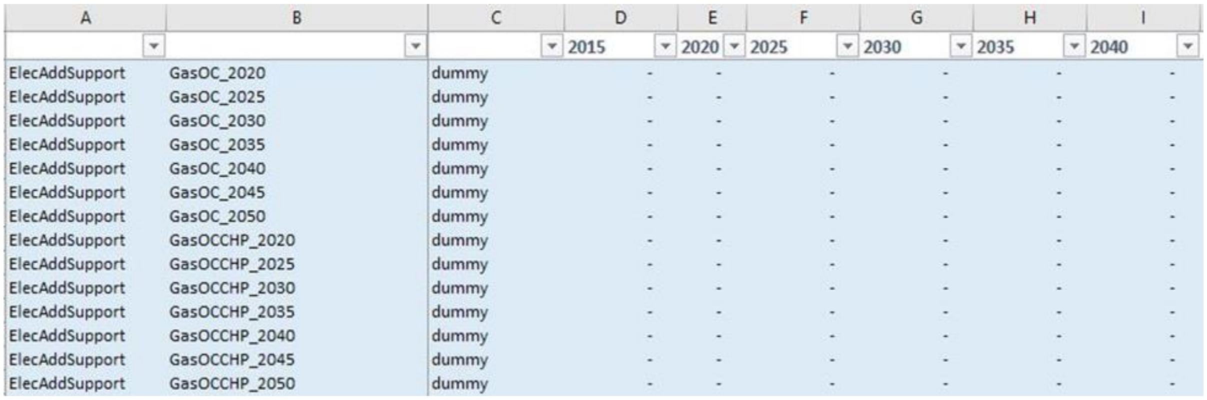


A	B	C	D	E	F	G	H	I	J	K
			2015	2020	2025	2030	2035	2040	2045	2050
FITyears	WATER_TREATMENT_1	dummy	15	15						
FITyears	WATER_TREATMENT_2	dummy	15	15	15					
FITyears	SMALL_CHP_Waste	dummy	15	15						
FITyears	SMALL_CHP_Biomass	dummy	15	15	15					
FITyears	KOSICE_KOSIT	dummy	15	15	15					
FITyears	ZARNOVICA	dummy	15	15	15					
FITyears	BIOMASS_1	dummy	15	15	15					
FITyears	BIOMASS_2	dummy	15	15	15					
FITyears	BIOMASS_3	dummy	15	15	15					
FITyears	BiomassOCST_2020	dummy								
FITyears	BiomassOCST_2025	dummy								
FITyears	BiomassOCST_2030	dummy								
FITyears	BiomassOCST_2035	dummy								
FITyears	BiomassOCST_2040	dummy								
FITyears	BiomassOCST_2045	dummy								
FITyears	BiomassOCST_2050	dummy								

Figure 86 Add FiT years

6) How to add a new policy promoting the electricity generation of a plant - **Policy_power_data sheet**

The user has the ability to introduce policies promoting the electricity generation of certain plant types. These policies are reflected with the use of "shadow values" – virtual subsidies. The user selects the eligible plants (rows) and the years for which this policy will be introduced (columns D-K) and enter the values (€/MWhe). It must be noted that these virtual subsidies are not real subsidies and are not taken into account in the pricing calculations.

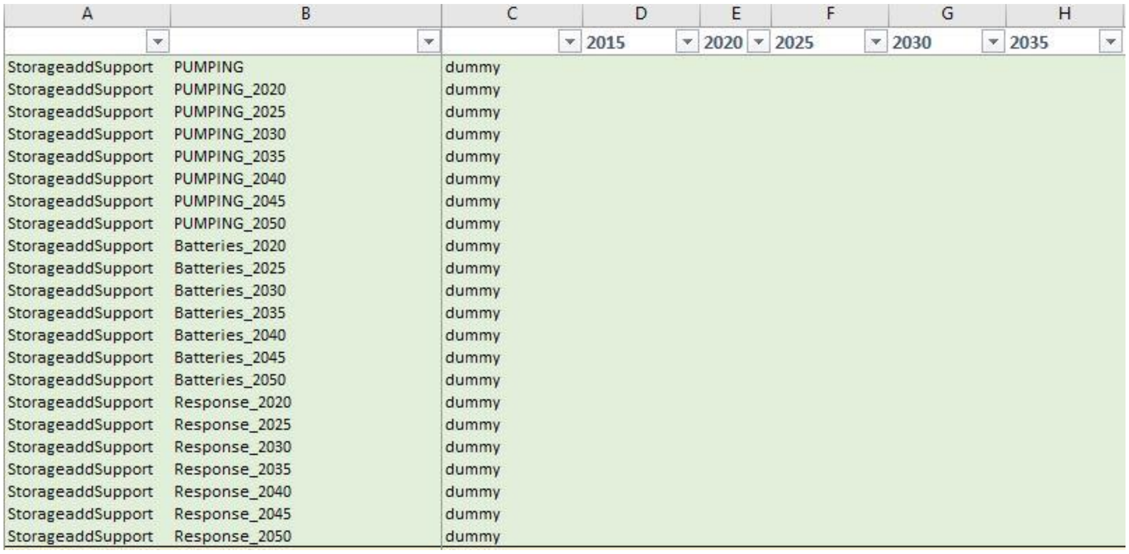


A	B	C	D	E	F	G	H	I
			2015	2020	2025	2030	2035	2040
ElecAddSupport	GasOC_2020	dummy	-	-	-	-	-	-
ElecAddSupport	GasOC_2025	dummy	-	-	-	-	-	-
ElecAddSupport	GasOC_2030	dummy	-	-	-	-	-	-
ElecAddSupport	GasOC_2035	dummy	-	-	-	-	-	-
ElecAddSupport	GasOC_2040	dummy	-	-	-	-	-	-
ElecAddSupport	GasOC_2045	dummy	-	-	-	-	-	-
ElecAddSupport	GasOC_2050	dummy	-	-	-	-	-	-
ElecAddSupport	GasOCCHP_2020	dummy	-	-	-	-	-	-
ElecAddSupport	GasOCCHP_2025	dummy	-	-	-	-	-	-
ElecAddSupport	GasOCCHP_2030	dummy	-	-	-	-	-	-
ElecAddSupport	GasOCCHP_2035	dummy	-	-	-	-	-	-
ElecAddSupport	GasOCCHP_2040	dummy	-	-	-	-	-	-
ElecAddSupport	GasOCCHP_2045	dummy	-	-	-	-	-	-
ElecAddSupport	GasOCCHP_2050	dummy	-	-	-	-	-	-

Figure 87 How to introduce policies promoting electricity generation from a plant

7) How to add a new policy promoting the use of energy storage systems - **Policy_power_data sheet**

Similarly with the above, the user is able to introduce policies supporting the use of energy storage systems. The user selects the eligible storage type (rows) and the years for which this policy will be introduced (columns D-K) and enter the values (€/MWh_{elec}). It must be noted that these virtual subsidies are not real subsidies and are not taken into account in the pricing calculations.

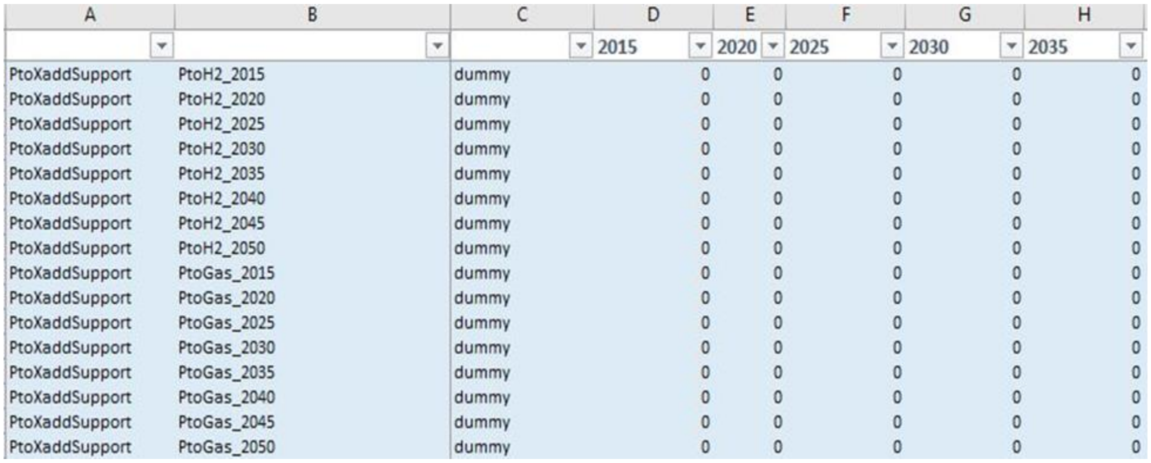


A	B	C	D	E	F	G	H
			2015	2020	2025	2030	2035
StorageaddSupport	PUMPING	dummy					
StorageaddSupport	PUMPING_2020	dummy					
StorageaddSupport	PUMPING_2025	dummy					
StorageaddSupport	PUMPING_2030	dummy					
StorageaddSupport	PUMPING_2035	dummy					
StorageaddSupport	PUMPING_2040	dummy					
StorageaddSupport	PUMPING_2045	dummy					
StorageaddSupport	PUMPING_2050	dummy					
StorageaddSupport	Batteries_2020	dummy					
StorageaddSupport	Batteries_2025	dummy					
StorageaddSupport	Batteries_2030	dummy					
StorageaddSupport	Batteries_2035	dummy					
StorageaddSupport	Batteries_2040	dummy					
StorageaddSupport	Batteries_2045	dummy					
StorageaddSupport	Batteries_2050	dummy					
StorageaddSupport	Response_2020	dummy					
StorageaddSupport	Response_2025	dummy					
StorageaddSupport	Response_2030	dummy					
StorageaddSupport	Response_2035	dummy					
StorageaddSupport	Response_2040	dummy					
StorageaddSupport	Response_2045	dummy					
StorageaddSupport	Response_2050	dummy					

Figure 88 How to introduce policies promoting the use of energy storage systems

8) How to add a new policy promoting the use of Power-to-X technologies - **Policy_power_data sheet**

The user is able to introduce policies supporting the use of Power-to-X technologies in the power sector. The user selects the eligible storage type (rows) and the years for which this policy will be introduced (columns D-K) and enter the values (€/MWh$_{fuel}$). It must be noted that these virtual subsidies are not real subsidies and are not taken into account in the pricing calculations.

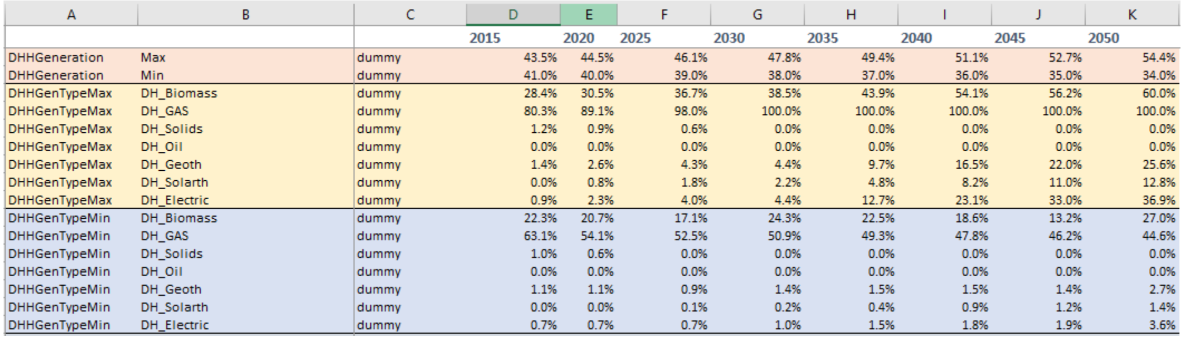


A	B	C	D	E	F	G	H
			2015	2020	2025	2030	2035
PtoXaddSupport	PtoH2_2015	dummy	0	0	0	0	0
PtoXaddSupport	PtoH2_2020	dummy	0	0	0	0	0
PtoXaddSupport	PtoH2_2025	dummy	0	0	0	0	0
PtoXaddSupport	PtoH2_2030	dummy	0	0	0	0	0
PtoXaddSupport	PtoH2_2035	dummy	0	0	0	0	0
PtoXaddSupport	PtoH2_2040	dummy	0	0	0	0	0
PtoXaddSupport	PtoH2_2045	dummy	0	0	0	0	0
PtoXaddSupport	PtoH2_2050	dummy	0	0	0	0	0
PtoXaddSupport	PtoGas_2015	dummy	0	0	0	0	0
PtoXaddSupport	PtoGas_2020	dummy	0	0	0	0	0
PtoXaddSupport	PtoGas_2025	dummy	0	0	0	0	0
PtoXaddSupport	PtoGas_2030	dummy	0	0	0	0	0
PtoXaddSupport	PtoGas_2035	dummy	0	0	0	0	0
PtoXaddSupport	PtoGas_2040	dummy	0	0	0	0	0
PtoXaddSupport	PtoGas_2045	dummy	0	0	0	0	0
PtoXaddSupport	PtoGas_2050	dummy	0	0	0	0	0

Figure 89 How to introduce policies promoting the use of Power-to-X technologies

9) How to change the maximum and minimum shares for heat/steam generation - **Policy_power_data sheet**

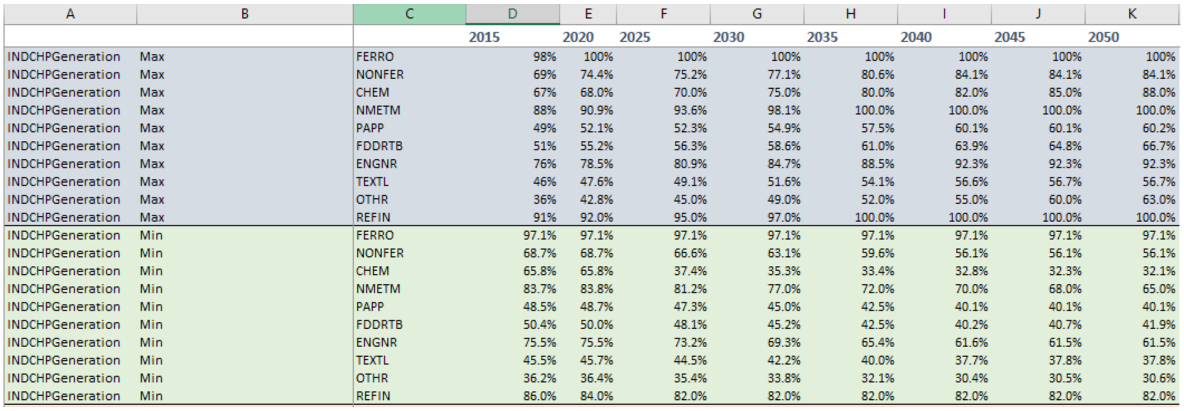
The user can change the minimum and maximum shares of District heating per generation type as shown in Figure 90. The production of heat is possible from cogeneration power plants (CHP plants) and heat plants. The first two rows represent the maximum and minimum share of heat produced by heat plants (ratio of heat generated from heat plants to total heat demand). The next rows represent the maximum and minimum share of heat produced by each heat plant type.



A	B	C	D	E	F	G	H	I	J	K
			2015	2020	2025	2030	2035	2040	2045	2050
DHHGeneration	Max	dummy	43.5%	44.5%	46.1%	47.8%	49.4%	51.1%	52.7%	54.4%
DHHGeneration	Min	dummy	41.0%	40.0%	39.0%	38.0%	37.0%	36.0%	35.0%	34.0%
DHHGenTypeMax	DH_Biomass	dummy	28.4%	30.5%	36.7%	38.5%	43.9%	54.1%	56.2%	60.0%
DHHGenTypeMax	DH_GAS	dummy	80.3%	89.1%	98.0%	100.0%	100.0%	100.0%	100.0%	100.0%
DHHGenTypeMax	DH_Solids	dummy	1.2%	0.9%	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%
DHHGenTypeMax	DH_Oil	dummy	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DHHGenTypeMax	DH_Geoth	dummy	1.4%	2.6%	4.3%	4.4%	9.7%	16.5%	22.0%	25.6%
DHHGenTypeMax	DH_Solarth	dummy	0.0%	0.8%	1.8%	2.2%	4.8%	8.2%	11.0%	12.8%
DHHGenTypeMax	DH_Electric	dummy	0.9%	2.3%	4.0%	4.4%	12.7%	23.1%	33.0%	36.9%
DHHGenTypeMin	DH_Biomass	dummy	22.3%	20.7%	17.1%	24.3%	22.5%	18.6%	13.2%	27.0%
DHHGenTypeMin	DH_GAS	dummy	63.1%	54.1%	52.5%	50.9%	49.3%	47.8%	46.2%	44.6%
DHHGenTypeMin	DH_Solids	dummy	1.0%	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DHHGenTypeMin	DH_Oil	dummy	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DHHGenTypeMin	DH_Geoth	dummy	1.1%	1.1%	0.9%	1.4%	1.5%	1.5%	1.4%	2.7%
DHHGenTypeMin	DH_Solarth	dummy	0.0%	0.0%	0.1%	0.2%	0.4%	0.9%	1.2%	1.4%
DHHGenTypeMin	DH_Electric	dummy	0.7%	0.7%	0.7%	1.0%	1.5%	1.8%	1.9%	3.6%

Figure 90 How to change District Heating shares

Following the same philosophy, the user can change the minimum and maximum shares of industrial CHP plants. Steam can be generated from CHP plants or industrial boilers. These shares represent the maximum and minimum ratio of steam produced by CHP plant to the total steam demand in each industrial sector.

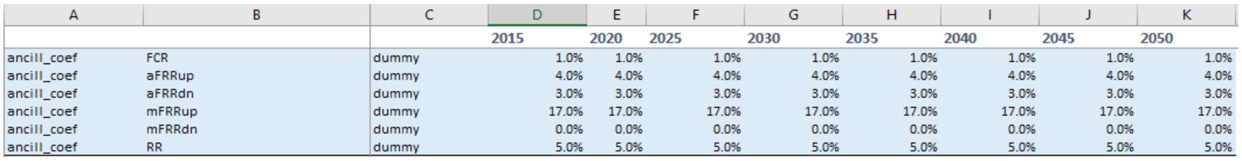


A	B	C	D	E	F	G	H	I	J	K
			2015	2020	2025	2030	2035	2040	2045	2050
INDCHPGeneration	Max	FERRO	98%	100%	100%	100%	100%	100%	100%	100%
INDCHPGeneration	Max	NONFER	69%	74.4%	75.2%	77.1%	80.6%	84.1%	84.1%	84.1%
INDCHPGeneration	Max	CHEM	67%	68.0%	70.0%	75.0%	80.0%	82.0%	85.0%	88.0%
INDCHPGeneration	Max	NMETM	88%	90.9%	93.6%	98.1%	100.0%	100.0%	100.0%	100.0%
INDCHPGeneration	Max	PAPP	49%	52.1%	52.3%	54.9%	57.5%	60.1%	60.1%	60.2%
INDCHPGeneration	Max	FDDRTB	51%	55.2%	56.3%	58.6%	61.0%	63.9%	64.8%	66.7%
INDCHPGeneration	Max	ENGNR	76%	78.5%	80.9%	84.7%	88.5%	92.3%	92.3%	92.3%
INDCHPGeneration	Max	TEXTL	46%	47.6%	49.1%	51.6%	54.1%	56.6%	56.7%	56.7%
INDCHPGeneration	Max	OTHR	36%	42.8%	45.0%	49.0%	52.0%	55.0%	60.0%	63.0%
INDCHPGeneration	Max	REFIN	91%	92.0%	95.0%	97.0%	100.0%	100.0%	100.0%	100.0%
INDCHPGeneration	Min	FERRO	97.1%	97.1%	97.1%	97.1%	97.1%	97.1%	97.1%	97.1%
INDCHPGeneration	Min	NONFER	68.7%	68.7%	66.6%	63.1%	59.6%	56.1%	56.1%	56.1%
INDCHPGeneration	Min	CHEM	65.8%	65.8%	37.4%	35.3%	33.4%	32.8%	32.3%	32.1%
INDCHPGeneration	Min	NMETM	83.7%	83.8%	81.2%	77.0%	72.0%	70.0%	68.0%	65.0%
INDCHPGeneration	Min	PAPP	48.5%	48.7%	47.3%	45.0%	42.5%	40.1%	40.1%	40.1%
INDCHPGeneration	Min	FDDRTB	50.4%	50.0%	48.1%	45.2%	42.5%	40.2%	40.7%	41.9%
INDCHPGeneration	Min	ENGNR	75.5%	75.5%	73.2%	69.3%	65.4%	61.6%	61.5%	61.5%
INDCHPGeneration	Min	TEXTL	45.5%	45.7%	44.5%	42.2%	40.0%	37.7%	37.8%	37.8%
INDCHPGeneration	Min	OTHR	36.2%	36.4%	35.4%	33.8%	32.1%	30.4%	30.5%	30.6%
INDCHPGeneration	Min	REFIN	86.0%	84.0%	82.0%	82.0%	82.0%	82.0%	82.0%	82.0%

Figure 91 How to change Industrial CHP shares

10) How to change the level of reserve requirements - **Policy_power_data sheet**

The user can change the level of reserve requirements for each reserve type, by increasing or decreasing the values in rows 2-7, as shown in Figure 92. The level of reserve requirements is calculated as a percentage of the peak demand for each projection year.



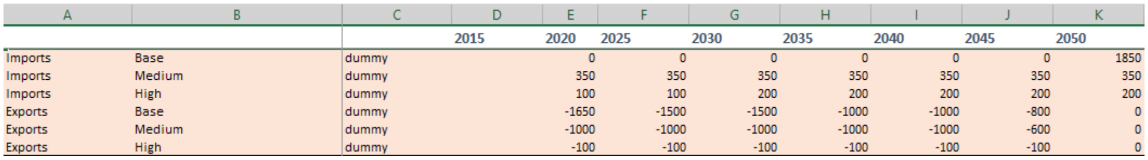
A	B	C	D	E	F	G	H	I	J	K
			2015	2020	2025	2030	2035	2040	2045	2050
ancill_coef	FCR	dummy	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%
ancill_coef	aFRRup	dummy	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%
ancill_coef	aFRRdn	dummy	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%
ancill_coef	mFRRup	dummy	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%
ancill_coef	mFRRdn	dummy	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ancill_coef	RR	dummy	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%

Figure 92 How to change the level of system requirements

11) How to change net imports - **Policy_power_data sheet**

The user can control the level of imports from rows 800-802 at **Policy_power_data** sheet and the level of exports from rows 803-805.

Note that imports have positive values while exports have negative values, see Figure 93.

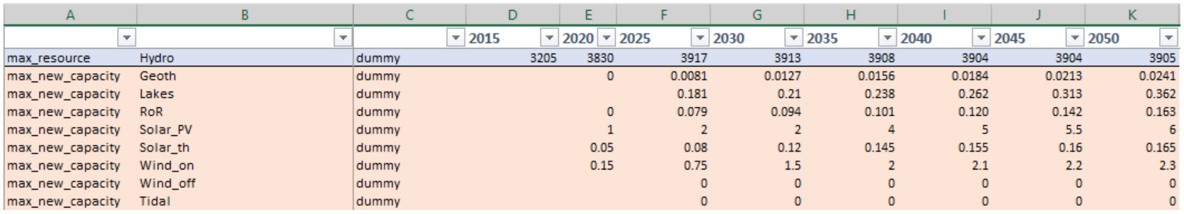


A	B	C	D	E	F	G	H	I	J	K
			2015	2020	2025	2030	2035	2040	2045	2050
Imports	Base	dummy		0	0	0	0	0	0	1850
Imports	Medium	dummy		350	350	350	350	350	350	350
Imports	High	dummy		100	100	200	200	200	200	200
Exports	Base	dummy		-1650	-1500	-1500	-1000	-1000	-800	0
Exports	Medium	dummy		-1000	-1000	-1000	-1000	-1000	-600	0
Exports	High	dummy		-100	-100	-100	-100	-100	-100	0

Figure 93 How to change the level of net imports

12) How to change the potential for RES - **Policy_power_data sheet**

The user has the ability to change the potential for the Renewable Energy Sources, by increasing or decreasing the value of the corresponding cell of rows 427-434 (max_new_capcity), as shown in Figure 94. Unlike all other RES, in order to change the potential for Hydro lakes the user has to change also the corresponding cell of row 426 (max_resource), which represents the energy stored in the lake.

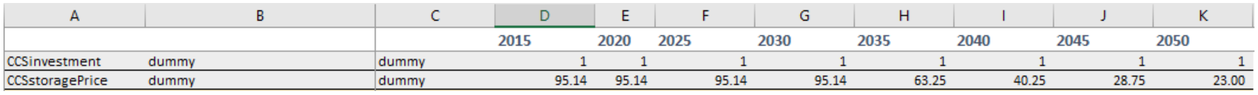


A	B	C	D	E	F	G	H	I	J	K
			2015	2020	2025	2030	2035	2040	2045	2050
max_resource	Hydro	dummy	3205	3830	3917	3913	3908	3904	3904	3905
max_new_capacity	Geoth	dummy		0	0.0081	0.0127	0.0156	0.0184	0.0213	0.0241
max_new_capacity	Lakes	dummy			0.181	0.21	0.238	0.262	0.313	0.362
max_new_capacity	RoR	dummy		0	0.079	0.094	0.101	0.120	0.142	0.163
max_new_capacity	Solar_PV	dummy		1	2	2	4	5	5.5	6
max_new_capacity	Solar_th	dummy		0.05	0.08	0.12	0.145	0.155	0.16	0.165
max_new_capacity	Wind_on	dummy		0.15	0.75	1.5	2	2.1	2.2	2.3
max_new_capacity	Wind_off	dummy			0	0	0	0	0	0
max_new_capacity	Tidal	dummy			0	0	0	0	0	0

Figure 94 Change RES potential

13) How to change CCS assumptions - **Policy_power_data sheet**

The user can change the assumptions for CCS. The CCSinvestment row (row 16) is filled only with 1 or 0. By having 1 in the CCSinvesment row means that CCS is **not** permitted while having 0 means that CCS is permitted. In the CCSstoragePrice row (row 17) the user can control the price (€/tnCO_2 captured).

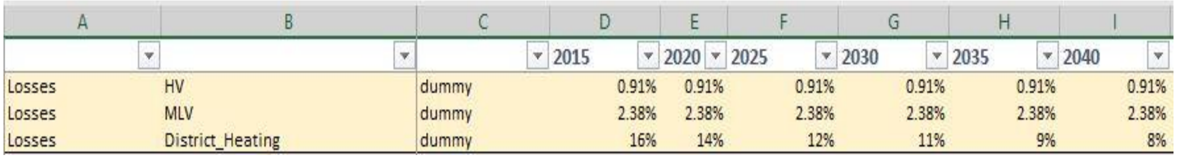


A	B	C	D	E	F	G	H	I	J	K
			2015	2020	2025	2030	2035	2040	2045	2050
CCSinvestment	dummy	dummy	1	1	1	1	1	1	1	1
CCSstoragePrice	dummy	dummy	95.14	95.14	95.14	95.14	63.25	40.25	28.75	23.00

Figure 95 Change CCS assumptions

14) How to change network losses - **Policy_power_data sheet**

The user can affect the level of network losses by changing the values of the loss rate. As shown in Figure 96, the user may change the loss rates of High voltage, Medium/Low voltage and/or the losses of the district heating network. It must be noted that the loss rates are ratio of the total final demand.

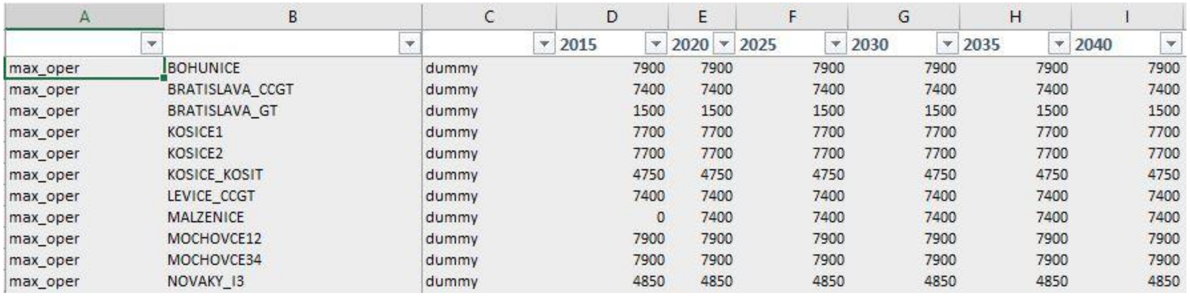


A	B	C	D	E	F	G	H	I
			2015	2020	2025	2030	2035	2040
Losses	HV	dummy	0.91%	0.91%	0.91%	0.91%	0.91%	0.91%
Losses	MLV	dummy	2.38%	2.38%	2.38%	2.38%	2.38%	2.38%
Losses	District_Heating	dummy	16%	14%	12%	11%	9%	8%

Figure 96 How to change network losses

15) How to change the maximum operating hours of a power plant - **Policy_power_data sheet**

The user is able to change the maximum operating hours of a power plant for each year of projection. This feature enables the user to reflect policies limiting the operation of power plants or some limitation due to technical reasons.



A	B	C	D	E	F	G	H	I
			2015	2020	2025	2030	2035	2040
max_oper	BOHUNICE	dummy	7900	7900	7900	7900	7900	7900
max_oper	BRATISLAVA_CCGT	dummy	7400	7400	7400	7400	7400	7400
max_oper	BRATISLAVA_GT	dummy	1500	1500	1500	1500	1500	1500
max_oper	KOSICE1	dummy	7700	7700	7700	7700	7700	7700
max_oper	KOSICE2	dummy	7700	7700	7700	7700	7700	7700
max_oper	KOSICE_KOSIT	dummy	4750	4750	4750	4750	4750	4750
max_oper	LEVICE_CCGT	dummy	7400	7400	7400	7400	7400	7400
max_oper	MALZENICE	dummy	0	7400	7400	7400	7400	7400
max_oper	MOCHOVCE12	dummy	7900	7900	7900	7900	7900	7900
max_oper	MOCHOVCE34	dummy	7900	7900	7900	7900	7900	7900
max_oper	NOVAKY_I3	dummy	4850	4850	4850	4850	4850	4850

Figure 97 How to change maximum operating hours of a power plant

6. Overview of the CPS Biomass Module

This chapter provides an overview of the main principles of the CPS Biomass Module.

- Section 6.1: Basic concepts in the CPS Biomass Module
- Section 6.2: Mathematical Structure, unknown variables and exogenous parameters
- Section 6.3: Model features, considerations and assumptions
- Section 6.4: Policy Focus – Biomass
- Section 6.5: Explaining the biomass-related scenario input sheets

6.1 Basic concepts in the CPS Biomass Module

The CPS Biomass Module projects the primary energy/feedstock consumption required to satisfy the demand for bioenergy from all demand sectors, as well as the power and heat generation system.

The CPS Biomass Module simulates the economics of supply of biomass and waste consumed for energy purposes and decides on the optimal use of the available resources (feedstock) and the optimum technology type mix of investments required to meet the given demand of final biomass energy products. The model decides endogenously the required investments for the biomass transformation technologies, projects the primary energy/feedstock consumption, decides the imported amounts of biomass feedstock and biofuels and also calculates the biofuel prices, as the total average of production costs.

The structure of the CPS Biomass Module and its' linkage to the other CPS Modules is presented in Figure 98.

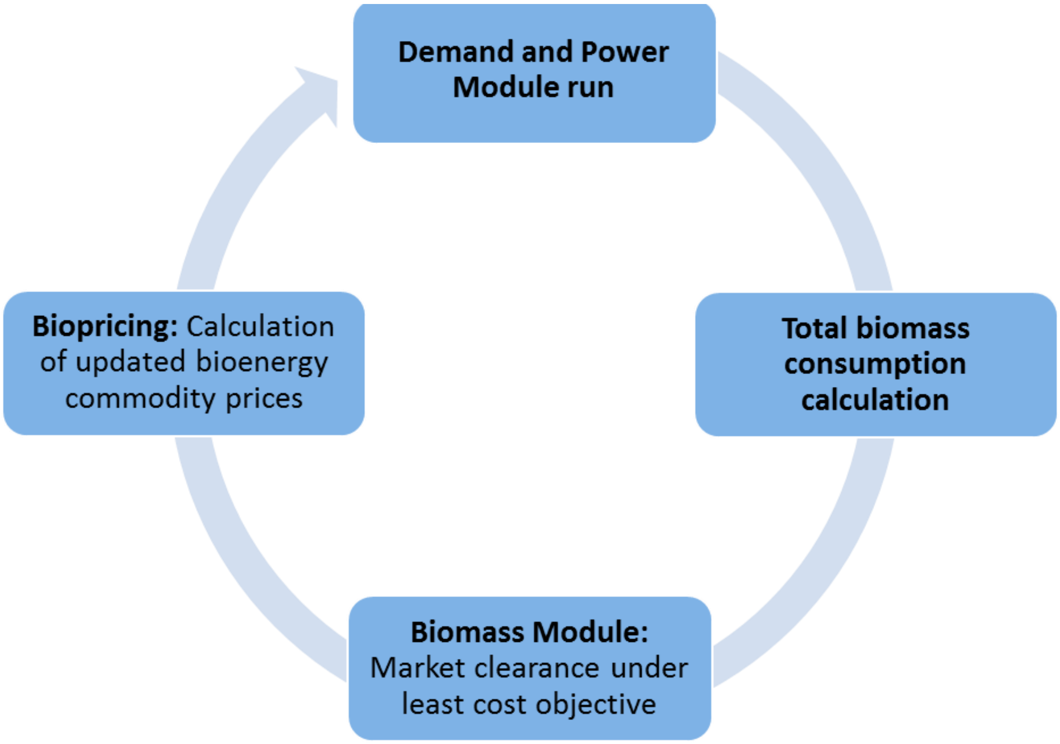


Figure 98 CPS Biomass Module linkage

The calculation sequence of the CPS Biomass Module is:

- Initially, biomass, biogas and waste demand consumed in power plants, district heating, industry, households, services and agriculture is inserted as input in the Biomass Module. Demand of biogas and biofuel (conventional- first generation and advanced- second generation) consumed in the transport sector is also included in the calculation of total bioenergy demand
- The CPS Biomass Module solves an optimization problem: the satisfaction of biomass energy system demand with simultaneous **minimization** of total biomass supply costs *for the whole projection period (2020 to 2050)*. In this optimization problem constraints of technology capacity as well as limited availability of feedstock apply
- Pricing at total average cost takes place at the end of *each iteration* based on the CPS Biomass Module’s results. Bioenergy prices are subsequently provided to the CPS Demand and Power Modules as input *for the next iteration*.

In the CPS Biomass Module primary energy-feedstock is transformed into final form bioenergy commodities, through the application of biomass technologies. A wide variety of different, mature and non-mature technologies producing biofuels (conventional and advanced), biogas, biomass and waste are incorporated in the Module. A detailed description of the CPS biomass technologies is presented in Section 6.2.4.2 Biomass Production Technologies.

Biomass technologies compete with each other based on their techno-economic characteristics, in order to enter into the market. In this decision making process, the model takes into account:

- cost and availability of primary energy feedstock of biomass and waste (domestic production)
- cost and availability of imported feedstock
- cost of imported final energy commodities - bioenergy
- required investments in biomass technologies.

The definition of biomass technologies which will enter the market, as well as the volume of imported biofuels, is based on the minimization of the cumulative cost throughout the whole projection period. Thus the model solves the optimization problem intertemporally.

Once again, cost supply curves of ascending slope are used to calculate the cost impact of potential resources exhaustion, which is included in the cost of primary energy feedstock.

6.2 Mathematical structure, unknown variables and exogenous parameters

The CPS Biomass Module solves intertemporally the optimization problem of minimizing the total biomass supply costs under certain constraints.

6.2.1. Mathematical structure

6.2.1.1 Least cost objective function

The objective function of the optimization problem is given by the below formula. It must be noted that, in the Biomass Module *the vintage is the construction year of the equipment* (e.g. 2000, 2005, 2010 etc):

- Objective function of CPS Biomass Module

$$
\begin{aligned}
min\ obj = \sum_{t}\sum_{v\leq t}\sum_{SFbio}\Bigg(& invcost_{SFbio,v}\cdot \mathrm{anfact}_{SFbio,v}\cdot INV_{SFbio,v}\cdot e\_surv_{SFbio,v,t}+omcost_{SFbio,v}\\
& \cdot\left(1+omgr_{SFbio,v}\right)^{t-v}\cdot CAP_{SFbio,v,t}\cdot t\_surv_{SFbio,v,t}+varcost_{SFbio,v}\\
& \cdot\sum_{fout,t} BIOPROD_{SFbio,v,fout,t}+\sum_{ffeed} FEEDSTOCK_{SFbio,v,ffeed,t}\cdot FEEDCOST_{SFbio,v,ffeed,t}\\
& +\sum_{f} BFUEL_{SFbio,v,f,t}\cdot\left(pribfuel_{SFbio,f,t}+emf_{f}\cdot carbonprice_{t}\right)\\
& -LBD\_bio_{SFbio,v,t}\sum_{fout} BIOPROD_{SFbio,v,fout,t}-\sum_{fout} resvalue_{fout,t}\cdot BIOPROD_{SFbio,v,fout,t}\Bigg)
\end{aligned}
$$

Where

$fout$: Output fuel of biomass technologies

$ffeed$: Feedstock fuel for biomass technologies

$SFbio$: Biomass technologies

v: Vintage

t: Year

f: Fuel consumed for self-consumption of biomass technologies

$invcost_{SFbio,v}$: Investment cost of technology $SFbio$ of vintage v

$\text{anfact}_{SFbio,v}$: Annuity factor of investment cost of technology $SFbio$ of vintage v

$e\_surv_{SFbio,v,t}$: Economic survival of technology $SFbio$ of vintage v (0 or 1)

$INV_{SFbio,v}$: Investment in biomass technology $SFbio$ of vintage v

$omcost_{SFbio,v}$: O&M cost of technology $SFbio$ of vintage v

$omgr_{SFbio,v}$: O&M cost growth rate of technology $SFbio$ of vintage v

$t\_surv_{SFbio,v,t}$: Technical survival of technology $SFbio$ of vintage v (0 or 1)

$CAP_{SFbio,v,t}$: Capacity of biomass technology $SFbio$ of vintage v in year t

$$CAP_{SFbio,v,t} \coloneqq INV_{SFbio,t} + prob\_surv_{SFbio,v,t} \cdot CAP_{SFbio,v,t-1}$$

$prob\_surv_{SFbio,v,t}$: Probability of survival of an equipment of technology $SFbio$ of vintage v

$varcost_{SFbio,v}$: Variable cost of technology $SFbio$ of vintage v

$BIOPROD_{SFbio,v,fout,t}$: Production of bioenergy $fout$ of technology $SFbio$ of vintage v

$FEEDSTOCK_{SFbio,v,ffeed,t}$: Consumption of feedstock $ffeed$ of technology $SFbio$ of vintage v

$FEEDCOST_{SFbio,v,ffeed,t}$: Cost of feedstock $ffeed$ including the cost impact of potential exhaustion

$$FEEDCOST_{SFbio,v,ffeed,t} \coloneqq mc\_feed_{ffeed,t} - nc\_feed_{ffeed,t} \cdot \log\left(1 - \frac{RESCONS_{ffeed,t}}{respot_{ffeed,t}}\right)$$

$mc\_feed_{ffeed,t}$: Cost of feedstock $ffeed$ excluding the cost impact potential exhaustion

$nc\_feed_{ffeed,t}$: Nonlinear parameter of cost supply curve of feedstock $ffeed$

$RESCONS_{ffeed,t}$: Consumption of resources/feedstock $ffeed$

$respot_{ffeed,t}$: Availability potential of feedstock $ffeed$

$$RESCONS_{ffeed,t} \coloneqq \sum_{SFbio} \sum_{v \le t} FEEDSTOCK_{SFbio,v,ffeed,t}$$

$BFUEL_{SFbio,v,f,t}$: Fuel consumption of fuel f of technology $SFbio$ of vintage v

$pribfuel_{SFbio,f,t}$: Price of fuel f of technology $SFbio$ of vintage v

emf_f: CO₂ emission factor of fuel f

$carbonprice_t$: Carbon price for year t

$LBD\_bio_{SFbio,v,t}$: Learning-by-doing parameter for technology $SFbio$ of vintage v

$resvalue_{fout,t}$: Renewable value of bioenergy fuel $fout$

6.2.1.2 Constraints

The constraints applied in the CPS Biomass Module are:

- Biomass production constraint (market clearance)

$$\sum_{SFbio} \sum_{v \le t} BIOPROD_{SFbio,v,fout,t} \ge biodemand_{fout,t}$$

$biodemand_{fout,t}$: Biomass demand of output fuel $fout$

- Upper bound of biomass production (feedstock related)

$$\frac{\sum_{,ffeed} FEEDSTOCK_{SFbio,v,ffeed,t}}{heatrate_{SFbio,v}} \ge \sum_{fout} BIOPROD_{SFbio,v,fout,t}$$

$heatrate_{SFbio,v}$: Heatrate of technologies $SFbio$ of vintage v

- Upper bound of biomass production (capacity related)

$$CAP_{SFbio,v,t} \cdot util_{SFbio} \cdot 8760 \ge \sum_{fout} BIOPROD_{SFbio,v,fout,t}$$

$util_{SFbio}$: Utilization rate of biomass technology $SFbio$

- Availability potential constraint

$$respot_{ffeed,t} \ge RESCONS_{ffeed,t}$$

- Upper bound of biomass production (fuel consumption related excluding electricity)

$$\frac{\sum_{f\ not\ elec} BFUEL_{SFbio,v,f,t}}{heatrate^{fuel}_{SFbio,v,t}} \ge \sum_{fout} BIOPROD_{SFbio,v,fout,t}$$

$heatrate^{fuel}_{SFbio,v,t}$: Heatrate of fuel consumption of biomass technology $SFbio$ of vintage v

- Upper bound of biomass production (electricity consumption related)

$$\frac{BFUEL_{SFbio,v,elec,t}}{heatrate^{elec}_{SFbio,v,t}} \geq \sum_{fout} BIOPROD_{SFbio,v,fout,t}$$

$heatrate^{elec}_{SFbio,v,t}$: Heatrate of electricity consumption of biomass technology $SFbio$ of vintage v

6.2.1.3 Commodity pricing

Biofuel prices are calculated as the total average price of the production costs and are provided as input to the Demand and Power Module, through the described linkage of the CPS Modules.

- Price of biomass technologies

$$priceSFbio_{SFbio,t} = \frac{CostSFbio_{SFbio,t}}{\sum_{v\leq t}\sum_{fout} BIOPROD_{SFbio,v,fout,t}}$$

- Cost of biomass technologies

$$\begin{aligned}
&CostSFbio_{SFbio,t}\\
&\quad= \sum_{v\leq t}\Bigg(invcost_{SFbio,v}\cdot \mathrm{anfact}_{SFbio,v}\cdot INV_{SFbio,v}\cdot e\_surv_{SFbio,v,t} + omcost_{SFbio,v}\\
&\quad\cdot \left(1+omgr_{SFbio,v}\right)^{t-v}\cdot CAP_{SFbio,v,t}\cdot t\_surv_{SFbio,v,t} + varcost_{SFbio,v}\\
&\quad\cdot \sum_{fout,t} BIOPROD_{SFbio,v,fout,t} + \sum_{ffeed} FEEDSTOCK_{SFbio,v,ffeed,t}\cdot mc\_feed_{ffeed,t}\\
&\quad+ \sum_{f} BFUEL_{SFbio,v,f,t}\cdot \left(pribfuel_{SFbio,f,t} + emf_f\cdot carbonprice_t\right)\\
&\quad- LBD\_bio_{SFbio,v,t}\sum_{fout} BIOPROD_{SFbio,v,fout,t}\Bigg)
\end{aligned}$$

- Commodity price of bioenergy

$$pricebio_{fout,t} = \frac{\sum_{SFbio} priceSFbio_{SFbio,t}\cdot \sum_{v\leq t} BIOPROD_{SFbio,v,fout,t}}{\sum_{v\leq t}\sum_{SFbio} BIOPROD_{SFbio,v,fout,t}}$$

6.2.2. Unknown variables

The unknown variables of the CPS Biomass Module include at least the following;

- Production of bioenergy per output fuel $fout$, technology $SFbio$ and vintage v
- Capacity of biomass technology $SFbio$ of vintage v

- Investment in biomass technology $SFbio$ of vintage v
- Consumption of input fuel $ffeed$ of biomass technology $SFbio$ of vintage v
- Consumption of fuel f of biomass technology $SFbio$ of vintage v
- Total consumption of feedstock per input fuel $ffeed$

6.2.3. Exogenous Parameters

The parameters provided by the user include:

- Probability of survival of an equipment of technology $SFbio$ of vintage v
- Lifetime of equipment of technology $SFbio$
- Economic survival of technology $SFbio$ of vintage v
- Technical survival of technology $SFbio$ of vintage v
- Scale parameter of survival function of equipment per technology $SFbio$
- Survival rate of equipment at the end of lifetime per technology $SFbio$
- Survival rate of equipment at 80% of lifetime per technology $SFbio$
- Annuity factor of investment cost of technology $SFbio$ of vintage v
- Discount rate per vintage v
- Heatrate of equipment of technology $SFbio$
- Heatrate of fuel consumption of biomass technology $SFbio$ of vintage v
- Heatrate of electricity consumption of biomass technology $SFbio$ of vintage v
- Availability potential of feedstock $ffeed$
- Investment cost of technology $SFbio$ of vintage v
- O&M cost of technology $SFbio$ of vintage v
- O&M cost growth rate of technology $SFbio$ of vintage v
- Variable cost of technology $SFbio$ of vintage v
- Cost of feedstock $ffeed$ excluding the cost impact potential exhaustion
- Nonlinear parameter of cost supply curve of feedstock $ffeed$
- Learning-by-doing parameter for technology $SFbio$ of vintage v
- Renewable value of bioenergy fuel $fout$

6.2.4. Model features, considerations and assumptions Feedstock

6.2.4.1 Feedstock

The feedstock/input fuels of biomass technologies included in the CPS Biomass Module are:

- Food crops
- Food crops sun flower
- Lignocellulosic crops
- Wood and wood waste

- Waste solid
- Waste liquid
- Waste gas
- Agricultural and animal waste
- Algae

6.2.4.2 Biomass Production Technologies

The biomass technologies incorporated in the CPS Biomass Module are shown in Table 16.

Table 16 CPS Biomass Module technologies

Feedstock	Technology	Final Product
Lignocellulosic crops Wood and wood waste Imported wood	Enzymatic hydrolysis of lignocellulose	Advanced Biofuels
Lignocellulosic crops Wood and wood waste Imported wood	Hydro Thermal Upgrading	Advanced Biofuels
Lignocellulosic crops Wood and wood waste Imported wood	Gasification and Fischer-Tropsch conversion	Advanced Biofuels
Lignocellulosic crops Wood and wood waste Imported wood	Catalytic Pyrolysis	Advanced Biofuels
Food crops	Fermentation of crops	Conventional Biofuels
Food crops sun flower	Transesterefication of crops	Conventional Biofuels
Agricultural and animal waste	Anaerobic digestion of organic waste to biogas	Biogas
Algae	Advanced processes, aquatic, microbial, photosynthesis	Biogas
Wood and wood waste Imported wood	Biomass solids processing	Biomass Solids
Waste solid Waste liquid	Waste solids and liquid collection and processing	Waste Solids, Black Liquor
Waste gas	Waste gas collection and processing	Waste Gas

As indicated in Table 16 there are several biomass conversion technologies producing a variety of final biofuels. Some of them, such as fermentation and transesterification of crops for the production of conventional biofuels, are technologically and economically mature processes and are already well established in Europe for the production of biofuels. Other technologies, such as pyrolysis of lignocellulosic crops, offer significant benefits, regarding mainly the utilisation of cheaper and abundant feedstock, but need further research in order to become economically competitive. The choice of the technologies that are finally selected to be included in the Biomass Module was based on the current status of technical and economic development, research efforts and possibilities for future improvements, type of feedstock and type and characteristics of final products. The biomass technologies that are incorporated in the CPS Biomass Module are based on different conversion chains and are presented below:

• Conventional Biofuel production – Fermentation and Transesterification of Crops

Conventional biofuels, such as bio-diesel, are merely produced from vegetable oils by catalytic **transesterification** with methanol. The bio-diesel produced has similar properties with fossil diesel and may be used to conventional engines blended up to a proportion of 20% with fossil diesel or to modified engines in higher proportions. Vegetable oils may be produced from several biomass sources. In Europe the most common feedstock for the production of vegetable oil as feedstock for further conversion into biodiesel is rapeseed. Other vegetable and animal fats as well as used oils may also be used as feedstock to the transesterification process. Transesterification is a well-established technology and is largely deployed in Europe. Bioethanol is used in spark ignition vehicle engines either blended with gasoline or in pure form, if the engines are properly modified. At present bio-ethanol is mainly produced from sugar crops via **fermentation**. In Europe, sugar beet and sweet sorghum are mainly used as feedstock. Starch crops are also used as feedstock, although in that case more extensive preprocessing is needed.

• Advanced Biofuel production – Enzymatic hydrolysis, Hydro thermal Upgrading (HTU), Gasification and FT Catalytic Pyrolysis

Lignocellulosic biomass constitutes the main feedstock for the production of advanced biofuels. Four different technologies for the production of advanced bio-ethanol, bio-diesel and bio-kerosene have been incorporated in the CPS Model:

o Enzymatic hydrolysis of lignocellulose

Enzymatic hydrolysis and consequent fermentation of lignocellulosic crops is currently the most mature technology for the production of advanced biofuels, compared to competing technologies for advanced biofuels. However, enzymatic hydrolysis is still under development, though a lot of research is taking place both in Europe and in the USA, implying significant future development potential.

o Biomass Gasification - Fischer-Tropsch diesel

Conversion of biomass into synthesis gas (or syngas) is done by means of a gasification process. The resulting syngas can be used as fuel in gas engines and power & steam generation units. It is also possible to be further cleaned and upgraded to natural gas quality so as to be mixed in the natural gas supply network. Furthermore, syngas may be converted into liquid fuel by processes such as Fischer-Tropsch. The production of diesel from coal via the Fischer-Tropsch process is a well-established technology with long history. Recently the utilisation of biomass derived syngas is proposed for the production of Fischer-

Tropsch bio-diesel. However, the production of Fischer-Tropsch diesel requires thorough cleaning and conditioning of the biomass derived syngas, which currently bears a lot of technical difficulties, which challenge and deteriorate the economics of the technology. However, the combination of the multiple feedstock gasification with the synthesis of Fischer-Tropsch diesel is an attractive alternative for the production of a fossil diesel substitute.

o Hydro Thermal Upgrading

Another substitute of fossil diesel is proposed by converting almost all types of biomass into liquid bio-fuel via a process called hydro thermal upgrading (HTU). During HTU process, the biomass is decomposed in water to produce a crude oil-like liquid called ‘bio-crude’. The resulting ‘bio-crude’ is further upgraded through hydrogenation methods to achieve fossil diesel quality and may be blended in any proportion with conventional fossil diesel. The technological status of the HTU process has not reached technological maturity yet. Furthermore, it is a highly energy intensive process which further reduces its economic performance. Nevertheless, the utilisation of a wide variety of feedstock ranks HTU as a candidate technology for future production of bio-diesel.

o Catalytic Pyrolysis

Pyrolytic oil is produced by a thermo-chemical conversion process called flash pyrolysis. In order to be used as transport fuel, pyrolytic oil has to be upgraded and stabilised to reach specific quality requirements. Since it is not mixable with fossil diesel, the resulting fuel may only be used directly in modified diesel engines. Pyrolytic oil can also be used for co-firing in power & steam generating units, or may be gasified for the production of syngas. The technology has not reached to a maturity status yet and there are significant difficulties that have to be overcome. However, since almost any type of biomass can be used in flash pyrolysis, including lignocellulosic biomass, the technology is attractive and bears significant potential for future deployment.

6.3 Policy Focus - Biomass

The model is designed in order to assist on the analysis of policies in terms of sustainability issues related with the development of the biomass sector. Biomass supply and final production cost may be influenced by technology progress, volume of demand, taxes or subsidies, environmental policies, as well as agricultural and waste management policies. Further analysis regarding sustainability issues is facilitated by the endogenous or ex-post calculation of indicators such as:

- Total cost of biomass
- Production cost of end use biomass and biofuels
- Energy requirements and emissions related to the production and delivery of biomass and biofuels

The policy drivers included in the CPS Biomass Module are presented below. All drivers are available in the supply-related input file and can be modified by the user, as described in Section 6.4.3 Options for changing parameters’ values exogenously.

- *Carbon Price (EU ETS)*: The price of the EU ETS Emission Allowances, as defined for the demand and power sectors, affects also the choice of fuel consumption in the biomass technologies. The user can specify the price of the European Union Allowances for each projected year.
- *RES value*: RES value in the CPS Biomass Module represents non – identified policies aiming at the increase of RES use, as in the Demand and Power Module, reflecting the shadow cost (marginal benefit) of the implicit RES target. RES value is defined by output fuel.
- *LBD*: Learning-by-doing parameter represents the reduction of total biomass production costs of a new technology, via a learning-by-doing process. In CPS Biomass Module, the LBD parameter of a technology $SFbio$ is multiplied with the bioenergy production of this technology, implying that increased use of a biomass technology for bioenergy production reduces the cost of production of the specific technology.

6.4 Explaining the biomass-related scenario input sheets

To run alternative scenarios the user would need to modify accordingly *the sheets that include the parameters of the Biomass Module, in the supply-related scenario input file* located in the *Scenarios\”Scenario name”\Inputxlsx* folder (see section 2.4 The structure of the *Scenario name* subfolder) and named “*Scenario name*”_Input_Supply.xlsb.

The two sheets from where the user can affect parameters of the Biomass Module and assess the impact of alternative policy options are:

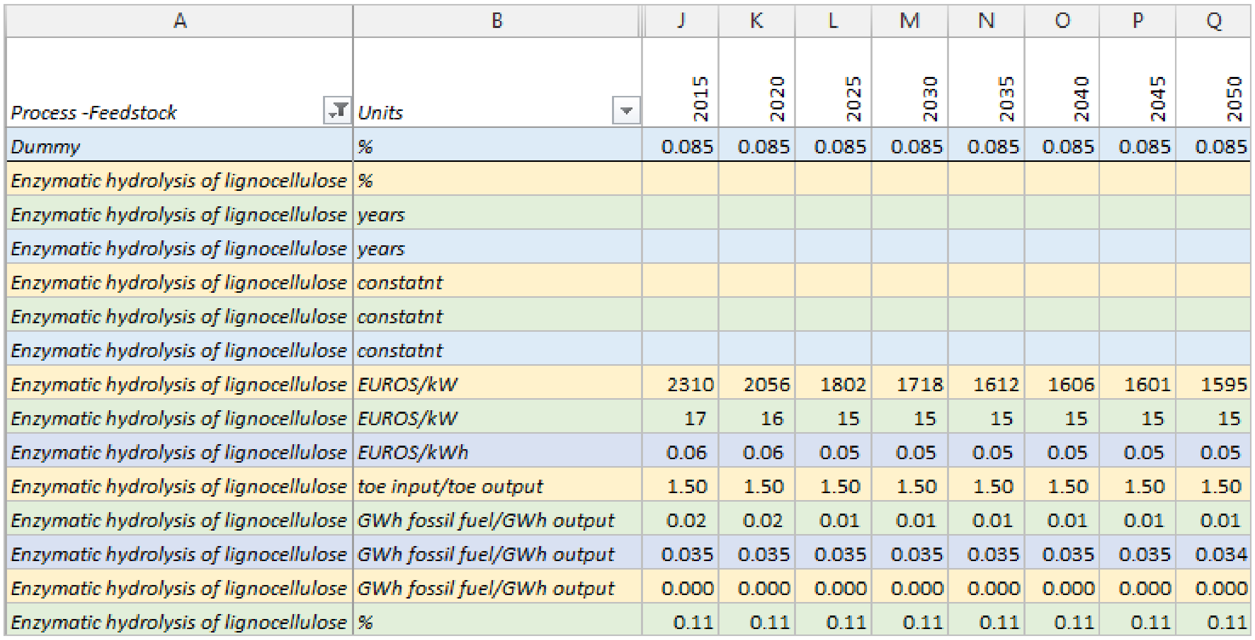
1) **Techdata_bio**: This sheet summarises all technical characteristics of the Biomass Module technologies, such as utilization rate, economic lifetime, technical lifetime, parameters for the calculation of probability of survival function, investment cost, variable cost, operation & maintenance cost, growth rate of operation & maintenance cost, heatrate, heatrate of fuel consumption, heatrate of electricity consumption, availability potential of feedstock, cost of feedstock and discount rate
2) **Policy_biofuels**: This sheet includes RES value per output fuel and LBD parameter per biomass technology and vintage.

A more detailed presentation of the Biomass Module sheets is cited below:

6.4.1. Techdata_bio

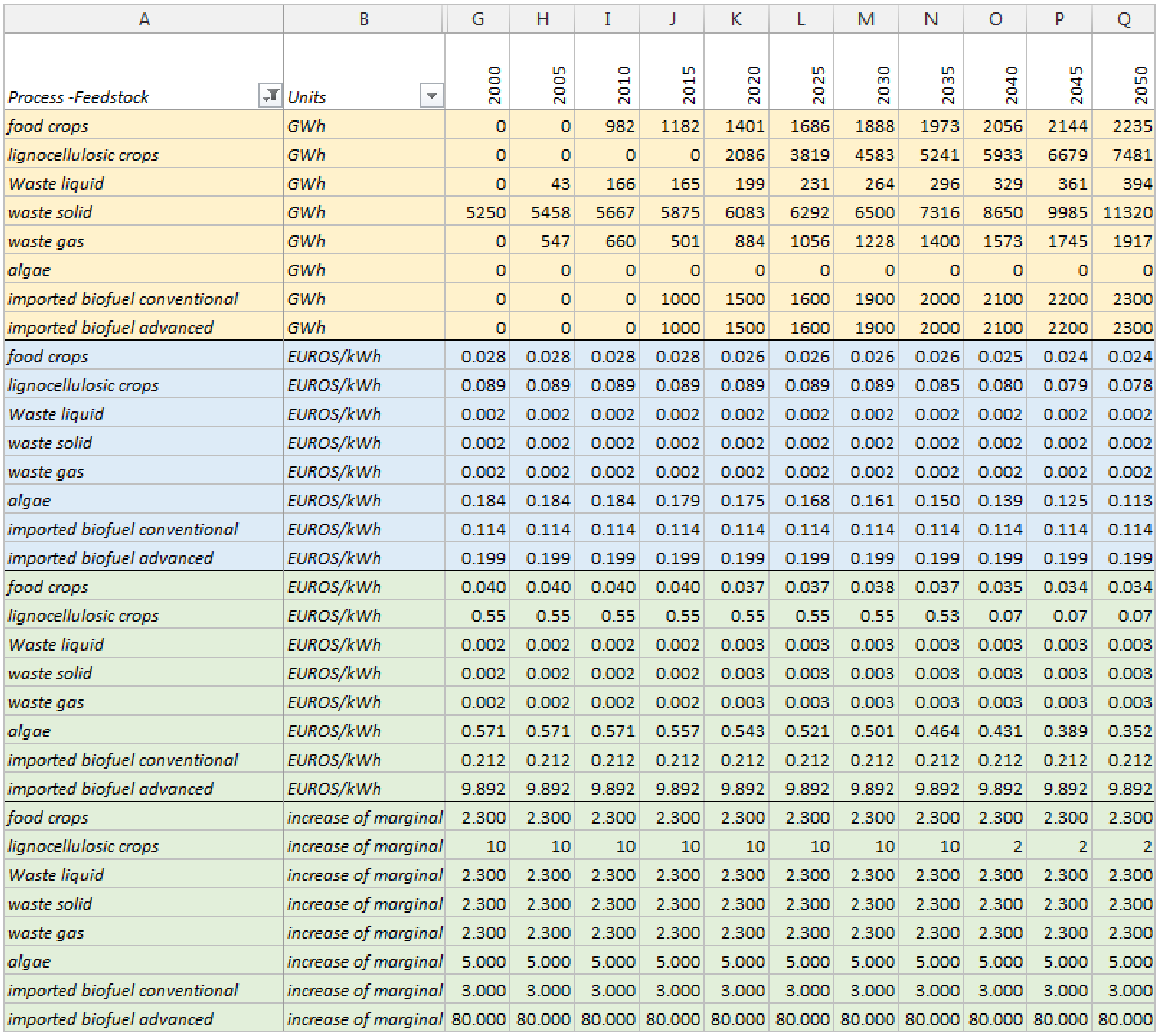
- PrivateDiscount: Discount rate for investments - uniform for all biomass technologies – per vintage
- Utilisation_rate: Utilisation rate per biomass technology
- Econ_lifetime: Economic lifetime per biomass technology in years
- Tech_lifetime: Technical lifetime per biomass technology in years
- sva_bio: Scale parameter of survival function of equipment per biomass technology

- svt_bio: Survival rate of equipment at the end of lifetime per biomass technology
- sv80_bio: Survival rate of equipment at 80% of lifetime per biomass technology
- Capital: Investment cost per biomass technology and vintage in €/kW
- FixedOMCost: O&M cost per biomass technology and vintage in €/kW
- VariableNonFuelCost: Variable cost per biomass technology and vintage in €/kWh
- heatrate: Heatrate per biomass technology and vintage in toe input/toe output
- Self_Cons_Diesel: Heatrate of diesel consumption per biomass technology and vintage in GWh_{fuel}/GWh of output fuel
- Self_Cons_Electricity: Heatrate of electricity consumption per biomass technology and vintage in GWh_{fuel}/GWh of output fuel
- Self_Cons_Gas: Heatrate of gas consumption per biomass technology and vintage in GWh_{fuel}/GWh of output fuel
- bio_omgr: O&M cost growth rate per biomass technology and vintage
- bio_respotential: Availability potential of feedstock per feedstock/input fuel and year in GWh
- mc_resourcebio: Cost of feedstock excluding the cost impact of potential exhaustion per feedstock/input fuel and year in €/kWh
- nc_resourcebio: Nonlinear parameter of cost supply curve per feedstock/input fuel and year in €/kWh
- incr_mc_cost: Index denoting the increase of feedstock cost at 80% of availability potential per biomass feedstock/input fuel and year



A	B	J	K	L	M	N	O	P	Q
Process -Feedstock	*Units*	2015	2020	2025	2030	2035	2040	2045	2050
Dummy	*%*	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085
Enzymatic hydrolysis of lignocellulose	*%*								
Enzymatic hydrolysis of lignocellulose	*years*								
Enzymatic hydrolysis of lignocellulose	*years*								
Enzymatic hydrolysis of lignocellulose	*constatnt*								
Enzymatic hydrolysis of lignocellulose	*constatnt*								
Enzymatic hydrolysis of lignocellulose	*constatnt*								
Enzymatic hydrolysis of lignocellulose	*EUROS/kW*	2310	2056	1802	1718	1612	1606	1601	1595
Enzymatic hydrolysis of lignocellulose	*EUROS/kW*	17	16	15	15	15	15	15	15
Enzymatic hydrolysis of lignocellulose	*EUROS/kWh*	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.05
Enzymatic hydrolysis of lignocellulose	*toe input/toe output*	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Enzymatic hydrolysis of lignocellulose	*GWh fossil fuel/GWh output*	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
Enzymatic hydrolysis of lignocellulose	*GWh fossil fuel/GWh output*	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.034
Enzymatic hydrolysis of lignocellulose	*GWh fossil fuel/GWh output*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Enzymatic hydrolysis of lignocellulose	*%*	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11

Figure 99 CPS supply input file: Techdata_bio sheet (first part)

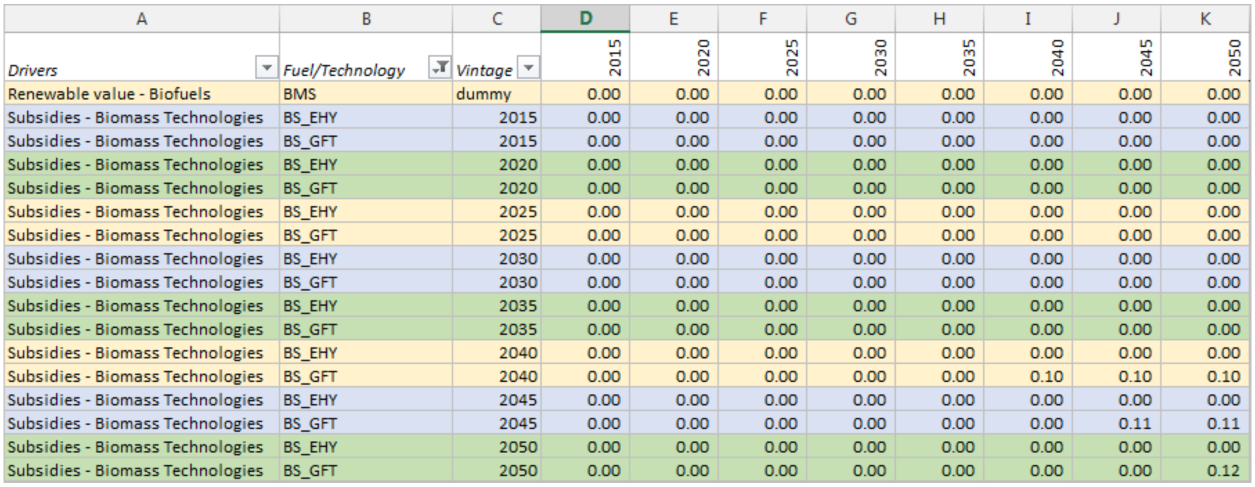


A	B	G	H	I	J	K	L	M	N	O	P	Q
Process -Feedstock	*Units*	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
food crops	*GWh*	0	0	982	1182	1401	1686	1888	1973	2056	2144	2235
lignocellulosic crops	*GWh*	0	0	0	0	2086	3819	4583	5241	5933	6679	7481
Waste liquid	*GWh*	0	43	166	165	199	231	264	296	329	361	394
waste solid	*GWh*	5250	5458	5667	5875	6083	6292	6500	7316	8650	9985	11320
waste gas	*GWh*	0	547	660	501	884	1056	1228	1400	1573	1745	1917
algae	*GWh*	0	0	0	0	0	0	0	0	0	0	0
imported biofuel conventional	*GWh*	0	0	0	1000	1500	1600	1900	2000	2100	2200	2300
imported biofuel advanced	*GWh*	0	0	0	1000	1500	1600	1900	2000	2100	2200	2300
food crops	*EUROS/kWh*	0.028	0.028	0.028	0.028	0.026	0.026	0.026	0.026	0.025	0.024	0.024
lignocellulosic crops	*EUROS/kWh*	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.085	0.080	0.079	0.078
Waste liquid	*EUROS/kWh*	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
waste solid	*EUROS/kWh*	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
waste gas	*EUROS/kWh*	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
algae	*EUROS/kWh*	0.184	0.184	0.184	0.179	0.175	0.168	0.161	0.150	0.139	0.125	0.113
imported biofuel conventional	*EUROS/kWh*	0.114	0.114	0.114	0.114	0.114	0.114	0.114	0.114	0.114	0.114	0.114
imported biofuel advanced	*EUROS/kWh*	0.199	0.199	0.199	0.199	0.199	0.199	0.199	0.199	0.199	0.199	0.199
food crops	*EUROS/kWh*	0.040	0.040	0.040	0.040	0.037	0.037	0.038	0.037	0.035	0.034	0.034
lignocellulosic crops	*EUROS/kWh*	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.53	0.07	0.07	0.07
Waste liquid	*EUROS/kWh*	0.002	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.003	0.003	0.003
waste solid	*EUROS/kWh*	0.002	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.003	0.003	0.003
waste gas	*EUROS/kWh*	0.002	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.003	0.003	0.003
algae	*EUROS/kWh*	0.571	0.571	0.571	0.557	0.543	0.521	0.501	0.464	0.431	0.389	0.352
imported biofuel conventional	*EUROS/kWh*	0.212	0.212	0.212	0.212	0.212	0.212	0.212	0.212	0.212	0.212	0.212
imported biofuel advanced	*EUROS/kWh*	9.892	9.892	9.892	9.892	9.892	9.892	9.892	9.892	9.892	9.892	9.892
food crops	*increase of marginal*	2.300	2.300	2.300	2.300	2.300	2.300	2.300	2.300	2.300	2.300	2.300
lignocellulosic crops	*increase of marginal*	10	10	10	10	10	10	10	10	2	2	2
Waste liquid	*increase of marginal*	2.300	2.300	2.300	2.300	2.300	2.300	2.300	2.300	2.300	2.300	2.300
waste solid	*increase of marginal*	2.300	2.300	2.300	2.300	2.300	2.300	2.300	2.300	2.300	2.300	2.300
waste gas	*increase of marginal*	2.300	2.300	2.300	2.300	2.300	2.300	2.300	2.300	2.300	2.300	2.300
algae	*increase of marginal*	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
imported biofuel conventional	*increase of marginal*	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
imported biofuel advanced	*increase of marginal*	80.000	80.000	80.000	80.000	80.000	80.000	80.000	80.000	80.000	80.000	80.000

Figure 100 CPS supply input file: Techdata_bio sheet (second part)

6.4.2. Policy_biofuels

- Renewable value – Biofuels: RES value per output fuel and year in €/kWh
- Subsidies - Biomass Technologies: LBD parameter per biomass technology, vintage and year in €/kWh



A	B	C	D	E	F	G	H	I	J	K
Drivers	*Fuel/Technology*	*Vintage*	2015	2020	2025	2030	2035	2040	2045	2050
Renewable value - Biofuels	BMS	dummy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies - Biomass Technologies	BS_EHY	2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies - Biomass Technologies	BS_GFT	2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies - Biomass Technologies	BS_EHY	2020	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies - Biomass Technologies	BS_GFT	2020	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies - Biomass Technologies	BS_EHY	2025	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies - Biomass Technologies	BS_GFT	2025	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies - Biomass Technologies	BS_EHY	2030	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies - Biomass Technologies	BS_GFT	2030	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies - Biomass Technologies	BS_EHY	2035	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies - Biomass Technologies	BS_GFT	2035	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies - Biomass Technologies	BS_EHY	2040	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies - Biomass Technologies	BS_GFT	2040	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.10
Subsidies - Biomass Technologies	BS_EHY	2045	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies - Biomass Technologies	BS_GFT	2045	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.11
Subsidies - Biomass Technologies	BS_EHY	2050	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies - Biomass Technologies	BS_GFT	2050	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12

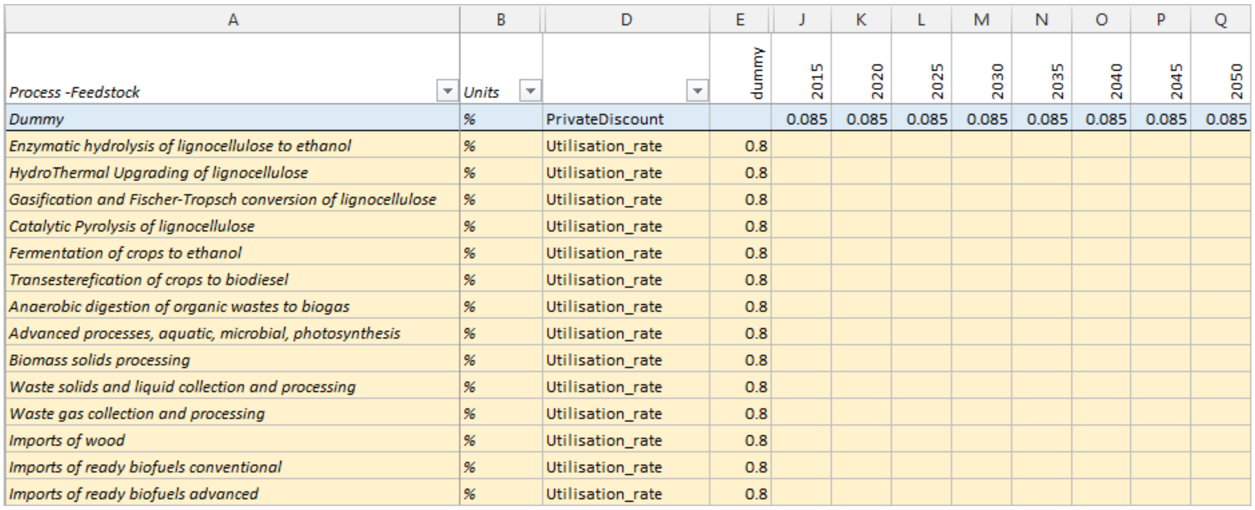
Figure 101 CPS supply input file: Policy_biofuels sheet

6.4.3. Options for changing parameters' values exogenously

The user has the ability to change the parameters of the Biomass Module in order to simulate different scenarios or policies:

1) How to change the discount rate - **Techdata_bio sheet**

The user has the ability to change the discount rate (PrivateDiscount) used in the calculation of the annuity factor for investments in biomass technologies, by changing the content of the cells in the corresponding row, in columns J to Q, as shown in Figure 102.



A	B	D	E	J	K	L	M	N	O	P	Q
Process -Feedstock	*Units*		dummy	2015	2020	2025	2030	2035	2040	2045	2050
Dummy	%	PrivateDiscount		0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085
Enzymatic hydrolysis of lignocellulose to ethanol	%	Utilisation_rate	0.8								
HydroThermal Upgrading of lignocellulose	%	Utilisation_rate	0.8								
Gasification and Fischer-Tropsch conversion of lignocellulose	%	Utilisation_rate	0.8								
Catalytic Pyrolysis of lignocellulose	%	Utilisation_rate	0.8								
Fermentation of crops to ethanol	%	Utilisation_rate	0.8								
Transesterefication of crops to biodiesel	%	Utilisation_rate	0.8								
Anaerobic digestion of organic wastes to biogas	%	Utilisation_rate	0.8								
Advanced processes, aquatic, microbial, photosynthesis	%	Utilisation_rate	0.8								
Biomass solids processing	%	Utilisation_rate	0.8								
Waste solids and liquid collection and processing	%	Utilisation_rate	0.8								
Waste gas collection and processing	%	Utilisation_rate	0.8								
Imports of wood	%	Utilisation_rate	0.8								
Imports of ready biofuels conventional	%	Utilisation_rate	0.8								
Imports of ready biofuels advanced	%	Utilisation_rate	0.8								

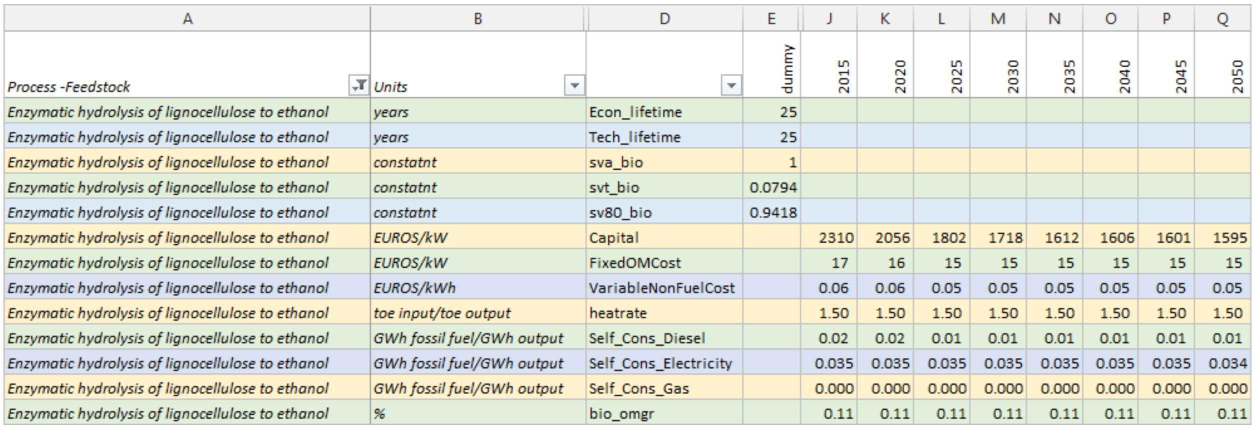
Figure 102 How to change the discount rate and the utilisation rate

2) How to change the utilisation rate - **Techdata_bio sheet**

The user has the ability to change the utilisation rate of each biomass technologies (column A), by changing the content of the relevant cells in column E, as shown in Figure 102.

3) How to change the lifetime and survival rate parameters - **Techdata_bio sheet**

The user can control the input values of economic and technical lifetime, as well as the parameters sva_bio, svt_bio and sv80_bio of the survival rate function, per biomass technology (column A), in the corresponding rows of column E, as shown in Figure 103.



A	B	D	E	J	K	L	M	N	O	P	Q
Process -Feedstock	*Units*		dummy	2015	2020	2025	2030	2035	2040	2045	2050
Enzymatic hydrolysis of lignocellulose to ethanol	*years*	Econ_lifetime	25								
Enzymatic hydrolysis of lignocellulose to ethanol	*years*	Tech_lifetime	25								
Enzymatic hydrolysis of lignocellulose to ethanol	*constatnt*	sva_bio	1								
Enzymatic hydrolysis of lignocellulose to ethanol	*constatnt*	svt_bio	0.0794								
Enzymatic hydrolysis of lignocellulose to ethanol	*constatnt*	sv80_bio	0.9418								
Enzymatic hydrolysis of lignocellulose to ethanol	*EUROS/kW*	Capital		2310	2056	1802	1718	1612	1606	1601	1595
Enzymatic hydrolysis of lignocellulose to ethanol	*EUROS/kW*	FixedOMCost		17	16	15	15	15	15	15	15
Enzymatic hydrolysis of lignocellulose to ethanol	*EUROS/kWh*	VariableNonFuelCost		0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.05
Enzymatic hydrolysis of lignocellulose to ethanol	*toe input/toe output*	heatrate		1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Enzymatic hydrolysis of lignocellulose to ethanol	*GWh fossil fuel/GWh output*	Self_Cons_Diesel		0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
Enzymatic hydrolysis of lignocellulose to ethanol	*GWh fossil fuel/GWh output*	Self_Cons_Electricity		0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.034
Enzymatic hydrolysis of lignocellulose to ethanol	*GWh fossil fuel/GWh output*	Self_Cons_Gas		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Enzymatic hydrolysis of lignocellulose to ethanol	*%*	bio_omgr		0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11

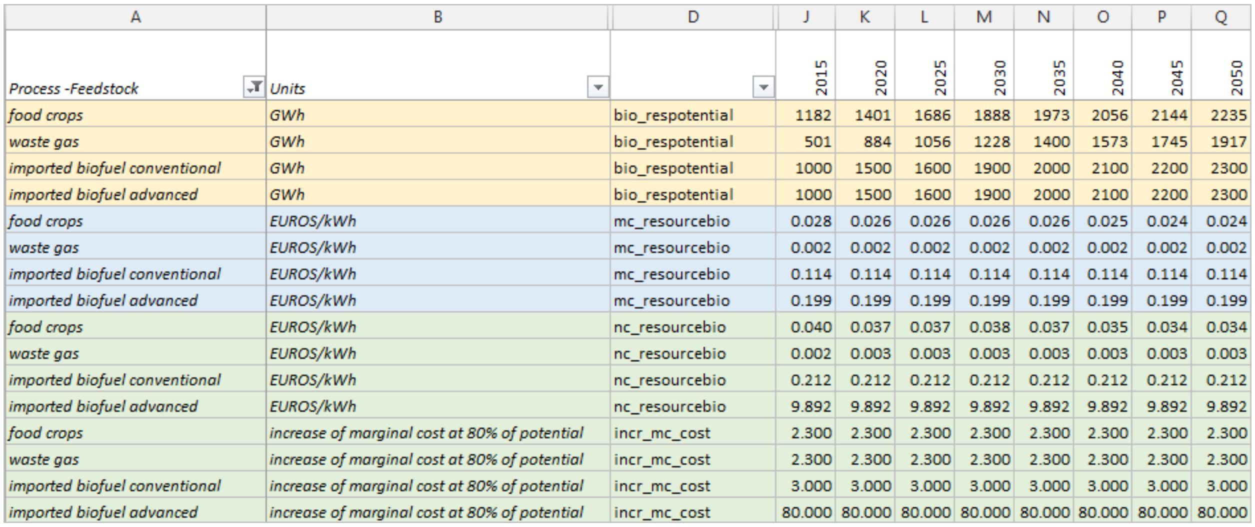
Figure 103 How to change the lifetime and survival rate parameters

4) How to change the cost and heatrate parameters - **Techdata_bio sheet**

The user has the ability to change the investment cost (Capital), variable cost (VariableNonFuel), operation & maintenance cost (FixedOMcost) and growth rate of operation & maintenance cost (bio_omgr) per biomass technology (column A), by changing the values of the corresponding cells in columns J to Q, as shown in Figure 103. Further down in the same columns, the values of heatrate, heatrate of fuel consumption, heatrate of electricity consumption and heatrate of gas consumption can be changed, as shown also in Figure 103.

5) How to change the availability potential and cost impact of potential exhaustion parameters - **Techdata_bio sheet**

The user may alter the availability potential (bio_respotential), the cost of feedstock (mc_resourcebio), the nonlinear parameter of cost-supply curve per feedstock/input fuel (nc_resourcebio) and the index denoting the increase of feedstock cost at 80% of availability potential (incr_mc_cost) values for each feedstock/input fuel (column A), by changing the cells of the corresponding rows, from columns J to Q, as shown in Figure 104.

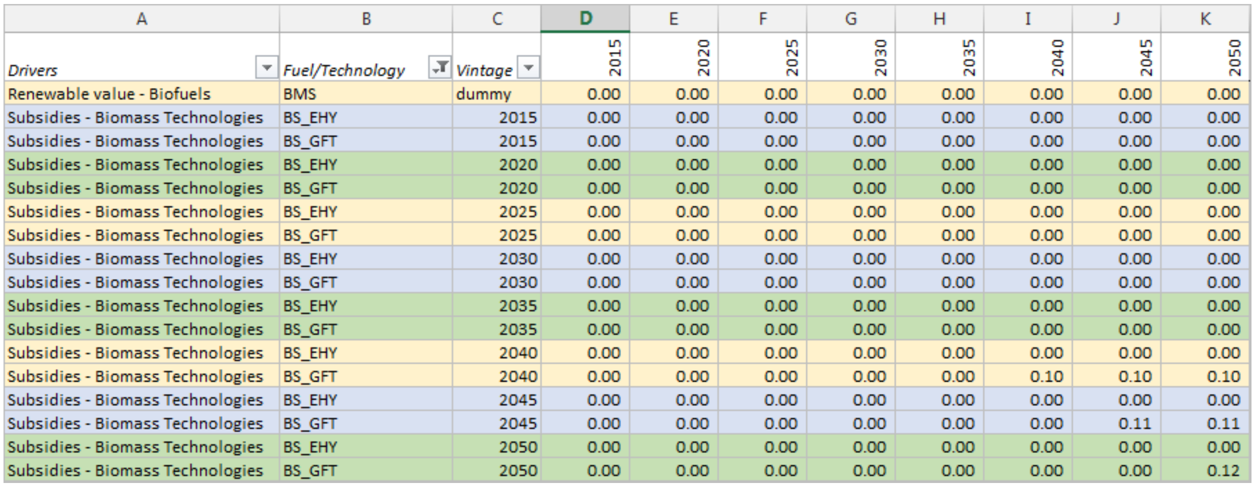


A	B	D	J	K	L	M	N	O	P	Q
Process -Feedstock	*Units*		2015	2020	2025	2030	2035	2040	2045	2050
food crops	*GWh*	bio_respotential	1182	1401	1686	1888	1973	2056	2144	2235
waste gas	*GWh*	bio_respotential	501	884	1056	1228	1400	1573	1745	1917
imported biofuel conventional	*GWh*	bio_respotential	1000	1500	1600	1900	2000	2100	2200	2300
imported biofuel advanced	*GWh*	bio_respotential	1000	1500	1600	1900	2000	2100	2200	2300
food crops	*EUROS/kWh*	mc_resourcebio	0.028	0.026	0.026	0.026	0.026	0.025	0.024	0.024
waste gas	*EUROS/kWh*	mc_resourcebio	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
imported biofuel conventional	*EUROS/kWh*	mc_resourcebio	0.114	0.114	0.114	0.114	0.114	0.114	0.114	0.114
imported biofuel advanced	*EUROS/kWh*	mc_resourcebio	0.199	0.199	0.199	0.199	0.199	0.199	0.199	0.199
food crops	*EUROS/kWh*	nc_resourcebio	0.040	0.037	0.037	0.038	0.037	0.035	0.034	0.034
waste gas	*EUROS/kWh*	nc_resourcebio	0.002	0.003	0.003	0.003	0.003	0.003	0.003	0.003
imported biofuel conventional	*EUROS/kWh*	nc_resourcebio	0.212	0.212	0.212	0.212	0.212	0.212	0.212	0.212
imported biofuel advanced	*EUROS/kWh*	nc_resourcebio	9.892	9.892	9.892	9.892	9.892	9.892	9.892	9.892
food crops	*increase of marginal cost at 80% of potential*	incr_mc_cost	2.300	2.300	2.300	2.300	2.300	2.300	2.300	2.300
waste gas	*increase of marginal cost at 80% of potential*	incr_mc_cost	2.300	2.300	2.300	2.300	2.300	2.300	2.300	2.300
imported biofuel conventional	*increase of marginal cost at 80% of potential*	incr_mc_cost	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
imported biofuel advanced	*increase of marginal cost at 80% of potential*	incr_mc_cost	80.000	80.000	80.000	80.000	80.000	80.000	80.000	80.000

Figure 104 How to change availability potential and cost impact parameters

6) How to change policy drivers – **Policy_biofuels sheet**

The user has the ability to change the RES value per output fuel (column B) and the LBD value per biomass technology (column B) and vintage (column C), by changing the values of the corresponding cells in columns D to K, as shown in Figure 105.



A	B	C	D	E	F	G	H	I	J	K
Drivers	*Fuel/Technology*	*Vintage*	2015	2020	2025	2030	2035	2040	2045	2050
Renewable value - Biofuels	BMS	dummy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies - Biomass Technologies	BS_EHY	2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies - Biomass Technologies	BS_GFT	2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies - Biomass Technologies	BS_EHY	2020	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies - Biomass Technologies	BS_GFT	2020	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies - Biomass Technologies	BS_EHY	2025	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies - Biomass Technologies	BS_GFT	2025	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies - Biomass Technologies	BS_EHY	2030	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies - Biomass Technologies	BS_GFT	2030	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies - Biomass Technologies	BS_EHY	2035	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies - Biomass Technologies	BS_GFT	2035	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies - Biomass Technologies	BS_EHY	2040	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies - Biomass Technologies	BS_GFT	2040	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.10
Subsidies - Biomass Technologies	BS_EHY	2045	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies - Biomass Technologies	BS_GFT	2045	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.11
Subsidies - Biomass Technologies	BS_EHY	2050	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies - Biomass Technologies	BS_GFT	2050	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12

Figure 105 How to change the policy drivers

Appendix I CPS Model's Sets

Table 17 Sets of the CPS Model

#	Set	Description
1	labels	Superset of labels
2	balreplabels	Set of labels of Balance and Report Modules
3	voltage	Set of voltage types
4	sectors_all	Superset of Demand Module sectors
5	sectors	Demand sectors considered in the Power Module
6	year_all	Superset of years
7	region	Regions
8	year	Set of basis and projection years
9	hour	Set of hours
10	day	Set of days
11	hour_day	Mapping of hours belonging to the same day
12	plant	Superset of all plants of Power Module
13	cluster	Labels of unit clusters
14	unit	Set of power plants
15	unit_region	Locations for units
16	unit_limit	Power plants with operation constraints in unit commitment
17	indCHP	Onsite CHP power plants
18	storage	Storage facilities
19	PtoX	Power to X plants
20	dhh	District heating plants producing heat
21	CCS	Plants with a carbon capture and storage possibility
22	ancillary_all	Ancillary services
23	ancillary_up	Upward ancillary services
24	ancillary_down	Downward ancillary services
25	fuel_all	Superset of fuels
26	f	Fuels used in the demand\refinery&biomass sectors
27	f_bioout	Output fuels of biomass submodel
28	f_biofeed	Feedstock fuels used in biomass submodel
29	bioout	Mapping of supply chains and output fuels
30	bioinp	Mapping of feedstock fuels used in supply chains
31	fself	Self-Produced fuels
32	fuel	Fuels used in the power and the district heating plants including clean fuels
33	fuel_dhh	Fuels used in district heating plants
34	fuel_limit	Fuels with a nonlinear cost supply curve
35	cleanfuel	Clean fuels

36	cleanfuel_dhh	Clean fuels used in district heating plants
37	resource	Resources of biomass model
38	type	Types of plants
39	report_type	Reporting types of plants
40	report_elec	Power plant types
41	report_heat	Heat plant types
42	report_storage	Storage types
43	report_PtoX	Power to X types
44	type_dhh	Types of district heating plants
45	type_limit	Types of plants with nonlinear cost supply curves
46	type_storage	Types of storage power plants with nonlinear cost supply curves
47	level	Levels in the cost supply curves
48	mapday	Mapping of hours in days
49	resourcemap	Resources used by a plant
50	hour_seq	Map indicating the sequence of hours
51	fuelplant_init	Fuels used by a plant
52	PtoXmap	Cleanfuels produced by a power to X plant
53	planttype	Categorization of plants in types
54	reportplanttype	Mapping of plants and report types
55	unit_cluster	Mapping of units and clusters
56	load_type	Types of load
57	SA_all	Superset of demand sectors upper level
58	SB_all	Superset of demand sectors second level
59	SC_all	Superset of demand sectors third level
60	SD_all	Superset of demand sectors fourth level
61	SE_all	Superset of supply of demand sectors upper level
62	SF_all	Superset of supply of demand sectors second level - supply processes
63	SA	Demand sectors upper level
64	SB	Demand sectors second level
65	SC	Demand sectors third level
66	SD	Demand sectors fourth level
67	SE	Supply of demand sectors upper level
68	SF	Supply of demand sectors second level - supply process
69	Sftra	Processes belonging to the transport sector
70	SA_SB	Mapping SA to SB
71	SB_SC	Mapping SB to SC
72	SC_SD	Mapping SC to SD
73	SD_SE	Mapping SD to SE

74	SE_SF	Mapping SE to SF
75	SA_EP	Mapping SA to EP
76	EP	Self-Producing equipment/cokery
77	EP_F	Input fuels used in self-producing equipments
78	AG	Representative agent
79	SD_AG	Mapping of subsectors SD and corresponding agents
80	SFbio	Supply chains used in biomass submodels
81	resourcebio	Resources used in biomass model
82	fuel_bio	Fuels consumed for self consumption in supply chains of biomass submodel
83	SW	Technology categories
84	SWord	Ordinary technology subset
85	TC	Equipement\Technology\Buildings vintages
86	tc_SW	Mapping of equipment vintage and technology categories
87	basic_prices	Basic prices from macroeconomic projection
88	fuel_cat1	Fuel category 1
89	fuel_cat2	Fuel category 2
90	fuel_cat3	Fuel category 3
91	PRI_DRIV	Prices driver
92	SE_CAT	Mapping of sectors and sector categories
93	SE_CAT_MAP	Mapping of sectors and sector categories
94	Fuel_SE_CAT	Mapping of fuels and sector categories
95	DIS_CAT	Categories of fuel transport infrastructure used to set the transport cost of fuels
96	map_fuel_main	Mapping of fuels and fuels used in district heating or industrial plants
97	map_sectors_all_sd	Mapping of sectors and subsectors
98	Stndrds	Types of standards
99	SF_F	Input fuels used in processes (except heat recovery)
100	SF_FMain	Main input fuels used in processes
101	SA_SF	Mapping SA to SF
102	fres	Subset of fuels considered as RES for RES value calculations
103	pollprice	Flag to force pollutant marginal price for processes
104	pollvalue	Flag to force pollutant marginal value for processes
105	pollprice_EP	Flag to force pollutant marginal price for self-producing equipments
106	pollvalue_EP	Flag to force pollutant marginal value for self-producing equipments
107	stndrds_SD	Enforcement of a standard on an enrgy use at a level SD
108	foutprimary	Fuels that are primary outputs of self-producing equipments
109	foutsecondary	Fuels that are secondary outputs of self-producing equipments
110	fpot_SD	Fuel subset for SD for which a potential constraint applies
111	yearlag	Association to define the lagged year

112	po	Pollutants
113	sectors_EP	Mapping of self-producing equipments and sectors
114	sectors_SF	Mapping of self-producing equipments and sectors
115	lifecat	Categories of lifetime
116	cok_EP	Eligibility of an self-producing equipment to coke production
117	Indboil	Industrial boiler
118	fuel_ind	Fuels used in industrial plants
119	cleanfuel_ind	Clean fuels used in district heating plants
120	report_steam	Steam types
121	type_indboil	Types of industrial boiler
122	INDmapsectors	Mapping of industrial plants and sectors
123	type_indCHP	Types of industrial CHP units
124	fueltypeind	Categorization of fuel used in industrial plants in types
125	map_day	Mapping of hours belonging to the same day
126	demtype	Aggregate demand sectors
127	mapdemtype	Mapping
128	SA_hide_f	Sectors with hidden costs
129	year_rep	Reporting years
130	SF_HER	Sf to HER
131	report_res	Res types
132	sectors_all_bal	Set of the sectors for the balancing program
133	sectors_bal_SF	Mapping of supply process and sectors of the balancing program
134	sectors_bal_EP	Mapping of self-producing equipments and sectors of the balancing program
135	mapbasepri	Mapping of labels for prices
136	f_bioDHIND	Set of biofuels for industrial power plants and district heating
137	map_sectors_bal	Mapping of balance sectors and labels
138	sectors_labels	Labels of demand sectors
139	sectors_ind	Industrial sectors
140	rep_labels	Labels for reporting of demand results
141	plants_labels	Labels for reporting of supply results
142	dem_report_labels	Superset of labels for reporting
143	SAind	Industrial sectors SA
144	namesSAind	Labels of industrial sectors SA excluding non-energy
145	namesSAindnonen	Labels of industrial sectors SA including non-energy
146	namesSBind	Labels of industrial subsectors SB
147	namesphysoutSA	Labels of industrial sectors SA, whose activity is based on their physical output
148	namesphysoutSB	Labels of industrial subsectors SB, whose activity is based on their physical output
149	names_SA	Mapping between sectors SA and corresponding labels

150	names_SB	Mapping between subsectors SB and corresponding labels
151	names_SD	Mapping between subsectors SD and corresponding labels
152	namesSA_SB	Mapping between labels of SA and SB
153	namesSA_SD	Mapping between labels of SA and SD
154	names_fuels	Mapping between fuels and corresponding labels
155	names_biofeed	Mapping between fuels and corresponding labels for biomass model
156	fuelcat	Fuel categories
157	map_fuels	Mapping between fuels and fuel categories
158	Domestic_uses	Uses in domestic sector
159	map_HOU_uses	Mapping between processes SF for households and domestic uses
160	map_TER_uses	Mapping between processes SF for tertiary and domestic uses
161	PUBRDP	Subset of public road transport
162	PRIVRDP	Private Road Transport
163	RAILP	Rail Passenger
164	NAVP	Passenger Inland Navigation
165	AVIAP	Aviation
166	BUNK	Bunkers
167	VEHRDF	Road Tarnsport Freight
168	RAILF	Rail Freight
169	NAVF	Freight Inland Navigation
170	HDVFR	Heavy duty vehicles - Freight
171	LDVFR	Light duty vehicles - Freight
172	PASSTOT	Subsectors SD of Passenger transport
173	FREITOT	Subsectors SD of Freight transport
174	ROAD	Subsectors SD of Road transport
175	names_fuels_TRA	Mapping between fuels and corresponding labels for transport
176	label_f_TRA	Labels of transport fuels
177	map_year_tc	Mapping between year, vintage and age of equiment
178	map_tc_rep	Mapping between vintage, year of investment, year of reporting and age of equiment
179	resTdenom	Res fuels for RES-T denominator
180	resfuels	Res fuels
181	resSTEAMSUP	Res Plants generating steam
182	setHCDEM	Res fuels for RES-HC
183	heatuses	Heat uses
184	namesDOMTRA	Labels of domestic and transport sector
185	bioimp1	Imported fuels of biomass model - 1st set
186	bioimp2	Imported fuels of biomass model - 2nd set
187	bioproc	Processes of biomass model

188	namesbioproc	Labels of biomass processes
189	label_stock1	Labels of vehicles - 1st set
190	label_stock2	Labels of vehicles -2nd set
191	map_stock	Mapping between labels of vehicles and processes SF
192	baldat_fuels	Labels of fuels for balance reporting
193	baldat_names_fuels	Mapping between fuels and corresponding labels for balance reporting

Appendix II Sectoral structure of the CPS demand sectors

Sector	***Subsectors of activity***			***Supply processes***	
SA	***SB***	***SC***	***SD***	***SE***	***SF***
Iron & Steel	*I&S Electric Arc*	*I&S Electric Arc*	*Electric Arc*	*Raw material preparation*	*Raw material preparation*
				Product finishing	*Product finishing*
				Horizontal energy uses	*Specific electricity uses*
					Heat uses
				Thermal and electric processing	*Thermal processing*
					Electric arc
	I&S Integrated	*I&S Integrated*	*Basic Oxygen Furnace*	*Raw material preparation*	*Raw material preparation*
				Product finishing	*Product finishing*
				Horizontal energy uses	*Specific electricity uses*
					Heat uses
				Thermal and electric processing	*Thermal processing*
					Blast Furnace
			Direct Reduction of Ore	*Raw material preparation*	*Raw material preparation*
				Product finishing	*Product finishing*
				Horizontal energy uses	*Specific electricity uses*
					Heat uses
				Thermal and electric processing	*Direct Reduction Furnace*
					Electric arc

Non Ferrous Metals	*NFM Primary processing*	*NFM Primary processing*	*NFM Primary processing*	*Raw material preparation*	*Raw material preparation*
				Product finishing	*Product finishing*
				Horizontal energy uses	*Specific electricity uses*
					Heat uses
				Thermal and electric processing	*Thermal processing*
					Electric processing
					Smelting
	NFM Secondary processing	*NFM Secondary processing*	*NFM Secondary processing*	*Product finishing*	*Product finishing*
				Horizontal energy uses	*Specific electricity uses*
					Heat uses
				Thermal and electric processing	*Raw material preparation*
					Thermal processing
					Electric processing
Chemicals	*Fertilisers & Petrochemicals*	*Fertilisers & Petrochemicals*	*Fertilisers & Petrochemicals*	*Horizontal energy uses*	*Specific electricity uses*
					Heat uses
				Thermal and electric processing	*Thermal processing*
					Electric processing
	Basic Chemistry Pharmaceuticals & Cosmetics	*Basic Chemistry Pharmaceuticals & Cosmetics*	*Basic Chemistry Pharmaceuticals & Cosmetics*	*Horizontal energy uses*	*Specific electricity uses*
					Heat uses
				Thermal and electric processing	*Thermal processing*
					Electric processing
Non Metallic Minerals	*Cement and Others*	*Cement and Others*	*Cement and Others*	*Raw material preparation*	*Raw material preparation*

				Kilns	Kilns
				Product finishing	Product finishing
				Horizontal energy uses	Specific electricity uses
					Heat uses
	Glass and Ceramics	Glass and Ceramics	Glass and Ceramics	Raw material preparation	Raw material preparation
				Thermal processing	Thermal processing
				Kilns	Kilns
				Horizontal energy uses	Specific electricity uses
					Heat uses
				Product finishing	Product finishing
Paper Pulp & Printing	Paper Pulp & Printing	Paper Pulp & Printing	Paper Pulp & Printing	Thermal processing	Thermal processing
				Product finishing	Product finishing
				Horizontal energy uses	Specific electricity uses
					Heat uses
Food,Drink & Tobacco	Food,Drink & Tobacco	Food,Drink & Tobacco	Food,Drink & Tobacco	Thermal processing	Thermal processing
				Horizontal energy uses	Specific electricity uses
					Heat uses
Engineering	Engineering	Engineering	Engineering	Thermal processing	Thermal processing
				Horizontal energy uses	Specific electricity uses
					Heat uses
Textiles	Textiles	Textiles	Textiles	Product finishing	Product finishing

				Horizontal energy uses	*Specific electricity uses*
					Heat uses
Other Industries	*Other Industries*	*Other Industries*	*Other Industries*	*Thermal processing*	*Thermal processing*
				Horizontal energy uses	*Specific electricity uses*
					Heat uses
Non energy sector	*Non energy sector*	*Non energy sector*	*Non energy sector*	*Non energy uses*	*Non energy uses*
Refineries	*Refineries*	*Refineries*	*Refineries*	*Thermal processing*	*Thermal processing*

Sector	***Subsectors of activity***			***Supply processes***	
SA	***SB***	***SC***	***SD***	***SE***	***SF***
Households	*Lighting*	*Lighting*	*Lighting*	*Lighting*	*Lighting*
	Black Appliances	*Black Appliances*	*Black Appliances*	*Black Appliances*	*Black Appliances*
	White Appliances	*White Appliances*	*White Appliances*	*White Appliances*	*White Appliances*
	Thermal uses	*Thermal uses*	*Air Conditioning*	*Air Conditioning*	*Air Conditioning*
			Space Heating	*Space Heating*	*Space Heating Boilers*
					Space Heating Stoves
					Space Heating RES
					Space Heating Electricity
					Space Heating Disctrict Heating
			Cooking	*Cooking*	*Cooking Electricity*
					Cooking Gas
					Cooking Stove
			Water Heating	*Water Heating*	*Water Heating Boilers*
					Water Heating Stoves

					Water Heating RES
					Water Heating Electricity
					Water Heating Disctrict Heating
Tertiary	*Services*	*Air cooling*	*Air cooling*	*Air cooling*	*Air cooling*
		Electric uses	*Electric uses*	*Electric uses*	*Electric uses*
		Lighting	*Lighting*	*Lighting*	*Lighting*
		Space Heating	*Space Heating*	*Space Heating*	*Space Heating Boilers*
					Space Heating Stoves
					Space Heating RES
					Space Heating Electricity
					Space Heating Disctrict Heating
		Water Heating	*Water Heating*	*Water Heating*	*Water Heating Boilers*
					Water Heating Stoves
					Water Heating RES
					Water Heating Electricity
					Water Heating Disctrict Heating
	Agriculture	*Lighting*	*Lighting*	*Lighting*	*Lighting*
		Electric uses	*Electric uses*	*Electric uses*	*Electric uses*
		Heating	*Heating*	*Heating*	*Heating Boilers*
					Heating Electric
					Heating Disctrict Heating
					Heating Stoves
		Pumping & Motors	*Pumping & Motors*	*Pumping & Motors*	*Pumping & motors Diesel*
					Pumping & motors Electricity

Sector	***Subsectors of activity***			***Supply processes***	
SA	***SB***	***SC***	***SD***	***SE***	***SF***
Land/Water Passenger transport	*Land/Water Passenger transport*	*Passenger Inland navigation*	*Passenger Inland navigation*	*Passenger Oil Inland navigation*	*Oil Inland navigation*
				Passenger Gas Inland navigation	*Gas Inland navigation*
				Passenger Electric Inland navigation	*Electric Inland navigation*
					Fuel cell Inland navigation
		Private passenger transport	*Private cars*	*Electric Private cars*	*Electric cars*
				H2 Private cars	*H2 cars*
				ICE Private cars	*Diesel cars*
					Gasoline cars
					Gas cars
				Plug-in Hybrid Private cars	*Plug-in Hybrid Diesel cars*
					Plug-in Hybrid Gasoline cars
			2 wheelers	*Gasoline 2wheelers*	*Gasoline 2wheelers*
				Eletric 2wheelers	*Eletric 2wheelers*
		Public passenger transport	*Metro Tram Rail*	*Metro Tram Rail Public road transport*	*Electric Metro Tram Rail*
			Public road transport	*Electric Public road transport*	*Electric Public road transport*
				H2 Public road transport	*H2 Public road transport*
				ICE Public road transport	*Diesel Public road transport*

					Gas Public road transport
		Rail passenger transport	*Slow Rail passenger transport*	*Slow Rail passenger transport*	*Diesel Slow Rail passenger transport*
					Electric Slow Rail passenger transport
					Fuel cell Rail passenger transport
			Fast Rail passenger transport	*Fast Rail passenger transport*	*Electric Fast Rail passenger transport*
Freight transport	*Freight transport*	*Rail Freight transport*	*Rail Freight transport*	*Diesel Rail Freight transport*	*Diesel Rail Freight transport*
				Electric Rail Freight transport	*Electric Rail Freight transport*
					Fuel Cell Rail Freight transport
		Freight Inland navigation	*Freight Inland navigation*	*Oil Inland waterway navigation freight transport*	*Oil Inland navigation*
				Gas Inland waterway navigation freight transport	*Gas Inland navigation*
				Electric Inland waterway navigation freight transport	*Electric Inland navigation*
					Fuel cell Inland navigation
		Trucks	*Freight Heavy duty vehicles*	*Electric Heavy duty vehicles*	*Electric Heavy duty vehicles*
				H2 Heavy duty vehicles	*H2 Heavy duty vehicles*

				ICE Heavy duty vehicles	*Diesel Heavy duty vehicles*
					Gas Heavy duty vehicles
			Freight light duty vehicles	*Electric Light duty vehicles*	*Electric Light duty vehicles*
				H2 Light duty vehicles	*H2 Light duty vehicles*
				ICE Light duty vehicles	*Diesel Light duty vehicles*
					Gasoline Light duty vehicles
					Gas Light duty vehicles
				Plug-in Hybrid Light duty vehicles	*Plug-in Hybrid Diesel Light duty vehicles*
					Plug-in Hybrid Gasoline Light duty vehicles
Aviation	*Aviation*	*Aviation*	*Aviation*	*Kerosene Aviation*	*Kerosene Aviation*
				Electric Aviation	*Hybrid Electric aviation*
					Electric Aviation

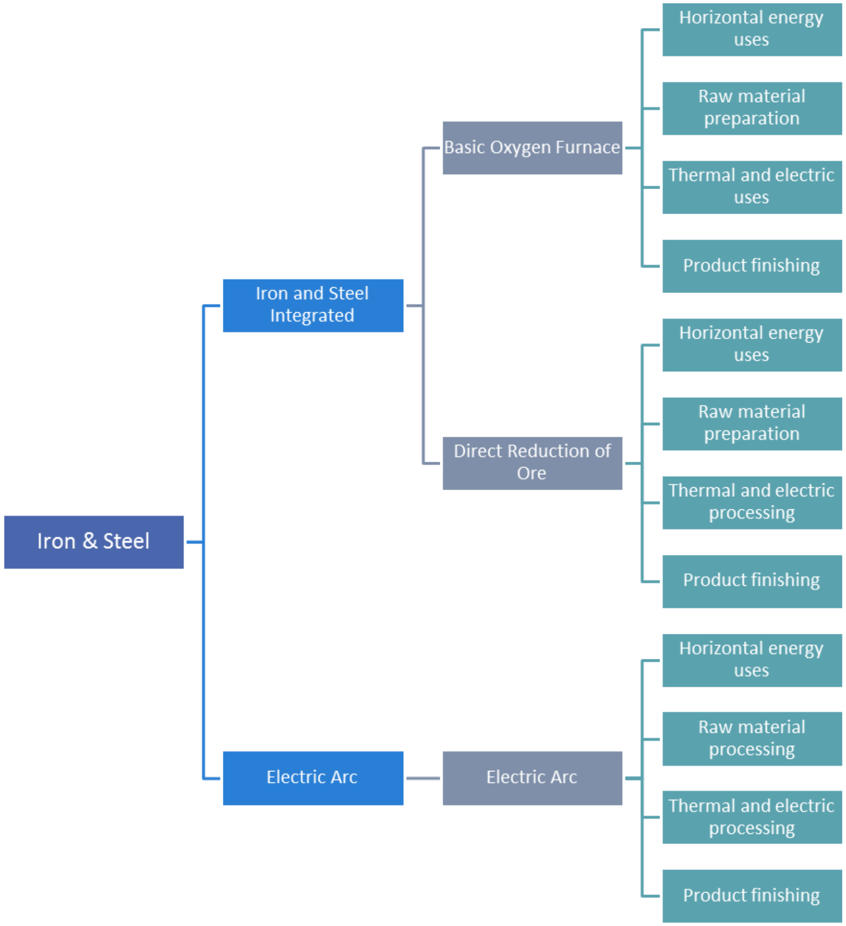


Figure 106 Iron & Steel Sector structure

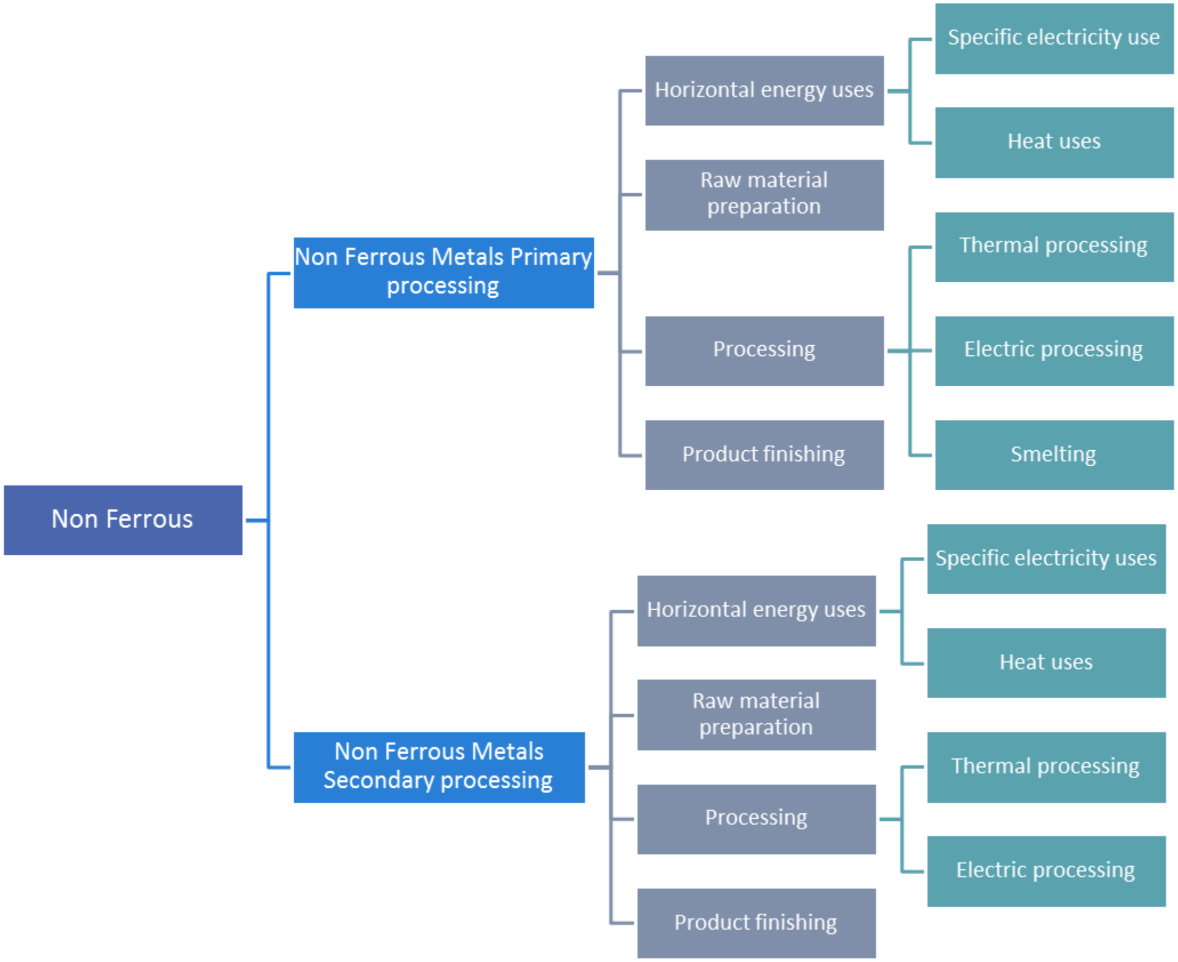


Figure 107 Non Ferrous Sector structure

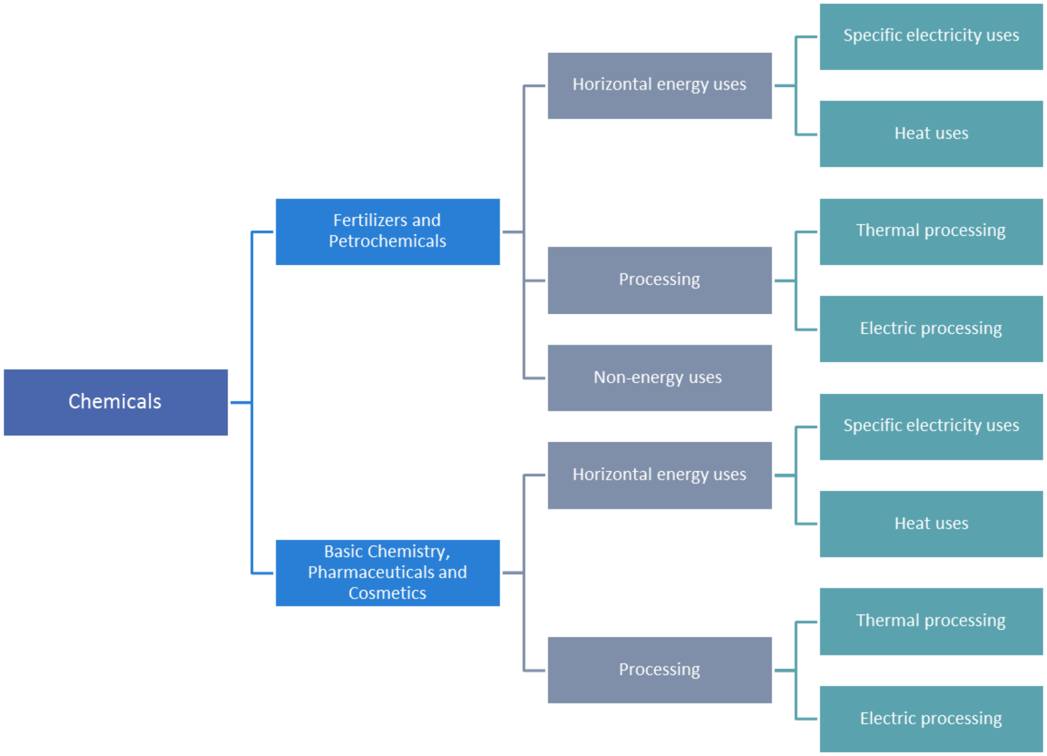


Figure 108 Chemicals Sector structure

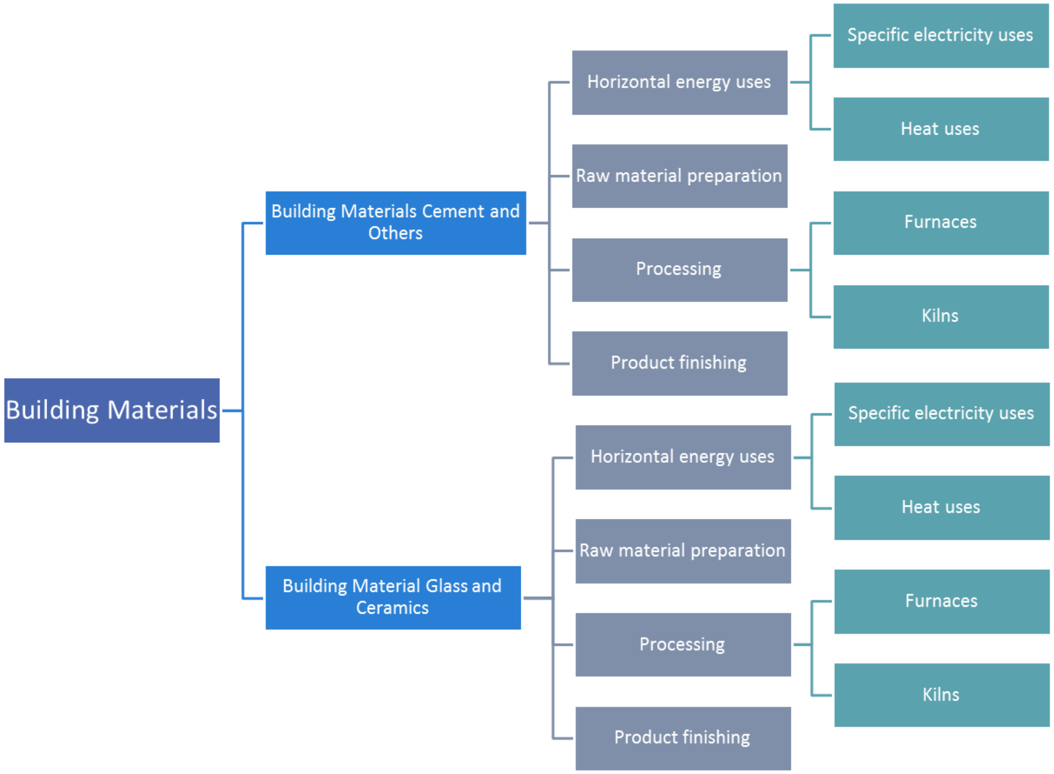


Figure 109 Building Materials Sector structure

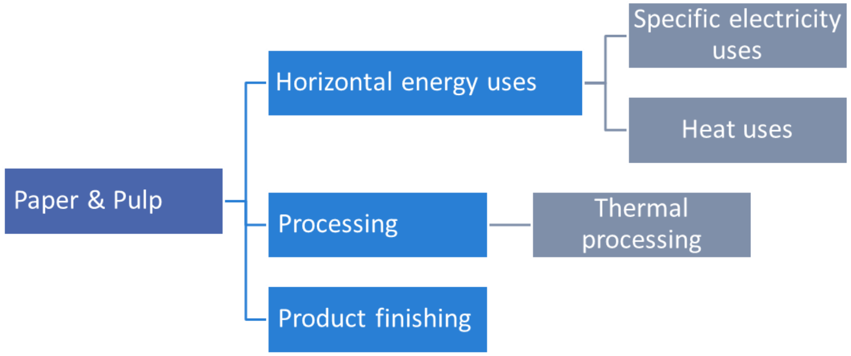


Figure 110 Paper & Pulp Sector structure

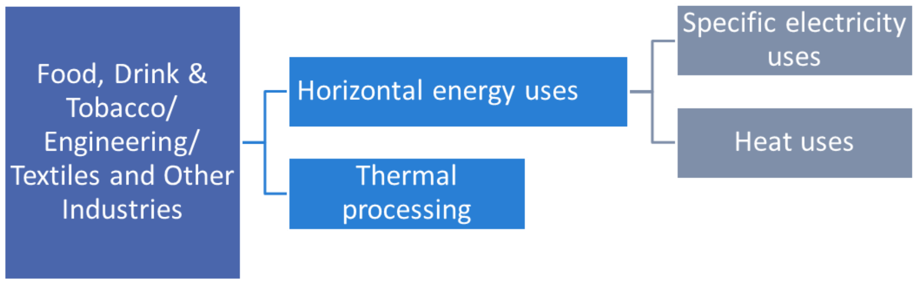


Figure 111 Other Sectors structure

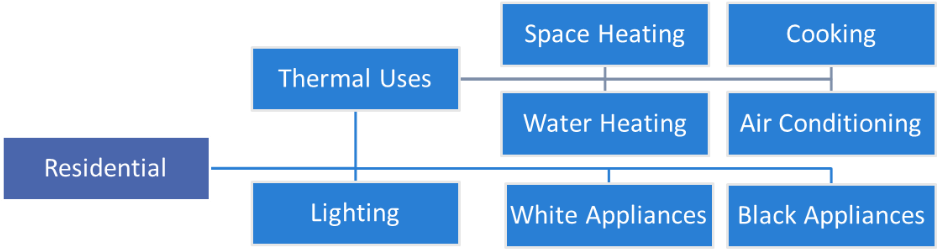


Figure 112 Residential Sector structure

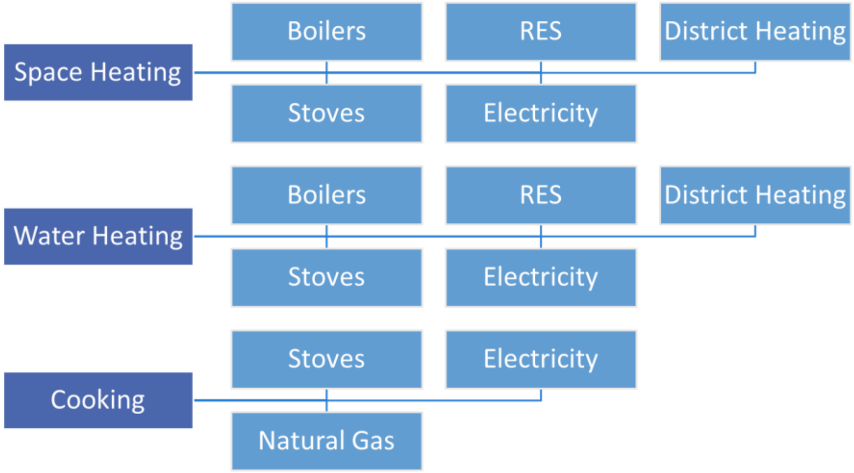


Figure 113 Supply processes of residential sector

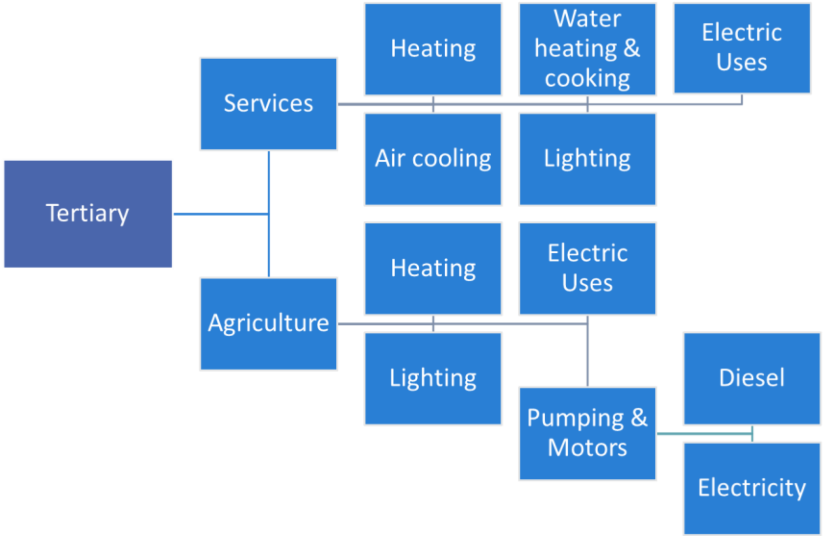


Figure 114 Tertiary Sector structure

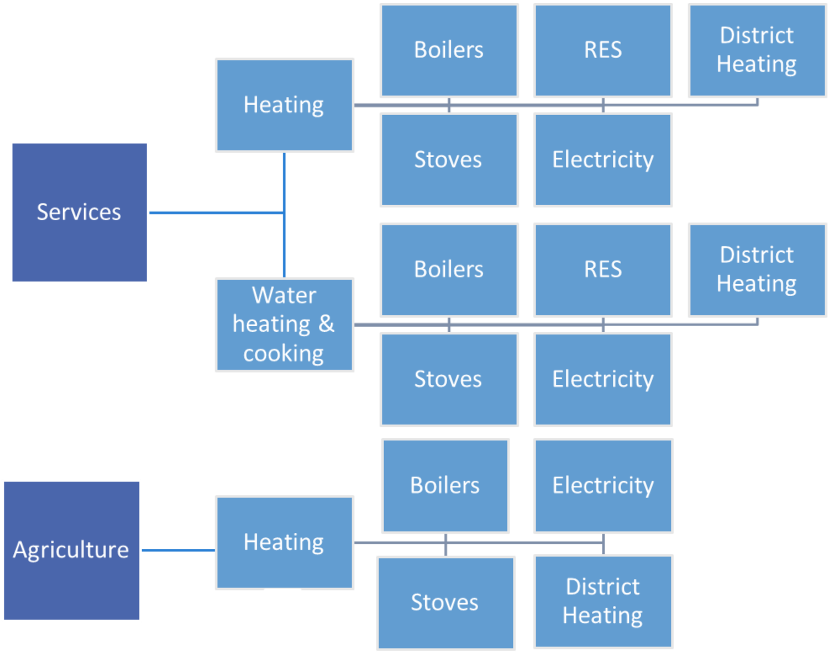


Figure 115 Supply processes of tertiary sector

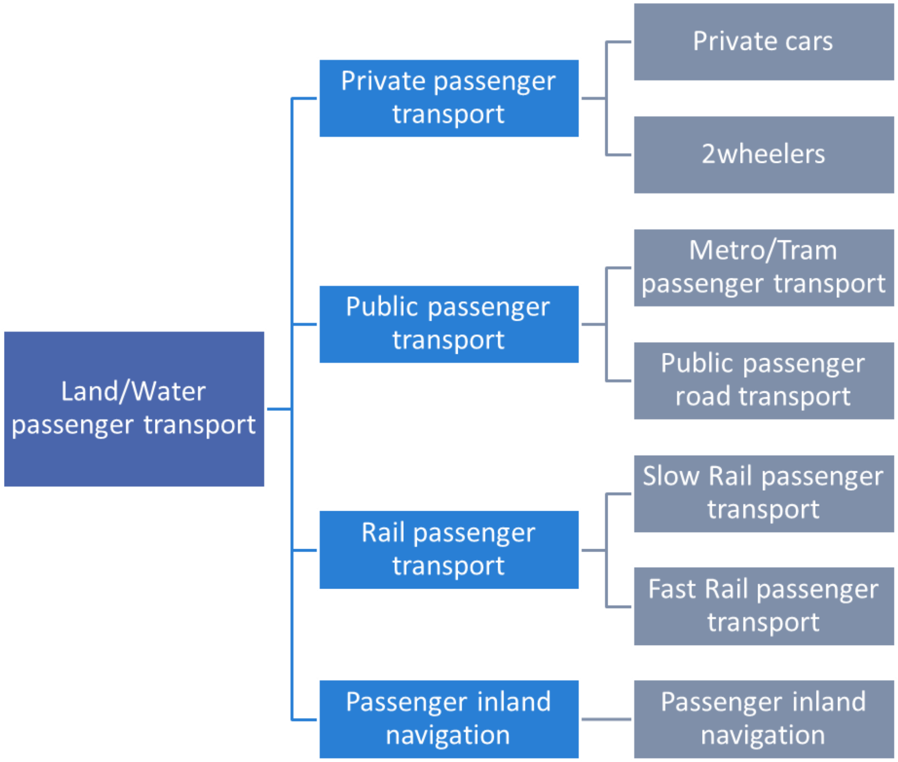


Figure 116 Land/Water Passenger Transport Sector structure

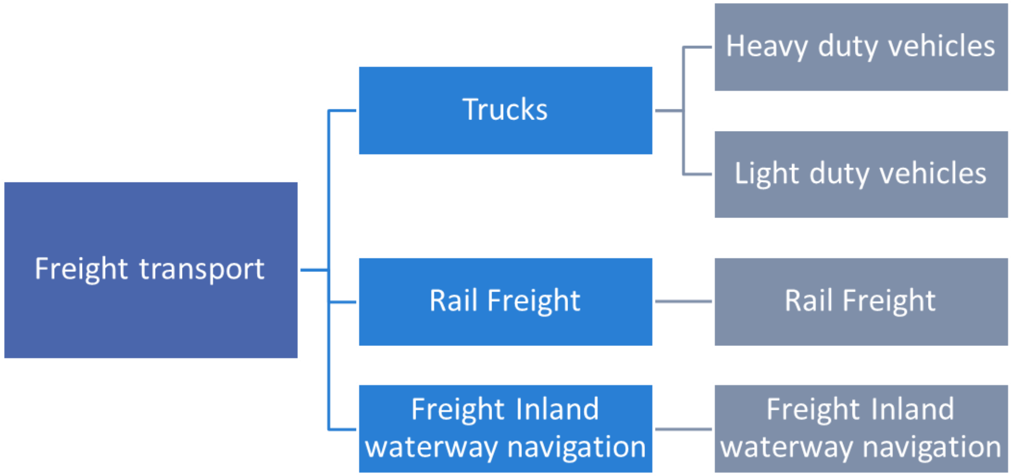


Figure 117 Freight Transport Sector structure

Appendix III Mathematical formulation of the CPS Demand Module

Symbols

Sets

Name	Domains	Description
labels	*	
year_all	labels	years
year	year_all	projection years
SA_all	labels	demand sectors upper level
SA	SA_all	demand sectors upper level
SAr	SA	running demand sectors upper level
SB_all	labels	demand sectors second level
SB	SB_all	demand sectors second level
SBr	SB	running demand sectors second level
SC_all	labels	demand sectors third level
SC, SCC	SC_all	demand sectors third level
SCr	SC	running demand sectors third level
SD_all	labels	demand sectors fourth level
SD, SDD	SD_all	demand sectors fourth level
SDr	SD	demand sectors fourth level
SE_all	labels	supply of demand sectors upper level
SE, SEE	SE_all	supply of demand sectors upper level
SEr	SE	supply of running demand sectors upper level
SF_all	labels	supply of demand sectors second level - supply process
SF, SFF	SF_all	supply of demand sectors second level - supply process
SFr	SF	supply of running demand sectors second level - supply process
SFtra	SF	processes belonging to the transport sector
EP, EPP	labels	self-producing equipment
EPr	EP	self-producing equipment
AG	labels	representative agent
SW, SWW	labels	technology categories
tc, tcc	labels	equipementvintage

Name	**Domains**	**Description**
tc_SW	tc, SW	mapping of equipment vintage and technology categories
po	labels	pollutants
SB_SC	SB, SC	mapping SB to SC
SC_SD	SC, SD	mapping SC to SD
SD_SE	SD, SE	mapping SD to SE
SE_SF	SE, SF	mapping SE to SF
SA_SF	SA, SF	mapping SA to SF
SD_SF	SD, SF	mapping SD to SF
SA_EP	SA, EP	mapping SA to EP
SD_AG	SD, AG	mapping of subsectors SD and corresponding agents
SE_AG	SE, AG	mapping of subsectors SE and corresponding agents
SF_AG	SF, AG	mapping of subsectors SF and corresponding agents
Stndrds	labels	types of standards
fuel_all	labels	set of fuels
f, ff, fff	fuel_all	fuels used in the demand&biomass sectors
fself	fuel_all	self produced fuels
fmarket	fuel_all	fuels purchased from the market
SF_fr	SF, fuel_all, year_all	input fuels used in processes (except HER)
SF_HER	SF, fuel_all	SF to HER
EP_f	EP, fuel_all	input fuels used in self-producing equipments
fres	fuel_all	subset of fuels considered as RES for the RES value
pollvalue	SF, year_all	flag to force pollutant marginal value for processes
pollprice	SF, year_all	flag to force pollutant marginal price for processes
pollprice_EP	EP, year_all	flag to force pollutant marginal price for self-producing equipments
Stndrds_SD	SD, Stndrds	enforcement of a standard on an enrgy use at a level SD
foutprimary	fuel_all, EP	fuels that are primary outputs of self-producing equipments
foutsecondary	fuel_all, EP	fuels that are secondary outputs of self-producing equipments
fpoteff_SD	SD, fuel_all, year_all	fuel subset for SD for which effectively a potential constraint applies
SWord [Singleton]	SW	ordinary technology subset
yearbasis [Singleton]	year_all	

Name	Domains	Description
SameAs	*, *	Set Element Comparison Without Checking

Parameters

Name	Domains	Description
Heatrate_AVRG	SF	
CAP_EFFEC_EP0	EP, SW, tc	
CAP_EFFEC_SF0	SF, SW, tc	
subs_EP	EP, SW, year_all	subsidy of self-producing equipment EP by technology category SW in EUR per kW
subs_SW	SF, SW, year_all	subsidy of supply process SF by technology category SW in EUR per kW ??????
RESvalue_SF	fuel_all, SF, year_all	renewable value for supply process SF by fuel f
RESvalue_EP	fuel_all, EP, year_all	renewable value for self-producing equipment EP
POvalue	po, SF, year_all	pollutant value for supply process SF (non-ETS)
POprice	po, SF, year_all	pollutant price for supply process SF in EUR per kWh (ETS)
POprice_EP	po, EP, year_all	pollutant price for self-producing equipment EP by fuel f [2eq]
HIDE_F	fuel_all, SF, year_all	perceived or hidden cost of fuel f in supply process SF in EUR per kWh
HIDE_EP_f	fuel_all, EP, year_all	perceived or hidden cost of fuel f in self-producing equipment EP in EUR per kWh
HIDE_SW	AG, SF, SW, year_all	perceived or hidden cost of supply process SF by technology category SW and agent AG in EUR per kWh
HIDE_EP	EP, SW, year_all	perceived or hidden cost of self-producing equipment EP by technology category SW in EUR per kWh
annfactor	AG, SF, year_all	annuity factor for supply process SF and agent AG
annfactor_EP	EP, year_all	annuity factor for self-producing equipment EP
PRIF_TAX_EP	fuel_all, EP, year_all	end user fuel price by self-producing equipment EP in EUR per kWh
PRIF_TAX_SF	fuel_all, SF, year_all	end user fuel prices [fuel]
fopportunity	fuel_all, fuel_all	ratio denoting fraction of price of marketed fuel saved due to the output of self-producing equipment - to calculate opportunity costs
HistAG_ACT_SE	AG, SE, year_all	activity historgramm of agent AG for sector SE
HistAG_ACT_SD	AG, SD, year_all	activity histogramm of subsectors SD
HistAG_ACT_SF	AG, SF, year_all	activity histogramm
aactsb	SB, year_all	additive parameter of power function activity
bspeed	SB	parameter denoting speed of convergence

Name	**Domains**	**Description**
macro	SB, year_all	macroeconomic driver
macro_IP	SB, year_all	macroeconomic driver equal to activity level at the inflection point
macro_BN	SB, year_all	benchmark value of macroeconomic driver
bactsb_BN	SB	benchmark elasticity
bactsb_MX	SB	maximum elasticity
Heatrate	fuel_all, SF, SW, tc, year_all	heat rate of supply process SF by fuel f technology category sw vintage tc
vqc_f	SF, fuel_all, year_all	variable cost of supply process SF by fuel f in EUR per kWh
vqc_SF	SF, year_all	variable cost of supply process SF in EUR per kW
omq_SF	SF, year_all	fixed O&M cost of supply process SF in EUR per kW annually
osmg_SF	SF, year_all	growth factor of fixed O&M cost of supply process SF
util_AG_SF	AG, SF, year_all	utilization rate of supply process SF and agent AG
capc_SW	SF, SW, year_all	capital cost of supply process SF by technology category SW in EUR per kW
vqc_ep_f	EP, fuel_all, year_all	variable cost of self-producing equipment EP by fuel f in EUR per kWh
Heatrate_EP	fuel_all, EP, SW, tc, year_all	heat rate of self-producing equipment EP by fuel f technology category sw vintage tc
vqc_ep	EP, year_all	variable cost of self-producing equipment EP in EUR per kWh
omq_ep	EP, year_all	fixed O&M cost of self-producing equipment EP in EUR per kW annually
util_EP	EP, year_all	utilization rate of self-producing equipment EP
osmg_EP	EP, year_all	growth factor of fixed O&M cost of self-producing equipment EP
capc_EP	EP, SW, year_all	capital cost of self-producing equipment EP by technology category SW in EUR per kW
outputratio	EP, fuel_all, fuel_all	ratio of primary fuel output over the secondary fuel both output from an self-producing equipment EP
Emfactor	po, fuel_all, year_all	emission factor of fuel f
mileage	AG, SF, year_all	Average travelling mileage of a vehicle per year in thousand vehicle km per year
occupancy	SF, year_all	Average number of persons or amount of tons per vehicle - trip in persons or tons per vehicle-trip
range_penalty	SF, SW	Penalty index multiplying capital cost of a technology relative to ordinary technology due to range limitations
prob_surv_SF	SF, SW, tc, year_all	probability of survival of supply process SF by technology category SW and vintage tc
prob_surv_EP	EP, SW, tc, year_all	probability of survival of self-producing equipment EP by technology category SW and vintage tc
aPROB_PREMR_SF	SF, SW, tc, year_all	multiplicative parameter of probability function for premature replacement of SF
ePROB_PREMR_SF	SF, SW, tc, year_all	additive parameter of probability function for premature replacement of SF
cPROB_PREMR_SF	SF, SW, tc, year_all	exponent parameter of probability function for premature replacement of SF
aPROB_PREMR_EP	EP, SW, tc, year_all	multiplicative parameter of probability function for self-producing equipment EP

Name	**Domains**	**Description**
ePROB_PREMR_EP	EP, SW, tc, year_all	additive parameter of probability function for self-producing equipment EP
cPROB_PREMR_EP	EP, SW, tc, year_all	exponent parameter of probability function for self-producing equipment EP
dACTSBC	SB, SC, year_all	scale parameter of nested logit 3d level
dACTSCD	SC, SD, year_all	scale parameter of nested logit 4th level
dACTSCD_Optimum	SC, SD, year_all	scale parameter of nested logit 4th level - Optimum
dACTSDE_AG_ST	AG, SD, SE, year_all	scale parameter of nested logit 5th level by agent - short-term
dACTSDE_AG_ST_Optimum	AG, SD, SE, year_all	scale parameter of nested logit 5th level by agent - short-term - Optimum
dACTSEF_AG_ST	AG, SE, SF, year_all	scale parameter of nested logit 6th level by agent - short-term
dACTSEF_AG_ST_Optimum	AG, SE, SF, year_all	scale parameter of nested logit 6th level by agent - short-term - Optimum
dACTSDE_AG_LT	AG, SD, SE, year_all	scale parameter of nested logit 5th level - long-term
dACTSDE_AG_LT_Optimum	AG, SD, SE, year_all	scale parameter of nested logit 5th level - long-term - optimum
dACTSEF_AG_LT	AG, SE, SF, year_all	scale parameter of nested logit 6th level - long-term
dACTSEF_AG_LT_Optimum	AG, SE, SF, year_all	scale parameter of nested logit 6th level - long-term - Optimum
dSW_F	SF, SW, tc, fuel_all, year_all	scale parameter of logit for fuel's share in a supply process SF by technology category sw vintage tc
dSF_SW_AG_ST	AG, SF, SW, tc, year_all	scale parameter of logit for technology category SW share in supply process SF by agent and vintage tc - short-term
dSF_SW_AG_LT	AG, SF, SW, year_all	scale parameter of logit for technology category SW share in supply process SF by agent and vintage tc - long-term
dEP_F	EP, SW, tc, fuel_all, year_all	scale parameter of logit for fuel's share in self-producing equipment EP by technology category sw vintage tc
dEP_SW_ST	EP, SW, tc, year_all	scale parameter of logit for technology category SW share in self-producing equipment EP by vintage tc - short-term
dEP_SW_LT	EP, SW, year_all	scale parameter of logit for technology category SW share in self-producing equipment EP by vintage tc - long-term
dEP_ST	SA, EP, fuel_all, year_all	scale parameter of logit for choice of type of self-producing equipment - short-term
dEP_LT	SA, EP, fuel_all, year_all	scale parameter of logit for choice of type of self-producing equipment - long-term
doff_SC	SC, year_all	off technology choice
doff_SB_SC	SB, SC, year_all	off technology choice
doff_SD	SD, year_all	off technology choice
doff_SC_SD	SC, SD, year_all	off technology choice
doff_SE	SE, year_all	off technology choice
doff_SD_SE	SD, SE, year_all	off technology choice
doff_SF	SF, year_all	off technology choice
doff_SE_SF	SE, SF, year_all	off technology choice

Name	**Domains**	**Description**
doff_SF_SW	SF, SW, year_all	off technology choice
doff_SF_tc	SF, SW, tc, year_all	off technology choice
doff_EP_tc	EP, SW, tc, year_all	off technology choice
Prob_premat_poss	SF, SW, tc, year_all	possibility of premature replacement
gACTSB	SB, year_all	exponent of nested logit 3d level
gACTSC	SC, year_all	exponent of nested logit 4th level
gACTSD_AG_ST	AG, SD, year_all	exponent of nested logit 5th level by agent - short-term
gACTSE_AG_ST	AG, SE, year_all	exponent of nested logit 6th level by agent - short-term
gACTSD_AG_LT	AG, SD, year_all	exponent of nested logit 5th level - long-term
gACTSE_AG_LT	AG, SE, year_all	exponent of nested logit 6th level - long-term
gSW_F	SF, year_all	exponent of logit for fuel's share in a supply process SF by technology category sw vintage tc
gSF_SW_AG_ST	AG, SF, year_all	exponent of logit for technology category SW share in supply process SF by agent and vintage tc - short-term
gSF_SW_AG_LT	AG, SF, year_all	exponent of logit for technology category SW share in supply process SF by agent and vintage tc - long-term
gEP_F	EP, year_all	exponent of logit for fuel's share in self-producing equipment EP by technology category sw vintage tc
gEP_SW_ST	EP, year_all	exponent of logit for technology category SW share in self-producing equipment EP by vintage tc - short-term
gEP_SW_LT	EP, year_all	exponent of logit for technology category SW share in self-producing equipment EP by vintage tc - long-term
gEP_ST	SA, year_all	exponent of logit for choice of type of self-producing equipment - short-term
gEP_LT	SA, year_all	exponent of logit for choice of type of self-producing equipment - long-term
gOptimumACTSC	SC, year_all	exponent of nested logit 4th level
gOptimumACTSD_AG_ST	AG, SD, year_all	exponent of nested logit 5th level by agent - short-term
gOptimumACTSE_AG_ST	AG, SE, year_all	exponent of nested logit 6th level by agent - short-term
gOptimumACTSD_AG_LT	AG, SD, year_all	exponent of nested logit 5th level - long-term
gOptimumACTSE_AG_LT	AG, SE, year_all	exponent of nested logit 6th level - long-term
gOptimumSW_F	SF, year_all	exponent of logit for fuel's share in a supply process SF by technology category sw vintage tc
gOptimumSF_SW_AG_ST	AG, SF, year_all	exponent of logit for technology category SW share in supply process SF by agent and vintage tc - short-term
gOptimumSF_SW_AG_LT	AG, SF, year_all	exponent of logit for technology category SW share in supply process SF by agent and vintage tc - long-term
gOptimumEP_F	EP, year_all	exponent of logit for fuel's share in self-producing equipment EP by technology category sw vintage tc
gOptimumEP_SW_ST	EP, year_all	exponent of logit for technology category SW share in self-producing equipment EP by vintage tc - short-term
gOptimumEP_SW_LT	EP, year_all	exponent of logit for technology category SW share in self-producing equipment EP by vintage tc - long-term
gOptimumEP_ST	SA, year_all	exponent of logit for type of self-producing equipment EP by vintage tc - short-term

Name	**Domains**	**Description**
gOptimumEP_LT	SA, year_all	exponent of logit for type of self-producing equipment EP by vintage tc - long-term (define by user)
SH_ACTSBC_conv_lag	SB, SC, year_all	
SH_ACTSCD_optimum_conv_lag	SC, SD, year_all	
SH_ACTSDE_AG_ST_Optimum_conv_lag	AG, SD, SE, year_all	
SH_ACTSDE_AG_LT_Optimum_conv_lag	AG, SD, SE, year_all	
SH_ACTSEF_AG_ST_Optimum_conv_lag	AG, SE, SF, year_all	
SH_ACTSEF_AG_LT_Optimum_conv_lag	AG, SE, SF, year_all	
SUBS_P_ACTSE	SE, year_all	subsidy in sector SE []
SUBS_P_ACTSF	SF, year_all	subsidy in sector SF []
EL_SB_CARD	SB, year_all	for SB
EL_SC_CARD	SC, year_all	for SC
EL_SD_CARD	SD, year_all	for SD
EL_SE_CARD	SE, year_all	for SE
TH_SH_ACTSCD	SC, year_all	theta function in subsector SC
TH_SH_ACTSDE_AG_ST	AG, SD, year_all	theta function for activity in subsector SD by agent AG short term
TH_SH_ACTSDE_AG_LT	AG, SD, year_all	theta function for activity in subsector SD by agent AG long term
TH_SH_ACTSEF_AG_ST	AG, SE, year_all	theta function for activity in subsector SE by agent AG short term
TH_SH_ACTSEF_AG_LT	AG, SE, year_all	theta function for activity in subsector SE by agent AG long term
TH_SH_SW_F	SF, year_all	theta function for fuel share in supply process SF by technology category SW and vintage tc
TH_SH_SF_SW_AG_ST	AG, SF, year_all	theta function for share of technology category SW in supply process SF by agent and vintage tc - short-term
TH_SH_SF_SW_AG_LT	AG, SF, year_all	theta function for share of technology category SW in supply process SF by agent - long-term
TH_SHINPUT_EP_F	EP, year_all	theta function for fuel share in self-producing equipment EP by technology category SW and vintage tc
TH_SH_EP_SW_ST	EP, year_all	theta function for share of technology category SW in self-producing equipment EP by vintage tc - short-term
TH_SH_EP_SW_LT	EP, year_all	theta function for share of technology category SW in self-producing equipment EP - long-term
TH_SH_EP_ST	SA, year_all	theta function for share of the type of self-producing equipment EP - short-term
TH_SH_EP_LT	SA, year_all	theta function for share of the type of self-producing equipment EP - long-term
POT_SD	SD, fuel_all, year_all	potential amount
a6_POT_SD	SD, fuel_all, year_all	
a5_POT_SD	SD, fuel_all, year_all	
a4_POT_SD	SD, fuel_all, year_all	

Name	Domains	Description
a3_POT_SD	SD, fuel_all, year_all	
a2_POT_SD	SD, fuel_all, year_all	
a1_POT_SD	SD, fuel_all, year_all	
a6_POT_HER	SF, SW, tc, year_all	
a5_POT_HER	SF, SW, tc, year_all	
a4_POT_HER	SF, SW, tc, year_all	
a3_POT_HER	SF, SW, tc, year_all	
a2_POT_HER	SF, SW, tc, year_all	
a1_POT_HER	SF, SW, tc, year_all	
SH_HER_lag	SF, SW, tc, year_all	survived share of total heat recovery
SH_POT_HER	SF, year_all	potential as share
capc_HER	SF, year_all	capital cost of equipment of heat recovery in EUR per kW
subs_HER	SF, year_all	subsidy of heat recovery equipment HER in EUR per kW
annfactor_HER	SF, year_all	annuity factor for heat recovery equipment HER
omq_HER	SF, year_all	fixed O&M cost of heatracovery equipment HER in EUR per kW annually
EEvalue_HER	SF, year_all	energy efficiency value of HEAT RECOVERY EUR per MWh saved
gHER	SF, year_all	exponent of logit for choice of heat recovery
dHER	SF, SW, tc, year_all	perceived cost of heat recovery
CAP_EFFEC_HER_lag	SF, SW, tc, year_all	effectively operational capacity of equipment of heat recovery in previous period in GW
prob_surv_HER	SF, SW, tc, year_all	probability of survival of capacity of equipment of heat recovery
stnd_SD_target	Stndrds, SD, year_all	value of target
lblstnd_SF	Stndrds, SF, SW, year_all	label of an equipment regarding a certain standard
macro_lag	SB, year_all	macroeconomic driver of the previous year
CAP_EFFEC_SF_lag	SF, SW, tc, year_all	effective capacity of supply process SF by technology category SW of the previous year in kW
CAP_EFFEC_EP_lag	EP, SW, tc, year_all	effective capacity of self-producing equipment EP by technology category SW of the previous year in kW
Prem_SF_flag	SF, year_all	if 1 premature replacement is possible if 0 not
Prem_EP_flag	EP, year_all	if 1 premature replacement is possible if 0 not

Variables

Name	**Domains**	**Description**
ACTSB	SB, year_all	activity of subsector SB
ACTSC	SC, year_all	activity of subsector SC
ACTSD	SD, year_all	activity of subsector SD
ACTSE_AG	AG, SE, year_all	activity of subsector SE by agent
ACTSE	SE, year_all	activity of subsector total
ACTSF_AG	AG, SF, year_all	activity of supply process SF by agent
ACTSF	SF, year_all	activity of supply process SF total
ACTSE_AG_LT	AG, SE, year_all	activity of subsector SE by agent - long-term
ACTSF_AG_LT	AG, SF, year_all	activity of supply process SF by agent - long-term
P_ACTSB	SB, year_all	unit cost of services provided to subsector SB [of activity]
P_ACTSC	SC, year_all	unit cost of services provided to subsector SC [of activity]
P_ACTSD	SD, year_all	unit cost of services provided to subsector SD [of activity]
P_ACTSE_AG_ST	AG, SE, year_all	short term unit cost of services SE provided to agent AG [of activity]
P_ACTSF_AG_ST	AG, SF, year_all	short term unit cost of supply process SF providing services to agent AG [of activity]
P_ACTSE_AG_LT	AG, SE, year_all	long term unit cost of services SE provided to agent AG [of activity]
P_ACTSE_AG_LT_Stndrds	AG, SE, year_all	penalty for car standards applying on the long term unit cost of services SE provided to agent AG [of activity]
P_ACTSF_AG_LT	AG, SF, year_all	long term unit cost of supply process SF providing services to agent AG [of activity]
P_ACTSF_AG_LT_Stndrds	AG, SF, year_all	penalty for car standards applying on the long term unit cost of supply process SF providing services to agent AG [of activity]
P_EXCESSSEC_EP	fuel_all, EP, year_all	penalty for polluting fuel produced and not fully used []
P_ACTSE_ST	SE, year_all	unit cost at the level of SE short term
P_ACTSE_LT	SE, year_all	unit cost at the level of SE long term
P_ACTSF_ST	SF, year_all	unit cost at the level of SF short term
P_ACTSF_LT	SF, year_all	unit cost at the level of SE long term
SH_HER	SF, SW, tc, year_all	share of total heat recovery
SH_SW_F	SF, SW, tc, fuel_all, year_all	share of fuel f in consumption of a supply process SF by technology category SW vintage tc
FE_SF	SF, fuel_all, year_all	final energy consumption of supply process SF by fuel f in GWh
SH_ACTSBC	SB, SC, year_all	share of activity of subsector SC in top-level subsector SB
SH_ACTSCD_Inert	SC, SD, year_all	share of activity of of subsector SD in top-level subsector SC - subject to inertia from previous year
SH_ACTSCD_Optimum	SC, SD, year_all	share of activity of of subsector SD in top-level subsector SC - optimum without inertia from previous year

Name	**Domains**	**Description**
SH_ACTSCD	SC, SD, year_all	share of activity of of subsector SD in top-level subsector SC
SH_ACTSDE_AG_ST_Inert	AG, SD, SE, year_all	share of activity of of subsector SE in top-level subsector SD for each agent AG - subject to inertia from previous year
SH_ACTSDE_AG_ST_Optimum	AG, SD, SE, year_all	share of activity of of subsector SE in top-level subsector SD for each agent AG - optimum without inertia from previous year
SH_ACTSDE_AG_ST	AG, SD, SE, year_all	share of activity of of subsector SE in top-level subsector SD for each agent AG
SH_ACTSEF_AG_ST_Inert	AG, SE, SF, year_all	share of activity of of supply process SF in top-level subsector SE for each agent AG - subject to inertia from previous year
SH_ACTSEF_AG_ST_Optimum	AG, SE, SF, year_all	share of activity of of supply process SF in top-level subsector SE for each agent AG - optimum without inertia from previous year
SH_ACTSEF_AG_ST	AG, SE, SF, year_all	share of activity of of supply process SF in top-level subsector SE for each agent AG
SH_ACTSDE_AG_LT_Inert	AG, SD, SE, year_all	share of SE in SD - long term - subject to inertia from previous year
SH_ACTSDE_AG_LT_Optimum	AG, SD, SE, year_all	share of SE in SD - long term - optimum without inertia from previous year
SH_ACTSDE_AG_LT	AG, SD, SE, year_all	share of SE in SD - long term
SH_ACTSEF_AG_LT_Inert	AG, SE, SF, year_all	share of SF in SE - long term - subject to inertia from previous year
SH_ACTSEF_AG_LT_Optimum	AG, SE, SF, year_all	share of SF in SE - long term - optimum without inertia from previous year
SH_ACTSEF_AG_LT	AG, SE, SF, year_all	share of SF in SE - long term
X_SH_ACTSBC	SB, SC, year_all	utility from the share of activity of subsector SC in top-level subsector SB
X_SH_ACTSCD_Inert	SC, SD, year_all	utility from the share of activity of of subsector SD in top-level subsector SC - subject to inertia from previous year
X_SH_ACTSCD_Optimum	SC, SD, year_all	utility from the share of activity of of subsector SD in top-level subsector SC - optimum without inertia from previous year
X_SH_ACTSDE_AG_ST_Inert	AG, SD, SE, year_all	utility from the share of activity of of subsector SE in top-level subsector SD for each agent AG - subject to inertia from previous year
X_SH_ACTSDE_AG_ST_Optimum	AG, SD, SE, year_all	utility from the share of activity of of subsector SE in top-level subsector SD for each agent AG - optimum without inertia from previous year
X_SH_ACTSEF_AG_ST_Inert	AG, SE, SF, year_all	utility from the share of activity of of supply process SF in top-level subsector SE for each agent AG - subject to inertia from previous year
X_SH_ACTSEF_AG_ST_Optimum	AG, SE, SF, year_all	utility from the share of activity of of supply process SF in top-level subsector SE for each agent AG - optimum without inertia from previous year
X_SH_ACTSDE_AG_LT_Inert	AG, SD, SE, year_all	utility from the share of SE in SD - long term - subject to inertia from previous year
X_SH_ACTSDE_AG_LT_Optimum	AG, SD, SE, year_all	utility from the share of SE in SD - long term - optimum without inertia from previous year

Name	**Domains**	**Description**
X_SH_ACTSEF_AG_LT_Inert	AG, SE, SF, year_all	utility from the share of SF in SE - long term - subject to inertia from previous year
X_SH_ACTSEF_AG_LT_Optimum	AG, SE, SF, year_all	utility from the share of SF in SE - long term - optimum without inertia from previous year
SH_SW_F_Inert	SF, SW, tc, fuel_all, year_all	share of fuel f in consumption of a supply process SF by technology category SW vintage tc - subject to inertia from previous year
SH_SW_F_Optimum	SF, SW, tc, fuel_all, year_all	share of fuel f in consumption of a supply process SF by technology category SW vintage tc - optimum without inertia from previous year
SH_SF_SW_AG_ST_Inert	AG, SF, SW, tc, year_all	share of technology category SW and vintage tc in consumption of a supply process SF by agent - short-term - subject to inertia from previous year
SH_SF_SW_AG_ST_Optimum	AG, SF, SW, tc, year_all	share of technology category SW and vintage tc in consumption of a supply process SF by agent - short-term - optimum without inertia from previous year
SH_SF_SW_AG_ST	AG, SF, SW, tc, year_all	share of technology category SW and vintage tc in consumption of a supply process SF by agent - short-term
SH_SF_SW_AG_LT_Inert	AG, SF, SW, year_all	share of technology category SW in consumption of a supply process SF by agent - long-term - subject to inertia from previous year
SH_SF_SW_AG_LT_Optimum	AG, SF, SW, year_all	share of technology category SW in consumption of a supply process SF by agent - long-term - optimum without inertia from previous year
SH_SF_SW_AG_LT	AG, SF, SW, year_all	share of technology category SW in consumption of a supply process SF by agent - long-term
SH_INV_SF	SF, SW, year_all	share of technology category SW in new investment
X_SH_SW_F_Inert	SF, SW, tc, fuel_all, year_all	utility from the share of fuel f in consumption of a supply process SF by technology category SW vintage tc - subject to inertia from previous year
X_SH_SW_F_Optimum	SF, SW, tc, fuel_all, year_all	utility from the share of fuel f in consumption of a supply process SF by technology category SW vintage tc - optimum without inertia from previous year
X_SH_SF_SW_AG_ST_Inert	AG, SF, SW, tc, year_all	utility from the share of technology category SW and vintage tc in consumption of a supply process SF by agent - short-term - subject to inertia from previous year
X_SH_SF_SW_AG_ST_Optimum	AG, SF, SW, tc, year_all	utility from the share of technology category SW and vintage tc in consumption of a supply process SF by agent - short-term - optimum without inertia from previous year
X_SH_SF_SW_AG_LT_Inert	AG, SF, SW, year_all	utility from the share of technology category SW in consumption of a supply process SF by agent - long-term - subject to inertia from previous year
X_SH_SF_SW_AG_LT_Optimum	AG, SF, SW, year_all	utility from the share of technology category SW in consumption of a supply process SF by agent - long-term - optimum without inertia from previous year

Name	**Domains**	**Description**
SHINPUT_EP_F_Inert	EP, SW, tc, fuel_all, year_all	share of input fuel f in consumption of an self-producing equipment EP of technology category SW and vintage tc - subject to inertia from previous year
SHINPUT_EP_F_Optimum	EP, SW, tc, fuel_all, year_all	share of input fuel f in consumption of an self-producing equipment EP of technology category SW and vintage tc - optimum without inertia from previous year
SHINPUT_EP_F	EP, SW, tc, fuel_all, year_all	share of input fuel f in consumption of an self-producing equipment EP of technology category SW and vintage tc
SH_EP_SW_ST_Inert	EP, SW, tc, year_all	share of technology category SW of vintage tc in consumption of self-producing equipment EP - short-term - subject to inertia from previous year
SH_EP_SW_ST_Optimum	EP, SW, tc, year_all	share of technology category SW of vintage tc in consumption of self-producing equipment EP - short-term - optimum without inertia from previous year
SH_EP_SW_ST	EP, SW, tc, year_all	share of technology category SW of vintage tc in consumption of self-producing equipment EP - short-term
SH_EP_ST_Inert	SA, EP, fuel_all, year_all	share of an EP type in the demand for the primary output that the EP type primarily produces based on short term costs - subject to inertia from previous year
SH_EP_ST_Optimum	SA, EP, fuel_all, year_all	share of an EP type in the demand for the primary output that the EP type primarily produces based on short term costs - optimum without inertia from previous year
SH_EP_ST	SA, EP, fuel_all, year_all	share of an EP type in the demand for the primary output that the EP type primarily produces based on short term costs
SH_EP_SW_LT_Inert	EP, SW, year_all	share of technology category SW in production of self-producing equipment EP - long-term - subject to inertia from previous year
SH_EP_SW_LT_Optimum	EP, SW, year_all	share of technology category SW in production of self-producing equipment EP - long-term - optimum without inertia from previous year
SH_EP_SW_LT	EP, SW, year_all	share of technology category SW in production of self-producing equipment EP - long-term
SH_EP_LT_Inert	SA, EP, fuel_all, year_all	share of an EP type in the demand for the primary output that the EP type produces as primary output based on long term costs - subject to inertia from previous year
SH_EP_LT_Optimum	SA, EP, fuel_all, year_all	share of an EP type in the demand for the primary output that the EP type produces as primary output based on long term costs - optimum without inertia from previous year
SH_EP_LT	SA, EP, fuel_all, year_all	share of an EP type in the demand for the primary output that the EP type produces as primary output based on long term costs
STC_SW_F	SF, SW, tc, fuel_all, year_all	short-term marginal cost of supply process SF by technology category SW vintage tc and fuel f in EUR per kWh or EUR per vehicle km
UCAUTO_SA	fuel_all, SA, year_all	unit cost of self supply of a fuel f in a sector SA in EUR per kWh

Name	**Domains**	**Description**
STC_SF_SW	SF, SW, tc, year_all	short-term marginal cost of supply process SF by technology category sw and vintage tc in EUR per kWh or EUR per vehicle km
LTC_SF_SW	SF, SW, year_all	long-term marginal cost of supply process SF by technology category sw in EUR per kWh or EUR per vehicle km
STC_SF_SW_AG	AG, SF, SW, tc, year_all	short-term marginal cost of supply process SF by technology category sw agent AG and vintage tc in EUR per kWh or EUR per vehicle km
M_STC_SF_SW_AG	AG, SF, SW, tc, year_all	short-term marginal cost of supply process SF by technology category sw agent AG and vintage tc in EUR per kWh or EUR per vehicle km (include capacity constraint)
LTC_SF_SW_AG	AG, SF, SW, year_all	long-term marginal cost of supply process SF by technology category sw and agent AG in EUR per kWh or EUR per vehicle km
LTC_SF_SW_AG_Stndrds	AG, SF, SW, year_all	penalty for car standards applying on the long-term marginal cost of supply process SF by technology category sw and agent AG in EUR per kWh or EUR per vehicle km
STC_EP_F	EP, SW, tc, fuel_all, year_all	short-term marginal cost of self-producing equipment EP by technology category SW vintage tc and fuel f in EUR per kWh
UCSUP_EP	fuel_all, EP, year_all	unit cost of self production of a fuel f from an self-producing equipment EP in EUR per kWh
STC_EP_SW	EP, SW, tc, year_all	short-term marginal cost of self-producing equipment EP by technology category SW and vintage tc in EUR per kWh
STC_EP	EP, year_all	short-term marginal cost of self-producing equipment EP after aggregating the optimal technology choice in EUR per kWh (include dual price of capacity constraint)
M_STC_EP_SW	EP, SW, tc, year_all	short-term marginal cost of self-producing equipment EP by technology category SW and vintage tc in EUR per kWh (include capacity constraint)
LTC_EP_SW	EP, SW, year_all	long-term marginal cost of self-producing equipment EP by technology category SW in EUR per kWh
LTC_EP	EP, year_all	long-term marginal cost of self-producing equipment EP after aggregating the optimal technology choice in EUR per kWh
LTC_EP_PRICE	EP, year_all	average long-term marginal cost of self-producing equipment EP used for pricing the output in EUR per kWh
OUTPRIM_EP	fuel_all, EP, year_all	primary output fuel from self-producing equipment EP
OUTSEC_EP	fuel_all, EP, year_all	secondary output fuel from self-producing equipment EP
UE_SF_SW	SF, SW, tc, year_all	useful energy of supply process SF by technology category SW and vintage tc in GWh
UE_SF	SF, year_all	useful energy of supply process SF in GWh
FE_SF_SW_f	SF, SW, tc, fuel_all, year_all	final energy consumption of supply process SF by fuel f technology category SW and vintage tc in GWh
FE_EP_SW_f	EP, SW, tc, fuel_all, year_all	final energy consumption of self-producing equipment EP by fuel f technology category SW and vintage tc in GWh
FE_EP	EP, fuel_all, year_all	final energy consumption of self-producing equipment EP by fuel f in GWh

Name	**Domains**	**Description**
PROB_PREMR_SF	SF, SW, tc, year_all	probability of premature replacement of supply process SF of technology category SW and vintage tc
PROB_PREMR_EP	EP, SW, tc, year_all	probability of premature replacement of self-producing equipment EP of technology category SW and vintage tc
CAP_SURV_SF	SF, SW, tc, year_all	survived capacity of supply process SF of technology category SW and vintage tc in GW
CAP_SURV_SF_TOT	SF, year_all	total survived capacity of supply process SF of technology category SW and vintage tc in GW
CAP_SURV_EP	EP, SW, tc, year_all	survived capacity of self-producing equipment EP of technology category SW and vintage tc in GW
CAP_DESIRED_SF	SF, SW, year_all	desired capacity of supply process SF of technology category SW in GW
CAP_DESIRED_SF_TOT	SF, year_all	total desired capacity of supply process SF of technology category SW in GW
CAP_DESIRED_EP	EP, SW, year_all	desired capacity of self-producing equipment EP of technology category SW in GW
CAP_EFFEC_SF	SF, SW, tc, year_all	effectively operational capacity of supply process SF of technology category SW in GW
CAP_EFFEC_EP	EP, SW, tc, year_all	effectively operational capacity of self-producing equipment EP of technology category SW in GW
M_POT_HER	SF, SW, tc, year_all	marginal cost of heat recovery to potential limitation in addition to investment price as used in a process
LTC_HER	SF, SW, tc, year_all	long-term marginal cost of equipment of heat recovery
STC_SF_SW_NoHER	SF, SW, tc, year_all	short-term marginal cost of supply process SF by technology category sw and vintage tc in EUR per kWh or EUR per vehicle km (Non new HER)
X_SH_HER_LT	SF, SW, tc, year_all	utility from the new share of heat recovery
X_SH_NoHER	SF, SW, tc, year_all	utility from the share of no new heat recovery
SH_HER_LT	SF, SW, tc, year_all	share of new heat recovery
CAP_SURV_HER	SF, SW, tc, year_all	survived capacity of equipment of heat recovery in GW
CAP_EFFEC_HER	SF, SW, tc, year_all	effectively operational capacity of equipment of heat recovery in GW
INV_HER	SF, SW, tc, year_all	investment in equipment of heat recovery in GW
INV_SF	SF, SW, year_all	investment in supply process SF of technology category SW in GW
INV_EP	EP, SW, year_all	investment in self-producing equipment EP of technology category SW in GW
M_POT_SD	SD, fuel_all, year_all	marginal cost of a fuel due to potential limitation in addition to its price as used in a process
M_STND_SD	Stndrds, SD, year_all	marginal cost of a standard constraint at a level SD
M_CAP_SF	SF, SW, tc, year_all	marginal cost of capacity constraints for processes by technology category SW vintage tc in EUR per kWh
M_CAP_EP	EP, SW, tc, year_all	marginal cost of capacity constraints for self-producing equipment EP by technology category SW vintage tc in EUR per kWh
M_OUTSEC_EP	f, EP, year_all	

Equations

Name	**Domains**	**Description**
QACTSB	SB, year_all	
QACTSC	SC, year_all	
QACTSD	SD, year_all	
QACTSE_AG	AG, SE, year_all	
QACTSE	SE, year_all	
QACTSE_AG_LT	AG, SE, year_all	
QACTSF_AG	AG, SF, year_all	
QACTSF	SF, year_all	
QACTSF_AG_LT	AG, SF, year_all	
QP_ACTSB	SB, year_all	
QP_ACTSC	SC, year_all	
QP_ACTSD	SD, year_all	
QP_ACTSE_AG_ST	AG, SE, year_all	
QP_ACTSE_AG_LT	AG, SE, year_all	
QP_ACTSE_AG_LT_Stndrds	AG, SE, year_all	
QP_ACTSF_AG_ST	AG, SF, year_all	
QP_ACTSF_AG_LT	AG, SF, year_all	
QP_ACTSF_AG_LT_Stndrds	AG, SF, year_all	
QP_ACTSE_ST	SE, year_all	
QP_ACTSE_LT	SE, year_all	
QP_ACTSF_ST	SF, year_all	
QP_ACTSF_LT	SF, year_all	
QX_SH_ACTSBC	SB, SC, year_all	
QSH_ACTSBC	SB, SC, year_all	
QX_SH_ACTSCD_Inert	SC, SD, year_all	
QX_SH_ACTSCD_Optimum	SC, SD, year_all	
QSH_ACTSCD_Inert	SC, SD, year_all	
QSH_ACTSCD_Optimum	SC, SD, year_all	
QSH_ACTSCD	SC, SD, year_all	
QX_SH_ACTSDE_AG_ST_Inert	AG, SD, SE, year_all	

Name	Domains	Description
QX_SH_ACTSDE_AG_ST_Optimum	AG, SD, SE, year_all	
QSH_ACTSDE_AG_ST_Inert	AG, SD, SE, year_all	
QSH_ACTSDE_AG_ST_Optimum	AG, SD, SE, year_all	
QSH_ACTSDE_AG_ST	AG, SD, SE, year_all	
QX_SH_ACTSEF_AG_ST_Inert	AG, SE, SF, year_all	
QX_SH_ACTSEF_AG_ST_Optimum	AG, SE, SF, year_all	
QSH_ACTSEF_AG_ST_Inert	AG, SE, SF, year_all	
QSH_ACTSEF_AG_ST_Optimum	AG, SE, SF, year_all	
QSH_ACTSEF_AG_ST	AG, SE, SF, year_all	
QX_SH_ACTSDE_AG_LT_Inert	AG, SD, SE, year_all	
QX_SH_ACTSDE_AG_LT_Optimum	AG, SD, SE, year_all	
QSH_ACTSDE_AG_LT_Inert	AG, SD, SE, year_all	
QSH_ACTSDE_AG_LT_Optimum	AG, SD, SE, year_all	
QSH_ACTSDE_AG_LT	AG, SD, SE, year_all	
QX_SH_ACTSEF_AG_LT_Inert	AG, SE, SF, year_all	
QX_SH_ACTSEF_AG_LT_Optimum	AG, SE, SF, year_all	
QSH_ACTSEF_AG_LT_Inert	AG, SE, SF, year_all	
QSH_ACTSEF_AG_LT_Optimum	AG, SE, SF, year_all	
QSH_ACTSEF_AG_LT	AG, SE, SF, year_all	
QSTC_SW_F	SF, SW, tc, f, year_all	
QUCAUTO_SA	f, SA, year_all	
QSTC_SF_SW_AG	AG, SF, SW, tc, year_all	
QM_STC_SF_SW_AG	AG, SF, SW, tc, year_all	
QLTC_SF_SW_AG	AG, SF, SW, year_all	
QLTC_SF_SW_AG_Stndrds	AG, SF, SW, year_all	
QSTC_SF_SW	SF, SW, tc, year_all	
QLTC_SF_SW	SF, SW, year_all	
QX_SH_SW_F_Inert	SF, SW, tc, f, year_all	
QX_SH_SW_F_Optimum	SF, SW, tc, f, year_all	
QSH_SW_F_Inert	SF, SW, tc, f, year_all	

Name	Domains	Description
QSH_SW_F_Optimum	SF, SW, tc, f, year_all	
QSH_SW_F	SF, SW, tc, f, year_all	
QX_SH_SF_SW_AG_ST_Inert	AG, SF, SW, tc, year_all	
QX_SH_SF_SW_AG_ST_Optimum	AG, SF, SW, tc, year_all	
QSH_SF_SW_AG_ST_Inert	AG, SF, SW, tc, year_all	
QSH_SF_SW_AG_ST_Optimum	AG, SF, SW, tc, year_all	
QSH_SF_SW_AG_ST	AG, SF, SW, tc, year_all	
QX_SH_SF_SW_AG_LT_Inert	AG, SF, SW, year_all	
QX_SH_SF_SW_AG_LT_Optimum	AG, SF, SW, year_all	
QSH_SF_SW_AG_LT_Inert	AG, SF, SW, year_all	
QSH_SF_SW_AG_LT_Optimum	AG, SF, SW, year_all	
QSH_SF_SW_AG_LT	AG, SF, SW, year_all	
QUE_SF_SW	SF, SW, tc, year_all	
QUE_SF	SF, year_all	
QFE_SF_SW_f	SF, SW, tc, f, year_all	
QFE_SF	SF, f, year_all	
QPROB_PREMR_SF	SF, SW, tc, year_all	
QCAP_SURV_SF	SF, SW, tc, year_all	
QCAP_DESIRED_SF	SF, SW, year_all	
QCAP_DESIRED_SF_TOT	SF, year_all	
QCAP_SURV_SF_TOT	SF, year_all	
QSH_INV_SF	SF, SW, year_all	
QINV_SF	SF, SW, year_all	
QCAP_EFFEC_SF	SF, SW, tc, year_all	
QM_CAP_SF	SF, SW, tc, year_all	
QM_POT_SD	SD, f, year_all	
QM_STND_SD	Stndrds, SD, year_all	
QSTC_EP_F	EP, SW, tc, f, year_all	
QSTC_EP_SW	EP, SW, tc, year_all	
QM_STC_EP_SW	EP, SW, tc, year_all	

Name	Domains	Description
QSTC_EP	EP, year_all	
QLTC_EP_SW	EP, SW, year_all	
QLTC_EP	EP, year_all	
QUCSUP_EP	f, EP, year_all	
QLTC_EP_PRICE	EP, year_all	
QOUTSEC_EP	f, EP, year_all	
QM_OUTSEC_EP	f, EP, year_all	
QOUTPRIM_EP	f, EP, year_all	
QSHINPUT_EP_F_Inert	EP, SW, tc, f, year_all	
QSHINPUT_EP_F_Optimum	EP, SW, tc, f, year_all	
QSHINPUT_EP_F	EP, SW, tc, f, year_all	
QSH_EP_SW_ST_Inert	EP, SW, tc, year_all	
QSH_EP_SW_ST_Optimum	EP, SW, tc, year_all	
QSH_EP_SW_ST	EP, SW, tc, year_all	
QSH_EP_ST_Inert	SA, EP, fuel_all, year_all	
QSH_EP_ST_Optimum	SA, EP, fuel_all, year_all	
QSH_EP_ST	SA, EP, fuel_all, year_all	
QSH_EP_SW_LT_Inert	EP, SW, year_all	
QSH_EP_SW_LT_Optimum	EP, SW, year_all	
QSH_EP_SW_LT	EP, SW, year_all	
QSH_EP_LT_Inert	SA, EP, fuel_all, year_all	
QSH_EP_LT_Optimum	SA, EP, fuel_all, year_all	
QSH_EP_LT	SA, EP, fuel_all, year_all	
QFE_EP_SW_f	EP, SW, tc, f, year_all	
QFE_EP	EP, f, year_all	
QPROB_PREMR_EP	EP, SW, tc, year_all	
QCAP_SURV_EP	EP, SW, tc, year_all	
QCAP_DESIRED_EP	EP, SW, year_all	
QINV_EP	EP, SW, year_all	
QCAP_EFFEC_EP	EP, SW, tc, year_all	

Name	Domains	Description
QM_CAP_EP	EP, SW, tc, year_all	
QM_POT_HER	SF, SW, tc, year_all	
QLTC_HER	SF, SW, tc, year_all	
QSTC_SF_SW_NoHER	SF, SW, tc, year_all	
QX_SH_HER_LT	SF, SW, tc, year_all	
QX_SH_NoHER	SF, SW, tc, year_all	
QSH_HER	SF, SW, tc, year_all	
QSH_HER_LT	SF, SW, tc, year_all	
QCAP_SURV_HER	SF, SW, tc, year_all	
QCAP_EFFEC_HER	SF, SW, tc, year_all	
QINV_HER	SF, SW, tc, year_all	

Equation Definitions

QACTSB$_{SBr_{SB},year}$

$$\log((\text{ACTSB}_{SB,year} + 1e-05)) = \\ \text{aactsb}_{SB,year} + (\text{bactsb\_BN}_{SB} + (\frac{\text{bactsb\_MX}_{SB} - \text{bactsb\_BN}_{SB}}{1+\exp((\text{bspeed}_{SB} \cdot (\frac{\text{macro\_lag}_{SB,year}}{\text{macro\_BN}_{SB,year}} - \frac{\text{macro\_IP}_{SB,year}}{\text{macro\_BN}_{SB,year}})))} \cdot (1 + \exp(-(\frac{\text{bspeed}_{SB} \cdot \text{macro\_IP}_{SB,year}}{\text{macro\_BN}_{SB,year}}))))[\text{aactsb}_{SB,year}]) \cdot \log((\text{macro}_{SB,year} + 1e-05)) \qquad \forall SBr_{SB}, year$$

QACTSC$_{SCr_{SC},year}$

$$\text{ACTSC}_{SC,year} = (1 - \text{doff\_SC}_{SC,year}) \cdot \sum_{SB|(\text{SBr}_{SB} \wedge \text{SB\_SC}_{SB,SC})} (\text{SH\_ACTSBC}_{SB,SC,year} \cdot \text{ACTSB}_{SB,year}) \qquad \forall SCr_{SC}, year$$

QACTSD$_{SDr_{SD},year}$

$$\text{ACTSD}_{SD,year} = (1 - \text{doff\_SD}_{SD,year}) \cdot \sum_{SC|(\text{SCr}_{SC} \wedge \text{SC\_SD}_{SC,SD})} (\text{SH\_ACTSCD}_{SC,SD,year} \cdot \text{ACTSC}_{SC,year}) \qquad \forall SDr_{SD}, year \mid ((1 - \text{doff\_SD}_{SD,year}) = 1)$$

$\mathbf{QACTSE\_AG}_{AG,SEr_{SE},year}$

$$\text{ACTSE\_AG}_{AG,SE,year} = (1 - \text{doff\_SE}_{SE,year}) \cdot \sum_{SD|(\text{SDr}_{SD} \wedge \text{SD\_SE}_{SD,SE} \wedge \text{SD\_AG}_{SD,AG})} (\text{SH\_ACTSDE\_AG\_ST}_{AG,SD,SE,year} \cdot \text{HistAG\_ACT\_SD}_{AG,SD,year} \cdot \text{ACTSD}_{SD,year})$$

$\forall AG, SEr_{SE}, year \mid (\text{SE\_AG}_{SE,AG} \wedge ((1 - \text{doff\_SE}_{SE,year}) = 1))$

$\mathbf{QACTSE}_{SEr_{SE},year}$

$$\text{ACTSE}_{SE,year} = (1 - \text{doff\_SE}_{SE,year}) \cdot \sum_{AG|\text{SE\_AG}_{SE,AG}} \text{ACTSE\_AG}_{AG,SE,year} \qquad \forall SEr_{SE}, year \mid ((1 - \text{doff\_SE}_{SE,year}) = 1)$$

$\mathbf{QACTSE\_AG\_LT}_{AG,SEr_{SE},year}$

$$\text{ACTSE\_AG\_LT}_{AG,SE,year} = (1 - \text{doff\_SE}_{SE,year}) \cdot \sum_{SD|(\text{SDr}_{SD} \wedge \text{SD\_SE}_{SD,SE} \wedge \text{SD\_AG}_{SD,AG})} (\text{SH\_ACTSDE\_AG\_LT}_{AG,SD,SE,year} \cdot \text{HistAG\_ACT\_SD}_{AG,SD,year} \cdot \text{ACTSD}_{SD,year})$$

$\forall AG, SEr_{SE}, year \mid (\text{SE\_AG}_{SE,AG} \wedge ((1 - \text{doff\_SE}_{SE,year}) = 1))$

$\mathbf{QACTSF\_AG}_{AG,SFr_{SF},year}$

$$\text{ACTSF\_AG}_{AG,SF,year} = (1 - \text{doff\_SF}_{SF,year}) \cdot \sum_{SE|(\text{SEr}_{SE} \wedge \text{SE\_SF}_{SE,SF} \wedge \text{SE\_AG}_{SE,AG})} (\text{SH\_ACTSEF\_AG\_ST}_{AG,SE,SF,year} \cdot \text{ACTSE\_AG}_{AG,SE,year})$$

$\forall AG, SFr_{SF}, year \mid (\text{SF\_AG}_{SF,AG} \wedge ((1 - \text{doff\_SF}_{SF,year}) = 1))$

$\mathbf{QACTSF}_{SFr_{SF},year}$

$$\text{ACTSF}_{SF,year} = (1 - \text{doff\_SF}_{SF,year}) \cdot \sum_{AG|\text{SF\_AG}_{SF,AG}} \text{ACTSF\_AG}_{AG,SF,year} \qquad \forall SFr_{SF}, year \mid ((1 - \text{doff\_SF}_{SF,year}) = 1)$$

QACTSF_AG_LT$_{AG,SFr_{SF},year}$

$$\text{ACTSF\_AG\_LT}_{AG,SF,year} = (1-\text{doff\_SF}_{SF,year})\cdot \sum_{SE|(\text{SEr}_{SE}\wedge\text{SE\_SF}_{SE,SF}\wedge\text{SE\_AG}_{SE,AG})} (\text{SH\_ACTSEF\_AG\_LT}_{AG,SE,SF,year}\cdot \text{ACTSE\_AG\_LT}_{AG,SE,year})$$

$\forall AG, SFr_{SF}, year \mid (\text{SF\_AG}_{SF,AG} \wedge ((1-\text{doff\_SF}_{SF,year})=1))$

QP_ACTSB$_{SBr_{SB},year}$

$$\text{P\_ACTSB}_{SB,year} \geq \sum_{SC|(\text{SCr}_{SC}\wedge\text{SB\_SC}_{SB,SC})} (\text{SH\_ACTSBC}_{SB,SC,year}\cdot \text{P\_ACTSC}_{SC,year}) \qquad \forall SBr_{SB}, year$$

QP_ACTSC$_{SCr_{SC},year}$

$$\text{P\_ACTSC}_{SC,year} \geq (1-\text{doff\_SC}_{SC,year})\cdot \sum_{SD|(\text{SDr}_{SD}\wedge\text{SC\_SD}_{SC,SD})} (\text{SH\_ACTSCD}_{SC,SD,year}\cdot \text{P\_ACTSD}_{SD,year}) \qquad \forall SCr_{SC}, year \mid ((1-\text{doff\_SC}_{SC,year})=1)$$

QP_ACTSD$_{SDr_{SD},year}$

$$\text{P\_ACTSD}_{SD,year} \geq (1-\text{doff\_SD}_{SD,year})\cdot \sum_{SE|(\text{SEr}_{SE}\wedge\text{SD\_SE}_{SD,SE})} \Big(\sum_{AG|(\text{SD\_AG}_{SD,AG}\wedge\text{SE\_AG}_{SE,AG})} (\text{HistAG\_ACT\_SD}_{AG,SD,year}\cdot \text{SH\_ACTSDE\_AG\_LT}_{AG,SD,SE,year}\cdot \text{P\_ACTSE\_AG\_LT}_{AG,SE,year}\cdot (1- \text{SUBS\_P\_ACTSE}_{SE,year}))\Big) \qquad \forall SDr_{SD}, year \mid ((1-\text{doff\_SD}_{SD,year})=1)$$

QP_ACTSE_AG_ST$_{AG,SEr_{SE},year}$

$$\text{P\_ACTSE\_AG\_ST}_{AG,SE,year} \geq (1-\text{doff\_SE}_{SE,year})\cdot \sum_{SF|(\text{SFr}_{SF}\wedge\text{SE\_SF}_{SE,SF}\wedge\text{SF\_AG}_{SF,AG})} (\text{SH\_ACTSEF\_AG\_ST}_{AG,SE,SF,year}\cdot \text{P\_ACTSF\_AG\_ST}_{AG,SF,year}\cdot (1-\text{SUBS\_P\_ACTSF}_{SF,year}))$$

$\forall AG, SEr_{SE}, year \mid (\text{SE\_AG}_{SE,AG} \wedge ((1-\text{doff\_SE}_{SE,year})=1))$

$\mathbf{QP\_ACTSE\_AG\_LT}_{AG,SEr_{SE},year}$

$$\mathrm{P\_ACTSE\_AG\_LT}_{AG,SE,year} \geq (1-\mathrm{doff\_SE}_{SE,year})\cdot(\sum_{SF|(\mathrm{SFr}_{SF}\wedge\mathrm{SE\_SF}_{SE,SF}\wedge\mathrm{SF\_AG}_{SF,AG})}(\mathrm{SH\_ACTSEF\_AG\_LT}_{AG,SE,SF,year}\cdot\mathrm{P\_ACTSF\_AG\_LT}_{AG,SF,year}\cdot(1-\mathrm{SUBS\_P\_ACTSF}_{SF,year}))$$

$$+\,\mathrm{P\_ACTSE\_AG\_LT\_Stndrds}_{AG,SE,year}) \qquad \forall AG, SEr_{SE}, year \mid (\mathrm{SE\_AG}_{SE,AG}\wedge((1-\mathrm{doff\_SE}_{SE,year})=1))$$

$\mathbf{QP\_ACTSE\_AG\_LT\_Stndrds}_{AG,SEr_{SE},year}$

$$\mathrm{P\_ACTSE\_AG\_LT\_Stndrds}_{AG,SE,year} \geq (1-\mathrm{doff\_SE}_{SE,year})\cdot(0.85\cdot\sum_{SD|A}(\sum_{Stndrds|B}(\frac{\sum_{SF|(\mathrm{SFr}_{SF}\wedge\mathrm{SE\_SF}_{SE,SF})}(C)-\mathrm{stnd\_SD\_target}_{Stndrds,SD,year}}{\mathrm{stnd\_SD\_target}_{Stndrds,SD,year}}\cdot\mathrm{M\_STND\_SD}_{Stndrds,SD,year})))$$

$\forall AG, SEr_{SE}, year \mid (\mathrm{SE\_AG}_{SE,AG}\wedge((1-\mathrm{doff\_SE}_{SE,year})=1))$

Where

A=($\mathrm{SDr}_{SD}\wedge\mathrm{SD\_AG}_{SD,AG}\wedge\mathrm{SD\_SE}_{SD,SE}$)

$$B=(\mathrm{Stndrds\_SD}_{SD,Stndrds}\wedge\mathrm{stnd\_SD\_target}_{Stndrds,SD,year}\wedge(min\{\mathrm{lblstnd\_SF}_{Stndrds,SF,\mathtt{FUT},year}\big|SF|(\mathrm{SFr}_{SF}\wedge\mathrm{SE\_SF}_{SE,SF})\}>\mathrm{stnd\_SD\_target}_{Stndrds,SD,year}))$$

$$C=(\mathrm{SH\_ACTSEF\_AG\_LT}_{AG,SE,SF,year}\cdot\sum_{SW}(\mathrm{SH\_SF\_SW\_AG\_LT}_{AG,SF,SW,year}\cdot\mathrm{lblstnd\_SF}_{Stndrds,SF,SW,year}))$$

$\mathbf{QP\_ACTSF\_AG\_ST}_{AG,SFr_{SF},year}$

$$\mathrm{P\_ACTSF\_AG\_ST}_{AG,SF,year} \geq (1-\mathrm{doff\_SF}_{SF,year})\cdot\sum_{SW,tc|\mathrm{tc\_SW}_{tc,SW}}(\mathrm{SH\_SF\_SW\_AG\_ST}_{AG,SF,SW,tc,year}\cdot\mathrm{M\_STC\_SF\_SW\_AG}_{AG,SF,SW,tc,year})$$

$\forall AG, SFr_{SF}, year \mid (\mathrm{SF\_AG}_{SF,AG}\wedge((1-\mathrm{doff\_SF}_{SF,year})=1))$

$\mathbf{QP\_ACTSF\_AG\_LT}_{AG,SFr_{SF},year}$

$$\mathrm{P\_ACTSF\_AG\_LT}_{AG,SF,year} \geq (1-\mathrm{doff\_SF}_{SF,year})\cdot(\sum_{SW}(\mathrm{SH\_SF\_SW\_AG\_LT}_{AG,SF,SW,year}\cdot\mathrm{LTC\_SF\_SW\_AG}_{AG,SF,SW,year})+\mathrm{P\_ACTSF\_AG\_LT\_Stndrds}_{AG,SF,year})$$

$\forall AG, SFr_{SF}, year \mid (\mathrm{SF\_AG}_{SF,AG}\wedge((1-\mathrm{doff\_SF}_{SF,year})=1))$

QP_ACTSF_AG_LT_Stndrds$_{AG,SFr_{SF},year}$

$$\text{P\_ACTSF\_AG\_LT\_Stndrds}_{AG,SF,year} \geq (1-\text{doff\_SF}_{SF,year})\cdot$$
$$\forall AG, SFr_{SF}, year \mid (\text{SF\_AG}_{SF,AG} \wedge ((1-\text{doff\_SF}_{SF,year})=1))$$

QP_ACTSE_ST$_{SEr_{SE},year}$

$$\text{P\_ACTSE\_ST}_{SE,year} \geq (1-\text{doff\_SE}_{SE,year})\cdot \sum_{AG|\text{SE\_AG}_{SE,AG}} \Big(\sum_{SF|(\text{SFr}_{SF}\wedge\text{SE\_SF}_{SE,SF}\wedge\text{SF\_AG}_{SF,AG})} (\text{HistAG\_ACT\_SE}_{AG,SE,year}\cdot\text{SH\_ACTSEF\_AG\_ST}_{AG,SE,SF,year}\cdot\text{P\_ACTSF\_AG\_ST}_{AG,SF,year}\cdot(1-\text{SUBS\_P\_ACTSF}_{SF,year}))\Big) \qquad \forall SEr_{SE}, year \mid ((1-\text{doff\_SE}_{SE,year})=1)$$

QP_ACTSE_LT$_{SEr_{SE},year}$

$$\text{P\_ACTSE\_LT}_{SE,year} \geq (1-\text{doff\_SE}_{SE,year})\cdot \sum_{AG|\text{SE\_AG}_{SE,AG}} \Big(\sum_{SF|(\text{SFr}_{SF}\wedge\text{SE\_SF}_{SE,SF}\wedge\text{SF\_AG}_{SF,AG})} (\text{HistAG\_ACT\_SE}_{AG,SE,year}\cdot\text{SH\_ACTSEF\_AG\_LT}_{AG,SE,SF,year}\cdot\text{P\_ACTSF\_AG\_LT}_{AG,SF,year}\cdot(1-\text{SUBS\_P\_ACTSF}_{SF,year})) + \text{P\_ACTSE\_AG\_LT\_Stndrds}_{AG,SE,year}\Big) \qquad \forall SEr_{SE}, year \mid ((1-\text{doff\_SE}_{SE,year})=1)$$

QP_ACTSF_ST$_{SFr_{SF},year}$

$$\text{P\_ACTSF\_ST}_{SF,year} \geq (1-\text{doff\_SF}_{SF,year})\cdot \sum_{AG|\text{SF\_AG}_{SF,AG}} (\text{HistAG\_ACT\_SF}_{AG,SF,year}\cdot\text{P\_ACTSF\_AG\_ST}_{AG,SF,year}\cdot(1-\text{SUBS\_P\_ACTSF}_{SF,year})) \quad \forall SFr_{SF}, year \mid ((1-\text{doff\_SF}_{SF,year})=1)$$

QP_ACTSF_LT$_{SFr_{SF},year}$

$$\text{P\_ACTSF\_LT}_{SF,year} \geq (1-\text{doff\_SF}_{SF,year})\cdot \sum_{AG|\text{SF\_AG}_{SF,AG}} (\text{HistAG\_ACT\_SF}_{AG,SF,year}\cdot\text{P\_ACTSF\_AG\_LT}_{AG,SF,year}\cdot(1-\text{SUBS\_P\_ACTSF}_{SF,year})) \quad \forall SFr_{SF}, year \mid ((1-\text{doff\_SF}_{SF,year})=1)$$

QX_SH_ACTSBC$_{SBr_{SB},SCr_{SC},year}$

$$\text{X\_SH\_ACTSBC}_{SB,SC,year} = \exp(-((\text{gACTSB}_{SB,year}\cdot\text{P\_ACTSC}_{SC,year}\cdot\text{SH\_ACTSBC\_conv\_lag}_{SB,SC,year}))) \qquad \forall SBr_{SB}, SCr_{SC}, year \mid (\text{SB\_SC}_{SB,SC} \wedge ((1-\text{doff\_SB\_SC}_{SB,SC,year})=1))$$

QSH_ACTSBC$_{SBr_{SB},SCr_{SC},year}$

$$\text{SH\_ACTSBC}_{SB,SC,year} = (\frac{\sum_{SCC|(\text{SCr}_{SCC}\wedge \text{SB\_SC}_{SB,SCC})} 1^{\text{EL\_SB\_CARD}_{SB,year}} \cdot (1-\text{doff\_SB\_SC}_{SB,SC,year}) \cdot \text{dACTSBC}_{SB,SC,year} \cdot \exp(-((\text{gACTSB}_{SB,year} \cdot \text{P\_ACTSC}_{SC,year} \cdot \text{SH\_ACTSBC\_conv\_lag}_{SB,SC,year})))}{\sum_{SCC|(\text{SCr}_{SCC}\wedge \text{SB\_SC}_{SB,SCC})} ((1-\text{doff\_SB\_SC}_{SB,SCC,year}) \cdot \text{dACTSBC}_{SB,SCC,year} \cdot \exp(-((\text{gACTSB}_{SB,year} \cdot \text{P\_ACTSC}_{SCC,year} \cdot \text{SH\_ACTSBC\_conv\_lag}_{SB,SCC,year}))))}[(\sum_{SCC|(\text{SCr}_{SCC}\wedge \text{SB\_SC}_{SB,SCC})} (1-\text{doff\_SB\_SC}_{SB,SCC,year}) > 1)] + (1-\text{doff\_SB\_SC}_{SB,SC,year})[(\sum_{SCC|(\text{SCr}_{SCC}\wedge \text{SB\_SC}_{SB,SCC})} (1-\text{doff\_SB\_SC}_{SB,SCC,year}) \leq 1)])[\text{gACTSB}_{SB,year}] + (\sum_{SCC|(\text{SCr}_{SCC}\wedge \text{SB\_SC}_{SB,SCC})} 1^{\text{EL\_SB\_CARD}_{SB,year}} \cdot (1-\text{doff\_SB\_SC}_{SB,SC,year}) \cdot \text{dACTSBC}_{SB,SC,year})[(\neg \text{gACTSB}_{SB,year})] \; \forall SBr_{SB}, SCr_{SC}, year \mid (\text{SB\_SC}_{SB,SC} \wedge ((1-\text{doff\_SB\_SC}_{SB,SC,year}) = 1))$$

QX_SH_ACTSCD_Inert$_{SCr_{SC},SDr_{SD},year}$

$$\text{X\_SH\_ACTSCD\_Inert}_{SC,SD,year} = \exp(-((\text{gACTSC}_{SC,year} \cdot \text{P\_ACTSD}_{SD,year} \cdot \text{SH\_ACTSCD\_optimum\_conv\_lag}_{SC,SD,year}))) \; \forall SCr_{SC}, SDr_{SD}, year \mid (\text{SC\_SD}_{SC,SD} \wedge ((1-\text{doff\_SC\_SD}_{SC,SD,year}) = 1))$$

QX_SH_ACTSCD_Optimum$_{SCr_{SC},SDr_{SD},year}$

$$\text{X\_SH\_ACTSCD\_Optimum}_{SC,SD,year} = \exp(-((\text{gOptimumACTSC}_{SC,year} \cdot \text{P\_ACTSD}_{SD,year} \cdot \text{SH\_ACTSCD\_optimum\_conv\_lag}_{SC,SD,year}))) \quad \forall SCr_{SC}, SDr_{SD}, year \mid (\text{SC\_SD}_{SC,SD} \wedge ((1-\text{doff\_SC\_SD}_{SC,SD,year}) = 1))$$

QSH_ACTSCD_Inert$_{SCr_{SC},SDr_{SD},year}$

$$\text{SH\_ACTSCD\_Inert}_{SC,SD,year} = (\frac{\sum_{SDD|(\text{SDr}_{SDD}\wedge \text{SC\_SD}_{SC,SDD})} 1^{\text{EL\_SC\_CARD}_{SC,year}} \cdot (1-\text{doff\_SC\_SD}_{SC,SD,year}) \cdot \text{dACTSCD}_{SC,SD,year} \cdot \exp(-((\text{gACTSC}_{SC,year} \cdot \text{P\_ACTSD}_{SD,year} \cdot \text{SH\_ACTSCD\_optimum\_conv\_lag}_{SC,SD,year})))}{\sum_{SDD|(\text{SDr}_{SDD}\wedge \text{SC\_SD}_{SC,SDD})} ((1-\text{doff\_SC\_SD}_{SC,SDD,year}) \cdot \text{dACTSCD}_{SC,SDD,year} \cdot \exp(-((\text{gACTSC}_{SC,year} \cdot \text{P\_ACTSD}_{SDD,year} \cdot \text{SH\_ACTSCD\_optimum\_conv\_lag}_{SC,SDD,year}))))}[(\sum_{SDD|(\text{SDr}_{SDD}\wedge \text{SC\_SD}_{SC,SDD})} (1-\text{doff\_SC\_SD}_{SC,SDD,year}) > 1)] + (1-\text{doff\_SC\_SD}_{SC,SD,year})[(\sum_{SDD|(\text{SDr}_{SDD}\wedge \text{SC\_SD}_{SC,SDD})} (1-\text{doff\_SC\_SD}_{SC,SDD,year}) \leq 1)])[\text{gACTSC}_{SC,year}] + ($$

$$\sum_{SDD|\text{SC\_SD}_{SC,SDD}} 1^{\text{EL\_SC\_CARD}_{SC,year}} \cdot (1 - \text{doff\_SC\_SD}_{SC,SD,year}) \cdot \text{dACTSCD}_{SC,SD,year})[(\neg\text{gACTSC}_{SC,year})] \qquad \forall SCr_{SC}, SDr_{SD}, year \mid (\text{SC\_SD}_{SC,SD} \wedge ((1 - \text{doff\_SC\_SD}_{SC,SD,year}) = 1))$$

QSH_ACTSCD_Optimum$_{SCr_{SC},SDr_{SD},year}$

$$\text{SH\_ACTSCD\_Optimum}_{SC,SD,year} = (\frac{\sum_{SDD|(\text{SDr}_{SDD} \wedge \text{SC\_SD}_{SC,SDD})} 1^{\text{EL\_SC\_CARD}_{SC,year}} \cdot (1 - \text{doff\_SC\_SD}_{SC,SD,year}) \cdot \text{dACTSCD\_Optimum}_{SC,SD,year} \cdot \exp(-((\text{gOptimumACTSC}_{SC,year} \cdot \text{P\_ACTSD}_{SD,year} \cdot \text{SH\_ACTSCD\_optimum\_conv\_lag}_{SC,SD,year})))}{\sum_{SDD|(\text{SDr}_{SDD} \wedge \text{SC\_SD}_{SC,SDD})} ((1 - \text{doff\_SC\_SD}_{SC,SDD,year}) \cdot \text{dACTSCD\_Optimum}_{SC,SDD,year} \cdot \exp(-((\text{gOptimumACTSC}_{SC,year} \cdot \text{P\_ACTSD}_{SDD,year} \cdot \text{SH\_ACTSCD\_optimum\_conv\_lag}_{SC,SDD,year}))))}[(\sum_{SDD|(\text{SDr}_{SDD} \wedge \text{SC\_SD}_{SC,SDD})} (1 - \text{doff\_SC\_SD}_{SC,SDD,year}) > 1)] + (1 - \text{doff\_SC\_SD}_{SC,SD,year})[(\sum_{SDD|(\text{SDr}_{SDD} \wedge \text{SC\_SD}_{SC,SDD})} (1 - \text{doff\_SC\_SD}_{SC,SDD,year}) \leq 1)])[\text{gOptimumACTSC}_{SC,year}] + (\sum_{SDD|\text{SC\_SD}_{SC,SDD}} 1^{\text{EL\_SC\_CARD}_{SC,year}} \cdot (1 - \text{doff\_SC\_SD}_{SC,SD,year}) \cdot \text{dACTSCD\_Optimum}_{SC,SD,year})[(\neg\text{gOptimumACTSC}_{SC,year})] \qquad \forall SCr_{SC}, SDr_{SD}, year \mid (\text{SC\_SD}_{SC,SD} \wedge ((1 - \text{doff\_SC\_SD}_{SC,SD,year}) = 1))$$

QSH_ACTSCD$_{SCr_{SC},SDr_{SD},year}$

$$\text{SH\_ACTSCD}_{SC,SD,year} = (1 - \text{doff\_SC\_SD}_{SC,SD,year}) \cdot ((1 - \text{TH\_SH\_ACTSCD}_{SC,year}) \cdot \text{SH\_ACTSCD\_Inert}_{SC,SD,year} + \text{TH\_SH\_ACTSCD}_{SC,year} \cdot \text{SH\_ACTSCD\_Optimum}_{SC,SD,year})$$
$$\forall SCr_{SC}, SDr_{SD}, year \mid (\text{SC\_SD}_{SC,SD} \wedge ((1 - \text{doff\_SC\_SD}_{SC,SD,year}) = 1))$$

QX_SH_ACTSDE_AG_ST_Inert$_{AG,SDr_{SD},SEr_{SE},year}$

$$\text{X\_SH\_ACTSDE\_AG\_ST\_Inert}_{AG,SD,SE,year} = \exp(-((\text{gACTSD\_AG\_ST}_{AG,SD,year} \cdot \text{P\_ACTSE\_AG\_ST}_{AG,SE,year} \cdot \text{SH\_ACTSDE\_AG\_ST\_Optimum\_conv\_lag}_{AG,SD,SE,year})))$$
$$\forall AG, SDr_{SD}, SEr_{SE}, year \mid (\text{SD\_SE}_{SD,SE} \wedge \text{SD\_AG}_{SD,AG} \wedge \text{SE\_AG}_{SE,AG} \wedge ((1 - \text{doff\_SD\_SE}_{SD,SE,year}) = 1))$$

QX_SH_ACTSDE_AG_ST_Optimum$_{AG,SDr_{SD},SEr_{SE},year}$

$$\text{X\_SH\_ACTSDE\_AG\_ST\_Optimum}_{AG,SD,SE,year} = \exp(-((\text{gOptimumACTSD\_AG\_ST}_{AG,SD,year} \cdot \text{P\_ACTSE\_AG\_ST}_{AG,SE,year} \cdot \text{SH\_ACTSDE\_AG\_ST\_Optimum\_conv\_lag}_{AG,SD,SE,year})))$$
$$\forall AG, SDr_{SD}, SEr_{SE}, year \mid (\text{SD\_SE}_{SD,SE} \wedge \text{SD\_AG}_{SD,AG} \wedge \text{SE\_AG}_{SE,AG} \wedge ((1 - \text{doff\_SD\_SE}_{SD,SE,year}) = 1))$$

QSH_ACTSDE_AG_ST_Inert$_{AG,SDr_{SD},SEr_{SE},year}$

$$\text{SH\_ACTSDE\_AG\_ST\_Inert}_{AG,SD,SE,year} =$$
$$\left(\frac{\sum\limits_{SEE|(\text{SEr}_{SEE}\wedge\text{SD\_SE}_{SD,SEE}\wedge\text{SE\_AG}_{SEE,AG})} 1^{\text{EL\_SD\_CARD}_{SD,year}\cdot(1-\text{doff\_SD\_SE}_{SD,SE,year})\cdot\text{dACTSDE\_AG\_ST}_{AG,SD,SE,year}\cdot(A)}}{\sum\limits_{SEE|(\text{SEr}_{SEE}\wedge\text{SD\_SE}_{SD,SEE}\wedge\text{SE\_AG}_{SEE,AG})} ((1-\text{doff\_SD\_SE}_{SD,SEE,year})\cdot\text{dACTSDE\_AG\_ST}_{AG,SD,SEE,year}\cdot(B))}\right.$$
$$[(\sum\limits_{SEE|(\text{SEr}_{SEE}\wedge\text{SD\_SE}_{SD,SEE}\wedge\text{SE\_AG}_{SEE,AG})} (1-\text{doff\_SD\_SE}_{SD,SEE,year}) > 1)] +$$
$$(1-\text{doff\_SD\_SE}_{SD,SE,year})[(\sum\limits_{SEE|(\text{SEr}_{SEE}\wedge\text{SD\_SE}_{SD,SEE}\wedge\text{SE\_AG}_{SEE,AG})} (1-\text{doff\_SD\_SE}_{SD,SEE,year}) \leq 1)])[\text{gACTSD\_AG\_ST}_{AG,SD,year}] +$$
$$(\sum\limits_{SEE|(\text{SEr}_{SEE}\wedge\text{SD\_SE}_{SD,SEE}\wedge\text{SE\_AG}_{SEE,AG})} 1^{\text{EL\_SD\_CARD}_{SD,year}}\cdot(1-\text{doff\_SD\_SE}_{SD,SE,year})\cdot\text{dACTSDE\_AG\_ST}_{AG,SD,SE,year})[(\neg\text{gACTSD\_AG\_ST}_{AG,SD,year})]\ \forall AG, SDr_{SD}, SEr_{SE}, year \mid (\text{SD\_SE}_{SD,SE}\wedge$$
$$\text{SD\_AG}_{SD,AG}\wedge\text{SE\_AG}_{SE,AG}\wedge((1-\text{doff\_SD\_SE}_{SD,SE,year}) = 1))$$

Where

$\text{A} = \exp\ (\ \text{-}\ (\ (\ \text{gACTSD\_AG\_ST}_{AG,SD,year}\cdot\text{P\_ACTSE\_AG\_ST}_{AG,SE,year}\cdot\text{SH\_ACTSDE\_AG\_ST\_Optimum\_conv\_lag}_{AG,SD,SE,year})))$

$B = \exp(-((\text{gACTSD\_AG\_ST}_{AG,SD,year}\cdot\text{P\_ACTSE\_AG\_ST}_{AG,SEE,year}\cdot\text{SH\_ACTSDE\_AG\_ST\_Optimum\_conv\_lag}_{AG,SD,SEE,year})))$

QSH_ACTSDE_AG_ST_Optimum$_{AG,SDr_{SD},SEr_{SE},year}$

$$\text{SH\_ACTSDE\_AG\_ST\_Optimum}_{AG,SD,SE,year} =$$
$$\left(\frac{\sum\limits_{SEE|(\text{SEr}_{SEE}\wedge\text{SD\_SE}_{SD,SEE}\wedge\text{SE\_AG}_{SEE,AG})} 1^{\text{EL\_SD\_CARD}_{SD,year}\cdot(1-\text{doff\_SD\_SE}_{SD,SE,year})\cdot\text{dACTSDE\_AG\_ST\_Optimum}_{AG,SD,SE,year}\cdot(A)}}{\sum\limits_{SEE|(\text{SEr}_{SEE}\wedge\text{SD\_SE}_{SD,SEE}\wedge\text{SE\_AG}_{SEE,AG})} ((1-\text{doff\_SD\_SE}_{SD,SEE,year})\cdot\text{dACTSDE\_AG\_ST\_Optimum}_{AG,SD,SEE,year}\cdot(B))}\right.[(\sum\limits_{SEE|(\text{SEr}_{SEE}\wedge\text{SD\_SE}_{SD,SEE}\wedge\text{SE\_AG}_{SEE,AG})} (1-\text{doff\_SD\_SE}_{SD,SEE,year}) >$$
$$1)] + (1-\text{doff\_SD\_SE}_{SD,SE,year})[(\sum\limits_{SEE|(\text{SEr}_{SEE}\wedge\text{SD\_SE}_{SD,SEE}\wedge\text{SE\_AG}_{SEE,AG})} (1-\text{doff\_SD\_SE}_{SD,SEE,year}) \leq 1)])[\text{gOptimumACTSD\_AG\_ST}_{AG,SD,year}] +$$

$$(\sum_{SEE|(\text{SEr}_{SEE} \wedge \text{SD\_SE}_{SD,SEE} \wedge \text{SE\_AG}_{SEE,AG})} 1^{\text{EL\_SD\_CARD}_{SD,year}} \cdot (1 - \text{doff\_SD\_SE}_{SD,SE,year}) \cdot \text{dACTSDE\_AG\_ST\_Optimum}_{AG,SD,SE,year})[(\neg \text{gOptimumACTSD\_AG\_ST}_{AG,SD,year})]$$

$\forall AG, SDr_{SD}, SEr_{SE}, year \mid (\text{SD\_SE}_{SD,SE} \wedge \text{SD\_AG}_{SD,AG} \wedge \text{SE\_AG}_{SE,AG} \wedge ((1 - \text{doff\_SD\_SE}_{SD,SE,year}) = 1))$

$Where$

$A = \exp(-((\text{gOptimumACTSD\_AG\_ST}_{AG,SD,year} \cdot \text{P\_ACTSE\_AG\_ST}_{AG,SE,year} \cdot \text{SH\_ACTSDE\_AG\_ST\_Optimum\_conv\_lag}_{AG,SD,SE,year})))$

$B = \exp(-((\text{gOptimumACTSD\_AG\_ST}_{AG,SD,year} \cdot \text{P\_ACTSE\_AG\_ST}_{AG,SEE,year} \cdot \text{SH\_ACTSDE\_AG\_ST\_Optimum\_conv\_lag}_{AG,SD,SEE,year})))$

QSH_ACTSDE_AG_ST$_{AG,SDr_{SD},SEr_{SE},year}$

$$\text{SH\_ACTSDE\_AG\_ST}_{AG,SD,SE,year} = (1 - \text{doff\_SD\_SE}_{SD,SE,year}) \cdot ((1 - \text{TH\_SH\_ACTSDE\_AG\_ST}_{AG,SD,year}) \cdot \text{SH\_ACTSDE\_AG\_ST\_Inert}_{AG,SD,SE,year} + \text{TH\_SH\_ACTSDE\_AG\_ST}_{AG,SD,year} \cdot \text{SH\_ACTSDE\_AG\_ST\_Optimum}_{AG,SD,SE,year}) \quad \forall AG, SDr_{SD}, SEr_{SE}, year \mid (\text{SD\_SE}_{SD,SE} \wedge \text{SD\_AG}_{SD,AG} \wedge \text{SE\_AG}_{SE,AG} \wedge ((1 - \text{doff\_SD\_SE}_{SD,SE,year}) = 1))$$

QX_SH_ACTSEF_AG_ST_Inert$_{AG,SEr_{SE},SFr_{SF},year}$

$$\text{X\_SH\_ACTSEF\_AG\_ST\_Inert}_{AG,SE,SF,year} = \exp(-((\text{gACTSE\_AG\_ST}_{AG,SE,year} \cdot \text{P\_ACTSF\_AG\_ST}_{AG,SF,year} \cdot \text{SH\_ACTSEF\_AG\_ST\_Optimum\_conv\_lag}_{AG,SE,SF,year})))$$

$\forall AG, SEr_{SE}, SFr_{SF}, year \mid (\text{SE\_SF}_{SE,SF} \wedge \text{SF\_AG}_{SF,AG} \wedge \text{SE\_AG}_{SE,AG} \wedge ((1 - \text{doff\_SE\_SF}_{SE,SF,year}) = 1))$

QX_SH_ACTSEF_AG_ST_Optimum$_{AG,SEr_{SE},SFr_{SF},year}$

$$\text{X\_SH\_ACTSEF\_AG\_ST\_Optimum}_{AG,SE,SF,year} = \exp(-((\text{gOptimumACTSE\_AG\_ST}_{AG,SE,year} \cdot \text{P\_ACTSF\_AG\_ST}_{AG,SF,year} \cdot \text{SH\_ACTSEF\_AG\_ST\_Optimum\_conv\_lag}_{AG,SE,SF,year})))$$

$\forall AG, SEr_{SE}, SFr_{SF}, year \mid (\text{SE\_SF}_{SE,SF} \wedge \text{SF\_AG}_{SF,AG} \wedge \text{SE\_AG}_{SE,AG} \wedge ((1 - \text{doff\_SE\_SF}_{SE,SF,year}) = 1))$

QSH_ACTSEF_AG_ST_Inert$_{AG,SEr_{SE},SFr_{SF},year}$

$$\text{SH\_ACTSEF\_AG\_ST\_Inert}_{AG,SE,SF,year} = (\frac{\sum_{SFF|(\text{SFr}_{SFF} \wedge \text{SE\_SF}_{SE,SFF} \wedge \text{SF\_AG}_{SFF,AG})} 1^{\text{EL\_SE\_CARD}_{SE,year}} \cdot (1 - \text{doff\_SE\_SF}_{SE,SF,year}) \cdot \text{dACTSEF\_AG\_ST}_{AG,SE,SF,year} \cdot (A)}{\sum_{SFF|(\text{SFr}_{SFF} \wedge \text{SE\_SF}_{SE,SFF} \wedge \text{SF\_AG}_{SFF,AG})} ((1 - \text{doff\_SE\_SF}_{SE,SFF,year}) \cdot \text{dACTSEF\_AG\_ST}_{AG,SE,SFF,year} \cdot (B))}[$$

$$(\sum_{SFF|(\text{SFr}_{SFF} \wedge \text{SE\_SF}_{SE,SFF} \wedge \text{SF\_AG}_{SFF,AG})} (1 - \text{doff\_SE\_SF}_{SE,SFF,year}) > 1)] +$$

$$(1-\text{doff\_SE\_SF}_{SE,SF,year})[(\sum_{SFF|(\text{SFr}_{SFF}\wedge\text{SE\_SF}_{SE,SFF}\wedge\text{SF\_AG}_{SFF,AG})}(1-\text{doff\_SE\_SF}_{SE,SFF,year})\leq 1)])[\text{gACTSE\_AG\_ST}_{AG,SE,year}]+$$

$$(\sum_{SFF|(\text{SFr}_{SFF}\wedge\text{SE\_SF}_{SE,SFF}\wedge\text{SF\_AG}_{SFF,AG})}1^{\text{EL\_SE\_CARD}_{SE,year}}\cdot(1-\text{doff\_SE\_SF}_{SE,SF,year})\cdot\text{dACTSEF\_AG\_ST}_{AG,SE,SF,year})[(\neg\text{gACTSE\_AG\_ST}_{AG,SE,year})]\ \forall AG,SEr_{SE},SFr_{SF},year\mid(\text{SE\_SF}_{SE,SF}\wedge$$

$$\text{SF\_AG}_{SF,AG}\wedge\text{SE\_AG}_{SE,AG}\wedge((1-\text{doff\_SE\_SF}_{SE,SF,year})=1))$$

$Where$

$A=\exp(-((\text{gACTSE\_AG\_ST}_{AG,SE,year}\cdot\text{P\_ACTSF\_AG\_ST}_{AG,SF,year}\cdot\text{SH\_ACTSEF\_AG\_ST\_Optimum\_conv\_lag}_{AG,SE,SF,year})))$

$B=\exp(-((\text{gACTSE\_AG\_ST}_{AG,SE,year}\cdot\text{P\_ACTSF\_AG\_ST}_{AG,SFF,year}\cdot\text{SH\_ACTSEF\_AG\_ST\_Optimum\_conv\_lag}_{AG,SE,SFF,year})))$

QSH_ACTSEF_AG_ST_Optimum$_{AG,SEr_{SE},SFr_{SF},year}$

$$\text{SH\_ACTSEF\_AG\_ST\_Optimum}_{AG,SE,SF,year}=(\frac{\sum_{SFF|(\text{SFr}_{SFF}\wedge\text{SE\_SF}_{SE,SFF}\wedge\text{SF\_AG}_{SFF,AG})}1^{\text{EL\_SE\_CARD}_{SE,year}}\cdot(1-\text{doff\_SE\_SF}_{SE,SF,year})\cdot\text{dACTSEF\_AG\_ST\_Optimum}_{AG,SE,SF,year}\cdot(A)}{\sum_{SFF|(\text{SFr}_{SFF}\wedge\text{SE\_SF}_{SE,SFF}\wedge\text{SF\_AG}_{SFF,AG})}((1-\text{doff\_SE\_SF}_{SE,SFF,year})\cdot\text{dACTSEF\_AG\_ST\_Optimum}_{AG,SE,SFF,year}\cdot(B))}[$$

$$(\sum_{SFF|(\text{SFr}_{SFF}\wedge\text{SE\_SF}_{SE,SFF}\wedge\text{SF\_AG}_{SFF,AG})}(1-\text{doff\_SE\_SF}_{SE,SFF,year})>1)]+$$

$$(1-\text{doff\_SE\_SF}_{SE,SF,year})[(\sum_{SFF|(\text{SFr}_{SFF}\wedge\text{SE\_SF}_{SE,SFF}\wedge\text{SF\_AG}_{SFF,AG})}(1-\text{doff\_SE\_SF}_{SE,SFF,year})\leq 1)])[\text{gOptimumACTSE\_AG\_ST}_{AG,SE,year}]+$$

$$(\sum_{SFF|(\text{SFr}_{SFF}\wedge\text{SE\_SF}_{SE,SFF}\wedge\text{SF\_AG}_{SFF,AG})}1^{\text{EL\_SE\_CARD}_{SE,year}}\cdot(1-\text{doff\_SE\_SF}_{SE,SF,year})\cdot\text{dACTSEF\_AG\_ST\_Optimum}_{AG,SE,SF,year})[(\neg\text{gOptimumACTSE\_AG\_ST}_{AG,SE,year})]$$

$$\forall AG,SEr_{SE},SFr_{SF},year\mid(\text{SE\_SF}_{SE,SF}\wedge\text{SF\_AG}_{SF,AG}\wedge\text{SE\_AG}_{SE,AG}\wedge((1-\text{doff\_SE\_SF}_{SE,SF,year})=1))$$

$Where$

$A=\exp(-((\text{gOptimumACTSE\_AG\_ST}_{AG,SE,year}\cdot\text{P\_ACTSF\_AG\_ST}_{AG,SF,year}\cdot\text{SH\_ACTSEF\_AG\_ST\_Optimum\_conv\_lag}_{AG,SE,SF,year})))$

$B=\exp(-((\text{gOptimumACTSE\_AG\_ST}_{AG,SE,year}\cdot\text{P\_ACTSF\_AG\_ST}_{AG,SFF,year}\cdot\text{SH\_ACTSEF\_AG\_ST\_Optimum\_conv\_lag}_{AG,SE,SFF,year})))$

$\mathbf{QSH\_ACTSEF\_AG\_ST}_{AG,SEr_{SE},SFr_{SF},year}$

$$\text{SH\_ACTSEF\_AG\_ST}_{AG,SE,SF,year} = (1-\text{doff\_SE\_SF}_{SE,SF,year})\cdot((1-\text{TH\_SH\_ACTSEF\_AG\_ST}_{AG,SE,year})\cdot\text{SH\_ACTSEF\_AG\_ST\_Inert}_{AG,SE,SF,year}+\text{TH\_SH\_ACTSEF\_AG\_ST}_{AG,SE,year}\cdot\text{SH\_ACTSEF\_AG\_ST\_Optimum}_{AG,SE,SF,year})$$

$$\forall AG, SEr_{SE}, SFr_{SF}, year \mid (\text{SE\_SF}_{SE,SF}\wedge\text{SF\_AG}_{SF,AG}\wedge\text{SE\_AG}_{SE,AG}\wedge((1-\text{doff\_SE\_SF}_{SE,SF,year})=1))$$

$\mathbf{QX\_SH\_ACTSDE\_AG\_LT\_Inert}_{AG,SDr_{SD},SEr_{SE},year}$

$$\text{X\_SH\_ACTSDE\_AG\_LT\_Inert}_{AG,SD,SE,year} = \exp(-((\text{gACTSD\_AG\_LT}_{AG,SD,year}\cdot\text{P\_ACTSE\_AG\_LT}_{AG,SE,year}\cdot\text{SH\_ACTSDE\_AG\_LT\_Optimum\_conv\_lag}_{AG,SD,SE,year})))$$

$$\forall AG, SDr_{SD}, SEr_{SE}, year \mid (\text{SD\_SE}_{SD,SE}\wedge\text{SD\_AG}_{SD,AG}\wedge\text{SE\_AG}_{SE,AG}\wedge((1-\text{doff\_SD\_SE}_{SD,SE,year})=1))$$

$\mathbf{QX\_SH\_ACTSDE\_AG\_LT\_Optimum}_{AG,SDr_{SD},SEr_{SE},year}$

$$\text{X\_SH\_ACTSDE\_AG\_LT\_Optimum}_{AG,SD,SE,year} = \exp(-((\text{gOptimumACTSD\_AG\_LT}_{AG,SD,year}\cdot\text{P\_ACTSE\_AG\_LT}_{AG,SE,year}\cdot\text{SH\_ACTSDE\_AG\_LT\_Optimum\_conv\_lag}_{AG,SD,SE,year})))$$

$$\forall AG, SDr_{SD}, SEr_{SE}, year \mid (\text{SD\_SE}_{SD,SE}\wedge\text{SD\_AG}_{SD,AG}\wedge\text{SE\_AG}_{SE,AG}\wedge((1-\text{doff\_SD\_SE}_{SD,SE,year})=1))$$

$\mathbf{QSH\_ACTSDE\_AG\_LT\_Inert}_{AG,SDr_{SD},SEr_{SE},year}$

$$\text{SH\_ACTSDE\_AG\_LT\_Inert}_{AG,SD,SE,year} = (\frac{\sum_{SEE|(\text{SEr}_{SEE}\wedge\text{SD\_SE}_{SD,SEE}\wedge\text{SE\_AG}_{SEE,AG})} 1^{\text{EL\_SD\_CARD}_{SD,year}}\cdot(1-\text{doff\_SD\_SE}_{SD,SE,year})\cdot\text{dACTSDE\_AG\_LT}_{AG,SD,SE,year}\cdot(A)}{\sum_{SEE|(\text{SEr}_{SEE}\wedge\text{SD\_SE}_{SD,SEE}\wedge\text{SE\_AG}_{SEE,AG})}((1-\text{doff\_SD\_SE}_{SD,SEE,year})\cdot\text{dACTSDE\_AG\_LT}_{AG,SD,SEE,year}\cdot(B))}[$$

$$(\sum_{SEE|(\text{SEr}_{SEE}\wedge\text{SD\_SE}_{SD,SEE}\wedge\text{SE\_AG}_{SEE,AG})}(1-\text{doff\_SD\_SE}_{SD,SEE,year})>1)]+$$

$$(1-\text{doff\_SD\_SE}_{SD,SE,year})[(\sum_{SEE|(\text{SEr}_{SEE}\wedge\text{SD\_SE}_{SD,SEE}\wedge\text{SE\_AG}_{SEE,AG})}(1-\text{doff\_SD\_SE}_{SD,SEE,year})\leq 1)])[\text{gACTSD\_AG\_LT}_{AG,SD,year}]+$$

$$(\sum_{SEE|(\text{SEr}_{SEE}\wedge\text{SD\_SE}_{SD,SEE}\wedge\text{SE\_AG}_{SEE,AG})} 1^{\text{EL\_SD\_CARD}_{SD,year}}\cdot(1-\text{doff\_SD\_SE}_{SD,SE,year})\cdot\text{dACTSDE\_AG\_LT}_{AG,SD,SE,year})[(\neg\text{gACTSD\_AG\_LT}_{AG,SD,year})]$$

$$\forall AG, SDr_{SD}, SEr_{SE}, year \mid (\text{SD\_SE}_{SD,SE}\wedge\text{SD\_AG}_{SD,AG}\wedge\text{SE\_AG}_{SE,AG}\wedge((1-\text{doff\_SD\_SE}_{SD,SE,year})=1))$$

$Where$

$A = \exp(-((\text{gACTSD\_AG\_LT}_{AG,SD,year} \cdot \text{P\_ACTSE\_AG\_LT}_{AG,SE,year} \cdot \text{SH\_ACTSDE\_AG\_LT\_Optimum\_conv\_lag}_{AG,SD,SE,year})))$
$B = \exp(-((\text{gACTSD\_AG\_LT}_{AG,SD,year} \cdot \text{P\_ACTSE\_AG\_LT}_{AG,SEE,year} \cdot \text{SH\_ACTSDE\_AG\_LT\_Optimum\_conv\_lag}_{AG,SD,SEE,year})))$

QSH_ACTSDE_AG_LT_Optimum$_{AG,SDr_{SD},SEr_{SE},year}$

$$\text{SH\_ACTSDE\_AG\_LT\_Optimum}_{AG,SD,SE,year} = (\frac{\sum_{SEE|(\text{SEr}_{SEE} \wedge \text{SD\_SE}_{SD,SEE} \wedge \text{SE\_AG}_{SEE,AG})} 1^{\text{EL\_SD\_CARD}_{SD,year}} \cdot (1 - \text{doff\_SD\_SE}_{SD,SE,year}) \cdot \text{dACTSDE\_AG\_LT\_Optimum}_{AG,SD,SE,year} \cdot (A)}{\sum_{SEE|(\text{SEr}_{SEE} \wedge \text{SD\_SE}_{SD,SEE} \wedge \text{SE\_AG}_{SEE,AG})} ((1 - \text{doff\_SD\_SE}_{SD,SEE,year}) \cdot \text{dACTSDE\_AG\_LT\_Optimum}_{AG,SD,SEE,year} \cdot (B))}[$$
$$(\sum_{SEE|(\text{SEr}_{SEE} \wedge \text{SD\_SE}_{SD,SEE} \wedge \text{SE\_AG}_{SEE,AG})} (1 - \text{doff\_SD\_SE}_{SD,SEE,year}) > 1)] +$$
$$(1 - \text{doff\_SD\_SE}_{SD,SE,year})[(\sum_{SEE|(\text{SEr}_{SEE} \wedge \text{SD\_SE}_{SD,SEE} \wedge \text{SE\_AG}_{SEE,AG})} (1 - \text{doff\_SD\_SE}_{SD,SEE,year}) \leq 1)])[\text{gOptimumACTSD\_AG\_LT}_{AG,SD,year}] +$$
$$(\sum_{SEE|(\text{SEr}_{SEE} \wedge \text{SD\_SE}_{SD,SEE} \wedge \text{SE\_AG}_{SEE,AG})} 1^{\text{EL\_SD\_CARD}_{SD,year}} \cdot (1 - \text{doff\_SD\_SE}_{SD,SE,year}) \cdot \text{dACTSDE\_AG\_LT\_Optimum}_{AG,SD,SE,year})[(\neg \text{gOptimumACTSD\_AG\_LT}_{AG,SD,year})]$$

$\forall AG, SDr_{SD}, SEr_{SE}, year \mid (\text{SD\_SE}_{SD,SE} \wedge \text{SD\_AG}_{SD,AG} \wedge \text{SE\_AG}_{SE,AG} \wedge ((1 - \text{doff\_SD\_SE}_{SD,SE,year}) = 1))$
$Where$
$A = \exp(-((\text{gOptimumACTSD\_AG\_LT}_{AG,SD,year} \cdot \text{P\_ACTSE\_AG\_LT}_{AG,SE,year} \cdot \text{SH\_ACTSDE\_AG\_LT\_Optimum\_conv\_lag}_{AG,SD,SE,year})))$
$B = \exp(-((\text{gOptimumACTSD\_AG\_LT}_{AG,SD,year} \cdot \text{P\_ACTSE\_AG\_LT}_{AG,SEE,year} \cdot \text{SH\_ACTSDE\_AG\_LT\_Optimum\_conv\_lag}_{AG,SD,SEE,year})))$

QSH_ACTSDE_AG_LT$_{AG,SDr_{SD},SEr_{SE},year}$

$\text{SH\_ACTSDE\_AG\_LT}_{AG,SD,SE,year} = (1 - \text{doff\_SD\_SE}_{SD,SE,year}) \cdot ((1 - \text{TH\_SH\_ACTSDE\_AG\_LT}_{AG,SD,year}) \cdot \text{SH\_ACTSDE\_AG\_LT\_Inert}_{AG,SD,SE,year} + \text{TH\_SH\_ACTSDE\_AG\_LT}_{AG,SD,year} \cdot \text{SH\_ACTSDE\_AG\_LT\_Optimum}_{AG,SD,SE,year})$ $\forall AG, SDr_{SD}, SEr_{SE}, year \mid (\text{SD\_SE}_{SD,SE} \wedge \text{SD\_AG}_{SD,AG} \wedge \text{SE\_AG}_{SE,AG} \wedge ((1 - \text{doff\_SD\_SE}_{SD,SE,year}) = 1))$

QX_SH_ACTSEF_AG_LT_Inert$_{AG,SEr_{SE},SFr_{SF},year}$

$\text{X\_SH\_ACTSEF\_AG\_LT\_Inert}_{AG,SE,SF,year} = \exp(-((\text{gACTSE\_AG\_LT}_{AG,SE,year} \cdot \text{P\_ACTSF\_AG\_LT}_{AG,SF,year} \cdot \text{SH\_ACTSEF\_AG\_LT\_Optimum\_conv\_lag}_{AG,SE,SF,year})))$

$\forall AG, SEr_{SE}, SFr_{SF}, year \mid (\text{SE\_SF}_{SE,SF} \wedge \text{SF\_AG}_{SF,AG} \wedge \text{SE\_AG}_{SE,AG} \wedge ((1 - \text{doff\_SE\_SF}_{SE,SF,year}) = 1))$

QX_SH_ACTSEF_AG_LT_Optimum$_{AG,SEr_{SE},SFr_{SF},year}$

$$\text{X\_SH\_ACTSEF\_AG\_LT\_Optimum}_{AG,SE,SF,year} = \exp(-((\text{gOptimumACTSE\_AG\_LT}_{AG,SE,year} \cdot \text{P\_ACTSF\_AG\_LT}_{AG,SF,year} \cdot \text{SH\_ACTSEF\_AG\_LT\_Optimum\_conv\_lag}_{AG,SE,SF,year})))$$

$$\forall AG, SEr_{SE}, SFr_{SF}, year \mid (\text{SE\_SF}_{SE,SF} \wedge \text{SF\_AG}_{SF,AG} \wedge \text{SE\_AG}_{SE,AG} \wedge ((1 - \text{doff\_SE\_SF}_{SE,SF,year}) = 1))$$

QSH_ACTSEF_AG_LT_Inert$_{AG,SEr_{SE},SFr_{SF},year}$

$$\text{SH\_ACTSEF\_AG\_LT\_Inert}_{AG,SE,SF,year} = (\frac{\sum\limits_{SFF|(\text{SFr}_{SFF}\wedge\text{SE\_SF}_{SE,SFF}\wedge\text{SF\_AG}_{SFF,AG})} 1^{\text{EL\_SE\_CARD}_{SE,year}} \cdot (1-\text{doff\_SE\_SF}_{SE,SF,year}) \cdot \text{dACTSEF\_AG\_LT}_{AG,SE,SF,year} \cdot (A)}{\sum\limits_{SFF|(\text{SFr}_{SFF}\wedge\text{SE\_SF}_{SE,SFF}\wedge\text{SF\_AG}_{SFF,AG})} ((1 - \text{doff\_SE\_SF}_{SE,SFF,year}) \cdot \text{dACTSEF\_AG\_LT}_{AG,SE,SFF,year} \cdot (B))}[$$

$$(\sum_{SFF|(\text{SFr}_{SFF}\wedge\text{SE\_SF}_{SE,SFF}\wedge\text{SF\_AG}_{SFF,AG})} (1 - \text{doff\_SE\_SF}_{SE,SFF,year}) > 1)] +$$

$$(1 - \text{doff\_SE\_SF}_{SE,SF,year})[(\sum_{SFF|(\text{SFr}_{SFF}\wedge\text{SE\_SF}_{SE,SFF}\wedge\text{SF\_AG}_{SFF,AG})} (1 - \text{doff\_SE\_SF}_{SE,SFF,year}) \leq 1)])[\text{gACTSE\_AG\_LT}_{AG,SE,year}] +$$

$$(\sum_{SFF|(\text{SFr}_{SFF}\wedge\text{SE\_SF}_{SE,SFF}\wedge\text{SF\_AG}_{SFF,AG})} 1^{\text{EL\_SE\_CARD}_{SE,year}} \cdot (1 - \text{doff\_SE\_SF}_{SE,SF,year}) \cdot \text{dACTSEF\_AG\_LT}_{AG,SE,SF,year})[(\neg\text{gACTSE\_AG\_LT}_{AG,SE,year})]$$

$$\forall AG, SEr_{SE}, SFr_{SF}, year \mid (\text{SE\_SF}_{SE,SF} \wedge \text{SF\_AG}_{SF,AG} \wedge \text{SE\_AG}_{SE,AG} \wedge ((1 - \text{doff\_SE\_SF}_{SE,SF,year}) = 1))$$

$Where$

$$A = \exp(-((\text{gACTSE\_AG\_LT}_{AG,SE,year} \cdot \text{P\_ACTSF\_AG\_LT}_{AG,SF,year} \cdot \text{SH\_ACTSEF\_AG\_LT\_Optimum\_conv\_lag}_{AG,SE,SF,year})))$$

$$B = \exp(-((\text{gACTSE\_AG\_LT}_{AG,SE,year} \cdot \text{P\_ACTSF\_AG\_LT}_{AG,SFF,year} \cdot \text{SH\_ACTSEF\_AG\_LT\_Optimum\_conv\_lag}_{AG,SE,SFF,year})))$$

QSH_ACTSEF_AG_LT_Optimum$_{AG,SEr_{SE},SFr_{SF},year}$

$$\text{SH\_ACTSEF\_AG\_LT\_Optimum}_{AG,SE,SF,year} = (\frac{\sum_{SFF|(\text{SFr}_{SFF} \wedge \text{SE\_SF}_{SE,SFF} \wedge \text{SF\_AG}_{SFF,AG})} 1^{\text{EL\_SE\_CARD}_{SE,year}} \cdot (1 - \text{doff\_SE\_SF}_{SE,SF,year}) \cdot \text{dACTSEF\_AG\_LT\_Optimum}_{AG,SE,SF,year} \cdot (A)}{\sum_{SFF|(\text{SFr}_{SFF} \wedge \text{SE\_SF}_{SE,SFF} \wedge \text{SF\_AG}_{SFF,AG})} ((1 - \text{doff\_SE\_SF}_{SE,SFF,year}) \cdot \text{dACTSEF\_AG\_LT\_Optimum}_{AG,SE,SFF,year} \cdot (B))}[$$
$$(\sum_{SFF|(\text{SFr}_{SFF} \wedge \text{SE\_SF}_{SE,SFF} \wedge \text{SF\_AG}_{SFF,AG})} (1 - \text{doff\_SE\_SF}_{SE,SFF,year}) > 1)] +$$
$$(1 - \text{doff\_SE\_SF}_{SE,SF,year})[(\sum_{SFF|(\text{SFr}_{SFF} \wedge \text{SE\_SF}_{SE,SFF} \wedge \text{SF\_AG}_{SFF,AG})} (1 - \text{doff\_SE\_SF}_{SE,SFF,year}) \leq 1)])[\text{gOptimumACTSE\_AG\_LT}_{AG,SE,year}] +$$
$$(\sum_{SFF|(\text{SFr}_{SFF} \wedge \text{SE\_SF}_{SE,SFF} \wedge \text{SF\_AG}_{SFF,AG})} 1^{\text{EL\_SE\_CARD}_{SE,year}} \cdot (1 - \text{doff\_SE\_SF}_{SE,SF,year}) \cdot \text{dACTSEF\_AG\_LT\_Optimum}_{AG,SE,SF,year})[(\neg \text{gOptimumACTSE\_AG\_LT}_{AG,SE,year})]$$
$$\forall AG, SEr_{SE}, SFr_{SF}, year \mid (\text{SE\_SF}_{SE,SF} \wedge \text{SF\_AG}_{SF,AG} \wedge \text{SE\_AG}_{SE,AG} \wedge ((1 - \text{doff\_SE\_SF}_{SE,SF,year}) = 1))$$

$Where$

$A = \exp(-((\text{gOptimumACTSE\_AG\_LT}_{AG,SE,year} \cdot \text{P\_ACTSF\_AG\_LT}_{AG,SF,year} \cdot \text{SH\_ACTSEF\_AG\_LT\_Optimum\_conv\_lag}_{AG,SE,SF,year})))$

$B = \exp(-((\text{gOptimumACTSE\_AG\_LT}_{AG,SE,year} \cdot \text{P\_ACTSF\_AG\_LT}_{AG,SFF,year} \cdot \text{SH\_ACTSEF\_AG\_LT\_Optimum\_conv\_lag}_{AG,SE,SFF,year})))$

QSH_ACTSEF_AG_LT$_{AG,SEr_{SE},SFr_{SF},year}$

$$\text{SH\_ACTSEF\_AG\_LT}_{AG,SE,SF,year} = (1 - \text{doff\_SE\_SF}_{SE,SF,year}) \cdot ((1 - \text{TH\_SH\_ACTSEF\_AG\_LT}_{AG,SE,year}) \cdot \text{SH\_ACTSEF\_AG\_LT\_Inert}_{AG,SE,SF,year} + \text{TH\_SH\_ACTSEF\_AG\_LT}_{AG,SE,year} \cdot \text{SH\_ACTSEF\_AG\_LT\_Optimum}_{AG,SE,SF,year}) \quad \forall AG, SEr_{SE}, SFr_{SF}, year \mid (\text{SE\_SF}_{SE,SF} \wedge \text{SF\_AG}_{SF,AG} \wedge \text{SE\_AG}_{SE,AG} \wedge ((1 - \text{doff\_SE\_SF}_{SE,SF,year}) = 1))$$

QSTC_SW_F$_{SFr_{SF},SW,tc,f,year}$

$$\text{STC\_SW\_F}_{SF,SW,tc,f,year} = (1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) \cdot (\text{vqc\_f}_{SF,f,year} + \text{PRIF\_TAX\_SF}_{f,SF,year}[\text{fmarket}_f] +$$
$$\sum_{SA|(\text{SAr}_{SA} \wedge \text{SA\_SF}_{SA,SF} \wedge \text{fself}_f \wedge (\neg \text{fmarket}_f))} \text{UCAUTO\_SA}_{f,SA,year} + \sum_{SD|(\text{SDr}_{SD} \wedge \text{SD\_SF}_{SD,SF} \wedge \text{fpoteff\_SD}_{SD,f,year})} \text{M\_POT\_SD}_{SD,f,year} - \text{RESvalue\_SF}_{f,SF,year}[\text{fres}_f] +$$
$$\sum_{po}((\text{POvalue}_{po,SF,year} \cdot \text{Emfactor}_{po,f,year})[\text{pollvalue}_{SF,year}] + (\text{POprice}_{po,SF,year} \cdot \text{Emfactor}_{po,f,year})[\text{pollprice}_{SF,year}])) \cdot \text{Heatrate}_{f,SF,SW,tc,year}$$
$$\forall SFr_{SF}, SW, tc, f, year \mid (((1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) = 1) \wedge \text{tc\_SW}_{tc,SW} \wedge (\text{SF\_fr}_{SF,f,year} \vee \text{SF\_HER}_{SF,f}))$$

$\mathbf{QUCAUTO\_SA}_{f,SAr_{SA},year}$

$$\text{UCAUTO\_SA}_{f,SA,year} = \sum_{EP|(\text{EPr}_{EP}\wedge\text{SA\_EP}_{SA,EP}\wedge(\text{foutprimary}_{f,EP}\vee\text{foutsecondary}_{f,EP}))} (\text{SH\_EP\_ST}_{SA,EP,f,year}\cdot\text{UCSUP\_EP}_{f,EP,year})$$

$$\forall f, SAr_{SA}, year \mid (\text{fself}_f \wedge (\sum_{SF,SFr_{SF}|(((1-\text{doff\_SF}_{SF,year})=1)\wedge\text{SA\_SF}_{SA,SF})} (\text{SF\_fr}_{SF,f,year}\vee\text{SF\_HER}_{SF,f}) \vee \sum_{EP|(\text{EPr}_{EP}\wedge\text{SA\_EP}_{SA,EP})} \text{EP\_f}_{EP,f}))$$

$\mathbf{QSTC\_SF\_SW\_AG}_{AG,SFr_{SF},SW,tc,year}$

$$\text{STC\_SF\_SW\_AG}_{AG,SF,SW,tc,year} = (1-\text{doff\_SF\_tc}_{SF,SW,tc,year})\cdot((\sum_{f|\text{SF\_fr}_{SF,f,year}} (\text{SH\_SW\_F}_{SF,SW,tc,f,year}\cdot\text{STC\_SW\_F}_{SF,SW,tc,f,year})\cdot(1-\text{SH\_HER}_{SF,SW,tc,year}[\sum_{ff,SF\_HER_{SF,ff}} 1]) + \text{vqc\_SF}_{SF,year}\cdot\text{Heatrate\_AVRG}_{SF} + \frac{\text{omq\_SF}_{SF,year}}{\frac{\text{util\_AG\_SF}_{AG,SF,year}\cdot 8760}{\text{Heatrate\_AVRG}_{SF}}}\cdot(1+\text{osmg\_SF}_{SF,year})^{\text{tc.val}})[(\neg\text{SFtra}_{SF})] + \frac{\sum_{f|\text{SF\_fr}_{SF,f,year}} (\text{SH\_SW\_F}_{SF,SW,tc,f,year}\cdot\text{STC\_SW\_F}_{SF,SW,tc,f,year}) + \text{vqc\_SF}_{SF,year} + \frac{\text{omq\_SF}_{SF,year}}{\text{mileage}_{AG,SF,year}\cdot 1000}\cdot(1+\text{osmg\_SF}_{SF,year})^{\text{tc.val}}}{\text{occupancy}_{SF,year}}[\text{SFtra}_{SF}])$$

$$\forall AG, SFr_{SF}, SW, tc, year \mid (\text{tc\_SW}_{tc,SW}\wedge\text{SF\_AG}_{SF,AG}\wedge((1-\text{doff\_SF\_tc}_{SF,SW,tc,year})=1))$$

$\mathbf{QM\_STC\_SF\_SW\_AG}_{AG,SFr_{SF},SW,tc,year}$

$$\text{M\_STC\_SF\_SW\_AG}_{AG,SF,SW,tc,year} = (1-\text{doff\_SF\_tc}_{SF,SW,tc,year})\cdot((\sum_{f|\text{SF\_fr}_{SF,f,year}} (\text{SH\_SW\_F}_{SF,SW,tc,f,year}\cdot\text{STC\_SW\_F}_{SF,SW,tc,f,year})\cdot(1-\text{SH\_HER}_{SF,SW,tc,year}[\sum_{ff|\text{SF\_HER}_{SF,ff}} 1]) + \text{vqc\_SF}_{SF,year}\cdot\text{Heatrate\_AVRG}_{SF} + \frac{\text{M\_CAP\_SF}_{SF,SW,tc,year}}{\text{util\_AG\_SF}_{AG,SF,year}\cdot 8760})[(\neg\text{SFtra}_{SF})] + \frac{\sum_{f|\text{SF\_fr}_{SF,f,year}} (\text{SH\_SW\_F}_{SF,SW,tc,f,year}\cdot\text{STC\_SW\_F}_{SF,SW,tc,f,year}) + \text{vqc\_SF}_{SF,year} + \frac{\text{M\_CAP\_SF}_{SF,SW,tc,year}}{\text{mileage}_{AG,SF,year}\cdot 1000}}{\text{occupancy}_{SF,year}}[\text{SFtra}_{SF}]) \qquad \forall AG, SFr_{SF}, SW, tc, year \mid (\text{tc\_SW}_{tc,SW}\wedge\text{SF\_AG}_{SF,AG}\wedge((1-\text{doff\_SF\_tc}_{SF,SW,tc,year})=1))$$

$\textbf{QLTC\_SF\_SW\_AG}_{AG,SFr_{SF},SW,year}$

$$
\begin{aligned}
&\text{LTC\_SF\_SW\_AG}_{AG,SF,SW,year} = (1 - \text{doff\_SF\_SW}_{SF,SW,year}) \cdot (((\frac{\text{capc\_SW}_{SF,SW,year} \cdot (1 - \text{subs\_SW}_{SF,SW,year}) \cdot \text{annfactor}_{AG,SF,year}}{\frac{\text{util\_AG\_SF}_{AG,SF,year} \cdot 8760}{\text{Heatrate\_AVRG}_{SF}}} + \\
&\sum_{f|\text{SF\_fr}_{SF,f,year}} (\text{SH\_SW\_F}_{SF,SW,0,f,year} \cdot \text{STC\_SW\_F}_{SF,SW,0,f,year} \cdot (1 + \text{HIDE\_F}_{f,SF,year})) \cdot (1 - \text{SH\_HER}_{SF,SW,0,year}[\sum_{ff|\text{SF\_HER}_{SF,ff}} 1]) + \\
&\text{vqc\_SF}_{SF,year} \cdot \text{Heatrate\_AVRG}_{SF} + \frac{\text{omq\_SF}_{SF,year}}{\frac{\text{util\_AG\_SF}_{AG,SF,year} \cdot 8760}{\text{Heatrate\_AVRG}_{SF}}}) \cdot (1 + \text{HIDE\_SW}_{AG,SF,SW,year}) + \text{LTC\_SF\_SW\_AG\_Stndrds}_{AG,SF,SW,year})[(\neg \text{SFtra}_{SF})] + \\
&\frac{(\frac{\text{capc\_SW}_{SF,SW,year} \cdot (1 - \text{subs\_SW}_{SF,SW,year}) \cdot \text{annfactor}_{AG,SF,year} \cdot \text{range\_penalty}_{SF,SW}}{\text{mileage}_{AG,SF,year} \cdot 1000} + \sum_{f|\text{SF\_fr}_{SF,f,year}} A + \text{vqc\_SF}_{SF,year} + \frac{\text{omq\_SF}_{SF,year}}{\text{mileage}_{AG,SF,year} \cdot 1000}) \cdot (1 + \text{HIDE\_SW}_{AG,SF,SW,year}) + B}{\text{occupancy}_{SF,year}}[\text{SFtra}_{SF}])
\end{aligned}
$$

$\forall AG, SFr_{SF}, SW, year \mid (\text{SF\_AG}_{SF,AG} \wedge ((1 - \text{doff\_SF\_SW}_{SF,SW,year}) = 1))$

$Where$

$A = (\text{SH\_SW\_F}_{SF,SW,0,f,year} \cdot \text{STC\_SW\_F}_{SF,SW,0,f,year} \cdot (1 + \text{HIDE\_F}_{f,SF,year}))$

$B = \text{LTC\_SF\_SW\_AG\_Stndrds}_{AG,SF,SW,year}$

$\textbf{QLTC\_SF\_SW\_AG\_Stndrds}_{AG,SFr_{SF},SW,year}$

$$
\begin{aligned}
&\text{LTC\_SF\_SW\_AG\_Stndrds}_{AG,SF,SW,year}[\text{SF\_AG}_{SF,AG}] = (1 - \text{doff\_SF\_SW}_{SF,SW,year}) \cdot \\
&(0.85 \cdot \sum_{SD,SE|(\text{SEr}_{SE} \wedge \text{SDr}_{SD} \wedge \text{SD\_SE}_{SD,SE} \wedge \text{SE\_SF}_{SE,SF})} (\sum_{A} (\frac{\text{lblstnd\_SF}_{Stndrds,SF,SW,year} - \text{stnd\_SD\_target}_{Stndrds,SD,year}}{\text{stnd\_SD\_target}_{Stndrds,SD,year}} \cdot \text{M\_STND\_SD}_{Stndrds,SD,year})) + \\
&0.15 \cdot \sum_{SD,SE|(\text{SEr}_{SE} \wedge \text{SDr}_{SD} \wedge \text{SD\_SE}_{SD,SE} \wedge \text{SE\_SF}_{SE,SF})} (\sum_{B} (\frac{\text{lblstnd\_SF}_{Stndrds,SF,SW,year} - \text{stnd\_SD\_target}_{Stndrds,SD,year}}{\text{stnd\_SD\_target}_{Stndrds,SD,year}} \cdot \text{M\_STND\_SD}_{Stndrds,SD,year})))
\end{aligned}
$$

$\forall AG, SFr_{SF}, SW, year \mid (\text{SF\_AG}_{SF,AG} \wedge ((1 - \text{doff\_SF\_SW}_{SF,SW,year}) = 1))$

$Where$

$A = Stndrds|(\text{Stndrds\_SD}_{SD,Stndrds} \wedge \text{stnd\_SD\_target}_{Stndrds,SD,year} \wedge (\text{lblstnd\_SF}_{Stndrds,SF,SW,year} > \text{stnd\_SD\_target}_{Stndrds,SD,year}) \wedge (\text{lblstnd\_SF}_{Stndrds,SF,\texttt{FUT},year} < \text{stnd\_SD\_target}_{Stndrds,SD,year}))$

$B = Stndrds|(\text{Stndrds\_SD}_{SD,Stndrds} \wedge \text{stnd\_SD\_target}_{Stndrds,SD,year} \wedge (\text{lblstnd\_SF}_{Stndrds,SF,SW,year} > \text{stnd\_SD\_target}_{Stndrds,SD,year}))$

$\mathbf{QSTC\_SF\_SW}_{SFr_{SF},SW,tc,year}$

$$\text{STC\_SF\_SW}_{SF,SW,tc,year} = (1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) \cdot \sum_{AG|\text{SF\_AG}_{SF,AG}} (\text{HistAG\_ACT\_SF}_{AG,SF,year} \cdot \text{STC\_SF\_SW\_AG}_{AG,SF,SW,tc,year})$$

$\forall SFr_{SF}, SW, tc, year \mid (\text{tc\_SW}_{tc,SW} \wedge ((1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) = 1))$

$\mathbf{QLTC\_SF\_SW}_{SFr_{SF},SW,year}$

$$\text{LTC\_SF\_SW}_{SF,SW,year} = (1 - \text{doff\_SF\_SW}_{SF,SW,year}) \cdot \sum_{AG|\text{SF\_AG}_{SF,AG}} (\text{HistAG\_ACT\_SF}_{AG,SF,year} \cdot \text{LTC\_SF\_SW\_AG}_{AG,SF,SW,year}) \qquad \forall SFr_{SF}, SW, year \mid ((1 - \text{doff\_SF\_SW}_{SF,SW,year}) = 1)$$

$\mathbf{QX\_SH\_SW\_F\_Inert}_{SFr_{SF},SW,tc,f,year}$

$$\text{X\_SH\_SW\_F\_Inert}_{SF,SW,tc,f,year} = \exp(-((\text{gSW\_F}_{SF,year} \cdot \text{STC\_SW\_F}_{SF,SW,tc,f,year}))) \qquad \forall SFr_{SF}, SW, tc, f, year \mid (\text{tc\_SW}_{tc,SW} \wedge \text{SF\_fr}_{SF,f,year} \wedge ((1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) = 1))$$

$\mathbf{QX\_SH\_SW\_F\_Optimum}_{SFr_{SF},SW,tc,f,year}$

$$\text{X\_SH\_SW\_F\_Optimum}_{SF,SW,tc,f,year} = \exp(-((\text{gOptimumSW\_F}_{SF,year} \cdot \text{STC\_SW\_F}_{SF,SW,tc,f,year}))) \; \forall SFr_{SF}, SW, tc, f, year \mid (\text{tc\_SW}_{tc,SW} \wedge \text{SF\_fr}_{SF,f,year} \wedge ((1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) = 1))$$

$\mathbf{QSH\_SW\_F\_Inert}_{SFr_{SF},SW,tc,f,year}$

$$\text{SH\_SW\_F\_Inert}_{SF,SW,tc,f,year} = (1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) \cdot ((\frac{\text{dSW\_F}_{SF,SW,tc,f,year} \cdot \exp(-((\text{gSW\_F}_{SF,year} \cdot \text{STC\_SW\_F}_{SF,SW,tc,f,year})))}{\sum_{ff|(\text{tc\_SW}_{tc,SW} \wedge \text{SF\_fr}_{SF,ff,year})} (\text{dSW\_F}_{SF,SW,tc,ff,year} \cdot \exp(-((\text{gSW\_F}_{SF,year} \cdot \text{STC\_SW\_F}_{SF,SW,tc,ff,year}))))}[$$

$$\sum_{ff|(\text{tc\_SW}_{tc,SW} \wedge \text{SF\_fr}_{SF,ff,year})} \text{dSW\_F}_{SF,SW,tc,ff,year}[(\sum_{ff|(\text{tc\_SW}_{tc,SW} \wedge \text{SF\_fr}_{SF,ff,year})} 1 > 1)]] + 1[(\sum_{ff|(\text{tc\_SW}_{tc,SW} \wedge \text{SF\_fr}_{SF,ff,year})} 1 \leq 1)])[\text{gSW\_F}_{SF,year}] + \text{dSW\_F}_{SF,SW,tc,f,year}[(\neg \text{gSW\_F}_{SF,year})])$$

$\forall SFr_{SF}, SW, tc, f, year \mid (\text{tc\_SW}_{tc,SW} \wedge \text{SF\_fr}_{SF,f,year} \wedge ((1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) = 1))$

QSH_SW_F_Optimum$_{SFr_{SF},SW,tc,f,year}$

$$\mathrm{SH\_SW\_F\_Optimum}_{SF,SW,tc,f,year} = (1-\mathrm{doff\_SF\_tc}_{SF,SW,tc,year})\cdot((\frac{\exp(-((\mathrm{gOptimumSW\_F}_{SF,year}\cdot\mathrm{STC\_SW\_F}_{SF,SW,tc,f,year})))}{\sum\limits_{ff|(\mathrm{tc\_SW}_{tc,SW}\wedge\mathrm{SF\_fr}_{SF,ff,year})}(\exp(-((\mathrm{gOptimumSW\_F}_{SF,year}\cdot\mathrm{STC\_SW\_F}_{SF,SW,tc,ff,year}))))}[(\sum\limits_{ff|(\mathrm{tc\_SW}_{tc,SW}\wedge\mathrm{SF\_fr}_{SF,ff,year})}1>1)]+1[(\sum\limits_{ff|(\mathrm{tc\_SW}_{tc,SW}\wedge\mathrm{SF\_fr}_{SF,ff,year})}1\leq 1)])[\mathrm{gOptimumSW\_F}_{SF,year}]+\mathrm{SH\_SW\_F\_Inert}_{SF,SW,tc,f,year}[(\neg\mathrm{gOptimumSW\_F}_{SF,year})])\quad\forall SFr_{SF},SW,tc,f,year\mid(\mathrm{tc\_SW}_{tc,SW}\wedge\mathrm{SF\_fr}_{SF,f,year}\wedge((1-\mathrm{doff\_SF\_tc}_{SF,SW,tc,year})=1))$$

QSH_SW_F$_{SFr_{SF},SW,tc,f,year}$

$$\mathrm{SH\_SW\_F}_{SF,SW,tc,f,year}\geq(1-\mathrm{doff\_SF\_tc}_{SF,SW,tc,year})\cdot((1-\mathrm{TH\_SH\_SW\_F}_{SF,year})\cdot\mathrm{SH\_SW\_F\_Inert}_{SF,SW,tc,f,year}+\mathrm{TH\_SH\_SW\_F}_{SF,year}\cdot\mathrm{SH\_SW\_F\_Optimum}_{SF,SW,tc,f,year})$$
$$\forall SFr_{SF},SW,tc,f,year\mid(\mathrm{tc\_SW}_{tc,SW}\wedge\mathrm{SF\_fr}_{SF,f,year}\wedge((1-\mathrm{doff\_SF\_tc}_{SF,SW,tc,year})=1))$$

QX_SH_SF_SW_AG_ST_Inert$_{AG,SFr_{SF},SW,tc,year}$

$$\mathrm{X\_SH\_SF\_SW\_AG\_ST\_Inert}_{AG,SF,SW,tc,year}=\exp(-((\mathrm{gSF\_SW\_AG\_ST}_{AG,SF,year}\cdot\mathrm{M\_STC\_SF\_SW\_AG}_{AG,SF,SW,tc,year})))\qquad\forall AG,SFr_{SF},SW,tc,year\mid(\mathrm{tc\_SW}_{tc,SW}\wedge\mathrm{SF\_AG}_{SF,AG}\wedge((1-\mathrm{doff\_SF\_tc}_{SF,SW,tc,year})=1))$$

QX_SH_SF_SW_AG_ST_Optimum$_{AG,SFr_{SF},SW,tc,year}$

$$\mathrm{X\_SH\_SF\_SW\_AG\_ST\_Optimum}_{AG,SF,SW,tc,year}=\exp(-((\mathrm{gOptimumSF\_SW\_AG\_ST}_{AG,SF,year}\cdot\mathrm{M\_STC\_SF\_SW\_AG}_{AG,SF,SW,tc,year})))\qquad\forall AG,SFr_{SF},SW,tc,year\mid(\mathrm{tc\_SW}_{tc,SW}\wedge\mathrm{SF\_AG}_{SF,AG}\wedge((1-\mathrm{doff\_SF\_tc}_{SF,SW,tc,year})=1))$$

QSH_SF_SW_AG_ST_Inert$_{AG,SFr_{SF},SW,tc,year}$

$$\mathrm{SH\_SF\_SW\_AG\_ST\_Inert}_{AG,SF,SW,tc,year}=\frac{(1-\mathrm{doff\_SF\_tc}_{SF,SW,tc,year})\cdot\mathrm{dSF\_SW\_AG\_ST}_{AG,SF,SW,tc,year}\cdot\exp(-((\mathrm{gSF\_SW\_AG\_ST}_{AG,SF,year}\cdot\mathrm{M\_STC\_SF\_SW\_AG}_{AG,SF,SW,tc,year})))}{\sum\limits_{tcc,SWW|\mathrm{tc\_SW}_{tcc,SWW}}((1-\mathrm{doff\_SF\_tc}_{SF,SWW,tcc,year})\cdot\mathrm{dSF\_SW\_AG\_ST}_{AG,SF,SWW,tcc,year}\cdot(A))}[\mathrm{gSF\_SW\_AG\_ST}_{AG,SF,year}]$$
$$[\sum\limits_{tcc,SWW|\mathrm{tc\_SW}_{tcc,SWW}}((1-\mathrm{doff\_SF\_tc}_{SF,SWW,tcc,year})\cdot\mathrm{dSF\_SW\_AG\_ST}_{AG,SF,SWW,tcc,year})]+((1-\mathrm{doff\_SF\_tc}_{SF,SW,tc,year})\cdot\mathrm{dSF\_SW\_AG\_ST}_{AG,SF,SW,tc,year})[(\neg\mathrm{gSF\_SW\_AG\_ST}_{AG,SF,year})]$$
$$\forall AG,SFr_{SF},SW,tc,year\mid(\mathrm{tc\_SW}_{tc,SW}\wedge\mathrm{SF\_AG}_{SF,AG}\wedge((1-\mathrm{doff\_SF\_tc}_{SF,SW,tc,year})=1))$$

$Where$

$A = \exp(-((\text{gSF\_SW\_AG\_ST}_{AG,SF,year} \cdot \text{M\_STC\_SF\_SW\_AG}_{AG,SF,SWW,tcc,year})))$

QSH_SF_SW_AG_ST_Optimum$_{AG,SFr_{SF},SW,tc,year}$

$$\text{SH\_SF\_SW\_AG\_ST\_Optimum}_{AG,SF,SW,tc,year} = \frac{(1-\text{doff\_SF\_tc}_{SF,SW,tc,year}) \cdot \exp(-((\text{gOptimumSF\_SW\_AG\_ST}_{AG,SF,year} \cdot \text{M\_STC\_SF\_SW\_AG}_{AG,SF,SW,tc,year})))}{\sum\limits_{tcc,SWW|\text{tc\_SW}_{tcc,SWW}} ((1-\text{doff\_SF\_tc}_{SF,SWW,tcc,year}) \cdot \exp(-((\text{gOptimumSF\_SW\_AG\_ST}_{AG,SF,year} \cdot \text{M\_STC\_SF\_SW\_AG}_{AG,SF,SWW,tcc,year}))))}$$

$$[\text{gOptimumSF\_SW\_AG\_ST}_{AG,SF,year}][\sum\limits_{tcc,SWW|\text{tc\_SW}_{tcc,SWW}} (1-\text{doff\_SF\_tc}_{SF,SWW,tcc,year})]+((1-\text{doff\_SF\_tc}_{SF,SW,tc,year}) \cdot \text{SH\_SF\_SW\_AG\_ST\_Inert}_{AG,SF,SW,tc,year})[(\neg\text{gOptimumSF\_SW\_AG\_ST}_{AG,SF,year})]$$

$\forall AG, SFr_{SF}, SW, tc, year \mid (\text{tc\_SW}_{tc,SW} \wedge \text{SF\_AG}_{SF,AG} \wedge ((1-\text{doff\_SF\_tc}_{SF,SW,tc,year}) = 1))$

QSH_SF_SW_AG_ST$_{AG,SFr_{SF},SW,tc,year}$

$\text{SH\_SF\_SW\_AG\_ST}_{AG,SF,SW,tc,year} = (1-\text{doff\_SF\_tc}_{SF,SW,tc,year}) \cdot ((1-\text{TH\_SH\_SF\_SW\_AG\_ST}_{AG,SF,year}) \cdot \text{SH\_SF\_SW\_AG\_ST\_Inert}_{AG,SF,SW,tc,year} + \text{TH\_SH\_SF\_SW\_AG\_ST}_{AG,SF,year} \cdot \text{SH\_SF\_SW\_AG\_ST\_Optimum}_{AG,SF,SW,tc,year})$ $\forall AG, SFr_{SF}, SW, tc, year \mid (\text{tc\_SW}_{tc,SW} \wedge \text{SF\_AG}_{SF,AG} \wedge ((1-\text{doff\_SF\_tc}_{SF,SW,tc,year}) = 1))$

QX_SH_SF_SW_AG_LT_Inert$_{AG,SFr_{SF},SW,year}$

$\text{X\_SH\_SF\_SW\_AG\_LT\_Inert}_{AG,SF,SW,year} = \exp(-((\text{gSF\_SW\_AG\_LT}_{AG,SF,year} \cdot \text{LTC\_SF\_SW\_AG}_{AG,SF,SW,year})))$ $\forall AG, SFr_{SF}, SW, year \mid (\text{SF\_AG}_{SF,AG} \wedge ((1-\text{doff\_SF\_tc}_{SF,SW,0,year}) = 1))$

QX_SH_SF_SW_AG_LT_Optimum$_{AG,SFr_{SF},SW,year}$

$\text{X\_SH\_SF\_SW\_AG\_LT\_Optimum}_{AG,SF,SW,year} = \exp(-((\text{gOptimumSF\_SW\_AG\_LT}_{AG,SF,year} \cdot \text{LTC\_SF\_SW\_AG}_{AG,SF,SW,year})))$ $\forall AG, SFr_{SF}, SW, year \mid (\text{SF\_AG}_{SF,AG} \wedge ((1-\text{doff\_SF\_tc}_{SF,SW,0,year}) = 1))$

$\textbf{QSH\_SF\_SW\_AG\_LT\_Inert}_{AG,SFr_{SF},SW,year}$

$$\text{SH\_SF\_SW\_AG\_LT\_Inert}_{AG,SF,SW,year} = \frac{(1-\text{doff\_SF\_tc}_{SF,SW,0,year})\cdot\text{dSF\_SW\_AG\_LT}_{AG,SF,SW,year}\cdot\exp(-((\text{gSF\_SW\_AG\_LT}_{AG,SF,year}\cdot\text{LTC\_SF\_SW\_AG}_{AG,SF,SW,year})))}{\sum\limits_{SWW}((1-\text{doff\_SF\_tc}_{SF,SWW,0,year})\cdot\text{dSF\_SW\_AG\_LT}_{AG,SF,SWW,year}\cdot\exp(-((\text{gSF\_SW\_AG\_LT}_{AG,SF,year}\cdot\text{LTC\_SF\_SW\_AG}_{AG,SF,SWW,year}))))}$$
$$[\text{gSF\_SW\_AG\_LT}_{AG,SF,year}][\sum_{SWW}((1-\text{doff\_SF\_tc}_{SF,SWW,0,year})\cdot\text{dSF\_SW\_AG\_LT}_{AG,SF,SWW,year})]+((1-\text{doff\_SF\_tc}_{SF,SW,0,year})\cdot\text{dSF\_SW\_AG\_LT}_{AG,SF,SW,year})[(\neg\text{gSF\_SW\_AG\_LT}_{AG,SF,year})]$$
$$\forall AG, SFr_{SF}, SW, year \mid (\text{SF\_AG}_{SF,AG} \land ((1-\text{doff\_SF\_tc}_{SF,SW,0,year})=1))$$

$\textbf{QSH\_SF\_SW\_AG\_LT\_Optimum}_{AG,SFr_{SF},SW,year}$

$$\text{SH\_SF\_SW\_AG\_LT\_Optimum}_{AG,SF,SW,year} = \frac{(1-\text{doff\_SF\_tc}_{SF,SW,0,year})\cdot\exp(-((\text{gOptimumSF\_SW\_AG\_LT}_{AG,SF,year}\cdot\text{LTC\_SF\_SW\_AG}_{AG,SF,SW,year})))}{\sum\limits_{SWW}((1-\text{doff\_SF\_tc}_{SF,SWW,0,year})\cdot\exp(-((\text{gOptimumSF\_SW\_AG\_LT}_{AG,SF,year}\cdot\text{LTC\_SF\_SW\_AG}_{AG,SF,SWW,year}))))}$$
$$[\text{gOptimumSF\_SW\_AG\_LT}_{AG,SF,year}][\sum_{tcc,SWW\mid\text{tc\_SW}_{tcc,SWW}}(1-\text{doff\_SF\_tc}_{SF,SWW,tcc,year})]+((1-\text{doff\_SF\_tc}_{SF,SW,0,year})\cdot\text{SH\_SF\_SW\_AG\_LT\_Inert}_{AG,SF,SW,year})[(\neg\text{gOptimumSF\_SW\_AG\_LT}_{AG,SF,year})]$$
$$\forall AG, SFr_{SF}, SW, year \mid (\text{SF\_AG}_{SF,AG} \land ((1-\text{doff\_SF\_tc}_{SF,SW,0,year})=1))$$

$\textbf{QSH\_SF\_SW\_AG\_LT}_{AG,SFr_{SF},SW,year}$

$$\text{SH\_SF\_SW\_AG\_LT}_{AG,SF,SW,year} = (1-\text{doff\_SF\_tc}_{SF,SW,0,year})\cdot((1-\text{TH\_SH\_SF\_SW\_AG\_LT}_{AG,SF,year})\cdot\text{SH\_SF\_SW\_AG\_LT\_Inert}_{AG,SF,SW,year} + \text{TH\_SH\_SF\_SW\_AG\_LT}_{AG,SF,year}\cdot\text{SH\_SF\_SW\_AG\_LT\_Optimum}_{AG,SF,SW,year})$$
$$\forall AG, SFr_{SF}, SW, year \mid (\text{SF\_AG}_{SF,AG} \land ((1-\text{doff\_SF\_tc}_{SF,SW,0,year})=1))$$

$\textbf{QUE\_SF\_SW}_{SFr_{SF},SW,tc,year}$

$$\text{UE\_SF\_SW}_{SF,SW,tc,year} = (1-\text{doff\_SF\_tc}_{SF,SW,tc,year})\cdot\sum_{AG\mid\text{SF\_AG}_{SF,AG}}(\text{SH\_SF\_SW\_AG\_ST}_{AG,SF,SW,tc,year}\cdot\text{ACTSF\_AG}_{AG,SF,year})$$
$$\forall SFr_{SF}, SW, tc, year \mid (\text{tc\_SW}_{tc,SW} \land ((1-\text{doff\_SF\_tc}_{SF,SW,tc,year})=1))$$

QUE_SF$_{SFr_{SF},year}$

$$\text{UE\_SF}_{SF,year} = (1 - \text{doff\_SF}_{SF,year}) \cdot \sum_{SW,tc|\text{tc\_SW}_{tc,SW}} \text{UE\_SF\_SW}_{SF,SW,tc,year}$$

$\forall SFr_{SF}, year$

QFE_SF_SW_f$_{SFr_{SF},SW,tc,f,year}$

$$\text{FE\_SF\_SW\_f}_{SF,SW,tc,f,year} = (1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) \cdot ((\text{Heatrate}_{f,SF,SW,tc,year} \cdot \text{SH\_SW\_F}_{SF,SW,tc,f,year} \cdot \text{UE\_SF\_SW}_{SF,SW,tc,year} \cdot (1 - \text{SH\_HER}_{SF,SW,tc,year}[\sum_{ff,SF\_HER_{SF,ff}} 1]))[(\neg\text{SFtra}_{SF})] + \frac{\text{Heatrate}_{f,SF,SW,tc,year} \cdot \text{SH\_SW\_F}_{SF,SW,tc,f,year} \cdot \text{UE\_SF\_SW}_{SF,SW,tc,year}}{\text{occupancy}_{SF,year}}[\text{SFtra}_{SF}])$$

$\forall SFr_{SF}, SW, tc, f, year \mid (\text{tc\_SW}_{tc,SW} \wedge \text{SF\_fr}_{SF,f,year} \wedge ((1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) = 1))$

QFE_SF$_{SFr_{SF},f,year}$

$$\text{FE\_SF}_{SF,f,year} \geq (1 - \text{doff\_SF}_{SF,year}) \cdot \sum_{SW,tc|\text{tc\_SW}_{tc,SW}} \text{FE\_SF\_SW\_f}_{SF,SW,tc,f,year} \qquad \forall SFr_{SF}, f, year \mid (\text{SF\_fr}_{SF,f,year} \wedge ((1 - \text{doff\_SF}_{SF,year}) = 1))$$

QPROB_PREMR_SF$_{SFr_{SF},SW,tc,year}$

$$\text{PROB\_PREMR\_SF}_{SF,SW,tc,year} = ((\frac{\exp(-((\text{aPROB\_PREMR\_SF}_{SF,SW,tc,year} \cdot \frac{\text{P\_ACTSF\_LT}_{SF,year} - 0.75 \cdot \text{STC\_SF\_SW}_{SF,\texttt{FUT},0,year}}{\text{STC\_SF\_SW}_{SF,\texttt{FUT},0,year}})))^{\text{cPROB\_PREMR\_SF}_{SF,SW,tc,year}}}{A})[(\neg\text{yearbasis}_{year})] + 0[\text{yearbasis}_{year}])[\text{Prob\_premat\_poss}_{SF,SW,tc,year}]$$

$\forall SFr_{SF}, SW, tc, year \mid (\text{tc\_SW}_{tc,SW} \wedge \text{SWord}_{SW} \wedge (\neg(tc = \texttt{0})) \wedge ((1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) = 1) \wedge \text{Prem\_SF\_flag}_{SF,year})$

$Where$

$A = \exp(-((\text{aPROB\_PREMR\_SF}_{SF,SW,tc,year} \cdot \frac{\text{P\_ACTSF\_LT}_{SF,year} - 0.75 \cdot \text{STC\_SF\_SW}_{SF,\texttt{FUT},0,year}}{\text{STC\_SF\_SW}_{SF,\texttt{FUT},0,year}}))) + \text{ePROB\_PREMR\_SF}_{SF,SW,tc,year} \cdot (B)$

$B = \exp(-((\text{aPROB\_PREMR\_SF}_{SF,SW,tc,year} \cdot \frac{\text{STC\_SF\_SW}_{SF,SW,tc,year} - 0.75 \cdot \text{STC\_SF\_SW}_{SF,\texttt{FUT},0,year}}{\text{STC\_SF\_SW}_{SF,\texttt{FUT},0,year}})))$

QCAP_SURV_SF$_{SFr_{SF},SW,tc,year}$

$$\text{CAP\_SURV\_SF}_{SF,SW,tc,year} = (1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) \cdot ((\text{CAP\_EFFEC\_SF\_lag}_{SF,SW,tc,year} \cdot \text{prob\_surv\_SF}_{SF,SW,tc,year} \cdot (1 - \text{PROB\_PREMR\_SF}_{SF,SW,tc,year}[(\neg(tc = \mathtt{0}))]))[(\neg\text{yearbasis}_{year})] + \text{CAP\_EFFEC\_SF}_{SF,SW,tc,year}[(\text{yearbasis}_{year} \wedge (\neg(tc = \mathtt{0})))]) \qquad \forall SFr_{SF}, SW, tc, year \mid (\text{tc\_SW}_{tc,SW} \wedge \text{SWord}_{SW} \wedge ((1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) = 1))$$

QCAP_DESIRED_SF$_{SFr_{SF},SW,year}$

$$\text{CAP\_DESIRED\_SF}_{SF,SW,year} = (1 - \text{doff\_SF\_SW}_{SF,SW,year}) \cdot ((\sum_{AG|\text{SF\_AG}_{SF,AG}} (\frac{\text{SH\_SF\_SW\_AG\_LT}_{AG,SF,SW,year} \cdot \text{ACTSF\_AG\_LT}_{AG,SF,year}}{\frac{\text{util\_AG\_SF}_{AG,SF,year} \cdot 8760}{\text{Heatrate\_AVRG}_{SF}}})[(\neg\text{yearbasis}_{year})] + \sum_{tc|\text{tc\_SW}_{tc,SW}} \text{CAP\_EFFEC\_SF}_{SF,SW,tc,year}[\text{yearbasis}_{year}])[(\neg\text{SFtra}_{SF})] + (\sum_{AG|\text{SF\_AG}_{SF,AG}} (\frac{\text{SH\_SF\_SW\_AG\_LT}_{AG,SF,SW,year} \cdot \text{ACTSF\_AG\_LT}_{AG,SF,year}}{\text{mileage}_{AG,SF,year} \cdot \text{occupancy}_{SF,year}})[(\neg\text{yearbasis}_{year})] + \sum_{tc|\text{tc\_SW}_{tc,SW}} \text{CAP\_EFFEC\_SF}_{SF,SW,tc,year}[\text{yearbasis}_{year}])[\text{SFtra}_{SF}]) \qquad \forall SFr_{SF}, SW, year \mid ((1 - \text{doff\_SF\_SW}_{SF,SW,year}) = 1)$$

QCAP_DESIRED_SF_TOT$_{SFr_{SF},year}$

$$\text{CAP\_DESIRED\_SF\_TOT}_{SF,year} = \sum_{SW} \text{CAP\_DESIRED\_SF}_{SF,SW,year} \qquad \forall SFr_{SF}, year \mid \sum_{SW|(1-\text{doff\_SF\_SW}_{SF,SW,year})} 1$$

QCAP_SURV_SF_TOT$_{SFr_{SF},year}$

$$\text{CAP\_SURV\_SF\_TOT}_{SF,year} = \sum_{SW,tc|(\text{tc\_SW}_{tc,SW} \wedge \text{SWord}_{SW} \wedge (\neg(tc=\mathtt{0})))} \text{CAP\_SURV\_SF}_{SF,SW,tc,year} \qquad \forall SFr_{SF}, year \mid \sum_{SW,tc|(\text{tc\_SW}_{tc,SW} \wedge \text{SWord}_{SW} \wedge ((1-\text{doff\_SF\_tc}_{SF,SW,tc,year})=1))} 1$$

QSH_INV_SF$_{SFr_{SF},SW,year}$

$$\text{SH\_INV\_SF}_{SF,SW,year} \cdot \sum_{SWW} \text{CAP\_DESIRED\_SF}_{SF,SWW,year} = \text{CAP\_DESIRED\_SF}_{SF,SW,year} \qquad \forall SFr_{SF}, SW, year \mid ((1 - \text{doff\_SF\_SW}_{SF,SW,year}) = 1)$$

QINV_SF$_{SFr_{SF},SW,year}$

$$\text{INV\_SF}_{SF,SW,year} = (1 - \text{doff\_SF\_SW}_{SF,SW,year}) \cdot ((0.5 \cdot (\text{CAP\_DESIRED\_SF\_TOT}_{SF,year} - \text{CAP\_SURV\_SF\_TOT}_{SF,year} + ((\text{CAP\_DESIRED\_SF\_TOT}_{SF,year} - \text{CAP\_SURV\_SF\_TOT}_{SF,year}) \cdot (\text{CAP\_DESIRED\_SF\_TOT}_{SF,year} - \text{CAP\_SURV\_SF\_TOT}_{SF,year}) + 1e - 06)^{0.5}) \cdot \text{SH\_INV\_SF}_{SF,SW,year})[(\neg \text{yearbasis}_{year})] + \text{CAP\_EFFEC\_SF}_{SF,SW,0,year}[\text{yearbasis}_{year}]) \quad \forall SFr_{SF}, SW, year \mid ((1 - \text{doff\_SF\_SW}_{SF,SW,year}) = 1)$$

QCAP_EFFEC_SF$_{SFr_{SF},SW,tc,year}$

$$\text{CAP\_EFFEC\_SF}_{SF,SW,tc,year} = (1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) \cdot ((\text{CAP\_SURV\_SF}_{SF,SW,tc,year}[(\neg(tc = 0))] + \text{INV\_SF}_{SF,SW,year}[(tc = 0)])[(\neg \text{yearbasis}_{year})] + \text{CAP\_EFFEC\_SF0}_{SF,SW,tc}[\text{yearbasis}_{year}])$$
$$\forall SFr_{SF}, SW, tc, year \mid (\text{tc\_SW}_{tc,SW} \wedge ((1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) = 1))$$

QM_CAP_SF$_{SFr_{SF},SW,tc,year}$

$$\text{CAP\_EFFEC\_SF}_{SF,SW,tc,year} \geq (1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) \cdot (\sum_{AG|\text{SF\_AG}_{SF,AG}} (\frac{\text{SH\_SF\_SW\_AG\_ST}_{AG,SF,SW,tc,year} \cdot \text{ACTSF\_AG}_{AG,SF,year}}{\frac{\text{util\_AG\_SF}_{AG,SF,year} \cdot 8760}{\text{Heatrate\_AVRG}_{SF}}})[(\neg \text{SFtra}_{SF})] + \sum_{AG|\text{SF\_AG}_{SF,AG}} (\frac{\text{SH\_SF\_SW\_AG\_ST}_{AG,SF,SW,tc,year} \cdot \text{ACTSF\_AG}_{AG,SF,year}}{\text{mileage}_{AG,SF,year} \cdot \text{occupancy}_{SF,year}})[\text{SFtra}_{SF}]) \quad \forall SFr_{SF}, SW, tc, year \mid (\text{tc\_SW}_{tc,SW} \wedge ((1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) = 1))$$

QM_POT_SD$_{SDr_{SD},f,year}$

$$\text{M\_POT\_SD}_{SD,f,year} = (1 - \text{doff\_SD}_{SD,year}) \cdot (\text{a6\_POT\_SD}_{SD,f,year} \cdot \frac{{\sum_{SF,SFr_{SF}|(\text{SD\_SF}_{SD,SF} \wedge \text{SF\_fr}_{SF,f,year})} \text{FE\_SF}_{SF,f,year}}^{6}}{\text{POT\_SD}_{SD,f,year} + 1e-06} + \text{a5\_POT\_SD}_{SD,f,year} \cdot \frac{{\sum_{SF,SFr_{SF}|(\text{SD\_SF}_{SD,SF} \wedge \text{SF\_fr}_{SF,f,year})} \text{FE\_SF}_{SF,f,year}}^{5}}{\text{POT\_SD}_{SD,f,year} + 1e-06} + \text{a4\_POT\_SD}_{SD,f,year} \cdot \frac{{\sum_{SF,SFr_{SF}|(\text{SD\_SF}_{SD,SF} \wedge \text{SF\_fr}_{SF,f,year})} \text{FE\_SF}_{SF,f,year}}^{4}}{\text{POT\_SD}_{SD,f,year} + 1e-06} + \text{a3\_POT\_SD}_{SD,f,year} \cdot \frac{{\sum_{SF,SFr_{SF}|(\text{SD\_SF}_{SD,SF} \wedge \text{SF\_fr}_{SF,f,year})} \text{FE\_SF}_{SF,f,year}}^{3}}{\text{POT\_SD}_{SD,f,year} + 1e-06} + \text{a2\_POT\_SD}_{SD,f,year} \cdot \frac{{\sum_{SF,SFr_{SF}|(\text{SD\_SF}_{SD,SF} \wedge \text{SF\_fr}_{SF,f,year})} \text{FE\_SF}_{SF,f,year}}^{2}}{\text{POT\_SD}_{SD,f,year} + 1e-06} + \text{a1\_POT\_SD}_{SD,f,year} \cdot \frac{{\sum_{SF,SFr_{SF}|(\text{SD\_SF}_{SD,SF} \wedge \text{SF\_fr}_{SF,f,year})} \text{FE\_SF}_{SF,f,year}}^{1}}{\text{POT\_SD}_{SD,f,year} + 1e-06})$$
$$\forall SDr_{SD}, f, year \mid (\text{fpoteff\_SD}_{SD,f,year} \wedge ((1 - \text{doff\_SD}_{SD,year}) = 1))$$

QM_STND_SD$_{Stndrds,SDr_{SD},year}$

$$\text{stnd\_SD\_target}_{Stndrds,SD,year} \cdot \sum_{SE,SF|(((1-\text{doff\_SE\_SF}_{SE,SF,year})=1)\wedge \text{SEr}_{SE}\wedge \text{SFr}_{SF}\wedge \text{SD\_SE}_{SD,SE}\wedge \text{SE\_SF}_{SE,SF})} (\sum_{SW} \text{INV\_SF}_{SF,SW,year}) \geq \sum_{SE,SF|(((1-\text{doff\_SE\_SF}_{SE,SF,year})=1)\wedge \text{SD\_SE}_{SD,SE}\wedge \text{SE\_SF}_{SE,SF})} (\sum_{SW} (\text{lblstnd\_SF}_{Stndrds,SF,SW,year} \cdot \text{INV\_SF}_{SF,SW,year}))$$

$$\forall Stndrds, SDr_{SD}, year \mid (\text{Stndrds\_SD}_{SD,Stndrds} \wedge \text{stnd\_SD\_target}_{Stndrds,SD,year} \wedge (\text{doff\_SD}_{SD,year} = 0))$$

QSTC_EP_F$_{EPr_{EP},SW,tc,f,year}$

$$\text{STC\_EP\_F}_{EP,SW,tc,f,year} = (\text{vqc\_ep\_f}_{EP,f,year} + \text{PRIF\_TAX\_EP}_{f,EP,year}[\text{fmarket}_f] + \sum_{SA|(\text{SAr}_{SA}\wedge \text{SA\_EP}_{SA,EP}\wedge \text{fself}_f\wedge(\neg \text{fmarket}_f))} \text{UCAUTO\_SA}_{f,SA,year} - \text{RESvalue\_EP}_{f,EP,year}[\text{fres}_f] + \sum_{po}((\text{POprice\_EP}_{po,EP,year} \cdot \text{Emfactor}_{po,f,year})[\text{pollprice\_EP}_{EP,year}])) \cdot \text{Heatrate\_EP}_{f,EP,SW,tc,year}$$

$$\forall EPr_{EP}, SW, tc, f, year \mid (\text{tc\_SW}_{tc,SW} \wedge \text{EP\_f}_{EP,f})$$

QSTC_EP_SW$_{EPr_{EP},SW,tc,year}$

$$\text{STC\_EP\_SW}_{EP,SW,tc,year} = \sum_{f|\text{EP\_f}_{EP,f}} (\text{SHINPUT\_EP\_F}_{EP,SW,tc,f,year} \cdot \text{STC\_EP\_F}_{EP,SW,tc,f,year}) + \text{vqc\_ep}_{EP,year} + \frac{\text{omq\_ep}_{EP,year}}{\text{util\_EP}_{EP,year} \cdot 8760} \cdot (1 + \text{osmg\_EP}_{EP,year})^{\text{tc.val}}$$

$$\forall EPr_{EP}, SW, tc, year \mid \text{tc\_SW}_{tc,SW}$$

QM_STC_EP_SW$_{EPr_{EP},SW,tc,year}$

$$\text{M\_STC\_EP\_SW}_{EP,SW,tc,year} = \sum_{f|\text{EP\_f}_{EP,f}} (\text{SHINPUT\_EP\_F}_{EP,SW,tc,f,year} \cdot \text{STC\_EP\_F}_{EP,SW,tc,f,year}) + \text{vqc\_ep}_{EP,year} + \text{M\_CAP\_EP}_{EP,SW,tc,year} \qquad \forall EPr_{EP}, SW, tc, year \mid \text{tc\_SW}_{tc,SW}$$

$\mathbf{QSTC\_EP}_{EPr_{EP},year}$

$$\text{STC\_EP}_{EP,year} = \sum_{SW,tc|\text{tc\_SW}_{tc,SW}} (\text{M\_STC\_EP\_SW}_{EP,SW,tc,year} \cdot \text{SH\_EP\_SW\_ST}_{EP,SW,tc,year}) -$$

$$\sum_{f,ff|(\text{foutprimary}_{f,EP} \wedge \text{foutsecondary}_{ff,EP} \wedge \text{outputratio}_{EP,f,ff})} (\frac{1}{\text{outputratio}_{EP,f,ff}} \cdot \sum_{fff|\text{fopportunity}_{ff,fff}} (\text{fopportunity}_{ff,fff} \cdot (\text{PRIF\_TAX\_EP}_{fff,EP,year} + \sum_{po}((\text{POprice\_EP}_{po,EP,year} \cdot (\text{Emfactor}_{po,fff,year} -$$

$$\text{Emfactor}_{po,ff,year}))[\text{pollprice\_EP}_{EP,year}])))) \qquad \forall EPr_{EP}, year$$

$\mathbf{QLTC\_EP\_SW}_{EPr_{EP},SW,year}$

$$\text{LTC\_EP\_SW}_{EP,SW,year} = (\frac{\text{capc\_EP}_{EP,SW,year} \cdot (1 - \text{subs\_EP}_{EP,SW,year}) \cdot \text{annfactor\_EP}_{EP,year}}{\text{util\_EP}_{EP,year} \cdot 8760} + \sum_{f|\text{EP\_f}_{EP,f}} (\text{SHINPUT\_EP\_F}_{EP,SW,0,f,year} \cdot \text{STC\_EP\_F}_{EP,SW,0,f,year} \cdot (1 + \text{HIDE\_EP\_f}_{f,EP,year})) + \text{vqc\_ep}_{EP,year} +$$

$$\frac{\text{omq\_ep}_{EP,year}}{\text{util\_EP}_{EP,year} \cdot 8760}) \cdot (1 + \text{HIDE\_EP}_{EP,SW,year}) \qquad \forall EPr_{EP}, SW, year$$

$\mathbf{QLTC\_EP}_{EPr_{EP},year}$

$$\text{LTC\_EP}_{EP,year} = \sum_{SW}(\text{SH\_EP\_SW\_LT}_{EP,SW,year} \cdot \text{LTC\_EP\_SW}_{EP,SW,year}) - \sum_{f,ff|(\text{foutprimary}_{f,EP} \wedge \text{foutsecondary}_{ff,EP} \wedge \text{outputratio}_{EP,f,ff})} (\frac{1}{\text{outputratio}_{EP,f,ff}} \cdot \sum_{fff|\text{fopportunity}_{ff,fff}} (\text{fopportunity}_{ff,fff} \cdot$$

$$(\text{PRIF\_TAX\_EP}_{fff,EP,year} + \sum_{po}((\text{POprice\_EP}_{po,EP,year} \cdot (\text{Emfactor}_{po,fff,year} - \text{Emfactor}_{po,ff,year}))[\text{pollprice\_EP}_{EP,year}])))) \qquad \forall EPr_{EP}, year$$

$\mathbf{QUCSUP\_EP}_{f,EPr_{EP},year}$

$$\text{UCSUP\_EP}_{f,EP,year} =$$

$$(\text{LTC\_EP\_PRICE}_{EP,year} - \sum_{ff|(\text{foutsecondary}_{ff,EP} \wedge \text{outputratio}_{EP,f,ff})} (\frac{1}{\text{outputratio}_{EP,f,ff}} \cdot \sum_{fff|\text{fopportunity}_{ff,fff}} (\text{fopportunity}_{ff,fff} \cdot (\text{PRIF\_TAX\_EP}_{fff,EP,year} +$$

$$\sum_{po}((\text{POprice\_EP}_{po,EP,year} \cdot (\text{Emfactor}_{po,fff,year} - \text{Emfactor}_{po,ff,year}))[\text{pollprice\_EP}_{EP,year}])))) + 0 \cdot \sum_{ff|\text{outputratio}_{EP,f,ff}} (\frac{1}{\text{outputratio}_{EP,f,ff}} \cdot \text{P\_EXCESSSEC\_EP}_{ff,EP,year}) +$$

$$0 \cdot \sum_{ff|\text{outputratio}_{EP,f,ff}} (\frac{1}{\text{outputratio}_{EP,f,ff}} \cdot \text{M\_OUTSEC\_EP}_{ff,EP,year}))[\text{foutprimary}_{f,EP}] + (\text{M\_OUTSEC\_EP}_{f,EP,year} - 0 \cdot \text{P\_EXCESSSEC\_EP}_{f,EP,year})[\text{foutsecondary}_{f,EP}]$$

$\forall f, EPr_{EP}, year \mid (\text{fself}_f \wedge (\text{foutprimary}_{f,EP} \vee \text{foutsecondary}_{f,EP}))$

QLTC_EP_PRICE$_{EPr_{EP},year}$

$$\text{LTC\_EP\_PRICE}_{EP,year} = \sum_{SW}(\text{SH\_EP\_SW\_LT}_{EP,SW,year} \cdot \text{LTC\_EP\_SW}_{EP,SW,year}) \qquad \forall EPr_{EP}, year$$

QOUTSEC_EP$_{ff,EPr_{EP},year}$

$$\text{OUTSEC\_EP}_{ff,EP,year} = \sum_{f|\text{foutprimary}_{f,EP}} (\frac{1}{\text{outputratio}_{EP,f,ff}} \cdot \text{OUTPRIM\_EP}_{f,EP,year}) \qquad \forall ff, EPr_{EP}, year \mid (\text{foutsecondary}_{ff,EP} \wedge \text{fself}_{ff})$$

QM_OUTSEC_EP$_{ff,EPr_{EP},year}$

$$\text{OUTSEC\_EP}_{ff,EP,year} \geq \sum_{SA|(\text{SAr}_{SA} \wedge \text{SA\_EP}_{SA,EP})} (\text{SH\_EP\_ST}_{SA,EP,ff,year} \cdot \sum_{SF|(((1-\text{doff\_SF}_{SF,year})=1) \wedge \text{SF\_fr}_{SF,ff,year} \wedge \text{SA\_SF}_{SA,SF})} \text{FE\_SF}_{SF,ff,year} +$$
$$\text{SH\_EP\_ST}_{SA,EP,ff,year} \cdot \sum_{EPP|(\text{EP\_f}_{EPP,ff} \wedge \text{SA\_EP}_{SA,EPP})} \text{FE\_EP}_{EPP,ff,year}) \qquad \forall ff, EPr_{EP}, year \mid (\text{foutsecondary}_{ff,EP} \wedge \text{fself}_{ff})$$

QOUTPRIM_EP$_{f,EPr_{EP},year}$

$$\text{OUTPRIM\_EP}_{f,EP,year} = \sum_{SA|(\text{SAr}_{SA} \wedge \text{SA\_EP}_{SA,EP})} (\text{SH\_EP\_ST}_{SA,EP,f,year} \cdot (\sum_{SF|(((1-\text{doff\_SF}_{SF,year})=1) \wedge \text{SFr}_{SF} \wedge \text{SF\_fr}_{SF,f,year} \wedge \text{SA\_SF}_{SA,SF})} \text{FE\_SF}_{SF,f,year} +$$
$$\sum_{SF|(((1-\text{doff\_SF}_{SF,year})=1) \wedge \text{SFr}_{SF} \wedge \text{SF\_HER}_{SF,f} \wedge \text{SA\_SF}_{SA,SF})} (\sum_{SW,tc|\text{tc\_SW}_{tc,SW}} (\text{Heatrate}_{f,SF,SW,tc,year} \cdot \text{SH\_HER}_{SF,SW,tc,year} \cdot \text{UE\_SF\_SW}_{SF,SW,tc,year})) + \sum_{EPP|(\text{EP\_f}_{EPP,f} \wedge \text{SA\_EP}_{SA,EPP} \wedge \text{SAr}_{SA})} \text{FE\_EP}_{EPP,f,year}))$$

$\forall f, EPr_{EP}, year \mid (\text{foutprimary}_{f,EP} \wedge \text{fself}_f)$

QSHINPUT_EP_F_Inert$_{EPr_{EP},SW,tc,f,year}$

$$\text{SHINPUT\_EP\_F\_Inert}_{EP,SW,tc,f,year} = (\frac{\text{dEP\_F}_{EP,SW,tc,f,year} \cdot \exp(-((\text{gEP\_F}_{EP,year} \cdot \text{STC\_EP\_F}_{EP,SW,tc,f,year})))}{\sum_{ff|(\text{tc\_SW}_{tc,SW} \wedge \text{EP\_f}_{EP,ff})} (\text{dEP\_F}_{EP,SW,tc,ff,year} \cdot \exp(-((\text{gEP\_F}_{EP,year} \cdot \text{STC\_EP\_F}_{EP,SW,tc,ff,year}))))} [\sum_{ff|(\text{tc\_SW}_{tc,SW} \wedge \text{EP\_f}_{EP,ff})} \text{dEP\_F}_{EP,SW,tc,ff,year}[(\sum_{ff|(\text{tc\_SW}_{tc,SW} \wedge \text{EP\_f}_{EP,ff})} 1 > 1)]] + 1[(\sum_{ff|(\text{tc\_SW}_{tc,SW} \wedge \text{EP\_f}_{EP,ff})} 1 \leq 1)])[\text{gEP\_F}_{EP,year}] + \text{dEP\_F}_{EP,SW,tc,f,year}[(\neg \text{gEP\_F}_{EP,year})]$$
$$\forall EPr_{EP}, SW, tc, f, year \mid (\text{tc\_SW}_{tc,SW} \wedge \text{EP\_f}_{EP,f})$$

QSHINPUT_EP_F_Optimum$_{EPr_{EP},SW,tc,f,year}$

$$\text{SHINPUT\_EP\_F\_Optimum}_{EP,SW,tc,f,year} = (\frac{\exp(-((\text{gOptimumEP\_F}_{EP,year} \cdot \text{STC\_EP\_F}_{EP,SW,tc,f,year})))}{\sum_{ff|(\text{tc\_SW}_{tc,SW} \wedge \text{EP\_f}_{EP,ff})} (\exp(-((\text{gOptimumEP\_F}_{EP,year} \cdot \text{STC\_EP\_F}_{EP,SW,tc,ff,year}))))}[(\sum_{ff|(\text{tc\_SW}_{tc,SW} \wedge \text{EP\_f}_{EP,ff})} 1 > 1)] + 1[(\sum_{ff|(\text{tc\_SW}_{tc,SW} \wedge \text{EP\_f}_{EP,ff})} 1 \leq 1)])[\text{gOptimumEP\_F}_{EP,year}] + \text{SHINPUT\_EP\_F\_Inert}_{EP,SW,tc,f,year}[(\neg \text{gOptimumEP\_F}_{EP,year})] \quad \forall EPr_{EP}, SW, tc, f, year \mid (\text{tc\_SW}_{tc,SW} \wedge \text{EP\_f}_{EP,f})$$

QSHINPUT_EP_F$_{EPr_{EP},SW,tc,f,year}$

$$\text{SHINPUT\_EP\_F}_{EP,SW,tc,f,year} = (1 - \text{TH\_SHINPUT\_EP\_F}_{EP,year}) \cdot \text{SHINPUT\_EP\_F\_Inert}_{EP,SW,tc,f,year} + \text{TH\_SHINPUT\_EP\_F}_{EP,year} \cdot \text{SHINPUT\_EP\_F\_Optimum}_{EP,SW,tc,f,year}$$
$$\forall EPr_{EP}, SW, tc, f, year \mid (\text{tc\_SW}_{tc,SW} \wedge \text{EP\_f}_{EP,f})$$

QSH_EP_SW_ST_Inert$_{EPr_{EP},SW,tc,year}$

$$\text{SH\_EP\_SW\_ST\_Inert}_{EP,SW,tc,year} = \frac{\text{dEP\_SW\_ST}_{EP,SW,tc,year} \cdot \exp(-((\text{gEP\_SW\_ST}_{EP,year} \cdot \text{M\_STC\_EP\_SW}_{EP,SW,tc,year})))}{\sum_{tcc,SWW|\text{tc\_SW}_{tcc,SWW}} (\text{dEP\_SW\_ST}_{EP,SWW,tcc,year} \cdot \exp(-((\text{gEP\_SW\_ST}_{EP,year} \cdot \text{M\_STC\_EP\_SW}_{EP,SWW,tcc,year}))))}[\text{gEP\_SW\_ST}_{EP,year}] [\sum_{tcc,SWW|\text{tc\_SW}_{tcc,SWW}} \text{dEP\_SW\_ST}_{EP,SWW,tcc,year}] + \text{dEP\_SW\_ST}_{EP,SW,tc,year}[(\neg \text{gEP\_SW\_ST}_{EP,year})] \quad \forall EPr_{EP}, SW, tc, year \mid \text{tc\_SW}_{tc,SW}$$

QSH_EP_SW_ST_Optimum$_{EPr_{EP},SW,tc,year}$

$$\mathrm{SH\_EP\_SW\_ST\_Optimum}_{EP,SW,tc,year} = \frac{(1-\mathrm{doff\_EP\_tc}_{EP,SW,tc,year})\cdot\exp(-((\mathrm{gOptimumEP\_SW\_ST}_{EP,year}\cdot\mathrm{M\_STC\_EP\_SW}_{EP,SW,tc,year})))}{\sum\limits_{tcc,SWW|\mathrm{tc\_SW}_{tcc,SWW}}((1-\mathrm{doff\_EP\_tc}_{EP,SWW,tcc,year})\cdot\exp(-((\mathrm{gOptimumEP\_SW\_ST}_{EP,year}\cdot\mathrm{M\_STC\_EP\_SW}_{EP,SWW,tcc,year}))))}$$
$$[\mathrm{gOptimumEP\_SW\_ST}_{EP,year}][\sum_{tcc,SWW|\mathrm{tc\_SW}_{tcc,SWW}}(1-\mathrm{doff\_EP\_tc}_{EP,SWW,tcc,year})]+\mathrm{SH\_EP\_SW\_ST\_Inert}_{EP,SW,tc,year}[(\neg\mathrm{gOptimumEP\_SW\_ST}_{EP,year})]$$
$$\forall EPr_{EP}, SW, tc, year \mid \mathrm{tc\_SW}_{tc,SW}$$

QSH_EP_SW_ST$_{EPr_{EP},SW,tc,year}$

$$\mathrm{SH\_EP\_SW\_ST}_{EP,SW,tc,year} = (1-\mathrm{TH\_SH\_EP\_SW\_ST}_{EP,year})\cdot\mathrm{SH\_EP\_SW\_ST\_Inert}_{EP,SW,tc,year}+\mathrm{TH\_SH\_EP\_SW\_ST}_{EP,year}\cdot\mathrm{SH\_EP\_SW\_ST\_Optimum}_{EP,SW,tc,year}$$
$$\forall EPr_{EP}, SW, tc, year \mid \mathrm{tc\_SW}_{tc,SW}$$

QSH_EP_ST_Inert$_{SAr_{SA},EPr_{EP},f,year}$

$$\mathrm{SH\_EP\_ST\_Inert}_{SA,EP,f,year} = \frac{\mathrm{dEP\_ST}_{SA,EP,f,year}\cdot\exp(-((\mathrm{gEP\_ST}_{SA,year}\cdot\mathrm{STC\_EP}_{EP,year})))}{\sum\limits_{EPP|\mathrm{SA\_EP}_{SA,EPP}}(\mathrm{dEP\_ST}_{SA,EPP,f,year}\cdot\exp(-((\mathrm{gEP\_ST}_{SA,year}\cdot\mathrm{STC\_EP}_{EPP,year}))))}[\mathrm{gEP\_ST}_{SA,year}]$$
$$[\sum_{EPP|\mathrm{SA\_EP}_{SA,EPP}}\mathrm{dEP\_ST}_{SA,EPP,f,year}]+\mathrm{dEP\_ST}_{SA,EP,f,year}[(\neg\mathrm{gEP\_ST}_{SA,year})]$$
$$\forall SAr_{SA}, EPr_{EP}, f, year \mid (\mathrm{SA\_EP}_{SA,EP}\wedge\mathrm{fself}_f\wedge(\mathrm{foutprimary}_{f,EP}\vee\mathrm{foutsecondary}_{f,EP}))$$

QSH_EP_ST_Optimum$_{SAr_{SA},EPr_{EP},f,year}$

$$\mathrm{SH\_EP\_ST\_Optimum}_{SA,EP,f,year} = \frac{\exp(-((\mathrm{gOptimumEP\_ST}_{SA,year}\cdot\mathrm{STC\_EP}_{EP,year})))}{\sum\limits_{EPP|\mathrm{SA\_EP}_{SA,EPP}}(\exp(-((\mathrm{gOptimumEP\_ST}_{SA,year}\cdot\mathrm{STC\_EP}_{EPP,year}))))}[\mathrm{gOptimumEP\_ST}_{SA,year}]+\mathrm{SH\_EP\_ST\_Inert}_{SA,EP,f,year}[(\neg\mathrm{gOptimumEP\_ST}_{SA,year})]$$
$$\forall SAr_{SA}, EPr_{EP}, f, year \mid (\mathrm{SA\_EP}_{SA,EP}\wedge\mathrm{fself}_f\wedge(\mathrm{foutprimary}_{f,EP}\vee\mathrm{foutsecondary}_{f,EP}))$$

QSH_EP_ST$_{SAr_{SA},EPr_{EP},f,year}$

$$\text{SH\_EP\_ST}_{SA,EP,f,year} = (1 - \text{TH\_SH\_EP\_ST}_{SA,year}) \cdot \text{SH\_EP\_ST\_Inert}_{SA,EP,f,year} + \text{TH\_SH\_EP\_ST}_{SA,year} \cdot \text{SH\_EP\_ST\_Optimum}_{SA,EP,f,year}$$
$$\forall SAr_{SA}, EPr_{EP}, f, year \mid (\text{SA\_EP}_{SA,EP} \wedge \text{fself}_{f} \wedge (\text{foutprimary}_{f,EP} \vee \text{foutsecondary}_{f,EP}))$$

QSH_EP_SW_LT_Inert$_{EPr_{EP},SW,year}$

$$\text{SH\_EP\_SW\_LT\_Inert}_{EP,SW,year} = \frac{\text{dEP\_SW\_LT}_{EP,SW,year} \cdot \exp(-((\text{gEP\_SW\_LT}_{EP,year} \cdot \text{LTC\_EP\_SW}_{EP,SW,year})))}{\sum_{SWW} (\text{dEP\_SW\_LT}_{EP,SWW,year} \cdot \exp(-((\text{gEP\_SW\_LT}_{EP,year} \cdot \text{LTC\_EP\_SW}_{EP,SWW,year}))))} [\text{gEP\_SW\_LT}_{EP,year}]$$
$$[\sum_{SWW} \text{dEP\_SW\_LT}_{EP,SWW,year}] + \text{dEP\_SW\_LT}_{EP,SW,year}[(\neg \text{gEP\_SW\_LT}_{EP,year})]$$
$$\forall EPr_{EP}, SW, year$$

QSH_EP_SW_LT_Optimum$_{EPr_{EP},SW,year}$

$$\text{SH\_EP\_SW\_LT\_Optimum}_{EP,SW,year} = \frac{\exp(-((\text{gOptimumEP\_SW\_LT}_{EP,year} \cdot \text{LTC\_EP\_SW}_{EP,SW,year})))}{\sum_{SWW} (\exp(-((\text{gOptimumEP\_SW\_LT}_{EP,year} \cdot \text{LTC\_EP\_SW}_{EP,SWW,year}))))} [\text{gOptimumEP\_SW\_LT}_{EP,year}] +$$
$$\text{SH\_EP\_SW\_LT\_Inert}_{EP,SW,year}[(\neg \text{gOptimumEP\_SW\_LT}_{EP,year})]$$
$$\forall EPr_{EP}, SW, year$$

QSH_EP_SW_LT$_{EPr_{EP},SW,year}$

$$\text{SH\_EP\_SW\_LT}_{EP,SW,year} = (1 - \text{TH\_SH\_EP\_SW\_LT}_{EP,year}) \cdot \text{SH\_EP\_SW\_LT\_Inert}_{EP,SW,year} + \text{TH\_SH\_EP\_SW\_LT}_{EP,year} \cdot \text{SH\_EP\_SW\_LT\_Optimum}_{EP,SW,year} \qquad \forall EPr_{EP}, SW, year$$

QSH_EP_LT_Inert$_{SAr_{SA},EPr_{EP},f,year}$

$$\text{SH\_EP\_LT\_Inert}_{SA,EP,f,year} = \frac{\text{dEP\_LT}_{SA,EP,f,year} \cdot \exp(-((\text{gEP\_LT}_{SA,year} \cdot \text{LTC\_EP}_{EP,year})))}{\sum_{EPP \mid \text{SA\_EP}_{SA,EPP}} (\text{dEP\_LT}_{SA,EPP,f,year} \cdot \exp(-((\text{gEP\_LT}_{SA,year} \cdot \text{LTC\_EP}_{EPP,year}))))} [\text{gEP\_LT}_{SA,year}]$$
$$[\sum_{EPP \mid \text{SA\_EP}_{SA,EPP}} \text{dEP\_LT}_{SA,EPP,f,year}] + \text{dEP\_LT}_{SA,EP,f,year}[(\neg \text{gEP\_LT}_{SA,year})]$$

$\forall SAr_{SA}, EPr_{EP}, f, year \mid (\text{SA\_EP}_{SA,EP} \wedge \text{fself}_{f} \wedge (\text{foutprimary}_{f,EP} \vee \text{foutsecondary}_{f,EP}))$

QSH_EP_LT_Optimum$_{SAr_{SA},EPr_{EP},f,year}$

$$\text{SH\_EP\_LT\_Optimum}_{SA,EP,f,year} = \frac{\exp(-((\text{gOptimumEP\_LT}_{SA,year} \cdot \text{LTC\_EP}_{EP,year})))}{\sum\limits_{EPP|\text{SA\_EP}_{SA,EPP}} (\exp(-((\text{gOptimumEP\_LT}_{SA,year} \cdot \text{LTC\_EP}_{EPP,year}))))} [\text{gOptimumEP\_LT}_{SA,year}] + \text{SH\_EP\_LT\_Inert}_{SA,EP,f,year} [(\neg \text{gOptimumEP\_LT}_{SA,year})]$$

$\forall SAr_{SA}, EPr_{EP}, f, year \mid (\text{SA\_EP}_{SA,EP} \wedge \text{fself}_{f} \wedge (\text{foutprimary}_{f,EP} \vee \text{foutsecondary}_{f,EP}))$

QSH_EP_LT$_{SAr_{SA},EPr_{EP},f,year}$

$\text{SH\_EP\_LT}_{SA,EP,f,year} = (1 - \text{TH\_SH\_EP\_LT}_{SA,year}) \cdot \text{SH\_EP\_LT\_Inert}_{SA,EP,f,year} + \text{TH\_SH\_EP\_LT}_{SA,year} \cdot \text{SH\_EP\_LT\_Optimum}_{SA,EP,f,year}$ $\forall SAr_{SA}, EPr_{EP}, f, year \mid (\text{SA\_EP}_{SA,EP} \wedge \text{fself}_{f} \wedge (\text{foutprimary}_{f,EP} \vee \text{foutsecondary}_{f,EP}))$

QFE_EP_SW_f$_{EPr_{EP},SW,tc,f,year}$

$$\text{FE\_EP\_SW\_f}_{EP,SW,tc,f,year} = \text{SHINPUT\_EP\_F}_{EP,SW,tc,f,year} \cdot \text{Heatrate\_EP}_{f,EP,SW,tc,year} \cdot \Big(\sum_{ff|\text{foutprimary}_{ff,EP}} (\text{SH\_EP\_SW\_ST}_{EP,SW,tc,year} \cdot \text{OUTPRIM\_EP}_{ff,EP,year}) + \sum_{ff|\text{foutsecondary}_{ff,EP}} (\text{SH\_EP\_SW\_ST}_{EP,SW,tc,year} \cdot \text{OUTSEC\_EP}_{ff,EP,year}) \Big)$$

$\forall EPr_{EP}, SW, tc, f, year \mid (\text{tc\_SW}_{tc,SW} \wedge \text{EP\_f}_{EP,f})$

QFE_EP$_{EPr_{EP},f,year}$

$$\text{FE\_EP}_{EP,f,year} = \sum_{SW,tc|\text{tc\_SW}_{tc,SW}} \text{FE\_EP\_SW\_f}_{EP,SW,tc,f,year} \qquad \forall EPr_{EP}, f, year \mid \text{EP\_f}_{EP,f}$$

$\mathbf{QPROB\_PREMR\_EP}_{EPr_{EP},SW,tc,year}$

$$\text{PROB\_PREMR\_EP}_{EP,SW,tc,year} = \left(\frac{\exp(-((\text{aPROB\_PREMR\_EP}_{EP,SW,tc,year}\cdot\frac{\text{LTC\_EP\_PRICE}_{EP,year}-0.75\cdot\text{STC\_EP\_SW}_{EP,\texttt{FUT},0,year}}{\text{STC\_EP\_SW}_{EP,\texttt{FUT},0,year}})))}{\exp(-((\text{aPROB\_PREMR\_EP}_{EP,SW,tc,year}\cdot\frac{\text{LTC\_EP\_PRICE}_{EP,year}-0.75\cdot\text{STC\_EP\_SW}_{EP,\texttt{FUT},0,year}}{\text{STC\_EP\_SW}_{EP,\texttt{FUT},0,year}})))+\text{ePROB\_PREMR\_EP}_{EP,SW,tc,year}\cdot(A)}^{\text{cPROB\_PREMR\_EP}_{EP,SW,tc,year}}\right)[(\neg\text{yearbasis}_{year})]+$$

$0[\text{yearbasis}_{year}]$
$\forall EPr_{EP}, SW, tc, year \mid (\text{tc\_SW}_{tc,SW} \wedge \text{SWord}_{SW} \wedge (\neg(tc = \texttt{0})) \wedge \text{Prem\_EP\_flag}_{EP,year})$
$Where$
$A = \exp(-((\text{aPROB\_PREMR\_EP}_{EP,SW,tc,year} \cdot \frac{\text{STC\_EP\_SW}_{EP,SW,tc,year}-0.75\cdot\text{STC\_EP\_SW}_{EP,\texttt{FUT},0,year}}{\text{STC\_EP\_SW}_{EP,\texttt{FUT},0,year}})))$

$\mathbf{QCAP\_SURV\_EP}_{EPr_{EP},SW,tc,year}$

$\text{CAP\_SURV\_EP}_{EP,SW,tc,year} = (\text{CAP\_EFFEC\_EP\_lag}_{EP,SW,tc,year} \cdot \text{prob\_surv\_EP}_{EP,SW,tc,year} \cdot (1 - \text{PROB\_PREMR\_EP}_{EP,SW,tc,year}[(\neg(tc = \texttt{0}))]))[(\neg\text{yearbasis}_{year})] +$
$\text{CAP\_EFFEC\_EP}_{EP,SW,tc,year}[\text{yearbasis}_{year}]$ $\forall EPr_{EP}, SW, tc, year \mid (\text{tc\_SW}_{tc,SW} \wedge \text{SWord}_{SW})$

$\mathbf{QCAP\_DESIRED\_EP}_{EPr_{EP},SW,year}$

$$\text{CAP\_DESIRED\_EP}_{EP,SW,year} = \frac{\text{SH\_EP\_SW\_LT}_{EP,SW,year}\cdot\sum_{f|(\text{foutprimary}_{f,EP}\wedge\text{fself}_f)}(\sum_{SA|(\text{SAr}_{SA}\wedge\text{SA\_EP}_{SA,EP})}(\text{SH\_EP\_LT}_{SA,EP,f,year}\cdot(A)))}{\text{util\_EP}_{EP,year}\cdot 8760}[(\neg\text{yearbasis}_{year})]+\sum_{tc|\text{tc\_SW}_{tc,SW}}\text{CAP\_EFFEC\_EP}_{EP,SW,tc,year}[\text{yearbasis}_{year}]$$

$\forall EPr_{EP}, SW, year$
$Where$

$$A = (\sum_{SF|(((1-\text{doff\_SF}_{SF,year})=1)\wedge\text{SFr}_{SF}\wedge\text{SF\_fr}_{SF,f,year}\wedge\text{SA\_SF}_{SA,SF})}\text{FE\_SF}_{SF,f,year}+\sum_{SF|(((1-\text{doff\_SF}_{SF,year})=1)\wedge\text{SFr}_{SF}\wedge\text{SF\_HER}_{SF,f}\wedge\text{SA\_SF}_{SA,SF})}(\sum_{SWW,tcc|\text{tc\_SW}_{tcc,SWW}}(\text{Heatrate}_{f,SF,SWW,tcc,year}\cdot\text{SH\_HER}_{SF,SWW,tcc,year}\cdot$$

$$\text{UE\_SF\_SW}_{SF,SWW,tcc,year})) + \sum_{EPP|(\text{EP\_f}_{EPP,f}\wedge\text{SA\_EP}_{SA,EPP})}\text{FE\_EP}_{EPP,f,year})$$

$\textbf{QINV\_EP}_{EPr_{EP},SW,year}$

$$\text{INV\_EP}_{EP,SW,year} = (0.5 \cdot (\text{CAP\_DESIRED\_EP}_{EP,SW,year} - \sum_{tc|(\text{tc\_SW}_{tc,SW} \wedge (\neg(tc=0)))} \text{CAP\_SURV\_EP}_{EP,SW,tc,year} + ((\text{CAP\_DESIRED\_EP}_{EP,SW,year} - \sum_{tc|(\text{tc\_SW}_{tc,SW} \wedge (\neg(tc=0)))} \text{CAP\_SURV\_EP}_{EP,SW,tc,year}) \cdot (\text{CAP\_DESIRED\_EP}_{EP,SW,year} - \sum_{tc|(\text{tc\_SW}_{tc,SW} \wedge (\neg(tc=0)))} \text{CAP\_SURV\_EP}_{EP,SW,tc,year}) + 1e-06)^{0.5}))[(\neg \text{yearbasis}_{year})] + \text{CAP\_EFFEC\_EP}_{EP,SW,0,year}[\text{yearbasis}_{year}]$$
$$\forall EPr_{EP}, SW, year$$

$\textbf{QCAP\_EFFEC\_EP}_{EPr_{EP},SW,tc,year}$

$$\text{CAP\_EFFEC\_EP}_{EP,SW,tc,year} = (\text{CAP\_SURV\_EP}_{EP,SW,tc,year}[(\neg(tc=0))] + \text{INV\_EP}_{EP,SW,year}[(tc=0)])[(\neg \text{yearbasis}_{year})] + \text{CAP\_EFFEC\_EP0}_{EP,SW,tc}[\text{yearbasis}_{year}]$$
$$\forall EPr_{EP}, SW, tc, year \mid \text{tc\_SW}_{tc,SW}$$

$\textbf{QM\_CAP\_EP}_{EPr_{EP},SW,tc,year}$

$$\text{CAP\_EFFEC\_EP}_{EP,SW,tc,year} \geq \frac{\text{SH\_EP\_SW\_ST}_{EP,SW,tc,year} \cdot \sum_{f|(\text{foutprimary}_{f,EP} \wedge \text{fself}_f)} (\sum_{SA|\text{SA\_EP}_{SA,EP}} (\text{SH\_EP\_ST}_{SA,EP,f,year} \cdot (A)))}{\text{util\_EP}_{EP,year} \cdot 8760}[(\neg \text{yearbasis}_{year})] + \text{CAP\_EFFEC\_EP0}_{EP,SW,tc}[\text{yearbasis}_{year}]$$
$$\forall EPr_{EP}, SW, tc, year \mid \text{tc\_SW}_{tc,SW}$$
$$Where$$
$$A = (\sum_{SF|(((1-\text{doff\_SF}_{SF,year})=1) \wedge \text{SF\_fr}_{SF,f,year} \wedge \text{SA\_SF}_{SA,SF})} \text{FE\_SF}_{SF,f,year} + \sum_{SF|(((1-\text{doff\_SF}_{SF,year})=1) \wedge \text{SF\_HER}_{SF,f} \wedge \text{SA\_SF}_{SA,SF})} (\sum_{SWW,tcc|\text{tc\_SW}_{tcc,SWW}} (\text{Heatrate}_{f,SF,SWW,tcc,year} \cdot \text{SH\_HER}_{SF,SWW,tcc,year} \cdot \text{UE\_SF\_SW}_{SF,SWW,tcc,year})) + \sum_{EPP|(\text{EP\_f}_{EPP,f} \wedge \text{SA\_EP}_{SA,EPP})} \text{FE\_EP}_{EPP,f,year})$$

$\textbf{QM\_POT\_HER}_{SFr_{SF},SW,tc,year}$

$$\text{M\_POT\_HER}_{SF,SW,tc,year} = (1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) \cdot (\text{a6\_POT\_HER}_{SF,SW,tc,year} \cdot \text{power}(\frac{\text{SH\_HER\_LT}_{SF,SW,tc,year} + \text{SH\_HER\_lag}_{SF,SW,tc,year}}{\text{SH\_POT\_HER}_{SF,year} + 1e-06}, 6) + \text{a5\_POT\_HER}_{SF,SW,tc,year} \cdot \text{power}(\frac{\text{SH\_HER\_LT}_{SF,SW,tc,year} + \text{SH\_HER\_lag}_{SF,SW,tc,year}}{\text{SH\_POT\_HER}_{SF,year} + 1e-06}, 5) + \text{a4\_POT\_HER}_{SF,SW,tc,year} \cdot \text{power}(\frac{\text{SH\_HER\_LT}_{SF,SW,tc,year} + \text{SH\_HER\_lag}_{SF,SW,tc,year}}{\text{SH\_POT\_HER}_{SF,year} + 1e-06}, 4) +$$

$$\text{a3\_POT\_HER}_{SF,SW,tc,year} \cdot \text{power}(\frac{\text{SH\_HER\_LT}_{SF,SW,tc,year}+\text{SH\_HER\_lag}_{SF,SW,tc,year}}{\text{SH\_POT\_HER}_{SF,year}+1e{-}06}, 3) + \text{a2\_POT\_HER}_{SF,SW,tc,year} \cdot \text{power}(\frac{\text{SH\_HER\_LT}_{SF,SW,tc,year}+\text{SH\_HER\_lag}_{SF,SW,tc,year}}{\text{SH\_POT\_HER}_{SF,year}+1e{-}06}, 2) + \text{a1\_POT\_HER}_{SF,SW,tc,year} \cdot \text{power}(\frac{\text{SH\_HER\_LT}_{SF,SW,tc,year}+\text{SH\_HER\_lag}_{SF,SW,tc,year}}{\text{SH\_POT\_HER}_{SF,year}+1e{-}06}, 1))$$

$\forall SFr_{SF}, SW, tc, year \mid (\text{SF\_HER}_{SF,\texttt{HER}} \wedge \text{tc\_SW}_{tc,SW} \wedge ((1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) = 1))$

QLTC_HER$_{SFr_{SF},SW,tc,year}$

$$\text{LTC\_HER}_{SF,SW,tc,year} = (\frac{\text{capc\_HER}_{SF,year} \cdot (1-\text{subs\_HER}_{SF,year}) \cdot \text{annfactor\_HER}_{SF,year}}{\text{util\_AG\_SF}_{\texttt{Medium},SF,year} \cdot 8760} \cdot (1 + \text{M\_POT\_HER}_{SF,SW,tc,year}) + \frac{\text{omq\_HER}_{SF,year}}{\text{util\_AG\_SF}_{\texttt{Medium},SF,year} \cdot 8760} - \text{EEvalue\_HER}_{SF,year}) \cdot \text{Heatrate}_{\texttt{HER},SF,SW,tc,year}$$

$\forall SFr_{SF}, SW, tc, year \mid (\text{SF\_HER}_{SF,\texttt{HER}} \wedge \text{tc\_SW}_{tc,SW} \wedge ((1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) = 1))$

QSTC_SF_SW_NoHER$_{SFr_{SF},SW,tc,year}$

$$\text{STC\_SF\_SW\_NoHER}_{SF,SW,tc,year} = (1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) \cdot (\sum_{AG|\text{SF\_AG}_{SF,AG}} (\text{HistAG\_ACT\_SF}_{AG,SF,year} \cdot (\sum_{f|\text{SF\_fr}_{SF,f,year}} (\text{SH\_SW\_F}_{SF,SW,tc,f,year} \cdot \text{STC\_SW\_F}_{SF,SW,tc,f,year}) \cdot (1 - \text{SH\_HER\_lag}_{SF,SW,tc,year}[\sum_{ff,SF\_HER_{SF,ff}} 1]) + \text{vqc\_SF}_{SF,year} \cdot \text{Heatrate\_AVRG}_{SF} + \frac{\text{omq\_SF}_{SF,year}}{\frac{\text{util\_AG\_SF}_{AG,SF,year} \cdot 8760}{\text{Heatrate\_AVRG}_{SF}}} \cdot (1 + \text{osmg\_SF}_{SF,year})^{\text{tc.val}}))[(\neg \text{SFtra}_{SF})] + \sum_{AG|\text{SF\_AG}_{SF,AG}} (\text{HistAG\_ACT\_SF}_{AG,SF,year} \cdot \frac{\sum_{f|\text{SF\_fr}_{SF,f,year}} (\text{SH\_SW\_F}_{SF,SW,tc,f,year} \cdot \text{STC\_SW\_F}_{SF,SW,tc,f,year}) + \text{vqc\_SF}_{SF,year} + \frac{\text{omq\_SF}_{SF,year}}{\text{mileage}_{AG,SF,year} \cdot 1000} \cdot (1 + \text{osmg\_SF}_{SF,year})^{\text{tc.val}}}{\text{occupancy}_{SF,year}})[\text{SFtra}_{SF}])$$

$\forall SFr_{SF}, SW, tc, year \mid (\text{tc\_SW}_{tc,SW} \wedge ((1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) = 1))$

QX_SH_HER_LT$_{SFr_{SF},SW,tc,year}$

$$\text{X\_SH\_HER\_LT}_{SF,SW,tc,year} = \exp(-((\text{gHER}_{SF,year} \cdot \text{LTC\_HER}_{SF,SW,tc,year}))) \qquad \forall SFr_{SF}, SW, tc, year \mid (\text{tc\_SW}_{tc,SW} \wedge \sum_{f|\text{SF\_HER}_{SF,f}} 1 \wedge ((1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) = 1))$$

$\mathbf{QX\_SH\_NoHER}_{SFr_{SF},SW,tc,year}$

$$\text{X\_SH\_NoHER}_{SF,SW,tc,year} = \exp(-((\text{gHER}_{SF,year} \cdot \text{STC\_SF\_SW\_NoHER}_{SF,SW,tc,year}))) \qquad \forall SFr_{SF}, SW, tc, year \mid (\text{tc\_SW}_{tc,SW} \wedge \sum_{f|\text{SF\_HER}_{SF,f}} 1 \wedge ((1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) = 1))$$

$\mathbf{QSH\_HER}_{SFr_{SF},SW,tc,year}$

$$\text{SH\_HER}_{SF,SW,tc,year} \geq \text{SH\_HER\_LT}_{SF,SW,tc,year} + \text{SH\_HER\_lag}_{SF,SW,tc,year} \qquad \forall SFr_{SF}, SW, tc, year \mid (\text{tc\_SW}_{tc,SW} \wedge \sum_{f|\text{SF\_HER}_{SF,f}} 1 \wedge ((1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) = 1))$$

$\mathbf{QSH\_HER\_LT}_{SFr_{SF},SW,tc,year}$

$$\text{SH\_HER\_LT}_{SF,SW,tc,year} = (1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) \cdot \frac{\exp(-((\text{gHER}_{SF,year} \cdot (\text{LTC\_HER}_{SF,SW,tc,year} + \text{dHER}_{SF,SW,tc,year}))))}{\exp(-((\text{gHER}_{SF,year} \cdot (\text{LTC\_HER}_{SF,SW,tc,year} + \text{dHER}_{SF,SW,tc,year})))) + \exp(-((\text{gHER}_{SF,year} \cdot \text{STC\_SF\_SW\_NoHER}_{SF,SW,tc,year})))}[\text{gHER}_{SF,year}]$$
$$\forall SFr_{SF}, SW, tc, year \mid (\text{tc\_SW}_{tc,SW} \wedge \sum_{f|\text{SF\_HER}_{SF,f}} 1 \wedge ((1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) = 1))$$

$\mathbf{QCAP\_SURV\_HER}_{SFr_{SF},SW,tc,year}$

$$\text{CAP\_SURV\_HER}_{SF,SW,tc,year} = \text{CAP\_EFFEC\_HER\_lag}_{SF,SW,tc,year} \cdot \text{prob\_surv\_HER}_{SF,SW,tc,year} \qquad \forall SFr_{SF}, SW, tc, year \mid (\text{SF\_HER}_{SF,\texttt{HER}} \wedge \text{tc\_SW}_{tc,SW} \wedge ((1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) = 1))$$

$\mathbf{QCAP\_EFFEC\_HER}_{SFr_{SF},SW,tc,year}$

$$\text{CAP\_EFFEC\_HER}_{SF,SW,tc,year} = (\text{CAP\_SURV\_HER}_{SF,SW,tc,year} + \text{INV\_HER}_{SF,SW,tc,year})[(\neg \text{yearbasis}_{year})] + 0[\text{yearbasis}_{year}] \qquad \forall SFr_{SF}, SW, tc, year \mid (\text{SF\_HER}_{SF,\texttt{HER}} \wedge \text{tc\_SW}_{tc,SW} \wedge ((1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) = 1))$$

$\mathbf{QINV\_HER}_{SFr_{SF},SW,tc,year}$

$$\text{INV\_HER}_{SF,SW,tc,year} = \frac{\text{Heatrate}_{\texttt{HER},SF,SW,tc,year} \cdot \text{SH\_HER\_LT}_{SF,SW,tc,year} \cdot \text{UE\_SF\_SW}_{SF,SW,tc,year}}{\text{util\_AG\_SF}_{\texttt{Medium},SF,year} \cdot 8760}[(\neg \text{yearbasis}_{year})] + 0[\text{yearbasis}_{year}] \qquad \forall SFr_{SF}, SW, tc, year \mid (\text{SF\_HER}_{SF,\texttt{HER}} \wedge \text{tc\_SW}_{tc,SW} \wedge ((1 - \text{doff\_SF\_tc}_{SF,SW,tc,year}) = 1))$$

$\text{P\_ACTSB}_{SB,year\_all} \geq 0 \;\forall SB, year\_all$
$\text{P\_ACTSC}_{SC,year\_all} \geq 0 \;\forall SC, year\_all$
$\text{P\_ACTSD}_{SD,year\_all} \geq 0 \;\forall SD, year\_all$
$\text{P\_ACTSE\_AG\_LT}_{AG,SE,year\_all} \geq 0 \;\forall AG, SE, year\_all$
$\text{P\_ACTSE\_AG\_ST}_{AG,SE,year\_all} \geq 0 \;\forall AG, SE, year\_all$
$\text{P\_ACTSF\_AG\_ST}_{AG,SF,year\_all} \geq 0 \;\forall AG, SF, year\_all$
$\text{P\_ACTSF\_AG\_LT}_{AG,SF,year\_all} \geq 0 \;\forall AG, SF, year\_all$
$\text{P\_ACTSE\_AG\_LT\_Stndrds}_{AG,SE,year\_all} \geq 0 \;\forall AG, SE, year\_all$
$\text{M\_STND\_SD}_{Stndrds,SD,year\_all} \geq 0 \;\forall Stndrds, SD, year\_all$
$\text{P\_ACTSF\_AG\_LT\_Stndrds}_{AG,SF,year\_all} \geq 0 \;\forall AG, SF, year\_all$
$\text{P\_ACTSE\_ST}_{SE,year\_all} \geq 0 \;\forall SE, year\_all$
$\text{P\_ACTSE\_LT}_{SE,year\_all} \geq 0 \;\forall SE, year\_all$
$\text{P\_ACTSF\_ST}_{SF,year\_all} \geq 0 \;\forall SF, year\_all$
$\text{P\_ACTSF\_LT}_{SF,year\_all} \geq 0 \;\forall SF, year\_all$
$\text{M\_POT\_SD}_{SD,fuel\_all,year\_all} \geq 0 \;\forall SD, fuel\_all, year\_all$
$\text{SH\_SW\_F}_{SF,SW,tc,fuel\_all,year\_all} \geq 0 \;\forall SF, SW, tc, fuel\_all, year\_all$
$\text{SH\_HER}_{SF,SW,tc,year\_all} \geq 0 \;\forall SF, SW, tc, year\_all$
$\text{M\_CAP\_SF}_{SF,SW,tc,year\_all} \geq 0 \;\forall SF, SW, tc, year\_all$
$\text{FE\_SF}_{SF,fuel\_all,year\_all} \geq 0 \;\forall SF, fuel\_all, year\_all$
$\text{INV\_SF}_{SF,SW,year\_all} \geq 0 \;\forall SF, SW, year\_all$
$\text{M\_CAP\_EP}_{EP,SW,tc,year\_all} \geq 0 \;\forall EP, SW, tc, year\_all$
$\text{P\_EXCESSSEC\_EP}_{fuel\_all,EP,year\_all} \geq 0 \;\forall fuel\_all, EP, year\_all$
$\text{M\_OUTSEC\_EP}_{f,EP,year\_all} \geq 0 \;\forall f, EP, year\_all$
$\text{INV\_EP}_{EP,SW,year\_all} \geq 0 \;\forall EP, SW, year\_all$
QACTSB⊥ACTSB, QACTSC⊥ACTSC, QACTSD⊥ACTSD, QACTSE_AG⊥ACTSE_AG, QACTSE⊥ACTSE, QACTSE_AG_LT⊥ACTSE_AG_LT, QACTSF_AG⊥ACTSF_AG, QACTSF⊥ACTSF,

QACTSF_AG_LT⊥ACTSF_AG_LT, QP_ACTSB⊥P_ACTSB, QP_ACTSC⊥P_ACTSC, QP_ACTSD⊥P_ACTSD, QP_ACTSE_AG_ST⊥P_ACTSE_AG_ST, QP_ACTSE_AG_LT⊥P_ACTSE_AG_LT,
QP_ACTSE_AG_LT_Stndrds⊥P_ACTSE_AG_LT_Stndrds, QP_ACTSF_AG_ST⊥P_ACTSF_AG_ST, QP_ACTSF_AG_LT⊥P_ACTSF_AG_LT, QP_ACTSF_AG_LT_Stndrds⊥P_ACTSF_AG_LT_Stndrds,
QP_ACTSE_ST⊥P_ACTSE_ST, QP_ACTSE_LT⊥P_ACTSE_LT, QP_ACTSF_ST⊥P_ACTSF_ST, QP_ACTSF_LT⊥P_ACTSF_LT, QX_SH_ACTSBC⊥X_SH_ACTSBC, QSH_ACTSBC⊥SH_ACTSBC,
QX_SH_ACTSCD_Inert⊥X_SH_ACTSCD_Inert, QSH_ACTSCD_Inert⊥SH_ACTSCD_Inert, QX_SH_ACTSCD_Optimum⊥X_SH_ACTSCD_Optimum, QSH_ACTSCD_Optimum⊥SH_ACTSCD_Optimum,
QSH_ACTSCD⊥SH_ACTSCD, QX_SH_ACTSDE_AG_ST_Inert⊥X_SH_ACTSDE_AG_ST_Inert, QSH_ACTSDE_AG_ST_Inert⊥SH_ACTSDE_AG_ST_Inert, QX_SH_ACTSDE_AG_ST_Optimum⊥X_SH_ACTS
QSH_ACTSDE_AG_ST_Optimum⊥SH_ACTSDE_AG_ST_Optimum, QSH_ACTSDE_AG_ST⊥SH_ACTSDE_AG_ST, QX_SH_ACTSEF_AG_ST_Inert⊥X_SH_ACTSEF_AG_ST_Inert, QSH_ACTSEF_AG_ST_Ine

QX_SH_ACTSEF_AG_ST_Optimum⊥X_SH_ACTSEF_AG_ST_Optimum, QSH_ACTSEF_AG_ST_Optimum⊥SH_ACTSEF_AG_ST_Optimum, QSH_ACTSEF_AG_ST⊥SH_ACTSEF_AG_ST, QX_SH_ACTSDE
QSH_ACTSDE_AG_LT_Inert⊥SH_ACTSDE_AG_LT_Inert, QX_SH_ACTSDE_AG_LT_Optimum⊥X_SH_ACTSDE_AG_LT_Optimum, QSH_ACTSDE_AG_LT_Optimum⊥SH_ACTSDE_AG_LT_Optimum,
QSH_ACTSDE_AG_LT⊥SH_ACTSDE_AG_LT, QX_SH_ACTSEF_AG_LT_Inert⊥X_SH_ACTSEF_AG_LT_Inert, QSH_ACTSEF_AG_LT_Inert⊥SH_ACTSEF_AG_LT_Inert, QX_SH_ACTSEF_AG_LT_Optimum
QSH_ACTSEF_AG_LT_Optimum⊥SH_ACTSEF_AG_LT_Optimum, QSH_ACTSEF_AG_LT⊥SH_ACTSEF_AG_LT, QSTC_SW_F⊥STC_SW_F, QSTC_SF_SW_AG⊥STC_SF_SW_AG, QM_STC_SF_SW_AG⊥M
QLTC_SF_SW_AG⊥LTC_SF_SW_AG, QLTC_SF_SW_AG_Stndrds⊥LTC_SF_SW_AG_Stndrds, QSTC_SF_SW⊥STC_SF_SW, QLTC_SF_SW⊥LTC_SF_SW, QX_SH_SW_F_Inert⊥X_SH_SW_F_Inert,
QSH_SW_F_Inert⊥SH_SW_F_Inert, QX_SH_SW_F_Optimum⊥X_SH_SW_F_Optimum, QSH_SW_F_Optimum⊥SH_SW_F_Optimum, QSH_SW_F⊥SH_SW_F, QX_SH_SF_SW_AG_ST_Inert⊥X_SH_SF_SW_AG_
QSH_SF_SW_AG_ST_Inert⊥SH_SF_SW_AG_ST_Inert, QX_SH_SF_SW_AG_ST_Optimum⊥X_SH_SF_SW_AG_ST_Optimum, QSH_SF_SW_AG_ST_Optimum⊥SH_SF_SW_AG_ST_Optimum, QSH_SF_SW_AG_
QX_SH_SF_SW_AG_LT_Inert⊥X_SH_SF_SW_AG_LT_Inert, QSH_SF_SW_AG_LT_Inert⊥SH_SF_SW_AG_LT_Inert, QX_SH_SF_SW_AG_LT_Optimum⊥X_SH_SF_SW_AG_LT_Optimum, QSH_SF_SW_AG_LT_O
QSH_SF_SW_AG_LT⊥SH_SF_SW_AG_LT, QUE_SF_SW⊥UE_SF_SW, QUE_SF⊥UE_SF, QFE_SF_SW_f⊥FE_SF_SW_f, QFE_SF⊥FE_SF, QPROB_PREMR_SF⊥PROB_PREMR_SF, QCAP_SURV_SF⊥CAP_
QCAP_SURV_SF_TOT⊥CAP_SURV_SF_TOT, QCAP_DESIRED_SF⊥CAP_DESIRED_SF, QCAP_DESIRED_SF_TOT⊥CAP_DESIRED_SF_TOT, QINV_SF⊥INV_SF, QSH_INV_SF⊥SH_INV_SF,
QCAP_EFFEC_SF⊥CAP_EFFEC_SF, QM_CAP_SF⊥M_CAP_SF, QM_POT_SD⊥M_POT_SD, QM_STND_SD⊥M_STND_SD, QUCAUTO_SA⊥UCAUTO_SA, QSTC_EP_F⊥STC_EP_F, QSTC_EP_SW⊥STC
QM_STC_EP_SW⊥M_STC_EP_SW, QSTC_EP⊥STC_EP, QLTC_EP_SW⊥LTC_EP_SW, QLTC_EP⊥LTC_EP, QUCSUP_EP⊥UCSUP_EP, QLTC_EP_PRICE⊥LTC_EP_PRICE, QOUTSEC_EP⊥OUTSEC_
QM_OUTSEC_EP⊥M_OUTSEC_EP, QOUTPRIM_EP⊥OUTPRIM_EP, QSHINPUT_EP_F_Inert⊥SHINPUT_EP_F_Inert, QSHINPUT_EP_F_Optimum⊥SHINPUT_EP_F_Optimum, QSHINPUT_EP_F⊥SH
QSH_EP_SW_ST_Inert⊥SH_EP_SW_ST_Inert, QSH_EP_SW_ST_Optimum⊥SH_EP_SW_ST_Optimum, QSH_EP_SW_ST⊥SH_EP_SW_ST, QSH_EP_ST_Inert⊥SH_EP_ST_Inert, QSH_EP_ST_Optimum⊥SH_E
QSH_EP_ST⊥SH_EP_ST, QSH_EP_SW_LT_Inert⊥SH_EP_SW_LT_Inert, QSH_EP_SW_LT_Optimum⊥SH_EP_SW_LT_Optimum, QSH_EP_SW_LT⊥SH_EP_SW_LT, QSH_EP_LT_Inert⊥SH_EP_LT_Inert,
QSH_EP_LT_Optimum⊥SH_EP_LT_Optimum, QSH_EP_LT⊥SH_EP_LT, QFE_EP_SW_f⊥FE_EP_SW_f, QFE_EP⊥FE_EP, QPROB_PREMR_EP⊥PROB_PREMR_EP, QCAP_SURV_EP⊥CAP_SURV_EP,
QCAP_DESIRED_EP⊥CAP_DESIRED_EP, QINV_EP⊥INV_EP, QCAP_EFFEC_EP⊥CAP_EFFEC_EP, QM_CAP_EP⊥M_CAP_EP, QM_POT_HER⊥M_POT_HER, QLTC_HER⊥LTC_HER,
QSTC_SF_SW_NoHER⊥STC_SF_SW_NoHER, QX_SH_HER_LT⊥X_SH_HER_LT, QX_SH_NoHER⊥X_SH_NoHER, QSH_HER⊥SH_HER, QSH_HER_LT⊥SH_HER_LT, QCAP_SURV_HER⊥CAP_SURV_HE
QCAP_EFFEC_HER⊥CAP_EFFEC_HER, QINV_HER⊥INV_HER

Appendix IV Mathematical formulation of the CPS Power Module

Symbols

Sets

Name	**Domains**	**Description**
labels	*	
sectors_all	labels	superset of the demand sectors
year_all, year1, vint	labels	years
year	year_all	projection years
region	labels	regions
hour, hour1	labels	hours
day	labels	days
SA_all	labels	demand sectors upper level
SA	SA_all	demand sectors upper level
plant	labels	all pants
unit	plant	power plants
unit_limit	unit	power plants with operation constraints in unit commitment
no_unit_limit	unit	power plants with operation constraints in unit commitment
unit_region	unit, region	location of a unit
unit_chp	unit	CHP units
storage	plant	storage facilities
PtoX	plant	power to X plants
dhh	plant	district heating plants producing heat
ind	plant	industrial plants
indboil	plant	industrial boiler
indCHP	plant	onsiteCHP power plants
CCS	plant	plants with a carbon capture and storage possibility
ancillary_all	labels	ancillary services
ancillary_up	ancillary_all	upward ancillary services
ancillary_down	ancillary_all	downward ancillary services
fuel_all	labels	set of fuels
fuel, fuel1	fuel_all	fuels used in the power and the district heating plants including clean fuels
fuel_limit	fuel_all	fuels with a nonlinear cost supply curve
fuel_ind	fuel_all	fuels used in industrial plants
cleanfuel	fuel_all	clean fuels
cleanfuel_dhh	fuel_all	clean fuels used in district heating plants

Name	Domains	Description
cleanfuel_ind	fuel_all	clean fuels used in district heating plants
map_fuel_main	fuel_all, fuel_all	mapping of fuels and fuels used in district heating or industrial plants
resource	labels	resources
type	labels	types of plants
type_dhh	type	types of district heating plants
type_limit	type	types of plants with nonlinear cost supply curves
type_storage	type	types of storage power plants with nonlinear cost supply curves
level	labels	levels in the cost supply curves
mapday	hour, day	mapping of hours in days
resourcemap	plant, resource	resources used by a plant
hour_seq	hour, hour	map indicating the sequence of hours
fuelplant	plant, fuel_all, year_all	fuels used by a plant
PtoXmap	PtoX, fuel_all	cleanfuels produced by a power to X plant
planttype	plant, type	categorization of plants in types
sectors	sectors_all	demand sectors considered in the power sector
report_type	report_type	reporting types of plants
report_res	report_type	res types
reportplanttype	plant, report_type	mapping of plants and report types
INDmapsectors	sectors_all, plant	mapping of industrial plants and sectors
SameAs	*, *	Set Element Comparison Without Checking

Parameters

Name	Domains	Description
drivers_data	labels, labels, labels, labels	drivers data
techdata_plants	labels, labels, labels	technical data
fuelswitch	labels, labels	data for power plant fuel switching
fuelblend	labels, labels	data for power plant fuel blending
policy_power_data	labels, labels, labels, labels	policy and system data
level_struct	labels, labels, labels, labels	data for the levels of the cost supply curves
blend	labels, labels	fuel blending for industrial plants
Demand_CHPBOI_DGS	SA, fuel_all, year_all	derived gasses quantity consumed in industrial plants
first	hour	first hour of each day
last	hour	last hour of each day

Name	Domains	Description
elec_load	hour, year_all	demand of electricity net of production by auto-producers
loss_load	hour, year_all	transmission and distribution losses of the distributed electricity
heatdemand	hour, year_all	demand for distributed heat
freq_hour	hour	annual frequency of an hour
freq_day	day	annual frequency of a day
elec_demand	sectors, year_all	sectoral electricity demand [GWh]
steam_demand	sectors, year_all	sectoral heat demand [GWh]
DemCleanfuel	fuel_all, year_all	demand of clean fuels from demand sectors [GWh]
netimportsexog	hour, year_all	Net imports [GW]
annuity_factor	labels, year_all	annual equivalent of a unit of investment using a WACC rate [%]
annuity_factor_type	labels, year_all, year_all	annual equivalent of a unit of investment using a WACC rate [%]
annuity_factor_ext	labels, year_all	annual equivalent of a unit of investment for refurbishment using a WACC rate [%]
annuity_factor_fs	labels, year_all	annual equivalent of a unit of investment for refurbishment using a WACC rate [%]
avail_plant	plant, year_all	existence or permission for a plant
fuelprice	fuel_all, year_all	fuel prices used in power sectors [fuel]
fuelpricedgs	sectors, fuel_all, year_all	fuel prices for derived gas used in power sectors [fuel]
surv_plant	plant, year_all	technical survival of a plant in a year [0 or 1]
surve_plant	plant, year_all	duration of capital costs in annual installments for a plant [0 or 1]
survext_plant	plant, year_all	duration of capital costs of plant refurbishment in annual installments for a plant [0 or 1]
survfs_plant	plant, year_all	duration of capital costs of plant fuel switch process in annual installments for a plant [0 or 1]
INDpattern	plant, hour	generation pattern from onsiteCHP plants [%]
capacity_factor	plant, hour	hourly capacity factor [%]
emission_factor	plant, fuel_all, year_all	emission factor [MtCO2]
Tper		

Variables

Name	Domains	Description
ELEC_CUT	hour, year_all	electricity cuts [GW elec per hour]
HEAT_CUT	hour, year_all	cut of heat demand [GW thermal per hour]
STEAM_CUT	sectors_all, year_all	cut of steam demand [GW thermal per hour]
DHH_ADD	type, year_all	additional dhh heat production [GW thermal per hour]
DHH_CUT	type, year_all	cut of dhh heat production [GW thermal per hour]
CHP_CUT	sectors_all, year_all	cut of dhh heat production [GW thermal per hour]

Name	**Domains**	**Description**
CHP_ADD	sectors_all, year_all	cut of dhh heat production [GW thermal per hour]
DGASCUT	year_all	cut of mandatory derived gas use [GWh fuel]
ELEC_OUTPUT	plant, hour, year_all	electricity generation by plants [GW elec per hour]
ELEC_OUTPUT_IND	plant, year_all	electricity generation by plants [GWh elec]
STEAM_OUTPUT	plant, hour, year_all	steam production by plants [GWh thermal]
STEAM_OUTPUT_IND	plant, year_all	steam production by plants [GWh thermal]
PtoX_OUTPUT	PtoX, hour, year_all	clean fuel output of a power to X plant [GW fuel per hour]
PToX_INPUT	PtoX, hour, year_all	consumption of electricity in a power to X facility [GW elec per hour]
STOR_DISCHARGE	storage, hour, year_all	discharging of a storage facility [GW elec per hour]
STOR_CHARGE	storage, hour, year_all	charging a storage facility [GW elec per hour]
UNIT_CUT	plant, hour, year_all	cut of production of a power plant [GW elec per hour]
ANCIL_UP	ancillary_all, unit, hour, year_all	delivery of upward ancillary services by a production plant [GW elec per hour]
ANCIL_DOWN	ancillary_all, unit, hour, year_all	delivery of downward ancillary services by a production plant [GW elec per hour]
ANCIL_CUT	ancillary_all, hour, year_all	cut of ancillary services [GW elec per hour]
COMM_STOR	plant	commissioning of GW capacity of a storage facility [GW]
COMM_PtoX	plant	commissioning of GW capacity of power to X plants [GW]
COMM_DHH	plant	commissioning of GW capacity of district heating heat plants [GWth]
COMM_IND	plant	commissioning of GW capacity of district heating heat plants [GWth]
FUEL_CONS	plant, fuel_all, year_all	fuel consumption in a power plant [GW fuel per hour]
LEV_UNITS	type, level, year_all	number of units of a certain type for commissioning categorized in a level of the cost supply curve
LEV_FUEL	fuel_all, level, year_all	fuel consumption categorized by level in the cost supply curve
LEV_STORAGE	type, level, year_all	storage capacities categorized by level in the cost supply curve
CO2_EMISSIONpower	year_all	tons of CO2 emissions in power generation
CO2_EMISSIONdhh	year_all	tons of CO2 emissions in district heating heat plants
CO2_EMISSIONind	sectors_all, year_all	tons of CO2 emissions in district heating heat plants
CO2_CAPTURE	year_all	tons of CO2 emissions captured in CCS plants
FITPAYMENT	year_all	payment in MEUR for feed in tariff or similar aupport
FIT_ELEC_OUTPUT	unit, year_all	electricity produced by plants supported by feed in tariff or similar [GWh]
ADDPOLICY	year_all	payment to support electricity or steam output of certain units
NETIMPORTSCUTP	hour, year_all	positive deviation of net imports
NETIMPORTSCUTM	hour, year_all	negative deviation of net imports
INVESTMENT	plant, year_all	investment in GW
DECOMMISSIONING	plant, year_all	decomissioning in GW
CAPA_UNITS	unit, year_all	power of installed unit in GW
INVE_UNITS	plant	power of units of a certain technology and vintage commissioned in GW

Name	**Domains**	**Description**
ADD_FITBUDGET	year_all	slack variable for FIT budget
REGIONCUT	region, year_all	slack variable for heat CHP per region [GWth]
ADDFUEL	fuel_all, year_all	slack variable for fuel consumption [GWhfuel]
ADDHOURS	plant, year_all	slack variable for maximum operating hours [hours]
NETIMPORTS	hour, year_all	net imports [GW]
Z		total system costs [MEuros]
INST_UNITS	unit, year_all	number of installed unit - integer
OP_UNITS	unit, hour, year_all	number of units in operation in an hour - integer
ShutDown	unit, hour, year_all	number of units shut down in an hour
StartUp	unit, hour, year_all	number of units started up in an hour
COMM_UNITS	plant	number of units of a certain technology and vintage commissioned - integer

Equations

Name	**Domains**	**Description**
QElcBal	hour, year_all	electricity balance
QAncBal	ancillary_all, hour, year_all	balance the ancillary services
QAncilCap	unit, ancillary_all, hour, year_all	maximum capacity constraint to offer ancillary services
QunitMax	unit, hour, year_all	maximum capacity constraint
QunitMin	unit, hour, year_all	minimum stable generation capacity constraint
QMaxOper	unit, year_all	maximum operating hours per year
QMaxProd	resource, year_all	maximum energy production per year due to resource constraint
QRampDo	unit, hour, year_all	ramping down constraint
QRampUp	unit, hour, year_all	ramping up constraint
QStartup	unit, hour, year_all	start up operation condition
QStartShut	unit, hour, year_all	start up and shut down operation condition
QMinUp	unit, hour, year_all	minimum up time technical operation condition
QMinDown	unit, hour, year_all	minimum down time technical operation condition
QOpInst	unit, hour, year_all	condition linking units in operation and installed
QInstall	unit, year_all	installed power plants from commissionings and decommissionings
QINVESTMENT	plant, year_all	accounting for investment in GW
QDECOMMISSIONING	plant, year_all	accounting for decommissioning in GW
QDECOMMISSIONING_unit	unit, year_all	accounting for decommissioning in GW
QCommLev	type, year_all	commissionings constrained by the cost supply curve by type of unit

Name	**Domains**	**Description**
QCommLevels	type, level, year_all	commissionings lower than the levels of the cost supply curve by type of unit
QMaxCapac	type, year_all	maximum limits to new capacities
QFuelCons	unit, year_all	fuel consumption per power plant
QFuelBlend	unit, fuel_all, year_all	fuel blending per power plant
QFuelLev	fuel_all, year_all	fuel consumption constrained by the cost supply curve
QFuelLevels	fuel_all, level, year_all	fuel consumption lower than the levels of the cost supply curve
QCHPslope1	unit, hour, year_all	operation constraint for CHP slope 1
QCHPslope2	unit, hour, year_all	operation constraint for CHP slope 2
QCHPeffic	unit, year_all	overall efficiency constraint for CHP
QSTORCAP	storage, hour, year_all	capacity of discharge of storage
QSTORBAL	storage, day, year_all	balance of storage
QSTORMAXPOT	storage, day, year_all	maximum stored energy
QStorLev	type, year_all	constraint of storage for the the cost supply curve
QStorLevels	type, level, year_all	storage lower than the levels of the cost supply curve
QEMISSIONpower	year_all	CO2 emissions of power plants
QEMISSIONdhh	year_all	CO2 emissions of power plants
QEMISSIONind	sectors, year_all	CO2 emissions of power plants
QCCSCapt	year_all	annually captured CO2 in CCS power plants
QCCSmax	year_all	cumulatively maximum quantity of capured CO2 in CCS
QCLeanCap	PtoX, hour, year_all	capacity constraint for clean fuel production
QCLeanBal	PtoX, day, year_all	balance constraint for clean fuel
QCLeanDemBal	fuel_all, year_all	balance constraint for demand and supply of clean fuels
QFITPAYMENT	year_all	projected payment for FIT policies supported generation
QFITPOLICYBUDGET	year_all	annually maximum budget for FIT policies
QMAXFITGENERATION1	unit, year_all	upper limit for FIT supported generation
QUniformFIT	unit, year_all	minimum FIT supported generation for the whole contracted period
QADDPOLICY	year_all	additional renewable policy
QNETIMPORTS	hour, year_all	net imports constraint
QHeatBal	hour, year_all	balance of demand and supply of heat
QCHPRegion	region, year_all	minimum share of CHP heat by region
QDHHMax	dhh, hour, year_all	maximum capacity constraint of district heating units
QMaxOperDHH	dhh, year_all	maximum operating hours per year of district heating units
QFuelConsDHH	dhh, year_all	fuel consumption of district heating units
QMinDHHGen	year_all	minimum share of heat produced by district heating units
QMaxDHHGen	year_all	maximum share of heat produced by district heating units

Name	**Domains**	**Description**
QMinDHHShare	type, year_all	minimum share of heat produced by type of district heating units
QMaxDHHShare	type, year_all	maximum share of heat produced by type of district heating units
QSteamBal	sectors, year_all	balance of demand and supply of steam
QINDElecMax	sectors_all, year_all	maximum electricity produced by CHP plants
QINDMax	plant, hour, year_all	maximum capacity constraint of industrial plants
QMaxOperIND	plant, year_all	maximum operating hours per year of industrial plants
QFuelConsIND	plant, year_all	fuel consumption of industrial plants
QFuelConsBlendMax	plant, fuel_all, year_all	fuel consumption of industrial plants
QFuelConsBlendMin	plant, fuel_all, year_all	fuel consumption of industrial plants
QFuelConsDGS	fuel_all, year_all	fuel consumption of industrial plants
QINDCHPSlope	plant, year_all	fixed steam to electricity ratio for industrial CHP
QMinINDGen	sectors_all, year_all	minimum share of steam produced by CHP industrial plants
QMaxINDGen	sectors_all, year_all	maximum share of steam produced by CHP industrial plants
QObjective		objective function minimizing net cost

Equation Definitions

QElcBal$_{hour,year}$

$$\begin{aligned}
&\text{freq\_hour}_{hour} \cdot \Big(\sum_{unit|\text{avail\_plant}_{unit,year}} \text{ELEC\_OUTPUT}_{unit,hour,year} + \sum_{indCHP|\text{avail\_plant}_{indCHP,year}} (\text{ELEC\_OUTPUT\_IND}_{indCHP,year} \cdot \text{INDpattern}_{indCHP,hour}) + \\
&\sum_{storage|\text{avail\_plant}_{storage,year}} \text{STOR\_DISCHARGE}_{storage,hour,year} + \text{NETIMPORTS}_{hour,year} + \text{ELEC\_CUT}_{hour,year}\Big) = \text{freq\_hour}_{hour} \cdot \Big(\text{elec\_load}_{hour,year} + \text{loss\_load}_{hour,year} + \\
&\sum_{storage|\text{avail\_plant}_{storage,year}} \text{STOR\_CHARGE}_{storage,hour,year} + \sum_{PtoX|\text{avail\_plant}_{PtoX,year}} \text{PToX\_INPUT}_{PtoX,hour,year} + \sum_{dhh|\text{avail\_plant}_{dhh,year}[\text{planttype}_{dhh,\texttt{DH\_Electric}}]} (\text{STEAM\_OUTPUT}_{dhh,hour,year} \cdot \text{techdata\_plants}_{dhh,\texttt{dummy},\texttt{heatrate}}) + \\
&\sum_{dhh|\text{avail\_plant}_{dhh,year}[\text{planttype}_{dhh,\texttt{DH\_Solarth}}]} \left(\frac{\frac{\text{FUEL\_CONS}_{dhh,\texttt{ELC\_DH},year}}{\text{techdata\_plants}_{dhh,\texttt{dummy},\texttt{heatrate}}} \cdot \text{heatdemand}_{hour,year}}{\sum_{hour1} \text{heatdemand}_{hour1,year}} \right) \Big[\sum_{hour1} \text{heatdemand}_{hour1,year} \Big] + \\
&\sum_{indboil|\text{avail\_plant}_{indboil,year}[\text{planttype}_{indboil,\texttt{INDBOIL\_Elec}}]} (\text{STEAM\_OUTPUT\_IND}_{indboil,year} \cdot \text{techdata\_plants}_{indboil,\texttt{dummy},\texttt{heatrate}} \cdot \text{INDpattern}_{indboil,hour})\Big) \qquad \forall hour, year
\end{aligned}$$

QAncBal$_{ancillary\_all,hour,year}$

$$\text{freq\_hour}_{hour}\cdot\Big(\sum_{unit|\text{avail\_plant}_{unit,year}}(\text{ANCIL\_UP}_{ancillary\_all,unit,hour,year}+\text{ANCIL\_DOWN}_{ancillary\_all,unit,hour,year})+\text{ANCIL\_CUT}_{ancillary\_all,hour,year}\Big)\geq$$
$$\text{freq\_hour}_{hour}\cdot\text{policy\_power\_data}_{\texttt{ancill\_coef},ancillary\_all,\texttt{dummy},year}\cdot(\text{elec\_load}_{hour,year}+\text{loss\_load}_{hour,year}-\text{ELEC\_CUT}_{hour,year}+$$
$$\sum_{dhh|(\text{avail\_plant}_{dhh,year}\wedge\text{fuelplant}_{dhh,\texttt{ELC\_DH},year})}(\text{STEAM\_OUTPUT}_{dhh,hour,year}\cdot\text{techdata\_plants}_{dhh,\texttt{dummy},\texttt{heatrate}})+$$
$$\sum_{indboil|(\text{avail\_plant}_{indboil,year}\wedge\text{fuelplant}_{indboil,\texttt{ELC\_IND},year})}(\text{STEAM\_OUTPUT\_IND}_{indboil,year}\cdot\text{techdata\_plants}_{indboil,\texttt{dummy},\texttt{heatrate}}\cdot\text{INDpattern}_{indboil,hour}))\qquad\forall ancillary\_all,hour,year$$

QAncilCap$_{unit,ancillary\_all,hour,year}$

$$\text{freq\_hour}_{hour}\cdot((\text{INST\_UNITS}_{unit,year}\cdot\text{techdata\_plants}_{unit,\texttt{dummy},ancillary\_all})[\text{unit\_limit}_{unit}]+\frac{\text{CAPA\_UNITS}_{unit,year}\cdot\text{techdata\_plants}_{unit,\texttt{dummy},ancillary\_all}}{\text{techdata\_plants}_{unit,\texttt{dummy},\texttt{size}}}[\text{no\_unit\_limit}_{unit}])\geq$$
$$\text{freq\_hour}_{hour}\cdot(\text{ANCIL\_UP}_{ancillary\_all,unit,hour,year}+\text{ANCIL\_DOWN}_{ancillary\_all,unit,hour,year})\qquad\forall unit,ancillary\_all,hour,year\mid\text{avail\_plant}_{unit,year}$$

QunitMax$_{unit,hour,year}$

$$\text{freq\_hour}_{hour}\cdot((\text{OP\_UNITS}_{unit,hour,year}\cdot\text{techdata\_plants}_{unit,\texttt{dummy},\texttt{size}}\cdot\text{capacity\_factor}_{unit,hour})[\text{unit\_limit}_{unit}]+(\text{CAPA\_UNITS}_{unit,year}\cdot\text{capacity\_factor}_{unit,hour})[\text{no\_unit\_limit}_{unit}])=$$
$$\text{freq\_hour}_{hour}\cdot(\text{ELEC\_OUTPUT}_{unit,hour,year}+\sum_{ancillary\_up}\text{ANCIL\_UP}_{ancillary\_up,unit,hour,year}+\text{UNIT\_CUT}_{unit,hour,year})\qquad\forall unit,hour,year\mid\text{avail\_plant}_{unit,year}$$

QunitMin$_{unit,hour,year}$

$$\text{freq\_hour}_{hour}\cdot(\text{ELEC\_OUTPUT}_{unit,hour,year}-\sum_{ancillary\_down}\text{ANCIL\_DOWN}_{ancillary\_down,unit,hour,year})\geq$$
$$\text{freq\_hour}_{hour}\cdot(\text{OP\_UNITS}_{unit,hour,year}\cdot\text{techdata\_plants}_{unit,\texttt{dummy},\texttt{size}}\cdot\text{techdata\_plants}_{unit,\texttt{dummy},\texttt{techn\_min}})[\text{unit\_limit}_{unit}]\qquad\forall unit,hour,year\mid\text{avail\_plant}_{unit,year}$$

QMaxOper$_{unit,year}$

$$(\text{INST\_UNITS}_{unit,year}\cdot\text{techdata\_plants}_{unit,\texttt{dummy},\texttt{size}}\cdot\text{policy\_power\_data}_{\texttt{max\_oper},unit,\texttt{dummy},year})[\text{unit\_limit}_{unit}]+(\text{CAPA\_UNITS}_{unit,year}\cdot\text{policy\_power\_data}_{\texttt{max\_oper},unit,\texttt{dummy},year})[\text{no\_unit\_limit}_{unit}]\geq$$
$$\sum_{hour}(\text{freq\_hour}_{hour}\cdot\text{ELEC\_OUTPUT}_{unit,hour,year})\qquad\forall unit,year\mid\text{avail\_plant}_{unit,year}$$

$\mathbf{QMaxProd}_{resource,year}$

$$\text{policy\_power\_data}_{\texttt{max\_resource},resource,\texttt{dummy},year} \geq \sum_{unit|(\text{resourcemap}_{unit,resource} \wedge \text{avail\_plant}_{unit,year})} (\sum_{hour} (\text{freq\_hour}_{hour} \cdot \text{ELEC\_OUTPUT}_{unit,hour,year})) \qquad \forall resource, year$$

$\mathbf{QRampDo}_{unit\_limit_{unit},hour,year}$

$$\sum_{hour1,hour\_seq_{hour1,hour}} (\text{OP\_UNITS}_{unit,hour1,year} \cdot \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{ramp\_down}} \cdot 60) + \text{ShutDown}_{unit,hour,year} \cdot \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{size}} \geq$$
$$\sum_{hour1,hour\_seq_{hour1,hour}} \text{ELEC\_OUTPUT}_{unit,hour1,year} - \text{ELEC\_OUTPUT}_{unit,hour,year} \qquad \forall unit\_limit_{unit}, hour, year \mid \text{avail\_plant}_{unit,year}$$

$\mathbf{QRampUp}_{unit\_limit_{unit},hour,year}$

$$\sum_{hour1,hour\_seq_{hour1,hour}} (\text{OP\_UNITS}_{unit,hour1,year} \cdot \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{ramp\_up}} \cdot 60) + \text{StartUp}_{unit,hour,year} \cdot \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{size}} \geq$$
$$\text{ELEC\_OUTPUT}_{unit,hour,year} - \sum_{hour1,hour\_seq_{hour1,hour}} \text{ELEC\_OUTPUT}_{unit,hour1,year} \qquad \forall unit\_limit_{unit}, hour, year \mid \text{avail\_plant}_{unit,year}$$

$\mathbf{QStartup}_{unit\_limit_{unit},hour,year}$

$$\text{OP\_UNITS}_{unit,hour,year} - \sum_{hour1,hour\_seq_{hour1,hour}} \text{OP\_UNITS}_{unit,hour1,year} = \text{StartUp}_{unit,hour,year} - \text{ShutDown}_{unit,hour,year} \qquad \forall unit\_limit_{unit}, hour, year \mid \text{avail\_plant}_{unit,year}$$

$\mathbf{QStartShut}_{unit\_limit_{unit},hour,year}$

$$\text{INST\_UNITS}_{unit,year} \geq \text{StartUp}_{unit,hour,year} + \text{ShutDown}_{unit,hour,year} \qquad \forall unit\_limit_{unit}, hour, year \mid \text{avail\_plant}_{unit,year}$$

$\mathbf{QMinUp}_{unit\_limit_{unit},hour,year}$

$$\text{OP\_UNITS}_{unit,hour,year} \geq \sum_{hour1|A} \text{StartUp}_{unit,hour1,year} \qquad \forall unit\_limit_{unit}, hour, year \mid \text{avail\_plant}_{unit,year}$$

Where

$A = (\ (\ (\ \mathrm{ord}(\ hour\ )\ \text{-}\ \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{uptime}}) \leq \mathrm{ord}(hour1)) \wedge (\mathrm{ord}(hour1) \leq \mathrm{ord}(hour)) \wedge (\mathrm{ord}(hour1) \leq \text{last}_{hour}) \wedge (\mathrm{ord}(hour1) \geq \text{first}_{hour}) \vee (\mathrm{ord}(hour1) \geq (\text{last}_{hour} + \mathrm{ord}(hour) - \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{uptime}})) \wedge (\mathrm{ord}(hour1) \geq \mathrm{ord}(hour)))$

QMinDown$_{unit\_limit_{unit},hour,year}$

$$\text{INST\_UNITS}_{unit,year} - \text{OP\_UNITS}_{unit,hour,year} \geq \sum_{hour1|A} \text{ShutDown}_{unit,hour1,year}$$

$\forall unit\_limit_{unit}, hour, year \mid \text{avail\_plant}_{unit,year}$

Where

$A = (\ (\ (\ \mathrm{ord}(\ hour\ )\ \text{-}\ \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{downtime}}) \leq \mathrm{ord}(hour1)) \wedge (\mathrm{ord}(hour1) \leq \mathrm{ord}(hour)) \wedge (\mathrm{ord}(hour1) \leq \text{last}_{hour}) \wedge (\mathrm{ord}(hour1) \geq \text{first}_{hour}) \vee (\mathrm{ord}(hour1) \geq (\text{last}_{hour} + \mathrm{ord}(hour) - \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{downtime}})) \wedge (\mathrm{ord}(hour1) \geq \mathrm{ord}(hour)))$

QOpInst$_{unit\_limit_{unit},hour,year}$

$\text{INST\_UNITS}_{unit,year} \geq \text{OP\_UNITS}_{unit,hour,year}$ $\quad \forall unit\_limit_{unit}, hour, year \mid \text{avail\_plant}_{unit,year}$

QInstall$_{unit,year}$

$(\text{COMM\_UNITS}_{unit} \cdot \text{surv\_plant}_{unit,year})[\text{unit\_limit}_{unit}] + (\text{INVE\_UNITS}_{unit} \cdot \text{surv\_plant}_{unit,year})[\text{no\_unit\_limit}_{unit}] = \text{INST\_UNITS}_{unit,year}[\text{unit\_limit}_{unit}] + \text{CAPA\_UNITS}_{unit,year}[\text{no\_unit\_limit}_{unit}]$ $\quad \forall unit, year \mid \text{avail\_plant}_{unit,year}$

QINVESTMENT$_{plant,year}$

$$\text{INVESTMENT}_{plant,year} = \sum_{unit|((unit=plant)\wedge \text{unit\_limit}_{unit})} (\text{techdata\_plants}_{plant,\texttt{dummy},\texttt{size}} \cdot \text{COMM\_UNITS}_{unit}) + \sum_{unit|((unit=plant)\wedge \text{no\_unit\_limit}_{unit})} \text{INVE\_UNITS}_{unit} + \text{COMM\_DHH}_{plant}[\text{dhh}_{plant}] + \text{COMM\_IND}_{plant}[\text{ind}_{plant}] + \text{COMM\_STOR}_{plant}[\text{storage}_{plant}] + \text{COMM\_PtoX}_{plant}[\text{PtoX}_{plant}]$$

$\forall plant, year \mid (\text{year.val} = \text{techdata\_plants}_{plant,\texttt{dummy},\texttt{commissioning}})$

QDECOMMISSIONING$_{plant,year}$

$$\text{DECOMMISSIONING}_{plant,year} = (\text{COMM\_DHH}_{plant}[\text{dhh}_{plant}] + \text{COMM\_IND}_{plant}[\text{ind}_{plant}] + \text{COMM\_STOR}_{plant}[\text{storage}_{plant}] + \text{COMM\_PtoX}_{plant}[\text{PtoX}_{plant}])[((\text{surv\_plant}_{plant,year} - \sum_{year1|(\text{year1.val}=(\text{year.val}-\text{Tper}))} \text{surv\_plant}_{plant,year1}) = -(1))]$$

$\forall plant, year \mid ((\text{year.val} > \text{techdata\_plants}_{plant,\texttt{dummy},\texttt{commissioning}}) \wedge (\neg \text{unit}_{plant}))$

QDECOMMISSIONING_unit$_{unit,year}$

$$\text{DECOMMISSIONING}_{unit,year} = \\ ((\text{COMM\_UNITS}_{unit} \cdot \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{size}})[\text{unit\_limit}_{unit}] + \text{INVE\_UNITS}_{unit}[\text{no\_unit\_limit}_{unit}])[((\text{surv\_plant}_{unit,year} - \sum_{year1|(\text{year1.val}=(\text{year.val}-\text{Tper}))} \text{surv\_plant}_{unit,year1}) = -(1))]$$

$$\forall unit, year \mid (\text{year.val} > \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{commissioning}})$$

QCommLev$_{type\_limit_{type},year}$

$$\sum_{unit|(\text{planttype}_{unit,type} \wedge (\text{techdata\_plants}_{unit,\texttt{dummy},\texttt{commissioning}} \leq \text{year.val}) \wedge (\text{techdata\_plants}_{unit,\texttt{dummy},\texttt{commissioning}} > 2015) \wedge \text{avail\_plant}_{unit,year} \wedge \text{unit\_limit}_{unit})} (\text{COMM\_UNITS}_{unit} \cdot \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{size}} \cdot \text{surv\_plant}_{unit,year}) + \\ \sum_{unit|(\text{planttype}_{unit,type} \wedge (\text{techdata\_plants}_{unit,\texttt{dummy},\texttt{commissioning}} \leq \text{year.val}) \wedge (\text{techdata\_plants}_{unit,\texttt{dummy},\texttt{commissioning}} > 2015) \wedge \text{avail\_plant}_{unit,year} \wedge \text{no\_unit\_limit}_{unit})} (\text{INVE\_UNITS}_{unit} \cdot \text{surv\_plant}_{unit,year}) = \sum_{level} \text{LEV\_UNITS}_{type,level,year}$$

$$\forall type\_limit_{type}, year$$

QCommLevels$_{type\_limit_{type},level,year}$

$$\text{policy\_power\_data}_{\texttt{max\_new\_capacity},type,\texttt{dummy},year} \cdot \text{level\_struct}_{type,level,\texttt{Quantity},year} + \sum_{unit|(\text{planttype}_{unit,type} \wedge (\text{techdata\_plants}_{unit,\texttt{dummy},\texttt{commissioning}} \leq 2015))} \text{DECOMMISSIONING}_{unit,year} \geq \text{LEV\_UNITS}_{type,level,year}$$

$$\forall type\_limit_{type}, level, year$$

QMaxCapac$_{type,year}$

$$\text{policy\_power\_data}_{\texttt{max\_new\_capacity},type,\texttt{dummy},year} \geq \sum_{plant|\text{planttype}_{plant,type}} (\text{INVESTMENT}_{plant,year} - \text{DECOMMISSIONING}_{plant,year}) \qquad \forall type, year \mid (\neg \text{type\_limit}_{type})$$

QFuelCons$_{unit,year}$

$$\sum_{fuel|\text{fuelplant}_{unit,fuel,year}} \text{FUEL\_CONS}_{unit,fuel,year} = \\ \sum_{hour} (\text{freq\_hour}_{hour} \cdot (\text{ELEC\_OUTPUT}_{unit,hour,year} + (\text{STEAM\_OUTPUT}_{unit,hour,year} \cdot \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{slope1\_CHP}})[\text{unit\_chp}_{unit}]) \cdot \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{heatrate}}) \qquad \forall unit, year \mid \text{avail\_plant}_{unit,year}$$

$\textbf{QFuelBlend}_{unit,fuel,year}$

$$\text{fuelblend}_{unit,fuel} \cdot \sum_{fuel1|\text{fuelplant}_{unit,fuel1,year}} \text{FUEL\_CONS}_{unit,fuel1,year} = \text{FUEL\_CONS}_{unit,fuel,year} \qquad \forall unit, fuel, year \mid (\text{avail\_plant}_{unit,year} \wedge \text{fuelblend}_{unit,fuel})$$

$\textbf{QFuelLev}_{fuel\_limit_{fuel\_all},year}$

$$\sum_{unit|(\text{avail\_plant}_{unit,year} \wedge \text{fuelplant}_{unit,fuel\_all,year})} \text{FUEL\_CONS}_{unit,fuel\_all,year} + \sum_{dhh|(\text{avail\_plant}_{dhh,year} \wedge \text{fuelplant}_{dhh,fuel\_all,year})} \text{FUEL\_CONS}_{dhh,fuel\_all,year} +$$
$$\sum_{ind|(\text{avail\_plant}_{ind,year} \wedge \text{fuelplant}_{ind,fuel\_all,year})} \text{FUEL\_CONS}_{ind,fuel\_all,year} = \sum_{level} \text{LEV\_FUEL}_{fuel\_all,level,year} \qquad \forall fuel\_limit_{fuel\_all}, year$$

$\textbf{QFuelLevels}_{fuel\_limit_{fuel\_all},level,year}$

$$\text{policy\_power\_data}_{\texttt{max\_fuel},fuel\_all,\texttt{dummy},year} \cdot \text{level\_struct}_{fuel\_all,level,\texttt{Quantity},year} +$$
$$\text{ADDFUEL}_{fuel\_all,year}[((level = \texttt{level5}) \wedge (\neg \text{fuel\_ind}_{fuel\_all}) \wedge \text{policy\_power\_data}_{\texttt{max\_fuel},fuel\_all,\texttt{dummy},year} \cdot \text{level\_struct}_{fuel\_all,level,\texttt{Quantity},year})]$$
$$+ \text{ADDFUEL}_{fuel\_all,year}[((level = \texttt{level1}) \wedge \text{fuel\_ind}_{fuel\_all} \wedge \text{policy\_power\_data}_{\texttt{max\_fuel},fuel\_all,\texttt{dummy},year} \cdot \text{level\_struct}_{fuel\_all,level,\texttt{Quantity},year})] \geq \text{LEV\_FUEL}_{fuel\_all,level,year}$$
$$\forall fuel\_limit_{fuel\_all}, level, year$$

$\textbf{QCHPslope1}_{unit\_chp_{unit},hour,year}$

$$(\text{freq\_hour}_{hour} \cdot \text{OP\_UNITS}_{unit,hour,year} \cdot \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{size}} \cdot \text{capacity\_factor}_{unit,hour})[\text{unit\_limit}_{unit}] + (\text{freq\_hour}_{hour} \cdot \text{CAPA\_UNITS}_{unit,year} \cdot \text{capacity\_factor}_{unit,hour})[\text{no\_unit\_limit}_{unit}] \geq$$
$$\text{freq\_hour}_{hour} \cdot (\text{ELEC\_OUTPUT}_{unit,hour,year} + \text{STEAM\_OUTPUT}_{unit,hour,year} \cdot \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{slope1\_CHP}}) \qquad \forall unit\_chp_{unit}, hour, year \mid \text{avail\_plant}_{unit,year}$$

$\textbf{QCHPslope2}_{unit\_chp_{unit},hour,year}$

$$\text{freq\_hour}_{hour} \cdot \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{helratio\_CHP}} \cdot \text{ELEC\_OUTPUT}_{unit,hour,year} \geq \text{freq\_hour}_{hour} \cdot \text{STEAM\_OUTPUT}_{unit,hour,year} \qquad \forall unit\_chp_{unit}, hour, year \mid \text{avail\_plant}_{unit,year}$$

$\textbf{QCHPeffic}_{unit\_chp_{unit},year}$

$$\sum_{fuel|\text{fuelplant}_{unit,fuel,year}} \text{FUEL\_CONS}_{unit,fuel,year} \geq \sum_{hour} (\text{freq\_hour}_{hour} \cdot \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{minheatrate\_CHP}} \cdot (\text{ELEC\_OUTPUT}_{unit,hour,year} + \text{STEAM\_OUTPUT}_{unit,hour,year}))$$
$$\forall unit\_chp_{unit}, year \mid \text{avail\_plant}_{unit,year}$$

QSTORCAP$_{storage,hour,year}$

$$\text{freq\_hour}_{hour} \cdot \text{COMM\_STOR}_{storage} \cdot \text{surv\_plant}_{storage,year} \geq \text{freq\_hour}_{hour} \cdot (\text{STOR\_CHARGE}_{storage,hour,year} + \text{STOR\_DISCHARGE}_{storage,hour,year}) \qquad \forall storage, hour, year \mid \text{avail\_plant}_{storage,year}$$

QSTORBAL$_{storage,day,year}$

$$\text{freq\_day}_{day} \cdot \sum_{hour|\text{mapday}_{hour,day}} \text{STOR\_CHARGE}_{storage,hour,year} = \text{freq\_day}_{day} \cdot \sum_{hour|\text{mapday}_{hour,day}} \text{STOR\_DISCHARGE}_{storage,hour,year} \cdot \text{techdata\_plants}_{storage,\texttt{dummy},\texttt{heatrate}}$$
$$\forall storage, day, year \mid \text{avail\_plant}_{storage,year}$$

QSTORMAXPOT$_{storage,day,year}$

$$\text{freq\_day}_{day} \cdot \text{policy\_power\_data}_{\texttt{daily},storage,\texttt{dummy},year} \cdot \text{COMM\_STOR}_{storage} \cdot \text{surv\_plant}_{storage,year} \geq \text{freq\_day}_{day} \cdot \sum_{hour|\text{mapday}_{hour,day}} \text{STOR\_DISCHARGE}_{storage,hour,year}$$
$$\forall storage, day, year \mid \text{avail\_plant}_{storage,year}$$

QStorLev$_{type\_storage_{type},year}$

$$\sum_{storage|(\text{planttype}_{storage,type} \wedge ((\text{techdata\_plants}_{storage,\texttt{dummy},\texttt{commissioning}} \leq \text{year.val}) \wedge (\text{techdata\_plants}_{storage,\texttt{dummy},\texttt{commissioning}} > 2015)))} (\text{COMM\_STOR}_{storage} \cdot \text{surv\_plant}_{storage,year}) =$$
$$\sum_{level} \text{LEV\_STORAGE}_{type,level,year} \qquad \forall type\_storage_{type}, year$$

QStorLevels$_{type\_storage_{type},level,year}$

$$\text{policy\_power\_data}_{\texttt{max\_new\_capacity},type,\texttt{dummy},year} \cdot \text{level\_struct}_{type,level,\texttt{Quantity},year} + \sum_{storage|A} (\text{COMM\_STOR}_{storage}[((\text{surv\_plant}_{storage,year} - \sum_{year1|(\text{year1.val}=(\text{year.val}-\text{Tper}))} \text{surv\_plant}_{storage,year1}) = -(1))]) \geq$$
$$\text{LEV\_STORAGE}_{type,level,year}$$
$$\forall type\_storage_{type}, level, year$$

Where

$$A = (\text{planttype}_{storage,type} \wedge ((\text{techdata\_plants}_{storage,\texttt{dummy},\texttt{commissioning}} \leq \text{year.val}) \wedge (\text{techdata\_plants}_{storage,\texttt{dummy},\texttt{commissioning}} \leq 2015)))$$

QEMISSIONpower$_{year}$

$$\text{CO2\_EMISSIONpower}_{year} = \sum_{unit,fuel|(\text{avail\_plant}_{unit,year} \wedge \text{fuelplant}_{unit,fuel,year})} (\text{FUEL\_CONS}_{unit,fuel,year} \cdot \text{emission\_factor}_{unit,fuel,year}[(\text{emission\_factor}_{unit,fuel,year} \geq 0)]) \qquad \forall year$$

QEMISSIONdhh$_{year}$

$$\text{CO2\_EMISSIONdhh}_{year} = \sum_{dhh,fuel|(\text{avail\_plant}_{dhh,year} \wedge \text{fuelplant}_{dhh,fuel,year})} (\text{emission\_factor}_{dhh,fuel,year} \cdot \text{FUEL\_CONS}_{dhh,fuel,year}) \qquad \forall year$$

QEMISSIONind$_{sectors,year}$

$$\text{CO2\_EMISSIONind}_{sectors,year} = \sum_{ind,fuel|(\text{avail\_plant}_{ind,year} \wedge \text{fuelplant}_{ind,fuel,year} \wedge \text{INDmapsectors}_{sectors,ind})} (\text{emission\_factor}_{ind,fuel,year} \cdot \text{FUEL\_CONS}_{ind,fuel,year}) \qquad \forall sectors, year$$

QCCSCapt$_{year}$

$$\text{CO2\_CAPTURE}_{year} = \sum_{unit,fuel|(\text{avail\_plant}_{unit,year} \wedge \text{CCS}_{unit} \wedge \text{fuelplant}_{unit,fuel,year})} (\text{FUEL\_CONS}_{unit,fuel,year} \cdot (\text{techdata\_plants}_{unit,\texttt{dummy},\texttt{EmissionFactor\_noCCS}} - \text{emission\_factor}_{unit,fuel,year})) \qquad \forall year$$

QCCSmax$_{year}$

$$\text{policy\_power\_data}_{\texttt{MaxCO2capt},\texttt{dummy},\texttt{dummy},year} \geq \sum_{year1|(\text{ord(year1)} \leq \text{ord(year)})} \text{CO2\_CAPTURE}_{year1} \qquad \forall year$$

QCLeanCap$_{PtoX,hour,year}$

$$\text{COMM\_PtoX}_{PtoX} \cdot \text{surv\_plant}_{PtoX,year} \geq \text{PtoX\_OUTPUT}_{PtoX,hour,year} \qquad \forall PtoX, hour, year \mid \text{avail\_plant}_{PtoX,year}$$

QCLeanBal$_{PtoX,day,year}$

$$\text{freq\_day}_{day} \cdot \sum_{hour|\text{mapday}_{hour,day}} \text{PToX\_INPUT}_{PtoX,hour,year} = \text{freq\_day}_{day} \cdot \sum_{hour|\text{mapday}_{hour,day}} (\text{techdata\_plants}_{PtoX,\texttt{dummy},\texttt{heatrate}} \cdot \text{PtoX\_OUTPUT}_{PtoX,hour,year}) \qquad \forall PtoX, day, year \mid \text{avail\_plant}_{PtoX,year}$$

QCLeanDemBal$_{cleanfuel,year}$

$$\begin{aligned}&\sum_{hour}(\sum_{PtoX|(\text{avail\_plant}_{PtoX,year}\wedge\text{PtoXmap}_{PtoX,cleanfuel})}(\text{freq\_hour}_{hour}\cdot\text{PtoX\_OUTPUT}_{PtoX,hour,year}))=\text{DemCleanfuel}_{cleanfuel,year}+\sum_{unit|(\text{avail\_plant}_{unit,year}\wedge\text{fuelplant}_{unit,cleanfuel,year})}\text{FUEL\_CONS}_{unit,cleanfuel,year}+\\&\sum_{dhh,cleanfuel\_dhh|(\text{avail\_plant}_{dhh,year}\wedge\text{fuelplant}_{dhh,cleanfuel\_dhh,year}\wedge\text{map\_fuel\_main}_{cleanfuel,cleanfuel\_dhh})}\text{FUEL\_CONS}_{dhh,cleanfuel\_dhh,year}+\\&\sum_{ind,cleanfuel\_ind|(\text{avail\_plant}_{ind,year}\wedge\text{fuelplant}_{ind,cleanfuel\_ind,year}\wedge\text{map\_fuel\_main}_{cleanfuel,cleanfuel\_ind})}\text{FUEL\_CONS}_{ind,cleanfuel\_ind,year}\qquad\forall cleanfuel,year\end{aligned}$$

QFITPAYMENT$_{year_{year\_all}}$

$$\begin{aligned}&\text{FITPAYMENT}_{year\_all}=\sum_{unit|A}(\sum_{year1|(\text{year1.val}=\text{techdata\_plants}_{unit,\mathtt{dummy},\mathtt{commissioning}})}\text{policy\_power\_data}_{\mathtt{FITtariff},unit,\mathtt{dummy},year1}\cdot\text{FIT\_ELEC\_OUTPUT}_{unit,year\_all})+\\&\sum_{unit|(\text{policy\_power\_data}_{\mathtt{FITsupport},unit,\mathtt{dummy},year\_all}\wedge(\text{techdata\_plants}_{unit,\mathtt{dummy},\mathtt{commissioning}}<2015))}(\text{policy\_power\_data}_{\mathtt{FITtariff},unit,\mathtt{dummy},2015}\cdot\text{FIT\_ELEC\_OUTPUT}_{unit,year\_all})\qquad\forall year_{year\_all}\end{aligned}$$

$Where$

$$A=\sum_{year1|(\text{year1.val}=\text{techdata\_plants}_{unit,\mathtt{dummy},\mathtt{commissioning}})}\text{policy\_power\_data}_{\mathtt{FITsupport},unit,\mathtt{dummy},year1}\wedge(\text{techdata\_plants}_{unit,\mathtt{dummy},\mathtt{commissioning}}\geq 2015)\wedge\text{policy\_power\_data}_{\mathtt{FITsupport},unit,\mathtt{dummy},year\_all})$$

QFITPOLICYBUDGET$_{year_{year\_all}}$

$$\text{policy\_power\_data}_{\mathtt{FITsupport},\mathtt{MaxBudget},\mathtt{dummy},year\_all}+\text{ADD\_FITBUDGET}_{year\_all}\geq\text{FITPAYMENT}_{year\_all}\qquad\forall year_{year\_all}$$

QMAXFITGENERATION1$_{unit,year_{year\_all}}$

$$\begin{aligned}&\sum_{hour}(\text{freq\_hour}_{hour}\cdot\text{ELEC\_OUTPUT}_{unit,hour,year\_all})[(\sum_{year1|(\text{year1.val}=\text{techdata\_plants}_{unit,\mathtt{dummy},\mathtt{commissioning}})}(A)\leq\sum_{year1|(\text{year1.val}=\text{techdata\_plants}_{unit,\mathtt{dummy},\mathtt{commissioning}})}(B))]+\\&\sum_{hour}(\text{freq\_hour}_{hour}\cdot\text{ELEC\_OUTPUT}_{unit,hour,year\_all})[((\text{techdata\_plants}_{unit,\mathtt{dummy},\mathtt{commissioning}}<2015)\wedge\text{policy\_power\_data}_{\mathtt{FITsupport},unit,\mathtt{dummy},year\_all}\wedge((\text{year\_all.val}-\text{techdata\_plants}_{unit,\mathtt{dummy},\mathtt{commissioning}})\leq\\&\text{policy\_power\_data}_{\mathtt{FITyears},unit,\mathtt{dummy},year\_all})\wedge(\text{year\_all.val}\geq\text{techdata\_plants}_{unit,\mathtt{dummy},\mathtt{commissioning}}))]\geq\text{FIT\_ELEC\_OUTPUT}_{unit,year\_all}\qquad\forall unit,year_{year\_all}\mid\text{avail\_plant}_{unit,year\_all}\end{aligned}$$

$Where$

$A=\text{policy\_power\_data}_{\mathtt{FITsupport},unit,\mathtt{dummy},year1}\wedge\text{policy\_power\_data}_{\mathtt{FITsupport},unit,\mathtt{dummy},year\_all}\wedge((\text{year\_all.val}-\text{techdata\_plants}_{unit,\mathtt{dummy},\mathtt{commissioning}})$

$B=\text{policy\_power\_data}_{\mathtt{FITyears},unit,\mathtt{dummy},year1})\wedge(\text{year\_all.val}\geq\text{techdata\_plants}_{unit,\mathtt{dummy},\mathtt{commissioning}})$

QUniformFIT$_{unit,year_{year\_all}}$

$$\mathrm{FIT\_ELEC\_OUTPUT}_{unit,year\_all} = \sum_{year1|A} \mathrm{FIT\_ELEC\_OUTPUT}_{unit,year1}$$

$\forall unit, year_{year\_all} \mid (\mathrm{avail\_plant}_{unit,year\_all} \wedge (\mathrm{techdata\_plants}_{unit,\mathtt{dummy},\mathtt{commissioning}} \geq 2015))$
Where
A=($\mathrm{policy\_power\_data}_{\mathtt{FITsupport},unit,\mathtt{dummy},year\_all} \wedge ((\mathrm{year1.val} = \mathrm{techdata\_plants}_{unit,\mathtt{dummy},\mathtt{commissioning}}) \wedge (\mathrm{year1.val} \leq \mathrm{year\_all.val}) \wedge ((\mathrm{year\_all.val} - \mathrm{techdata\_plants}_{unit,\mathtt{dummy},\mathtt{commissioning}}) \leq \mathrm{policy\_power\_data}_{\mathtt{FITyears},unit,\mathtt{dummy},year1}) \wedge (\mathrm{year\_all.val} \geq \mathrm{techdata\_plants}_{unit,\mathtt{dummy},\mathtt{commissioning}})))$

QADDPOLICY$_{year}$

$$\begin{aligned}
\mathrm{ADDPOLICY}_{year} = {} & \sum_{unit,hour|\mathrm{avail\_plant}_{unit,year}} (\mathrm{freq\_hour}_{hour} \cdot \mathrm{ELEC\_OUTPUT}_{unit,hour,year} \cdot \mathrm{policy\_power\_data}_{\mathtt{ElecaddSupport},unit,\mathtt{dummy},year}) + \\
& \sum_{unit|(\mathrm{avail\_plant}_{unit,year} \wedge \sum_{report\_res} \mathrm{reportplanttype}_{unit,report\_res})} ((\sum_{hour} (\mathrm{freq\_hour}_{hour} \cdot \mathrm{ELEC\_OUTPUT}_{unit,hour,year}) - \mathrm{FIT\_ELEC\_OUTPUT}_{unit,year}) \cdot \mathrm{drivers\_data}_{\mathtt{RenewableValue},\mathtt{Power},\mathtt{dummy},year}) + \\
& \sum_{unit,unit\_chp_{unit}|(\mathrm{avail\_plant}_{unit,year} \wedge \sum_{report\_res} \mathrm{reportplanttype}_{unit,report\_res})} (\sum_{hour} (\mathrm{freq\_hour}_{hour} \cdot \mathrm{STEAM\_OUTPUT}_{unit,hour,year} \cdot \mathrm{drivers\_data}_{\mathtt{RenewableValue},\mathtt{Demand},\mathtt{dummy},year})) + \\
& \sum_{dhh|(\mathrm{avail\_plant}_{dhh,year} \wedge \sum_{report\_res} \mathrm{reportplanttype}_{dhh,report\_res})} (\sum_{hour} (\mathrm{freq\_hour}_{hour} \cdot \mathrm{STEAM\_OUTPUT}_{dhh,hour,year} \cdot \mathrm{drivers\_data}_{\mathtt{RenewableValue},\mathtt{Demand},\mathtt{dummy},year})) + \\
& \sum_{ind|(\mathrm{avail\_plant}_{ind,year} \wedge \sum_{report\_res} \mathrm{reportplanttype}_{ind,report\_res})} (\mathrm{STEAM\_OUTPUT\_IND}_{ind,year} \cdot \mathrm{drivers\_data}_{\mathtt{RenewableValue},\mathtt{Demand},\mathtt{dummy},year}) + \\
& \sum_{unit,hour,unit\_chp_{unit}|\mathrm{avail\_plant}_{unit,year}} (\mathrm{freq\_hour}_{hour} \cdot \mathrm{drivers\_data}_{\mathtt{CHPvalue},\mathtt{DistrictHeating},\mathtt{dummy},year} \cdot \mathrm{STEAM\_OUTPUT}_{unit,hour,year}) + \\
& \sum_{ind,indCHP_{ind}|\mathrm{avail\_plant}_{ind,year}} (\mathrm{drivers\_data}_{\mathtt{CHPvalue},\mathtt{Industry},\mathtt{dummy},year} \cdot \mathrm{STEAM\_OUTPUT\_IND}_{ind,year}) + \\
& \sum_{PtoX,hour|\mathrm{avail\_plant}_{PtoX,year}} (\mathrm{freq\_hour}_{hour} \cdot \mathrm{policy\_power\_data}_{\mathtt{PtoXaddSupport},PtoX,\mathtt{dummy},year} \cdot \mathrm{PtoX\_OUTPUT}_{PtoX,hour,year}) +
\end{aligned}$$

$$\sum_{storage,hour|\text{avail\_plant}_{storage,year}} (\text{freq\_hour}_{hour} \cdot \text{policy\_power\_data}_{\texttt{StorageaddSupport},storage,\texttt{dummy},year} \cdot \text{STOR\_DISCHARGE}_{storage,hour,year}) \qquad \forall year$$

QNETIMPORTS$_{hour,year}$

$$\text{freq\_hour}_{hour} \cdot (\text{netimportsexog}_{hour,year} + \text{NETIMPORTSCUTP}_{hour,year} - \text{NETIMPORTSCUTM}_{hour,year}) = \text{freq\_hour}_{hour} \cdot \text{NETIMPORTS}_{hour,year} \qquad \forall hour, year$$

QHeatBal$_{hour,year}$

$$\text{freq\_hour}_{hour} \cdot (\sum_{dhh|\text{avail\_plant}_{dhh,year}} \text{STEAM\_OUTPUT}_{dhh,hour,year} + \sum_{unit,unit\_chp_{unit}|\text{avail\_plant}_{unit,year}} \text{STEAM\_OUTPUT}_{unit,hour,year}) = \text{freq\_hour}_{hour} \cdot (\text{heatdemand}_{hour,year} - \text{HEAT\_CUT}_{hour,year})$$
$$\forall hour, year$$

QCHPRegion$_{region,year}$

$$\sum_{unit,hour|(\text{avail\_plant}_{unit,year} \wedge \text{unit\_region}_{unit,region} \wedge \text{unit\_chp}_{unit})} (\text{freq\_hour}_{hour} \cdot \text{STEAM\_OUTPUT}_{unit,hour,year}) + \text{REGIONCUT}_{region,year} \geq$$
$$\text{policy\_power\_data}_{\texttt{MinimumCHPheat},region,\texttt{dummy},year} \cdot \text{policy\_power\_data}_{\texttt{HeatShare},region,\texttt{dummy},year} \cdot \sum_{hour} (\text{freq\_hour}_{hour} \cdot (\text{heatdemand}_{hour,year} - \text{HEAT\_CUT}_{hour,year})) \qquad \forall region, year$$

QDHHMax$_{dhh,hour,year}$

$$\text{freq\_hour}_{hour} \cdot \text{COMM\_DHH}_{dhh} \cdot \text{techdata\_plants}_{dhh,\texttt{dummy},\texttt{capacity\_factor}} \cdot \text{surv\_plant}_{dhh,year} \geq \text{freq\_hour}_{hour} \cdot \text{STEAM\_OUTPUT}_{dhh,hour,year} \qquad \forall dhh, hour, year \mid \text{avail\_plant}_{dhh,year}$$

QMaxOperDHH$_{dhh,year}$

$$\text{COMM\_DHH}_{dhh} \cdot \text{policy\_power\_data}_{\texttt{max\_oper},dhh,\texttt{dummy},year} \cdot \text{surv\_plant}_{dhh,year} + \text{ADDHOURS}_{dhh,year} \cdot \text{surv\_plant}_{dhh,year} \geq \sum_{hour} (\text{freq\_hour}_{hour} \cdot \text{STEAM\_OUTPUT}_{dhh,hour,year}) \qquad \forall dhh, year \mid \text{avail\_plant}_{dhh,year}$$

QFuelConsDHH$_{dhh,year}$

$$\sum_{fuel|\text{fuelplant}_{dhh,fuel,year}} \text{FUEL\_CONS}_{dhh,fuel,year} = \sum_{hour} (\text{freq\_hour}_{hour} \cdot \text{STEAM\_OUTPUT}_{dhh,hour,year} \cdot \text{techdata\_plants}_{dhh,\texttt{dummy},\texttt{heatrate}}) \qquad \forall dhh, year \mid \text{avail\_plant}_{dhh,year}$$

QMinDHHGen$_{year}$

$$\sum_{dhh,hour|\text{avail\_plant}_{dhh,year}} (\text{freq\_hour}_{hour} \cdot \text{STEAM\_OUTPUT}_{dhh,hour,year}) \geq \text{policy\_power\_data}_{\texttt{DHHGeneration},\texttt{Min},\texttt{dummy},year} \cdot \sum_{hour} (\text{freq\_hour}_{hour} \cdot \text{heatdemand}_{hour,year}) - \sum_{type,type\_dhh_{type}} \text{DHH\_CUT}_{type,year} \qquad \forall year$$

QMaxDHHGen$_{year}$

$$\text{policy\_power\_data}_{\texttt{DHHGeneration},\texttt{Max},\texttt{dummy},year} \cdot \sum_{hour} (\text{freq\_hour}_{hour} \cdot \text{heatdemand}_{hour,year}) + \sum_{type,type\_dhh_{type}} \text{DHH\_ADD}_{type,year} \geq \sum_{dhh,hour|\text{avail\_plant}_{dhh,year}} (\text{freq\_hour}_{hour} \cdot \text{STEAM\_OUTPUT}_{dhh,hour,year}) \qquad \forall year$$

QMinDHHShare$_{type\_dhh_{type},year}$

$$\begin{aligned} &\sum_{dhh,hour|\text{avail\_plant}_{dhh,year}[\text{planttype}_{dhh,type}]} (\text{freq\_hour}_{hour} \cdot \text{STEAM\_OUTPUT}_{dhh,hour,year}) \geq \\ &\text{policy\_power\_data}_{\texttt{DHHGenTypeMin},type,\texttt{dummy},year} \cdot \sum_{dhh,hour|\text{avail\_plant}_{dhh,year}} (\text{freq\_hour}_{hour} \cdot \text{STEAM\_OUTPUT}_{dhh,hour,year}) - \text{DHH\_CUT}_{type,year} \qquad \forall type\_dhh_{type}, year \end{aligned}$$

QMaxDHHShare$_{type\_dhh_{type},year}$

$$\begin{aligned} &\text{policy\_power\_data}_{\texttt{DHHGenTypeMax},type,\texttt{dummy},year} \cdot \sum_{dhh,hour|\text{avail\_plant}_{dhh,year}} (\text{freq\_hour}_{hour} \cdot \text{STEAM\_OUTPUT}_{dhh,hour,year}) + \text{DHH\_ADD}_{type,year} \geq \\ &\sum_{dhh,hour|\text{avail\_plant}_{dhh,year}[\text{planttype}_{dhh,type}]} (\text{freq\_hour}_{hour} \cdot \text{STEAM\_OUTPUT}_{dhh,hour,year}) \qquad \forall type\_dhh_{type}, year \end{aligned}$$

QSteamBal$_{sectors,year}$

$$\sum_{ind|(\text{avail\_plant}_{ind,year} \wedge \text{INDmapsectors}_{sectors,ind})} \text{STEAM\_OUTPUT\_IND}_{ind,year} = \text{steam\_demand}_{sectors,year} - \text{STEAM\_CUT}_{sectors,year} \qquad \forall sectors, year$$

QINDElecMax$_{sectors,year}$

$$\text{elec\_demand}_{sectors,year} \geq \sum_{indCHP|(\text{avail\_plant}_{indCHP,year} \wedge \text{INDmapsectors}_{sectors,indCHP})} \text{ELEC\_OUTPUT\_IND}_{indCHP,year} \qquad \forall sectors, year$$

QINDMax$_{ind,hour,year}$

$$\text{freq\_hour}_{hour} \cdot \text{COMM\_IND}_{ind} \cdot \text{surv\_plant}_{ind,year} \geq \text{freq\_hour}_{hour} \cdot (\text{ELEC\_OUTPUT\_IND}_{ind,year}[\text{indCHP}_{ind}] + \text{STEAM\_OUTPUT\_IND}_{ind,year}[\text{indboil}_{ind}]) \cdot \text{INDpattern}_{ind,hour} \qquad \forall ind, hour, year \mid \text{avail\_plant}_{ind,year}$$

QMaxOperIND$_{ind,year}$

$$\text{COMM\_IND}_{ind} \cdot 8760 \cdot \text{techdata\_plants}_{ind,\texttt{dummy},\texttt{capacity\_factor}} \cdot \text{surv\_plant}_{ind,year} + (\text{ADDHOURS}_{ind,year} + 250[(\text{year.val} = 2015)]) \cdot \text{surv\_plant}_{ind,year} \geq \text{ELEC\_OUTPUT\_IND}_{ind,year}[\text{indCHP}_{ind}] + \text{STEAM\_OUTPUT\_IND}_{ind,year}[\text{indboil}_{ind}] \qquad \forall ind, year \mid \text{avail\_plant}_{ind,year}$$

QFuelConsIND$_{ind,year}$

$$\sum_{fuel \mid \text{fuelplant}_{ind,fuel,year}} \text{FUEL\_CONS}_{ind,fuel,year} = \text{techdata\_plants}_{ind,\texttt{dummy},\texttt{heatrate}} \cdot (\text{ELEC\_OUTPUT\_IND}_{ind,year}[\text{indCHP}_{ind}] + \text{STEAM\_OUTPUT\_IND}_{ind,year}) \qquad \forall ind, year \mid \text{avail\_plant}_{ind,year}$$

QFuelConsBlendMax$_{ind,fuel,year}$

$$1.1 \cdot \text{blend}_{ind,fuel} \cdot \sum_{fuel1 \mid \text{fuelplant}_{ind,fuel1,year}} \text{FUEL\_CONS}_{ind,fuel1,year} \geq \text{FUEL\_CONS}_{ind,fuel,year}$$

$$\forall ind, fuel, year \mid (\text{avail\_plant}_{ind,year} \wedge \text{fuelplant}_{ind,fuel,year} \wedge \text{fuel\_ind}_{fuel} \wedge (\text{techdata\_plants}_{ind,\texttt{dummy},\texttt{commissioning}} \leq 2015))$$

QFuelConsBlendMin$_{ind,fuel,year}$

$$0.9 \cdot \text{blend}_{ind,fuel} \cdot \sum_{fuel1 \mid \text{fuelplant}_{ind,fuel1,year}} \text{FUEL\_CONS}_{ind,fuel1,year} \leq \text{FUEL\_CONS}_{ind,fuel,year}$$

$$\forall ind, fuel, year \mid (\text{avail\_plant}_{ind,year} \wedge \text{fuelplant}_{ind,fuel,year} \wedge \text{fuel\_ind}_{fuel} \wedge (\text{techdata\_plants}_{ind,\texttt{dummy},\texttt{commissioning}} \leq 2015))$$

QFuelConsDGS$_{fuel,year}$

$$\sum_{ind \mid (\text{avail\_plant}_{ind,year} \wedge \text{fuelplant}_{ind,fuel,year})} \text{FUEL\_CONS}_{ind,fuel,year} = \text{Demand\_CHPBOI\_DGS}_{\texttt{FERRO},\texttt{DGS},year} - \text{DGASCUT}_{year} \qquad \forall fuel, year \mid (fuel = \texttt{DGS\_IND})$$

QINDCHPSlope$_{indCHP,year}$

$$\text{ELEC\_OUTPUT\_IND}_{indCHP,year} \cdot \text{techdata\_plants}_{indCHP,\texttt{dummy},\texttt{helratio\_CHP}} = \text{STEAM\_OUTPUT\_IND}_{indCHP,year} \qquad \forall indCHP, year \mid \text{avail\_plant}_{indCHP,year}$$

QMinINDGen$_{sectors,year}$

$$\sum_{indCHP|(\text{avail\_plant}_{indCHP,year} \wedge \text{INDmapsectors}_{sectors,indCHP})} \text{STEAM\_OUTPUT\_IND}_{indCHP,year} \geq \text{policy\_power\_data}_{\texttt{INDCHPGeneration},\texttt{Min},sectors,year} \cdot \text{steam\_demand}_{sectors,year} - \text{CHP\_CUT}_{sectors,year} \qquad \forall sectors, year$$

QMaxINDGen$_{sectors,year}$

$$\text{policy\_power\_data}_{\texttt{INDCHPGeneration},\texttt{Max},sectors,year} \cdot \text{steam\_demand}_{sectors,year} + \text{CHP\_ADD}_{sectors,year} \geq \sum_{indCHP|(\text{avail\_plant}_{indCHP,year} \wedge \text{INDmapsectors}_{sectors,indCHP})} \text{STEAM\_OUTPUT\_IND}_{indCHP,year} \qquad \forall sectors, year$$

QObjective

$$\text{Z} = \sum_{year} ((1 + \text{policy\_power\_data}_{\texttt{SocialDiscount},\texttt{dummy},\texttt{dummy},year})^{(-\text{year.val}+2015)} \cdot$$

$$(\sum_{unit|\text{avail\_plant}_{unit,year}[\text{unit\_limit}_{unit}]} (\text{COMM\_UNITS}_{unit} \cdot \text{surve\_plant}_{unit,year} \cdot \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{size}} \cdot \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{Capital}} \cdot \text{annuity\_factor}_{unit,year} \cdot (1 - \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{Amort}})) +$$

$$\sum_{unit|\text{avail\_plant}_{unit,year}[\text{no\_unit\_limit}_{unit}]} (\text{INVE\_UNITS}_{unit} \cdot \text{surve\_plant}_{unit,year} \cdot \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{Capital}} \cdot \text{annuity\_factor}_{unit,year} \cdot (1 - \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{Amort}})) +$$

$$\sum_{ind|\text{avail\_plant}_{ind,year}} (\text{COMM\_IND}_{ind} \cdot \text{surve\_plant}_{ind,year} \cdot \text{techdata\_plants}_{ind,\texttt{dummy},\texttt{Capital}} \cdot \text{annuity\_factor}_{ind,year} \cdot (1 - \text{techdata\_plants}_{ind,\texttt{dummy},\texttt{Amort}})) +$$

$$\sum_{dhh|\text{avail\_plant}_{dhh,year}} (\text{COMM\_DHH}_{dhh} \cdot \text{surve\_plant}_{dhh,year} \cdot \text{techdata\_plants}_{dhh,\texttt{dummy},\texttt{Capital}} \cdot \text{annuity\_factor}_{dhh,year} \cdot (1 - \text{techdata\_plants}_{dhh,\texttt{dummy},\texttt{Amort}})) +$$

$$\sum_{storage|\text{avail\_plant}_{storage,year}} (\text{COMM\_STOR}_{storage} \cdot \text{surve\_plant}_{storage,year} \cdot \text{techdata\_plants}_{storage,\texttt{dummy},\texttt{Capital}} \cdot \text{annuity\_factor}_{storage,year} \cdot (1 - \text{techdata\_plants}_{storage,\texttt{dummy},\texttt{Amort}})) +$$

$$\sum_{PtoX|\text{avail\_plant}_{PtoX,year}} (\text{COMM\_PtoX}_{PtoX} \cdot \text{surve\_plant}_{PtoX,year} \cdot \text{techdata\_plants}_{PtoX,\texttt{dummy},\texttt{Capital}} \cdot \text{annuity\_factor}_{PtoX,year} \cdot (1 - \text{techdata\_plants}_{PtoX,\texttt{dummy},\texttt{Amort}})) +$$

$$\sum_{unit|\text{avail\_plant}_{unit,year}[\text{unit\_limit}_{unit}]} (\text{COMM\_UNITS}_{unit} \cdot \text{survext\_plant}_{unit,year} \cdot \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{size}} \cdot \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{Capital\_extension}} \cdot \text{annuity\_factor\_ext}_{unit,year}) +$$

$$\sum_{unit|\text{avail\_plant}_{unit,year}[\text{no\_unit\_limit}_{unit}]} (\text{INVE\_UNITS}_{unit} \cdot \text{survext\_plant}_{unit,year} \cdot \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{Capital\_extension}} \cdot \text{annuity\_factor\_ext}_{unit,year}) +$$

$$\sum_{unit|\text{avail\_plant}_{unit,year}[\text{unit\_limit}_{unit}]} (\text{COMM\_UNITS}_{unit} \cdot \text{survfs\_plant}_{unit,year} \cdot \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{size}} \cdot \text{fuelswitch}_{unit,\texttt{Cost of Fuel Switch}} \cdot \text{annuity\_factor\_fs}_{unit,year}) +$$

$$\sum_{unit|\text{avail\_plant}_{unit,year}[\text{no\_unit\_limit}_{unit}]} (\text{INVE\_UNITS}_{unit} \cdot \text{survfs\_plant}_{unit,year} \cdot \text{fuelswitch}_{unit,\texttt{Cost of Fuel Switch}} \cdot \text{annuity\_factor\_fs}_{unit,year}) +$$

$$\sum_{dhh|\text{avail\_plant}_{dhh,year}} (\text{COMM\_DHH}_{dhh} \cdot \text{survfs\_plant}_{dhh,year} \cdot \text{fuelswitch}_{dhh,\texttt{Cost of Fuel Switch}} \cdot \text{annuity\_factor\_fs}_{dhh,year}) +$$

$$\sum_{ind|\text{avail\_plant}_{ind,year}} (\text{COMM\_IND}_{ind} \cdot \text{survfs\_plant}_{ind,year} \cdot \text{fuelswitch}_{ind,\texttt{Cost of Fuel Switch}} \cdot \text{annuity\_factor\_fs}_{ind,year}) +$$

$$\sum_{unit|\text{avail\_plant}_{unit,year}[\text{unit\_limit}_{unit}]} (\text{INST\_UNITS}_{unit,year} \cdot \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{size}} \cdot \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{FixedOMCost}}) +$$

$$\sum_{unit|\text{avail\_plant}_{unit,year}[\text{no\_unit\_limit}_{unit}]} (\text{CAPA\_UNITS}_{unit,year} \cdot \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{FixedOMCost}}) +$$

$$\sum_{dhh|\text{avail\_plant}_{dhh,year}} (\text{COMM\_DHH}_{dhh} \cdot \text{surv\_plant}_{dhh,year} \cdot \text{techdata\_plants}_{dhh,\texttt{dummy},\texttt{FixedOMCost}}) +$$

$$\sum_{ind|\text{avail\_plant}_{ind,year}} (\text{COMM\_IND}_{ind} \cdot \text{surv\_plant}_{ind,year} \cdot \text{techdata\_plants}_{ind,\texttt{dummy},\texttt{FixedOMCost}}) +$$

$$\sum_{storage|\text{avail\_plant}_{storage,year}} (\text{COMM\_STOR}_{storage} \cdot \text{surv\_plant}_{storage,year} \cdot \text{techdata\_plants}_{storage,\texttt{dummy},\texttt{FixedOMCost}}) +$$

$$\sum_{PtoX|\text{avail\_plant}_{PtoX,year}} (\text{COMM\_PtoX}_{PtoX} \cdot \text{surv\_plant}_{PtoX,year} \cdot \text{techdata\_plants}_{PtoX,\texttt{dummy},\texttt{FixedOMCost}}) +$$

$$\sum_{fuel,fuel\_limit_{fuel}} (\text{fuelprice}_{fuel,year} \cdot \sum_{level} (\text{level\_struct}_{fuel,level,\texttt{Price},year} \cdot \text{LEV\_FUEL}_{fuel,level,year})) +$$

$$\sum_{plant|\text{avail\_plant}_{plant,year}} (\sum_{fuel|(\neg\text{fuel\_limit}_{fuel})[\text{fuelplant}_{plant,fuel,year}]} (\text{fuelprice}_{fuel,year} \cdot \text{FUEL\_CONS}_{plant,fuel,year})) +$$

$$\sum_{ind|\text{avail\_plant}_{ind,year}} (\sum_{fuel|(\text{avail\_plant}_{ind,year} \wedge \text{fuelplant}_{ind,fuel,year})} (\sum_{sectors|\text{INDmapsectors}_{sectors,ind}} \text{fuelpricedgs}_{sectors,fuel,year} \cdot \text{FUEL\_CONS}_{ind,fuel,year})) +$$

$$\text{CO2\_EMISSIONpower}_{year} \cdot \text{drivers\_data}_{\texttt{CarbonPricePower},\texttt{dummy},\texttt{dummy},year} + \text{CO2\_EMISSIONdhh}_{year} \cdot \text{drivers\_data}_{\texttt{CarbonPriceDHH},\texttt{dummy},\texttt{dummy},year} +$$

$$\sum_{sectors} (\text{CO2\_EMISSIONind}_{sectors,year} \cdot \text{drivers\_data}_{\texttt{CarbonPriceInd},\texttt{dummy},\texttt{dummy},year} \cdot \text{drivers\_data}_{\texttt{CarbonLeakage},sectors,\texttt{dummy},year}) +$$

$$\text{CO2\_CAPTURE}_{year} \cdot \text{policy\_power\_data}_{\texttt{CCSstoragePrice},\texttt{dummy},\texttt{dummy},year} +$$

$$\sum_{unit,hour|\text{avail\_plant}_{unit,year}} (\text{freq\_hour}_{hour} \cdot \text{ELEC\_OUTPUT}_{unit,hour,year} \cdot \text{techdata\_plants}_{unit,\texttt{dummy},\texttt{VariableNonFuelCost}}) +$$

$$\sum_{dhh,hour|\text{avail\_plant}_{dhh,year}} (\text{freq\_hour}_{hour} \cdot \text{STEAM\_OUTPUT}_{dhh,hour,year} \cdot \text{techdata\_plants}_{dhh,\texttt{dummy},\texttt{VariableNonFuelCost}}) +$$

$$\sum_{indCHP|\text{avail\_plant}_{indCHP,year}} (\text{ELEC\_OUTPUT\_IND}_{indCHP,year} \cdot \text{techdata\_plants}_{indCHP,\mathtt{dummy},\mathtt{VariableNonFuelCost}}) +$$

$$\sum_{indboil|\text{avail\_plant}_{indboil,year}} (\text{STEAM\_OUTPUT\_IND}_{indboil,year} \cdot \text{techdata\_plants}_{indboil,\mathtt{dummy},\mathtt{VariableNonFuelCost}}) +$$

$$\sum_{storage,hour|\text{avail\_plant}_{storage,year}} (\text{freq\_hour}_{hour} \cdot \text{STOR\_CHARGE}_{storage,hour,year} \cdot \text{techdata\_plants}_{storage,\mathtt{dummy},\mathtt{VariableNonFuelCost}}) +$$

$$\sum_{PtoX,hour|\text{avail\_plant}_{PtoX,year}} (\text{freq\_hour}_{hour} \cdot \text{PtoX\_OUTPUT}_{PtoX,hour,year} \cdot \text{techdata\_plants}_{PtoX,\mathtt{dummy},\mathtt{VariableNonFuelCost}}) - \text{FITPAYMENT}_{year} - \text{ADDPOLICY}_{year} +$$

$$\sum_{type,type\_limit_{type}} (\sum_{vint|((\text{vint.val} \leq \text{year.val}) \wedge (\text{vint.val} > 2015))} (\text{policy\_power\_data}_{\mathtt{AddCapitalCost},type,\mathtt{dummy},vint} \cdot \sum_{level} ((\text{level\_struct}_{type,level,\mathtt{Price},vint} - 1) \cdot \text{LEV\_UNITS}_{type,level,vint}) \cdot \text{annuity\_factor\_type}_{type,vint,year})) +$$

$$\sum_{type,type\_storage_{type}} (\sum_{vint|((\text{vint.val} \leq \text{year.val}) \wedge (\text{vint.val} > 2015))} (\text{policy\_power\_data}_{\mathtt{AddCapitalCost},type,\mathtt{dummy},vint} \cdot \sum_{level} ((\text{level\_struct}_{type,level,\mathtt{Price},vint} - 1) \cdot \text{LEV\_STORAGE}_{type,level,vint}) \cdot \text{annuity\_factor\_type}_{type,vint,year})) +$$

$$\sum_{unit,hour|\text{policy\_power\_data}_{\mathtt{CurtailmentCost},unit,\mathtt{dummy},year}} (\text{policy\_power\_data}_{\mathtt{CurtailmentCost},unit,\mathtt{dummy},year} \cdot \text{freq\_hour}_{hour} \cdot \text{UNIT\_CUT}_{unit,hour,year}) +$$

$$\sum_{hour|\text{policy\_power\_data}_{\mathtt{CurtailmentCost},\mathtt{Electricity},\mathtt{dummy},year}} (\text{policy\_power\_data}_{\mathtt{CurtailmentCost},\mathtt{Electricity},\mathtt{dummy},year} \cdot \text{freq\_hour}_{hour} \cdot \text{ELEC\_CUT}_{hour,year}) +$$

$$\sum_{hour|\text{policy\_power\_data}_{\mathtt{CurtailmentCost},\mathtt{Heat},\mathtt{dummy},year}} (\text{policy\_power\_data}_{\mathtt{CurtailmentCost},\mathtt{Heat},\mathtt{dummy},year} \cdot \text{freq\_hour}_{hour} \cdot \text{HEAT\_CUT}_{hour,year}) +$$

$$\sum_{sectors|\text{policy\_power\_data}_{\mathtt{CurtailmentCost},\mathtt{Steam},\mathtt{dummy},year}} (\text{policy\_power\_data}_{\mathtt{CurtailmentCost},\mathtt{Steam},\mathtt{dummy},year} \cdot 1000 \cdot \text{STEAM\_CUT}_{sectors,year}) +$$

$$\sum_{ancillary\_all,hour|\text{policy\_power\_data}_{\mathtt{CurtailmentCost},ancillary\_all,\mathtt{dummy},year}} (\frac{\text{policy\_power\_data}_{\mathtt{CurtailmentCost},ancillary\_all,\mathtt{dummy},year}}{1000} \cdot \text{freq\_hour}_{hour} \cdot \text{ANCIL\_CUT}_{ancillary\_all,hour,year}) +$$

$$\sum_{ancillary\_all,hour|\text{policy\_power\_data}_{\mathtt{CurtailmentCost},\mathtt{NetImports},\mathtt{dummy},year}} (\text{policy\_power\_data}_{\mathtt{CurtailmentCost},\mathtt{NetImports},\mathtt{dummy},year} \cdot \text{freq\_hour}_{hour} \cdot (\text{NETIMPORTSCUTP}_{hour,year} + \text{NETIMPORTSCUTM}_{hour,year})) +$$

$$\sum_{type,type\_dhh_{type}} (\text{DHH\_ADD}_{type,year} + \text{DHH\_CUT}_{type,year}) \cdot \text{policy\_power\_data}_{\mathtt{CurtailmentCost},\mathtt{Heat},\mathtt{dummy},year} +$$

$$\sum_{sectors} (\text{CHP\_ADD}_{sectors,year} + \text{CHP\_CUT}_{sectors,year}) \cdot \text{policy\_power\_data}_{\mathtt{CurtailmentCost},\mathtt{Steam},\mathtt{dummy},year} +$$

$$\sum_{fuel|((\neg(\text{year.val}=2015)) \wedge (\neg \text{fuel\_ind}_{fuel}))} (1000 \cdot \text{ADDFUEL}_{fuel,year}) +$$

$$\sum_{plant} (1000 \cdot \text{ADDHOURS}_{plant,year}) + \text{ADD\_FITBUDGET}_{year} \cdot 100))$$

$\text{ELEC\_OUTPUT}_{plant,hour,year\_all} \geq 0 \; \forall plant, hour, year\_all$
$\text{ELEC\_OUTPUT\_IND}_{plant,year\_all} \geq 0 \; \forall plant, year\_all$
$\text{STOR\_DISCHARGE}_{storage,hour,year\_all} \geq 0 \; \forall storage, hour, year\_all$
$\text{ELEC\_CUT}_{hour,year\_all} \geq 0 \; \forall hour, year\_all$
$\text{STOR\_CHARGE}_{storage,hour,year\_all} \geq 0 \; \forall storage, hour, year\_all$
$\text{PToX\_INPUT}_{PtoX,hour,year\_all} \geq 0 \; \forall PtoX, hour, year\_all$
$\text{STEAM\_OUTPUT}_{plant,hour,year\_all} \geq 0 \; \forall plant, hour, year\_all$
$\text{FUEL\_CONS}_{plant,fuel\_all,year\_all} \geq 0 \; \forall plant, fuel\_all, year\_all$
$\text{STEAM\_OUTPUT\_IND}_{plant,year\_all} \geq 0 \; \forall plant, year\_all$
$\text{ANCIL\_UP}_{ancillary\_all,unit,hour,year\_all} \geq 0 \; \forall ancillary\_all, unit, hour, year\_all$
$\text{ANCIL\_DOWN}_{ancillary\_all,unit,hour,year\_all} \geq 0 \; \forall ancillary\_all, unit, hour, year\_all$
$\text{ANCIL\_CUT}_{ancillary\_all,hour,year\_all} \geq 0 \; \forall ancillary\_all, hour, year\_all$
$\text{INST\_UNITS}_{unit,year\_all} \in \mathbb{Z}_+ \forall unit, year\_all$
$\text{CAPA\_UNITS}_{unit,year\_all} \geq 0 \; \forall unit, year\_all$
$\text{OP\_UNITS}_{unit,hour,year\_all} \in \mathbb{Z}_+ \forall unit, hour, year\_all$
$\text{UNIT\_CUT}_{plant,hour,year\_all} \geq 0 \; \forall plant, hour, year\_all$
$\text{ShutDown}_{unit,hour,year\_all} \in \mathbb{Z}_+ \forall unit, hour, year\_all$
$\text{StartUp}_{unit,hour,year\_all} \in \mathbb{Z}_+ \forall unit, hour, year\_all$
$\text{COMM\_UNITS}_{plant} \in \mathbb{Z}_+ \forall plant$
$\text{INVE\_UNITS}_{plant} \geq 0 \; \forall plant$
$\text{INVESTMENT}_{plant,year\_all} \geq 0 \; \forall plant, year\_all$
$\text{COMM\_DHH}_{plant} \geq 0 \; \forall plant$
$\text{COMM\_IND}_{plant} \geq 0 \; \forall plant$
$\text{COMM\_STOR}_{plant} \geq 0 \; \forall plant$
$\text{COMM\_PtoX}_{plant} \geq 0 \; \forall plant$
$\text{DECOMMISSIONING}_{plant,year\_all} \geq 0 \; \forall plant, year\_all$
$\text{LEV\_UNITS}_{type,level,year\_all} \geq 0 \; \forall type, level, year\_all$
$\text{LEV\_FUEL}_{fuel\_all,level,year\_all} \geq 0 \; \forall fuel\_all, level, year\_all$
$\text{ADDFUEL}_{fuel\_all,year\_all} \geq 0 \; \forall fuel\_all, year\_all$
$\text{LEV\_STORAGE}_{type,level,year\_all} \geq 0 \; \forall type, level, year\_all$
$\text{CO2\_EMISSIONpower}_{year\_all} \geq 0 \; \forall year\_all$
$\text{CO2\_EMISSIONdhh}_{year\_all} \geq 0 \; \forall year\_all$
$\text{CO2\_EMISSIONind}_{sectors\_all,year\_all} \geq 0 \; \forall sectors\_all, year\_all$
$\text{CO2\_CAPTURE}_{year\_all} \geq 0 \; \forall year\_all$

$\text{PtoX\_OUTPUT}_{PtoX,hour,year\_all} \geq 0\ \forall PtoX, hour, year\_all$
$\text{FITPAYMENT}_{year\_all} \geq 0\ \forall year\_all$
$\text{FIT\_ELEC\_OUTPUT}_{unit,year\_all} \geq 0\ \forall unit, year\_all$
$\text{ADD\_FITBUDGET}_{year\_all} \geq 0\ \forall year\_all$
$\text{ADDPOLICY}_{year\_all} \geq 0\ \forall year\_all$
$\text{NETIMPORTSCUTP}_{hour,year\_all} \geq 0\ \forall hour, year\_all$
$\text{NETIMPORTSCUTM}_{hour,year\_all} \geq 0\ \forall hour, year\_all$
$\text{HEAT\_CUT}_{hour,year\_all} \geq 0\ \forall hour, year\_all$
$\text{REGIONCUT}_{region,year\_all} \geq 0\ \forall region, year\_all$
$\text{ADDHOURS}_{plant,year\_all} \geq 0\ \forall plant, year\_all$
$\text{DHH\_CUT}_{type,year\_all} \geq 0\ \forall type, year\_all$
$\text{DHH\_ADD}_{type,year\_all} \geq 0\ \forall type, year\_all$
$\text{STEAM\_CUT}_{sectors\_all,year\_all} \geq 0\ \forall sectors\_all, year\_all$
$\text{DGASCUT}_{year\_all} \geq 0\ \forall year\_all$
$\text{CHP\_CUT}_{sectors\_all,year\_all} \geq 0\ \forall sectors\_all, year\_all$
$\text{CHP\_ADD}_{sectors\_all,year\_all} \geq 0\ \forall sectors\_all, year\_all$

Appendix V Mathematical formulation of the CPS Biomass Module

Symbols

Sets

Name	Domains	Description
labels	*	
year_all, year_lag	labels	years
year	year_all	projection years
SFbio	labels	supply chains used in biomass submodels
fuel_all	labels	set of fuels
f_bioout	fuel_all	output fuels of biomass submodel
f_biofeed	fuel_all	feedstock fuels used in biomass submodel
bioout	SFbio, fuel_all	mapping of supply chains and output fuels
bioinp	fuel_all, SFbio	mapping of feedstock fuels used in supply chains
fuel_bio	fuel_all	fuels consumed for self consumption in supply chains of biomass submodel
resource	labels	resources
resourcebio	resource	resources used in biomass model
yearlag	year_all, year_all	association to define the lagged year
vintbio	year_all	
SameAs	*, *	Set Element Comparison Without Checking

Parameters

Name	Domains	Description
drivers_data	labels, labels, labels, labels	drivers data
EmissionFactors	labels, labels	emission factors
PRIF_TAX_SFbio	fuel_all, SFbio, year_all	end user fuel prices [fuel]
prob_surv_bio	SFbio, year_all, year_all	probability of survival of an equipment
bio_esurv	SFbio, year_all, year_all	economic survival for amortization
bio_tsurv	SFbio, year_all, year_all	technical survival
bio_ann	SFbio, year_all	annuity factor for capital cost

Name	Domains	Description
bio_demand	f_bioout, year_all	demand for bio self-products
bio_heatrate	SFbio, year_all	heatrates of equipment
bio_self_fuel	SFbio, year_all, year_all	rate of consumption of fuels
bio_self_elec	SFbio, year_all, year_all	rate of consumption of electricity
bio_respotential	resourcebio, year_all	potgential of feedstock
bio_invcost	SFbio, year_all	investment cost
bio_omcost	SFbio, year_all	O&M cost
bio_omgr	SFbio, year_all	growth of O&M cost with age
bio_varcost	SFbio, year_all	variable non fuel cost
mc_resourcebio	resourcebio, year_all	margincal cost of potential cost curve for feedstock
nc_resourcebio	resourcebio, year_all	nonlinear parameter of potential cost curve for feedstock
lbd_bio	SFbio, year_all, year_all	learning by doing of bioenergy equipment
RESvalue_bio	fuel_all, labels, year_all	RES value for bioenergy equipment
CAP_SUPP_L2	SFbio, year_all, year_all	exogenous capacity
utilSFbio	SFbio, year_all	Utilization rate of biomass technology SFbio

Variables

Name	Domains	Description
BIO_SUPP	SFbio, year_all, fuel_all, year_all	supply of a biomass product in GWh
CAP_SUPP	SFbio, year_all, year_all	capacity of a bioenergy transformation process in GW
INV_SUPP	SFbio, year_all	capacity in a bioenergy transformation process in GW
BIO_FEEDSTOCK	SFbio, year_all, fuel_all, year_all	consumption of feedstock in a bioenergy transformation process in GWh
BIO_FUEL	SFbio, year_all, fuel_all, year_all	consumption of fuels in a bioenergy transformation process in Gwh
BIO_RESCONS	resourcebio, year_all	total use of a feedstock subject to potential constraints in GWh
BIO_Obj		value of objective function of the biomass model

Equations

Name	Domains	Description
QB_demand	fuel_all, year_all	
QB_capacity	SFbio, vintbio, year_all	
QB_capital	SFbio, vintbio, year_all	
QB_FEEDSTOCK	SFbio, vintbio, year_all	
QB_FUEL	SFbio, vintbio, year_all	
QB_ELEC	SFbio, vintbio, year_all	
QB_RESCONS	resourcebio, year_all	
QB_Resource	resourcebio, year_all	
QB_Obj		

Equation Definitions

QB_demand$_{f\_bioout,year}$

$$\sum_{SFbio,vintbio|(\text{vintbio.val}\leq\text{year.val})[\text{bioout}_{SFbio,f\_bioout}]} \text{BIO\_SUPP}_{SFbio,vintbio,f\_bioout,year} \geq \text{bio\_demand}_{f\_bioout,year} \qquad \forall f\_bioout, year$$

QB_capacity$_{SFbio,vintbio,year}$

$$\text{CAP\_SUPP}_{SFbio,vintbio,year} \cdot \text{utilSFbio}_{SFbio,year} \cdot 8760 \geq \sum_{f\_bioout|\text{bioout}_{SFbio,f\_bioout}} \text{BIO\_SUPP}_{SFbio,vintbio,f\_bioout,year} \qquad \forall SFbio, vintbio, year \mid (\text{vintbio.val} \leq \text{year.val})$$

QB_capital$_{SFbio,vintbio,year}$

$$\begin{aligned}&\text{CAP\_SUPP}_{SFbio,vintbio,year} = \\ &\text{INV\_SUPP}_{SFbio,year}[(\text{vintbio.val} = \text{year.val})] + \\ &\text{prob\_surv\_bio}_{SFbio,vintbio,year} \cdot \sum_{year\_lag|\text{yearlag}_{year,year\_lag}} ((\text{CAP\_SUPP}_{SFbio,vintbio,year\_lag} + \text{CAP\_SUPP\_L2}_{SFbio,vintbio,year\_lag}) \cdot \text{bio\_tsurv}_{SFbio,vintbio,year}[(\text{vintbio.val} \leq (\text{year.val} - 5))]) \\ &\forall SFbio, vintbio, year \mid (\text{vintbio.val} \leq \text{year.val})\end{aligned}$$

QB_FEEDSTOCK$_{SFbio,vintbio,year}$

$$\frac{\sum_{f\_biofeed|\text{bioinp}_{f\_biofeed,SFbio}} \text{BIO\_FEEDSTOCK}_{SFbio,vintbio,f\_biofeed,year}}{\text{bio\_heatrate}_{SFbio,vintbio}} \geq \sum_{f\_bioout|\text{bioout}_{SFbio,f\_bioout}} \text{BIO\_SUPP}_{SFbio,vintbio,f\_bioout,year} \qquad \forall SFbio, vintbio, year \mid (\text{vintbio.val} \leq \text{year.val})$$

QB_FUEL$_{SFbio,vintbio,year}$

$$\sum_{fuel\_bio|(\neg(fuel_{b}io=\texttt{ELC}))} \text{BIO\_FUEL}_{SFbio,vintbio,fuel\_bio,year} \geq \text{bio\_self\_fuel}_{SFbio,vintbio,year} \cdot \sum_{f\_bioout|\text{bioout}_{SFbio,f\_bioout}} \text{BIO\_SUPP}_{SFbio,vintbio,f\_bioout,year} \qquad \forall SFbio, vintbio, year \mid (\text{vintbio.val} \leq \text{year.val})$$

QB_ELEC$_{SFbio,vintbio,year}$

$$\sum_{fuel\_bio|(fuel_{b}io=\texttt{ELC})} \text{BIO\_FUEL}_{SFbio,vintbio,fuel\_bio,year} \geq \text{bio\_self\_elec}_{SFbio,vintbio,year} \cdot \sum_{f\_bioout|\text{bioout}_{SFbio,f\_bioout}} \text{BIO\_SUPP}_{SFbio,vintbio,f\_bioout,year} \qquad \forall SFbio, vintbio, year \mid (\text{vintbio.val} \leq \text{year.val})$$

QB_RESCONS$_{resourcebio,year}$

$$\text{BIO\_RESCONS}_{resourcebio,year} = \sum_{f\_biofeed|(f_{b}iofeed=resourcebio)} \Big(\sum_{SFbio,vintbio|(\text{vintbio.val}\leq\text{year.val})[\text{bioinp}_{f\_biofeed,SFbio}]} \text{BIO\_FEEDSTOCK}_{SFbio,vintbio,f\_biofeed,year}\Big) \qquad \forall resourcebio, year$$

QB_Resource$_{resourcebio,year}$

$$\text{bio\_respotential}_{resourcebio,year} \geq \text{BIO\_RESCONS}_{resourcebio,year} \qquad \forall resourcebio, year$$

QB_Obj

$$\text{BIO\_Obj} = \sum_{year}\Big(\sum_{vintbio|(\text{vintbio.val}\leq\text{year.val})} \Big(\sum_{SFbio} (\text{bio\_invcost}_{SFbio,vintbio} \cdot \text{bio\_ann}_{SFbio,vintbio} \cdot \text{INV\_SUPP}_{SFbio,vintbio} \cdot \text{bio\_esurv}_{SFbio,vintbio,year} + \text{bio\_omcost}_{SFbio,vintbio} \cdot (1 + \text{bio\_omgr}_{SFbio,vintbio})^{(\text{year.val}-\text{vintbio.val})}.$$

$$\text{CAP\_SUPP}_{SFbio,vintbio,year} \cdot \text{bio\_tsurv}_{SFbio,vintbio,year} + \text{bio\_varcost}_{SFbio,vintbio} \cdot \sum_{f\_bioout|\text{bioout}_{SFbio,f\_bioout}} \text{BIO\_SUPP}_{SFbio,vintbio,f\_bioout,year} +$$

$$\sum_{f\_biofeed|\text{bioinp}_{f\_biofeed,SFbio}} (\text{BIO\_FEEDSTOCK}_{SFbio,vintbio,f\_biofeed,year} \cdot$$

$$\sum_{resourcebio|(f_biofeed=resourcebio)} (\text{mc\_resourcebio}_{resourcebio,year} - \text{nc\_resourcebio}_{resourcebio,year} \cdot \log((1 - \frac{\text{BIO\_RESCONS}_{resourcebio,year}}{\text{bio\_respotential}_{resourcebio,year} + 1e-06})))) +$$

$$\sum_{fuel\_bio} (\text{BIO\_FUEL}_{SFbio,vintbio,fuel\_bio,year} \cdot (\text{PRIF\_TAX\_SFbio}_{fuel\_bio,SFbio,year} + \text{EmissionFactors}_{\texttt{CO2},fuel\_bio} \cdot \text{drivers\_data}_{\texttt{CarbonPriceETS},\texttt{dummy},\texttt{dummy},year})) -$$

$$\text{lbd\_bio}_{SFbio,vintbio,year} \cdot \sum_{f\_bioout|\text{bioout}_{SFbio,f\_bioout}} \text{BIO\_SUPP}_{SFbio,vintbio,f\_bioout,year} - \sum_{f\_bioout|\text{bioout}_{SFbio,f\_bioout}} (\text{RESvalue\_bio}_{f\_bioout,\texttt{dummy},year} \cdot \text{BIO\_SUPP}_{SFbio,vintbio,f\_bioout,year}))))$$

$\text{BIO\_SUPP}_{SFbio,year\_all,fuel\_all,year\_all} \geq 0 \ \forall SFbio, year\_all, fuel\_all, year\_all$
$\text{CAP\_SUPP}_{SFbio,year\_all,year\_all} \geq 0 \ \forall SFbio, year\_all, year\_all$
$\text{INV\_SUPP}_{SFbio,year\_all} \geq 0 \ \forall SFbio, year\_all$
$\text{BIO\_FEEDSTOCK}_{SFbio,year\_all,fuel\_all,year\_all} \geq 0 \ \forall SFbio, year\_all, fuel\_all, year\_all$
$\text{BIO\_FUEL}_{SFbio,year\_all,fuel\_all,year\_all} \geq 0 \ \forall SFbio, year\_all, fuel\_all, year\_all$
$\text{BIO\_RESCONS}_{resourcebio,year\_all} \geq 0 \ \forall resourcebio, year\_all$