Energy Technology Systems Analysis Programme

http://iea-etsap.org/index.php/documentation

Documentation for the TIMES Model

PART IV

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General Introduction

This documentation is composed of five Parts.

Part I provides a general description of the TIMES paradigm, with emphasis on the model's general structure and its economic significance. Part I also includes a simplified mathematical formulation of TIMES, a chapter comparing it to the MARKAL model, pointing to similarities and differences, and chapters describing new model options.

Part II constitutes a comprehensive reference manual intended for the technically minded modeler or programmer looking for an in-depth understanding of the complete model details, in particular the relationship between the input data and the model mathematics, or contemplating making changes to the model's equations. Part II includes a full description of the sets, attributes, variables, and equations of the TIMES model.

Part III describes the organization of the TIMES modeling environment and the GAMS control statements required to run the TIMES model. GAMS is a modeling language that translates a TIMES database into the Linear Programming matrix, and then submits this LP to an optimizer and generates the result files. Part III describes how the routines comprising the TIMES source code guide the model through compilation, execution, solve, and reporting; the files produced by the run process and their use; and the various switches that control the execution of the TIMES code according to the model instance, formulation options, and run options selected by the user. It also includes a section on identifying and resolving errors that may occur during the run process.

Part IV provides a step-by-step introduction to building a TIMES model in the VEDA-Front End (VEDA-FE) model management software. It first offers an orientation to the basic features of VEDA-FE, including software layout, data files and tables, and model management features. It then describes in detail twelve Demo models (available for download from the ETSAP website) that progressively introduce VEDA-TIMES principles and modeling techniques.

Part V describes the VEDA Back-End (VEDA-BE) software, which is widely used for analyzing results from TIMES models. It provides a complete guide to using VEDA-BE, including how to get started, import model results, create and view tables, and create and modify user sets, and step through results in the model Reference Energy System. It also describes advanced features and provides suggestions for best practices.

PART IV: Getting Started with the VEDA-TIMES Demo Models

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1 Introduction

This Part of the TIMES documentation provides a step-by-step introduction to building a TIMES model in the VEDA-Front End (VEDA-FE) model management software, using a series of twelve DemoS models (available for download from the ETSAP website) to progressively demonstrate VEDA-TIMES principles and modeling techniques. The remainder of Section 1 describes how to access and set up the TIMES DemoS models. Section 2 provides an orientation to the basic features of VEDA-FE, including software layout, commonly used data files and tables, and model management features. Section 3 then walks through the twelve DemoS models, providing for each a summary of the VEDA-TIMES features and model attributes introduced, a detailed guide to the templates and tables used, and a look at the model results.

1.1 Downloading and setting up the DemoS models

The complete set of VEDA-TIMES DemoS models is available, along with all five Parts of the TIMES documentation, on the ETSAP Documentation web page (http://www.iea-etsap.org/index.php/documentation) under 'VEDA-TIMES Demo Models'. You will also need VEDA-FE and Back End (BE) installed in order to follow along with this manual. VEDA Installation instructions are available at http://support.kanors-emr.org/.

The DemoS model zip folder include two sub-folders:

- ETSAP_DemoS_VFE. In this folder there are 12 subfolders, one for each of the twelve Demos. This folder should be pasted into your VEDA_Models folder (C:\VEDA\VEDA_Models, if you did not change the path during installation).
- DemoS_VBE. This folder contains a database with predefined tables for analyzing model results. This folder should be pasted into your VEDA-BE Databases folder (C:\VEDA\Veda_BE\Databases, if you did not change the path during installation).

To open the first DemoS from VEDA-FE and set up the VEDA-BE database:

- Launch VEDA-FE, and use the VEDA Navigator (described in Section 2.2) to browse to the folder in which the DemoS_001 is stored. (C:\VEDA\VEDA_Models\DemoS_001, if you have followed the default installation).
  - At this point VEDA-FE will load DemoS_001 into the Navigator.
- Launch VEDA-BE, select **Open** from the **File** menu, and browse to the folder where you have stored the DemoS_VBE database.
  - When the DemoS_VBE database is loaded, the list of pre-defined tables can be seen under **Table definition** at the top left of the main window. To view a particular table, scroll down/up the list and select one table, then click the **View Table(s)** button. The table will open with a pre-defined layout than can be modified in a very flexible manner. Note that not all the tables can be used for the first demo steps, in which only a few simple results will be available. If a VEDA-BE table is inconsistent or empty, you will get a pop up message saying that table is empty.

2 Introduction to VEDA Front End

This section provides a brief introduction to using VEDA-FE and VEDA Excel template workbooks for building, browsing, and running a TIMES model. VEDA-FE is used to facilitate TIMES model building based on a modular approach and heavily reliance on flexible Excel workbooks integrated into a core database visible via tabular and diagrammatic browsing tools. It is also used to develop and manage model runs. The main tools available in VEDA-FE are:

- A **Navigator** to oversee the management of the Excel workbooks.
- A **Browser** to view all model data (based on filter and search facilities).
- **Reference energy system** (RES) diagramming and **Commodity/Process Masters** with data views.
- A **Case Manager** window for composing and submitting model runs.

These are described in Section 2.4, following a description of the VEDA-FE template folder structure, file types, and tables used to create model input. VEDA-FE is complimented by VEDA Back End (BE) for analysis of model run results. (See Part V of this documentation for more on VEDA-BE.)

2.1 Folders and subfolders

All VEDA-TIMES model input data is organized in Excel workbooks (or files). VEDA-FE then integrates information from all of these workbooks into a single database to generate a TIMES model. The models managed by VEDA-FE are normally stored in a specific folder (by default \VEDA\VEDA_Models). Within this folder, there is a sub-folder for each individual model a user is working with, including all of the VEDA-TIMES Demo Models ((\VEDA\VEDA_Models\DemoS_001, etc.). The sub-folder structure is identical for each individual model (Figure 1, left side) and includes:

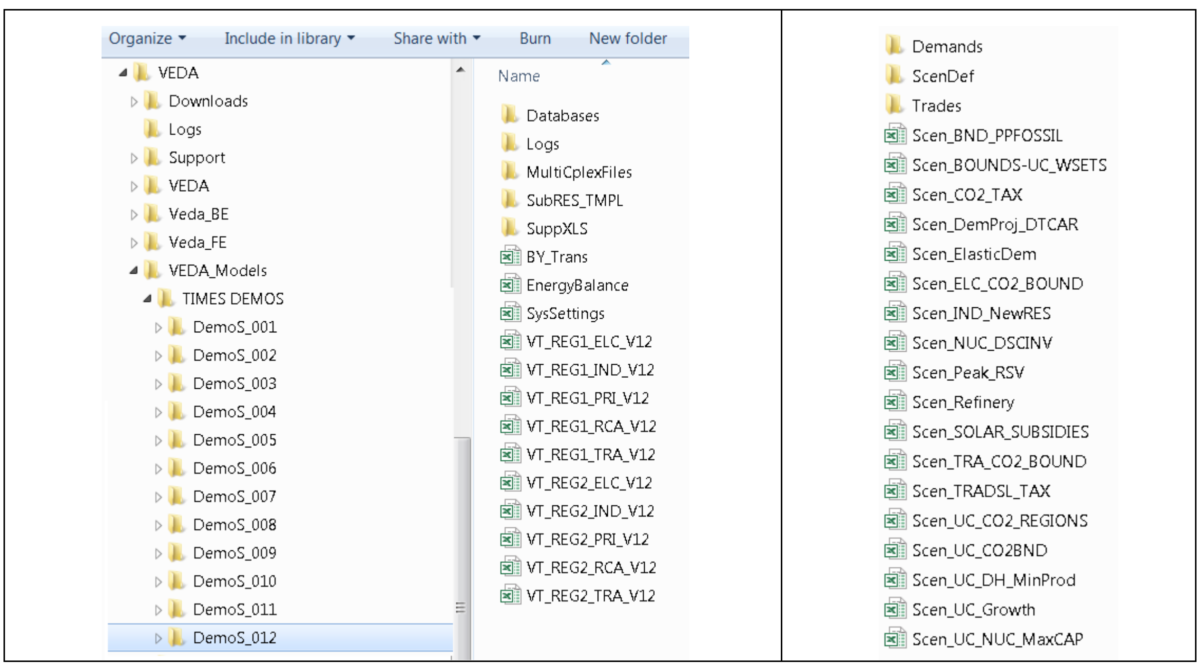


Figure 1. Sub-folders structure for each VEDA-FE model

- The B-Y Templates, the SysSettings files and the BY_Trans file.
- A sub-folder (**SubRES_TMPL**) to store all SubRES files and associated transformation files.
- A sub-folder (**SuppXLS**) to store all scenario files, as well sub-folders for trade files (**Trades**) and demand files (**Demands**) (Figure 1, right side).
- The **Logs** folder, which provides a location for VEDA-FE to write a variety of log files, including QA_Checks, error messages, and run summaries. Its contents are accessible via the **LOGs** button in the Case Manager.
- Users are not concerned with the other sub-folders.

2.2 VEDA-FE Navigator and types of workbook files

VEDA-FE opens displaying the VEDA-Navigator (Figure 2), which provides a comprehensive view of all the files in the various folders managed by VEDA-FE for the current model. The specific folder pathway associated with the active model is displayed on the top bar of the VEDA-Navigator form (in Figure 2, MODEL: C:\VEDA\VEDA_Models\TIMES DEMOS\DemoS_012). Clicking on this bar will open a window where the user can change the active model, by selecting a previously opened model from the list shown, or opening a new one by clicking the **New** button and navigating to the path of the new model folder.

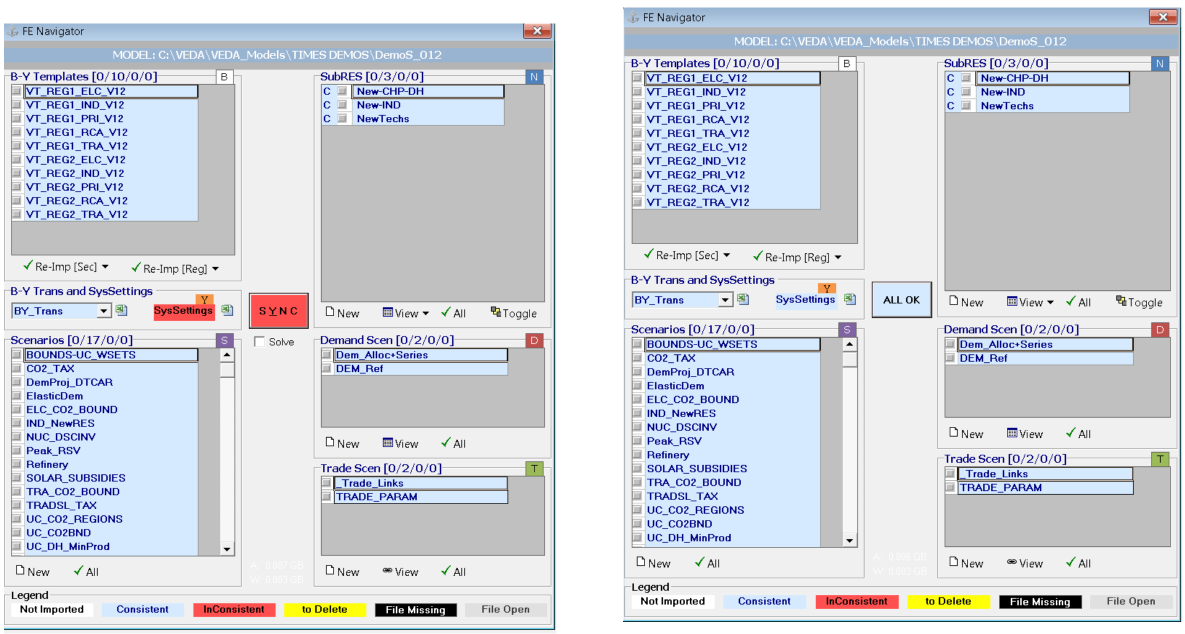


Figure 2. The VEDA-FE Navigator

The VEDA-Navigator is the main vehicle for accessing, importing, and coordinating the various files that make up a model. Its front screen is divided into sub-windows according to the various types of files managed by VEDA-FE:

- **B-Y (Base Year) Templates**: These templates can be used to set up the base-year structure of the model (existing process stock and the base-year end-use demand levels), such that the overall energy flows reflect the energy balance. In other words, the start year of the model can be calibrated to the energy balance in the B-Y Templates. The B-Y templates are named as VT_<workbook name>_<sector>_<Version> (e.g. VT_REG_PRI_V1). The number of B-Y templates and their names depend on both the model structure (e.g., the number of regions and sectors) and the organisation of the input data (e.g., how many regions and sectors in each file). The B-Y templates are introduced in DemoS_001 (Section 3.1) and are modified throughout the evolution of the 12 Demo steps.

- **SysSettings**: This file is used to declare the very basic structure of the model including regions, time slices, start year, etc. It also contains some settings for the synchronization process and can include some additional information. There is only one such file; it has a fixed name that stands for System Settings. The SysSettings file is described in Section 3.1.1.
- **BY_Trans**: These transformation files are used to update the information included in the B-Y templates (update existing values for existing attributes) and/or to insert new information (insert new attributes for existing processes) in the B-Y templates. They work like a scenario file (described below), but the rule-based filters and the update/insert changes apply only to those processes and commodities already existing in the B-Y templates. The BY_Trans file is introduced in DemoS_009 (Section 3.9.1.2).
- **Scenarios**: Scenario files are used to update existing information and/or to insert new information in any part of the RES, including B-Y templates, SubRES files, and Trade files. They are also used to include any additional user constraints in the model. The naming convention is: Scen_<scenario name>. These files can only manipulate (insert or update) information associated with previously declared RES components. New commodities and processes may not be added via scenario files, only new attributes. Scenario files are introduced in DemoS_004 (Section 3.4.3). Several different applications of scenario files are illustrated through the remainder of the Demos.
- **SubRES**: The SubRES files are used to introduce new processes and commodities in the RES that are not part of the B-Y templates. However, while the B-Y templates are region-specific, the SubRES are region independent. For each SubRES file, there is a corresponding transformation (Trans) file allowing the introduction of regional specificity of process attributes, including the availability (or not) of processes in each region. The naming conventions are: SubRES_<name> and SubRES_<name>_Trans. SubRES files are introduced in DemoS_006 (Section 3.6.3).
- **Demand Scen**: The demand files include all the information necessary to project end-use demands for energy services in each region, such as macroeconomic drivers and sensitivity series. Multiple demand files may be used, to model different demand growth scenarios for instance, and the naming convention is: ScenDem_<scenario name>. This section of the Navigator also contains a single file permitting assignment of a demand driver as well as a sensitivity (or elasticity) series each end-use demand to its driver in each region: Dem_Alloc+Series. Demand files and tables are described in DemoS_010 (Section 3.10.1).
- **Trade Scen**. The trade files include all of the attribute specifications for the trade processes. Multiple trade files may be used, to model different trade scenarios or for different commodities. The naming convention is: ScenTrade_<scenario name>. This section of the Navigator contains also a single file in which all uni- or bilateral trade links

between regions are declared: ScenTrade__Trade_Links. Trade files are introduced in DemoS_005 (Section 3.5.3).

The VEDA-Navigator enables easy access to any of the Excel files constituting the currently open model. Double-clicking directly on any file name (or the Excel icon next to it, in the case of the BY_Trans and SysSettings files) will open that file in Excel, while clicking on the bar above each section of the Navigator will open the associated folder in Windows Explorer. (For example clicking on **SubRES** in Figure 2 will open the folder VEDA\VEDA_Models\DemoS_012 \SubRES_TMPL).

The VEDA-Navigator also provides feedback as to the status of the various files and the integrated database managed by VEDA-FE. The consistency of the files and database is immediately evident based upon whether the central button is marked as **SYNC** in red (as shown on the left side of Figure 2) or as **ALL OK** in blue (right side of Figure 2). The status of individual templates is indicated by their colors in the template lists, according to the legend at the bottom of the form. A file is shown as inconsistent (in red) when it has a newer date/time stamp than in the database. <u>Note</u>: you may need to do a **Refresh** (from the **Window** menu, or hit **F5**) to see the current status of the files after a recent change.

Hitting the **SYNC** button will synchronize all files in the application folder marked as inconsistent. You may force synchronization of other files by checking the checkbox next to their names before hitting **SYNC**.

2.3 VEDA-FE workbook tables

The VEDA-FE import program reads each sheet in each file in sequence, looking for VEDA-FE tables to be read, which are identified by table tags including the special character " ~ ". VEDA-FE tables must be separated from the rest of the worksheet, which may contain any other contents, by blank rows and columns. Rows and columns starting with the character " ***** " or with "\I:", which stands for "ignore", are not read.

The most common types of tables are briefly described in this section. More information on how to use them for specific cases is shown in the sections associated with each step of the demo.

2.3.1 Basic tables needed for any model

The following tables are needed in any VEDA-TIMES model.

- Tables that exist only in the SysSetting file. (Section 3.1.1 describes how to use these tables).
    - **~BookRegions_Map** to declare the workbook name and the list of region names.
    - **~TimeSlices** to declare the time-slice resolution for the model.
    - **~StartYear** to declare the start year of the model.
    - **~ActivePDef** to declare the set of active periods.
    - **~TimePeriods** to declare the time horizon of the model for the ActivePdef.
    - **~ImpSettings** to define some settings for the synchronization process.
    - **~Currencies** to define a default currency for the whole model.
    - **~DefUnits** to define default units by activity, capacity, and commodity for each sector in the model.

- Commodity Definition Tables **(~FI_COMM)** for commodity declaration and definition. These tables can be used in BY, SubRES and SysSetting files. They are described further in Section 2.3.4.
- Process Definition Tables **(~FI_PROCESS)** for process declaration and definition. These tables can be used in BY, SubRES and SysSetting files. They are described further in Section 2.3.5.
- Flexible Import Tables **(~FI_T)** for topology and parameter definition. These tables can be used in BY and SubRES files. They are described further in Section 2.3.6.

2.3.2 Tables need for scenario and transformation files

The following tables can be used to improve and update the model in scenario files and transformation files.

- Transformation Insert Tables **(~TFM_INS)** in scenario and transformation files, used to define absolute values via additional parameters that were not defined in the base year templates.
- Transformation Update Tables **(~TFM_UPD)** in scenario and transformation files operate on existing data defined in previous scenarios. Updates are applied to seed values that are picked up from the closest alphabetically preceding scenario. As shown in Section 2.3.7, Insert and Update tables can use rules to pick out the processes and commodities whose data is to be adjusted.
- Transformation Direct Insert Tables **(~TFM_DINS)** are also used to insert data, but unlike in Insert tables, it is forbidden to define subsets of technologies using text/wildcards, and for each attribute all the required dimensions must be defined (no defaults). These tables can be useful when working with large, detailed source data tables, because VEDA-FE's processing of DINS tables is much faster than that of Insert tables.

2.3.3 Advanced tables

The following tables are special and/or advanced tables that can be used in different types of files to support users in model building.

- Special tags exist for emission commodity tables. With this type of table identifier the data are manipulated during the import process to provide for special calculations on emissions factors.
    - **~COMEMI** to link emissions to commodity consumption. An example on how to use this table is shown in Section 3.7.2.7.
    - **~COMAGG** to define an aggregated commodity TOTCO2.
- Fill tables in scenario files **(~TFM_FILL**) allow extraction of values from the rest of the model database for use in Update or Insert tables. An example is shown in Section 3.7.4.1.
    - The TFM_FILL table is also available in SubRES transformation file. The only difference is that it can only be populated with numbers from the BASE scenario.
    - The fill operation will color the Region cells upon processing to indicate the number of records found, as follow:
        - Blue color represents only one record found, and

- ➢ Purple color represents that more than one record was found for the specified parameter and its dimensions while filling the region value in the relevant row.
  - The user can specify whether multiple values are to be summed, averaged, or counted.
- Different tags exist for transformation tables indicating that the import process is different than from the standard input tables ~FI_T. With this type of table identifier the data are manipulated during the import process and not imported as provided. They are supported in the BY_Trans file, SubRES files, and all scenario files.
  - **~TFM_AVA** to declare the availability of processes in different regions.
- Special tables that exist only in the demand module:
  - **~DRVR_Allocation** to allocate a driver to each end-use demands.
  - **~Series** to define sensitivity and calibration series.
  - **~DRVR_Table** to define demand driver indexes (base-year =1).
- Special tables that exist only in the trade module:
  - **~TradeLinks** to declare uni- or bilateral trade links between regions.
- User constraints are identified with specific identifiers (**~UC_Sets:**)

2.3.4 Commodity definition tables ~FI_COMM

Commodity definition tables (~FI_Comm) are used to declare the non-numerical characteristics of commodities. The columns headers are fixed but their order can be changed. Each commodity needs to be declared (only) once in such a table as shown in Figure 3. They are supported in B-Y Templates, SubRES files, and the SysSettings template. Commodities that are declared in a SubRES can only be used in that SubRES. Care must be taken that commodities are declared only once, as problems can arise if the same commodity is declared twice with conflicting attributes, such as different time slice levels. In large complex models, therefore, a best practice would be to declare them in a single template location only, such as the SysSettings template.

~FI_Comm

Csets	Region	CommName	CommDesc	Unit	LimType	CTSLvl	PeakTS	Ctype
*Commodity Set Membership	Region Name	Commodity Name	Commodity Description	Unit	Sense of the Balance EQN.	Timeslice Level	Peak Monitoring	Electricity Indicator
NRG		COA	Solid Fuels	PJ				

Figure 3. How to use ~FI_COMM (table from DemoS_001)

The valid column headers for a commodity table ~FI_COMM are described in Table 1.

Table 1. Valid column headers for a commodity table ~FI_COMM

Header	Description
Csets*	The sets to which commodities belong. Valid entries are: NRG (energy), MAT (material), DEM (demand service), ENV (emissions) and FIN (financial). These declarations are inherited until the next one is encountered. In this example, COA (Solid Fuels) is an energy commodity (NRG).
Region*	The region name. By default, it is applied to all regions of the model when not specified. The region designation is used only in the B-Y templates and not allowed in SubRES.

CommName	The commodity name (COA).
CommDesc	The commodity description (Solid Fuels).
Unit	The commodity unit throughout the model (PJ). It is responsibility of the user to be consistent with units.
LimType	The sense of the balance equation for the commodity. Valid entries are LO (Production>=Consumption, FX (Production=Consumption), UP (Production<=Consumption). When not specified, the default is LO.
CTSLvl	The commodity time-slice tracking level. Valid entries are ANNUAL, SEASON, WEEKLY and DAYNITE. When not specified, the default is ANNUAL.
PeakTS*	Peak time slice monitoring. Valid entries are: ANNUAL to generate the peaking equation for all time slices or any specific time slices already defined in the SysSettings file (comma-separated entries allowed). If not specified the default is ANNUAL.
CType	Electricity commodities indicator (ELC).

* Note: Comma separated elements are allowed.

2.3.5 Process definition tables ~FI_PROCESS

Process definition tables (~FI_Process) are used to declare the non-numerical characteristics of processes. The columns headers are fixed but their order can be changed. Each process needs to be declared (only) once in such a table as shown in Figure 4. They are supported in B-Y Templates and SubRES files.

~FI_Process

Sets	Region	TechName	TechDesc	Tact	Tcap	Tslvl	PrimaryCG	Vintage
*Process Set Membership	Region Name	Technology Name	Technology Description	Activity Unit	Capacity Unit	TimeSlice level of Process Activity	Primary Commodity Group	Vintage Tracking
*								
MIN		MINCOA1	Domestic Supply of Solid Fuels Step 1	PJ				
		MINCOA2	Domestic Supply of Solid Fuels Step 2	PJ				
		MINCOA3	Domestic Supply of Solid Fuels Step 3	PJ				
IMP		IMPCOA1	Import of Solid Fuels Step 1	PJ				
EXP		EXPCOA1	Export of Solid Fuels Step 1	PJ				

Figure 4. How to use ~FI_PROCESS (table from DemoS_001)

The valid column headers for a process table ~FI_PROCESS are described in Table 2.

Table 2. Valid column headers for a process table ~FI_Process

Header	Description
Sets*	The sets to which processes belong. The process set indicates the nature of a process. Valid entries are: ELE (thermal or other power plant), CHP (combined heat and power), PRE (generic process), DMD (demand device), IMP (import process), EXP (export process), MIN (mining process), HPL (heating plant), IPS for inter-period storage, NST for night storage device, STG for general timeslice storage, STS for simultaneous DayNite/Weekly/Seasonal, STK for simultaneous DayNite/Weekly/Seasonal and interperiod storage process. These declarations are inherited until the next one is encountered. In this example, there are three mining processes (MINCOA*), one import process (IMPCOA1) and one export process (EXPCOA1), all related to the supply of solid fuels (COA).
Region	The region name where the process exists (comma-separated entries allowed).

	By default, it is applied to all regions of the model when not specified. The region designation is used only in the B-Y templates and not allowed in SubRES.
TechName	The process name (e.g. MINCOA1), up to 32 characters. (However, it is recommended to limit process names to 27 characters as VEDA-FE may internally add digits for vintaging issues or dummy imports.)
ProcessDesc	The process description (e.g., Domestic supply of Solid Fuels Step 1), up to 255 characters.
Tact	The activity unit of the process (in Figure 4, for example, it is in PJ). It is the user's responsibility to be consistent with units.
Tcap	The capacity unit of the process. It is the user's responsibility to be consistent with units.
Tslvl	The process time-slice operational level. Valid entries are ANNUAL, SEASON, WEEKLY and DAYNITE. When not specified, the default is based on the Sets declaration: DAYNITE (for ELE, STGTSS, and STGIPS), SEASON (for CHP and HPL), ANNUAL (for all others).
PrimaryCG	The Primary Commodity Group (PCG) of the process. Normally none specified as VEDA allocates the PCG by default. A declaration is needed only when the user wants to create a new PCG and/or override the default PCG.
Vintage	Vintage tracking. Valid entries are YES or NO. When not specified, the default is NO.

* Note: Comma separated elements are allowed.

2.3.6 Flexible import tables ~FI_T

The Flexible Import Table **(~FI_T**) is used to create model topology (process inputs and outputs) in B-Y templates and SubRES. It also provides a very flexible structure (hence the name) for specifying numerical parameter values. With this type of identifier, the data is imported as provided and not modified during the import process.

Unlike in most other table types (with the exception of UC tables, described in Section 2.3.8), the ~FI_T table tag is not placed directly above the upper-leftmost table cell. Instead it is placed in the row immediately above the table headers and in the column before the first column containing values. This placement allows any number of columns to be designated for row identifiers, rather than data, as shown in Figure 5.

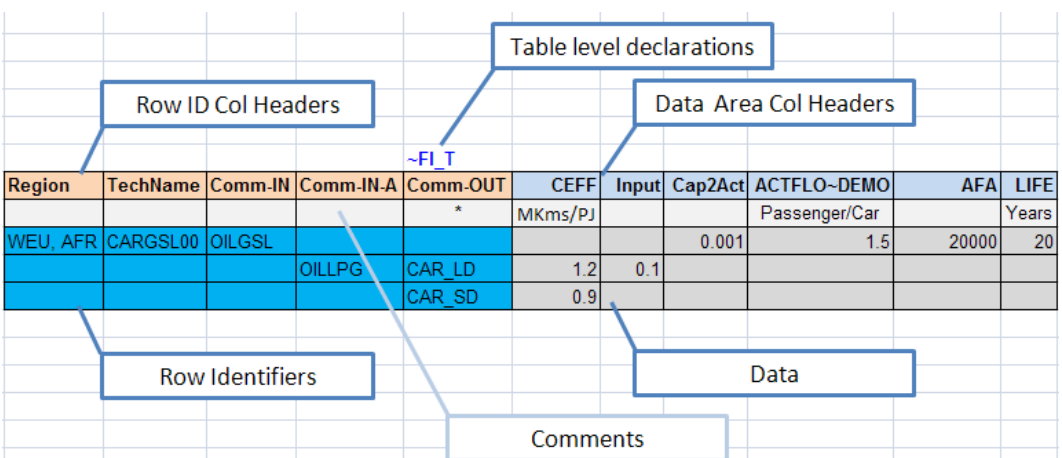


Figure 5. How to use the ~FI_T table

Indexes for the data, including attribute, region, year, and timeslice may be specified as either row identifiers or column headers, so that a table may be laid out to match the configuration of source data with minimal user intervention.

The ~FI_T table has six distinct regions. Valid entries in each of these are:

- Row ID Col Headers. The valid row ID column headers for a ~FI_T flexible import table are described in **Error! Not a valid bookmark self-reference.**.

Table 3. Valid row ID column headers for a flexible import table ~FI_T

Header	Description
Region*	Region declaration
TechName	Technology Name
Comm-IN*	Input Commodity
Comm-IN-A*	Auxiliary Input Commodity
Comm-OUT*	Output Commodity
Comm-OUT-A*	Auxiliary Output Commodity
Attribute	Attribute declaration; single entries permitted
Year	Year declaration; comma-separated entries allowed
TimeSlice*	Time slices declaration; comma-separated entries allowed
LimType	Valid entries are: UP (Upper), LO (Lower), FX (Fixed) and N (Non-binding)
CommGrp	User Defined Commodity Group
Curr	Currency declaration
Stage	For multi-stage stochastic models
SOW	State of the World (Stochastic models)
Other_Indexes	To enter special dimensions that are required in certain attributes

* Note: Comma separated elements are allowed.

- Row Identifiers: elements of the dimension indicated in the row ID column headers.
- Data Area Column Headers: Elements of the following dimensions (elements of multiple dimensions can be separated by ~)
  - Attribute
  - Year
  - TimeSlice
  - LimType
  - Commodity
  - CommGrp (only the internal VEDA commodity groups: DEMO/DEMI/NRGO/NRGI/MATO/MATI/ENVO/ENVI/FINO/FINI can be used as column headers)
  - Region
  - Currency
- Data: numerical entries
- Table level declarations: Declarations like those made in column headers can be included in the table header (following a colon) and will apply to all data that doesn't have a different value for that index specified. For example, ~FI_T: DEMAND would assign

DEMAND as the attribute for all values in the table that don't have an attribute specification at the column or row level.

- Comments: a comment row is identified by the character " ***** " or "\I:" as the first character in any of the cells below the Row ID Col Headers or the first character in any of the column headers. (However, caution should be exercised in using " ***** " to indicate a comment, because it may also be used to indicate a wildcard or an operation in some cells. "\I:" is the safer choice to indicate a comment row/column.)

2.3.7 Transformation Insert and Update tables ~TFM_INS and ~TFM_UPD

~TFM_INS is a transformation table used to insert new attributes and values in a rule-based manner. In this example from DemoS_001, it is used to declare three new attributes (G_DYEAR, Discount, and YRFR) by row as shown in Figure 6.

~TFM_INS					
TimeSlice	LimType	Attribute	AllRegions	REG1	Cset_CN
		G_DYEAR	2005		
		Discount	0.05		
ANNUAL		YRFR	1.00		

Figure 6. How to use ~TFM_INS table

~TFM_UPD is a transformation table used to update pre-existing data in a rule-based manner. For example, in Figure 7 it sets default prices (ACTCOST) for the backstop dummy processes for energy commodities (IMP*Z - dummy IMPort processes ending with "Z") and demands (IMPDEMZ - a dummy IMPDEMZ process that can feed any demand).

~TFM_UPD															
TimeSlice	LimType	Attribute	Year	Other_Inde	AllRegions	REG1	REG2	Pset_Set	Pset_PN	Pset_PD	Pset_CI	Pset_CO	Cset_Set	Cset_CN	Cset_CD
		ACTCOST			2222			IRE	IMP*Z						
		ACTCOST			8888			IRE	IMPDEMZ						

Figure 7. How to use ~TFM_UPD table

Valid column headers for data entry in transformation insert and update tables (to update existing values or insert new values) are presented in the top portion of Table 4. These tables can identify the items whose data is to updated or inserted using the criteria in the bottom portion of Table 4.

Table 4. Valid column headers for transformation tables

Header	Description
	Insert or update values
Attribute	Name of the attribute; single entries permitted
Year	Year declaration; comma-separated entries allowed; default value = start year
TimeSlice	Time slices declaration; comma-separated entries allowed; default=ANNUAL.
LimType	Valid entries are: UP (Upper), LO (Lower), FX (Fixed) and N (Non-binding)
CommGrp	User Defined Commodity Group
Curr	Currency declaration; default=CUR.

Stage	For multi-stage stochastic models
SOW	State of the World (Stochastic models)
Other_Indexes	To enter special dimensions that are required in certain attributes
AllRegions	Data value that is applicable to all regions
<Regions>	Region-specific data values; these will supersede any declaration in AllRegions column
Commodity and process filtering	
PSet_Set[1]	To identify processes based on TIMES set membership
PSet_PN[2]	To identify processes based on names
PSet_PD[2]	To identify processes based on descriptions
PSet_CI[2]	To identify processes based on commodity inputs
PSet_CO[2]	To identify processes based on commodity outputs
CSet_Set[1]	To identify commodities based on TIMES set membership
CSet_CN[2]	To identify commodities based on names
CSet_CD[2]	To identify commodities based on descriptions
Top_Check	To restrict application of attribute data to those process-commodity combinations where the specified topology already exists in the model, rather than creating new topology. Valid entries: **I/O/A.** **"I"** will retain those combinations where commodities are input to processes. **"O"** => Output; **"A"**=> Input or output. No topology check is performed by default.
Attrib_Cond	To filter based upon whether an attribute is present or missing (precede with "-") for specified processes.
Val_Cond	Used in conjunction with Attrib_Cond to filter on the value of the specified attribute. Define using '<', '>', '<>', or '='. The condition will be tested across all dimensions (for example, years) for the specified process, region, and attribute.

[1] Comma separated elements are allowed. Each of these fields can have comma-separated entries that are joined by OR.

[2] Comma separated elements and wild cards characters are allowed. The possible wild cards are:

"*" is used as wild card; for example *GAS* would refer to all elements that have GAS in the name with any possible characters before and after GAS.

"-" before the text used for exclusions; for example, *GAS*,-ELCGAS would refer to all elements that have GAS in the name except for ELCGAS.

"?" can be used to specify a single character; for example, ???GAS means there are 3 characters before GAS.

2.3.8 User constraints and their tables

User constraints provide the modeller with a flexible framework to add case-study specific constraints to the standard equation set embedded in TIMES. With the help of user constraints, virtually any possible linear relationship between core variables in TIMES can be formulated, and some input attributes can also be brought in as coefficients. User constraints can also be written to link variables across consecutive time slices or periods. Section 6.4 of Part II of the TIMES documentation contains an extensive discussion of the user constraint types available and their mathematics.

Defining user constraints in VEDA-FE templates is a two step process. They are first declared with one or more **~UC_SETS:** tags, which indicate their type and domain of coverage. Then their data is specified using a table with similar structure to that of a **~FI_T** table, as shown in Figure 8.

~UC_Sets: R_E: AllRegions													
~UC_Sets: T_E:													
								~UC_T:UC_RHSRTS					
UC_N	**Pset_Set**	**Pset_PN**	**Pset_CI**	**Pset_CO**	**Cset_CN**	**Attribute**	**Year**	**LimType**	**UC_COMNET**	REG1	REG2	**UC_RHSRTS~0**	**UC_Desc**
AU_CO2_BND					TRACO2,ELCCO2		2010	UP	1	1142284	1142284	5	CO2 Bound Constraint
					TRACO2,ELCCO2		2020	UP	1	1227958	1053944		

Figure 8. Defining a user constraint in VEDA-FE

Available UC sets are described in Table 5. Each set definition holds for the entire sheet, unless redefined. All the existing set definitions are applied to all user constraints in a table.

Table 5. UC sets available in VEDA-FE

~UC_SETS:	Signification	Application
R_E	Region_Each	REG1: apply to one particular region REG1,REG2: apply to more than one region (comma separated) AllRegions: will apply to all regions
R_S	Region_Sum	
T_E	Time period_Each	
T_S	Time period_Sum	
TS_E	Time slice_Each	
TS_S	Time slice_Sum	
T_SUC	Time period successive	

A UC table is then structured similarly to a Flexible Import table, with the **~UC_T** tag separating the column headings into row identifiers (UC_INDEXES) and data column headers. Valid row ID (UC_INDEX) column headers are:

Table 6. UC_INDEXES for user constraint tables

UC_INDEXES Column Header	Description
UC_N	Short Name of the UC
Region	Name of the region(s)
PSet_PN*	Comma separated list of process names
PSet_PD*	Comma separated list of process description
Pset_CI*	Comma separated list of (input) commodities to define a set of processes
Pset_CO*	Comma separated list of (output) commodities to define a set of processes
Cset_CN*	Comma separated list of commodity names
Cset_CD*	Comma separated list of commodity description
Side	LHS/RHS; RHS is applicable only in the case of dynamic (across periods) constraints.
Attribute	Any of the UC attributes available in the current TIMES code
UC_ATTR	• Allows modifiers to be applied to the variables used in the UC. These include the GROWTH modifier, to create a constraint that limits the percentage growth in a variable over periods; modifiers to pull input data, such as COST and EFF, into the UC's coefficients;

	and the NEWFLO modifier that applies the UC coefficient to the flows of the new vintage of a process only. More details are found in Section 6.4.6 of Part II. • The contents of this column are comma separated values of UC_Name and UC_GrpType. Several pairs can be separated by ";" • A pair can have UC_Name/GrpType in any order; any element in the list ACT, CAP, NCAP, FLO, IRE, COMCON, COMPRD, COMNET is taken as GrpType and the other one is designated as the UC_Name. Valid UC_Names are provided and described in Section 6.4.6 of Part II. • UC_ATTR can have a ~ appended to it; the default is LHS.
Year	Comma separated list of years is allowed
LimType	UP/LO/FX/N
Top_Check	To control the process-commodity combinations via topology when both indexes exist for the attribute in question. Valid entries: **I/O/A.** **"I"** will retain those combinations where commodities are input to processes. **"O"** => Output; **"A"**=> Input or output. Default = **A.**

* Wild cards allowed

Valid data column headers are:

- Any of the UC attributes available in the current TIMES code
- Years (including 0 for interpolation setting)
- Region
- UP/LO
- LHS/RHS

Multiple values can be separated by "~". Any specification without a region identifier in the column is applied to the region in the row identifier area. If there is no region, it applies to all regions in the active R_E/R_S specification.

A user constraint definition can span multiple rows of the table (to attach numbers/attributes and other indexes to different sets of processes/commodities).

2.4 VEDA-FE database tools

Once the templates have been imported and assembled as a model database within VEDA-FE, it is possible to review the resulting data by means of powerful filtering tools and dynamic data cubes (pivot tables), and it is also possible to view the RES by requesting that the network diagram be displayed.

2.4.1 Browser

The database browser can be accessed from the main menu (**Basic Functions, Browse/Edit, TIMES View** or **VEDA View)** or by pressing **F7**. The **TIMES View** shows the data with TIMES attribute names, while the **VEDA View** shows the same information, but with the attribute names as used in the files[1]. The browser allows the user to view subsets of the assembled data in a cube by selecting the scenario(s), region(s), process(es), commodity(ies),

[1] A variety of alternate attribute names, or *aliases*, are available for many TIMES parameters, as shown in the Attribute Master (see Section 2.4.4).

and/or the attribute(s) of interest: the new nuclear power plants in REG1 in the example shown in Figure 9.

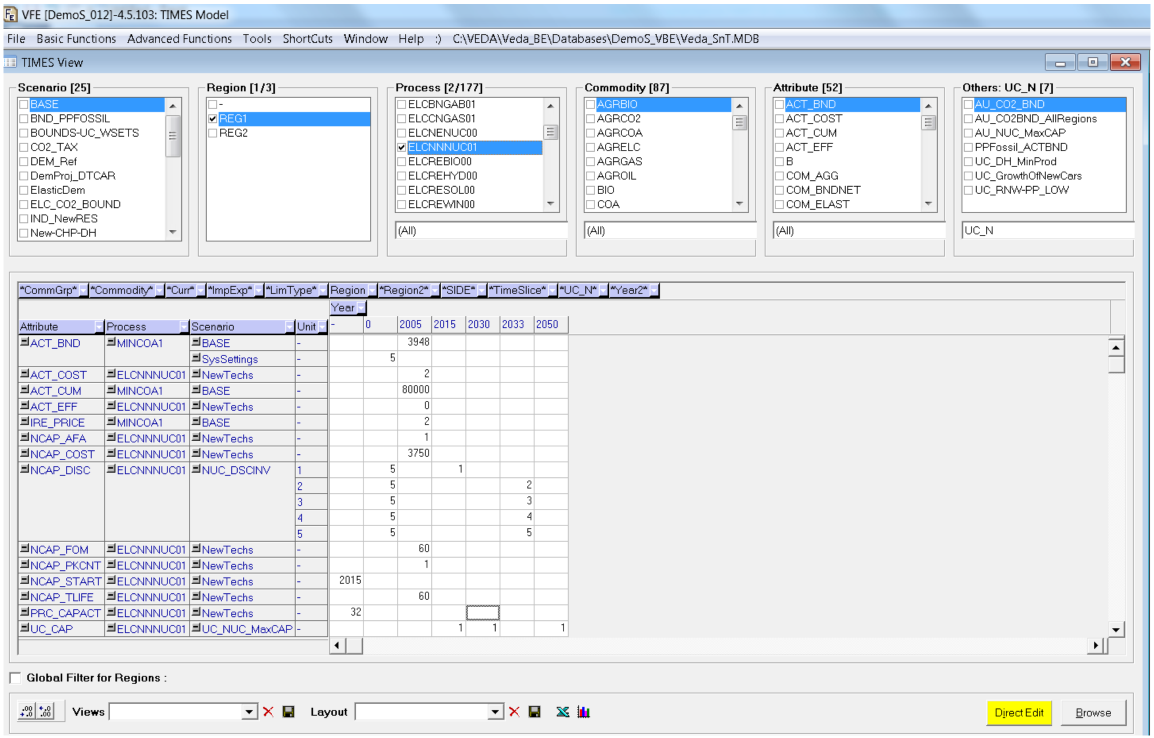


Figure 9. Browser for the model database

First, elements are selected manually or via search tools (right-click) in the different dimensions, and then the information is displayed in a default layout by clicking the **Browse** button. It is possible to rearrange the layout of the cube by adding/removing dimensions (columns and rows) to/from the table by dragging/dropping components from/to the area above the current row designator columns.

When the cursor is placed over a dimension a crosshair appears. Then, holding the left mouse button down and sliding to a new position, a green line will appear indicating that the dimension may now be dropped there. Any dimension not positioned as part of the row/column table layout definition appears at the top of the page. These dimensions have their values summed in the cube. For each dimension on top of the page, if more than one value exists for that dimension, its name will be displayed between two asterisks reinforcing that some values in the cube may be aggregates. Note that for any dimension where only a single value exists, said dimension is automatically moved up top. Using the pull-down arrow associated with each header, individual entries may temporarily be removed by unselecting them from the list of elements.

2.4.2 RES viewer

The RES viewer can be accessed from the main menu (Basic Functions, RES). It is possible to navigate around the model by clicking on the name of a commodity or process, allowing the user to see: 1) in the case of a commodity, all processes producing and consuming that commodity; and/or 2) in the case of a process, all input and output flows. The right panel of Figure 10 shows the RES viewer as zoomed in on commodity ELCNUC. We see the single process that produces it and the two that consume it. The legend in the left panel defines the color coding of the commodities and processes shown. By clicking on any item, the user can cascade through the RES to better visualize the interrelationships and competing processes throughout the network.

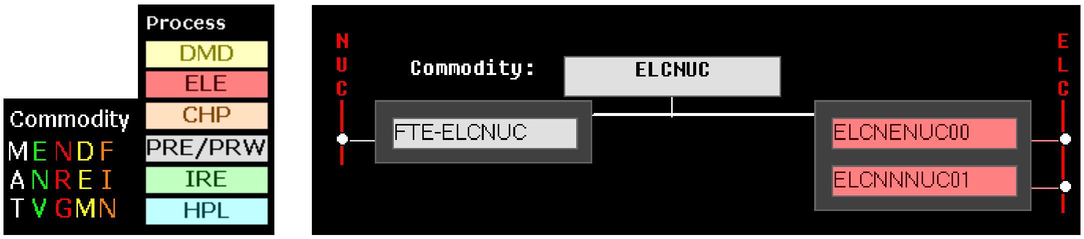


Figure 10. Schematic representation of the RES

2.4.3 Commodity/Process Master

The **Commodity/Process Master** viewer can be accessed from the main menu (**Advanced Functions**). This feature can be used to examine a proccess or commodity's declaration, connectivity, and data details. As in the RES viewer, it is possible to navigate around the model viewing all the commodities/processes immediately before/after the focus item in the RES. In addition, the **Information** and **Data** tabs provide all of the declaration and data information about the focus commodity/process (see Figure 11 and Figure 12). It is also possible to get a full list of commodities/processes in the model by clicking the label **All Commodities** (**Processes**).

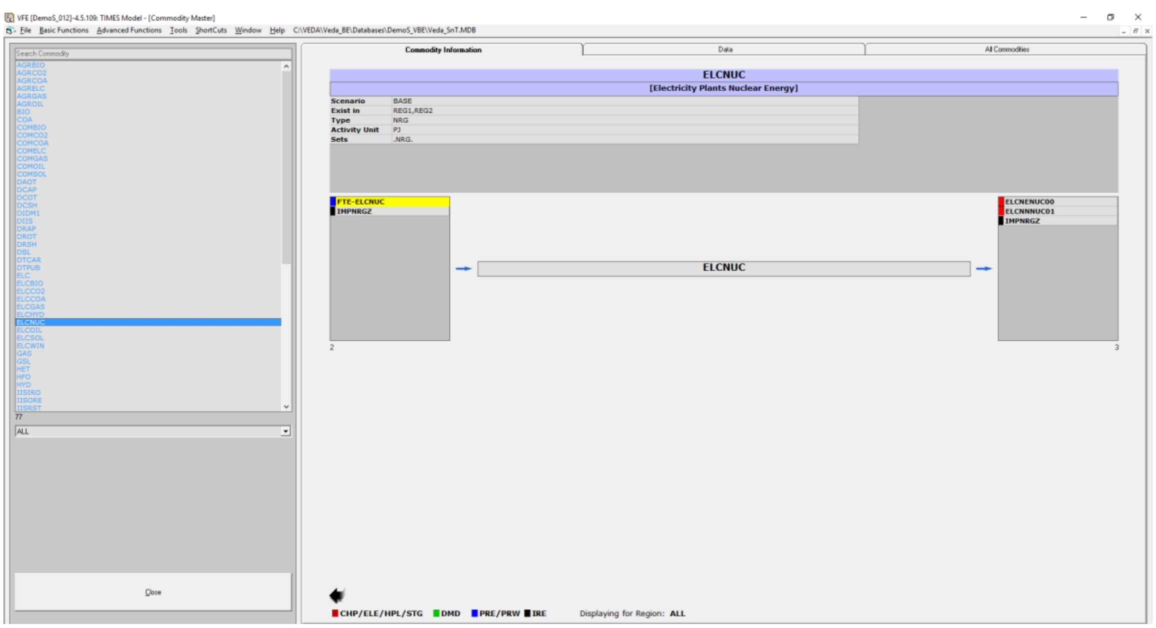


Figure 11. Commodity Master view

2.4.4 Attribute Master Table

The Attribute Master table is available under **Advanced Functions/Attribute Master** (as shown in Figure 13).

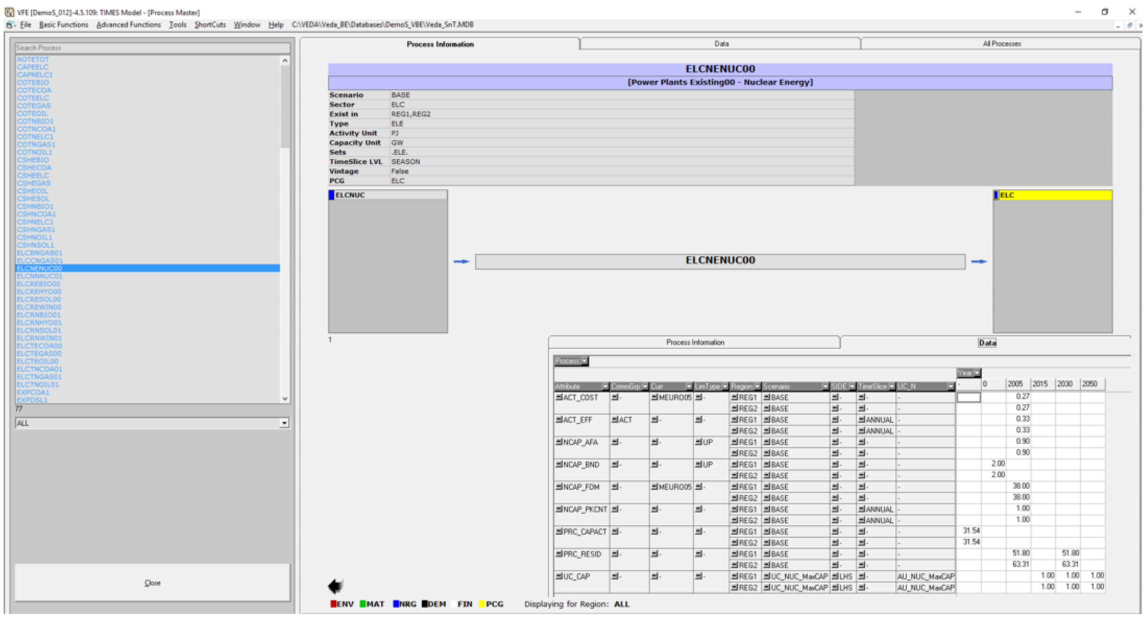


Figure 12. Process Master view and data view

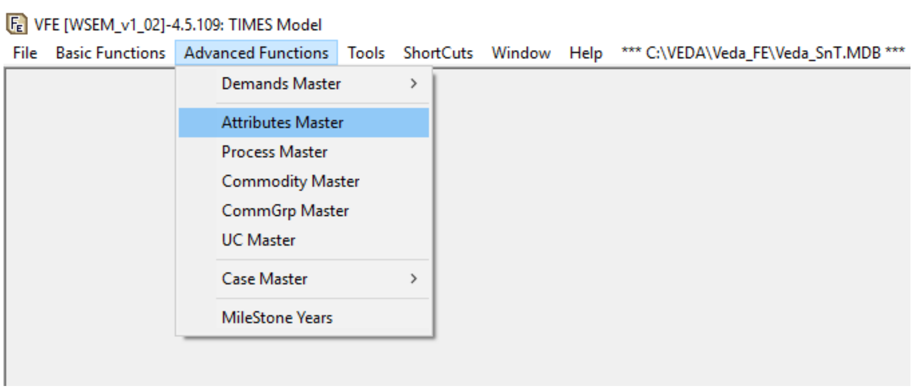


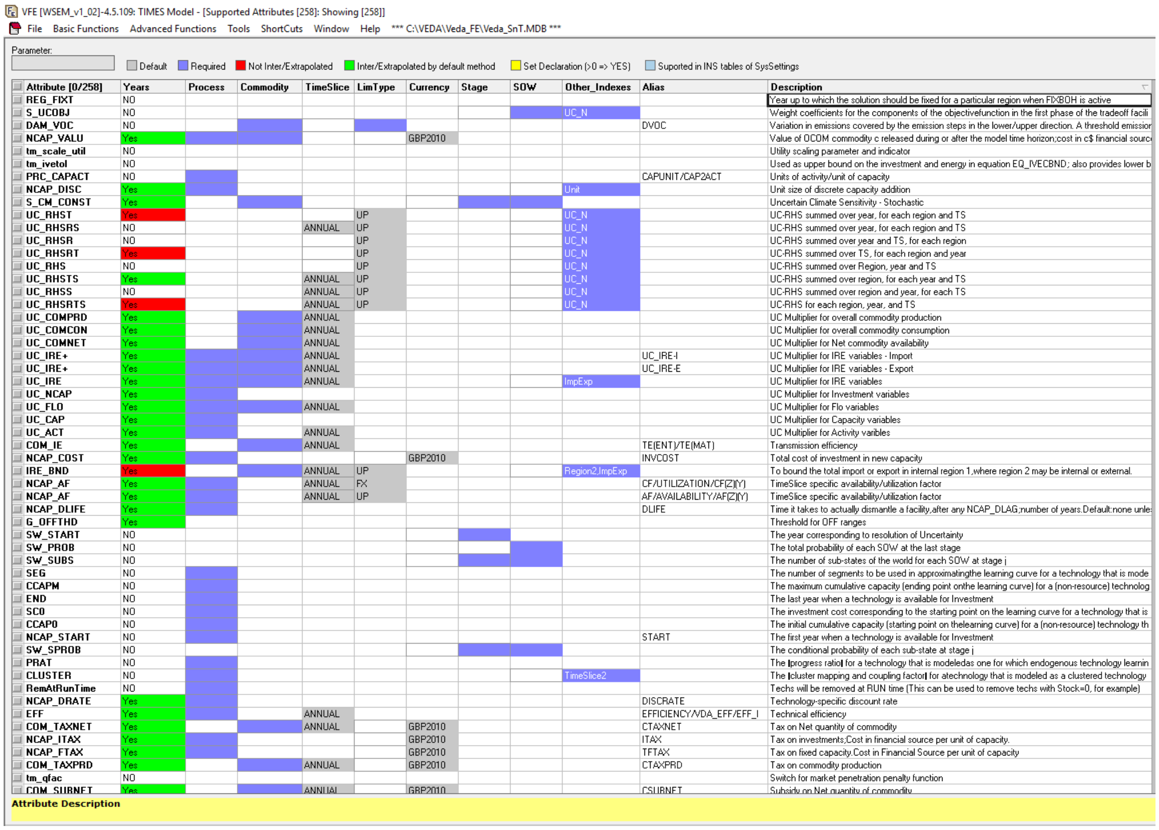
Figure 13. How to find the Attribute Master Table

The Attribute Master table (Figure 14) shows all the TIMES attributes/parameters supported by VEDA-FE and can assist in creating the FI_T, TFM_INS and UPD tables. The table uses the following color code:

- Grey cells indicate a VEDA-FE default applied to an attribute.
- Green or red cells are used to specify whether an attribute is interpolated/extrapolated by default or not (a user rule can always be defined).
- Light blue cells indicate that an attribute index is required.

The table consists of the following columns.

- Attribute: lists the name of each supported attribute that can be used in VEDA-FE tables.



VFE [WSEM_v1_02]-4.5.109: TIMES Model - [Supported Attributes [258]: Showing [258]]

File Basic Functions Advanced Functions Tools ShortCuts Window Help *** C:\VEDA\Veda_FE\Veda_SnT.MDB ***

Parameter:

Default | Required | Not Inter/Extrapolated | Inter/Extrapolated by default method | Set Declaration (>0 => YES) | Suported in INS tables of SysSettings

Attribute [0/258]	Years	Process	Commodity	TimeSlice	LimType	Currency	Stage	SOW	Other_Indexes	Alias	Description
REG_FIXT	NO										Year up to which the solution should be fixed for a particular region when FIXBOH is active
S_UCOBJ	NO								UC_N		Weight coefficients for the components of the objectivefunction in the first phase of the tradeoff facili
DAM_VOC	NO									DVOC	Variation in emissions covered by the emission steps in the lower/upper direction. A threshold emissior
NCAP_VALU	Yes					GBP2010					Value of OCOM commodity c released during or after the model time horizon;cost in c$ financial sourc
tm_scale_util	NO										Utility scaling parameter and indicator
tm_ivetol	NO										Used as upper bound on the investment and energy in equation EQ_IVECBND; also provides lower b
PRC_CAPACT	NO									CAPUNIT/CAP2ACT	Units of activity/unit of capacity
NCAP_DISC	Yes								Unit		Unit size of discrete capacity addition
S_CM_CONST	Yes										Uncertain Climate Sensitivity - Stochastic
UC_RHST	Yes				UP				UC_N		UC-RHS summed over year, for each region and TS
UC_RHSRS	NO			ANNUAL	UP				UC_N		UC-RHS summed over year, for each region and TS
UC_RHSR	NO				UP				UC_N		UC-RHS summed over year and TS, for each region
UC_RHSRT	Yes				UP				UC_N		UC-RHS summed over TS, for each region and year
UC_RHS	NO				UP				UC_N		UC-RHS summed over Region, year and TS
UC_RHSTS	Yes			ANNUAL	UP				UC_N		UC-RHS summed over region, for each year and TS
UC_RHSS	NO			ANNUAL	UP				UC_N		UC-RHS summed over region and year, for each TS
UC_RHSRTS	Yes			ANNUAL	UP				UC_N		UC-RHS for each region, year, and TS
UC_COMPRD	Yes			ANNUAL							UC Multiplier for overall commodity production
UC_COMCON	Yes			ANNUAL							UC Multiplier for overall commodity consumption
UC_COMNET	Yes			ANNUAL							UC Multiplier for Net commodity availability
UC_IRE+	Yes			ANNUAL						UC_IRE-I	UC Multiplier for IRE variables - Import
UC_IRE+	Yes			ANNUAL						UC_IRE-E	UC Multiplier for IRE variables - Export
UC_IRE	Yes			ANNUAL					ImpExp		UC Multiplier for IRE variables
UC_NCAP	Yes										UC Multiplier for Investment variables
UC_FLO	Yes			ANNUAL							UC Multiplier for Flo variables
UC_CAP	Yes										UC Multiplier for Capacity variables
UC_ACT	Yes			ANNUAL							UC Multiplier for Activity varibles
COM_IE	Yes			ANNUAL						TE(ENT)/TE(MAT)	Transmission efficiency
NCAP_COST	Yes					GBP2010				INVCOST	Total cost of investment in new capacity
IRE_BND	Yes			ANNUAL	UP				Region2,ImpExp		To bound the total import or export in internal region 1,where region 2 may be internal or external.
NCAP_AF	Yes			ANNUAL	FX					CF/UTILIZATION/CF(Z)(Y)	TimeSlice specific availability/utilization factor
NCAP_AF	Yes			ANNUAL	UP					AF/AVAILABILITY/AF(Z)(Y)	TimeSlice specific availability/utilization factor
NCAP_DLIFE	Yes									DLIFE	Time it takes to actually dismantle a facility,after any NCAP_DLAG;number of years.Default:none unle:
G_OFFTHD	Yes										Threshold for OFF ranges
SW_START	NO										The year corresponding to resolution of Uncertainty
SW_PROB	NO										The total probability of each SOW at the last stage
SW_SUBS	NO										The number of sub-states of the world for each SOW at stage j
SEG	NO										The number of segments to be used in approximatingthe learning curve for a technology that is mode
CCAPM	NO										The maximum cumulative capacity (ending point onthe learning curve) for a (non-resource) technolog
END	NO										The last year when a technology is available for Investment
SC0	NO										The investment cost corresponding to the starting point on the learning curve for a technology that is
CCAP0	NO										The initial cumulative capacity (starting point on thelearning curve) for a (non-resource) technology th
NCAP_START	NO									START	The first year when a technology is available for Investment
SW_SPROB	NO										The conditional probability of each sub-state at stage j
PRAT	NO										The progress ratio for a technology that is modeledas one for which endogenous technology learnin
CLUSTER	NO								TimeSlice2		The cluster mapping and coupling factor for atechnology that is modeled as a clustered technology
RemAtRunTime	NO										Techs will be removed at RUN time (This can be used to remove techs with Stock=0, for example)
NCAP_DRATE	Yes									DISCRATE	Technology-specific discount rate
EFF	Yes			ANNUAL						EFFICIENCY/VDA_EFF/EFF_I	Technical efficiency
COM_TAXNET	Yes			ANNUAL		GBP2010				CTAXNET	Tax on Net quantity of commodity
NCAP_ITAX	Yes					GBP2010				ITAX	Tax on investments;Cost in financial source per unit of capacity.
NCAP_FTAX	Yes					GBP2010				TFTAX	Tax on fixed capacity.Cost in Financial Source per unit of capacity
COM_TAXPRD	Yes			ANNUAL		GBP2010				CTAXPRD	Tax on commodity production
tm_qfac	NO										Switch for market penetration penalty function
COM_SUBNET	Yes			ANNUAL		GBP2010				CSUBNET	Subsidy on Net quantity of commodity

Attribute Description

Figure 14. Attribute Master table

- Years: specifies whether the attribute can be defined by year (YES) or not (NO). For attributes that can be, the color of the cell indicates the defaultinterpolation/extrapolation (I/E) behavior. If green, there is a default I/E applied. If red, there is not.
- Commodity/Process: specifies whether an attribute may be defined by commodity, process, or both.
- Timeslice column: specifies whether attribute can be defined by timeslice and lists any default applied by VEDA-FE.
- Limtype: specifies whether a limit type is required (light blue) and lists any default applied by VEDA-FE.
- Currency: shows the default currency that will be inserted if none is specified.
- Stage and SOW: these columns indicate where this information is required for attributes used in the stochastic version of TIMES.
- Other_Indexes: list additional information required by an attribute.
- Alias: lists alternative names for the TIMES attribute that can be used in templates.
- Description: provides a description of the attribute.

2.4.5 Case Manager

The Case Manager, available from the **Basic Functions** menu, or by pressing **F9**, is used to compose and submit a model run. Figure 15 illustrates the main features of the Case Manager, as follows:

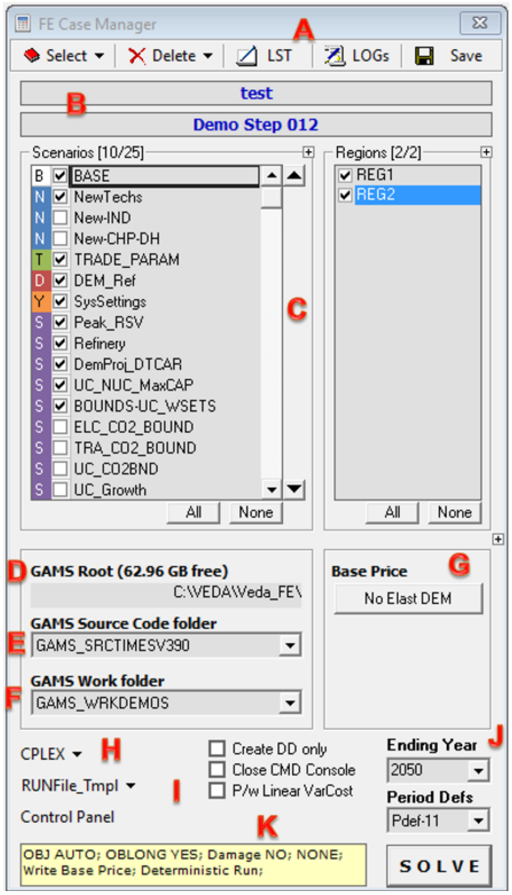


Figure 15. Case Manager

A. **Select**, **Delete**, **LST**, **LOGs** and **Save** buttons. **Select** can be used to choose a previously saved run configuration (run name, run description, scenarios, regions, ….), while **Delete** is used to delete an existing configuration.
LST opens the list file associated with a completed run, with information about the run and equations if enabled.
LOGs opens a QA check log file with information and any warnings about a completed run. (See Part III of the TIMES documentation for more on the LST and QA check files.)
Save is used to save a new configuration or update an existing one.

B. The first row is used to specify a scenario name (spaces in the name are not allowed), while the second row can be used for scenario description.

C. The **Scenarios** and **Regions** lists are used to check and uncheck which scenarios and regions are included in a run configuration. In Figure 15, for example, the scenario New-IND is unchecked, so its data will not be included in the model run. The colored letters in the scenario panel indicate the scenario type. (E.g., white is the BASE scenario from the VT files, light blue are the SubRES, and purple are the Scenario files).

D. Indicates the VEDA installation folder. Clicking on the path here will open a browse to select the installation folder .

E. Indicates the TIMES source code (model generator) installation folder. A left click on **GAMS Source** will open the folder.

F. Indicates the folder in which the results of this run will be saved. It is possible to create a new save folder by selecting **New Folder** from the dropdown menu here. A left click on **GAMS Work folder** will open the folder.

G. This button is used to choose the reference prices in the TIMES elastic demand variant.

H. The **Cplex** button opens a window used to set up options for the CPLEX solver. The dropdown menu allows selection of an alternative solver on your computer.
The RUNfile_Tmpl button opens the run file used by TIMES when the model is submitted to be solved. The dropdown allows selection from alternative versions of the run file.
Control Panel provides access to a selection of control panel switches (described in Part III of the TIMES documation) and TIMES variants (described in Parts I and II).

I. **Create DD** is used to create a data dictionary (DD) file without solving the model.
Close DMD Console if checked will automatically close the "DOS" window at the end of the run.
P/w Linear VarCost used to reduce run size by projecting linear variable costs.

J. **Ending Year** allows selection of the ending year of a run.
Period Defs allows selection among period definitions (saved in the SysSetting file).

K. Summary of run option selections.

More information on VEDA-FE and description of additional features are available at http://support.kanors-emr.org/. Each of the remaining sections of this document describes one incremental step of the VEDA-TIMES Demo Models.

3 TIMES demo models

This section explains how to progress in the use of TIMES features and variants using the set of VEDA-TIMES Demo Models. This is a set of VEDA-TIMES models that start from an energy balance and focus on building a model incrementally employing a standard approach to describe the underlying Reference Energy System (RES) as well as specific naming conventions.

The first step model starts with a simple supply curve feeding a single demand. The Demos then grow step by step to build out the RES, adding new commodities, processes (or technologies) and regions, while introducing new attributes (or parameters) and more advanced TIMES modelling features, and explaining the *why* of the different choices made in VEDA-FE for building these models.

The VEDA-TIMES Demo Models consist of several incremental steps. Steps 1 to 12 are considered the Basic Demo models (Table 7), and are described in this section.). For each step, it provides:

- A brief description of the step model and the objectives in terms of VEDA-TIMES features demonstrated;
- A summary of attributes introduced and files created, modified, and/or replaced;
- A step-by-step description of the template tables created and/or modified in each file; and
- A brief look at the results.

Table 7. The Basic Demo models

Demo	Folder name	Short description
001	DemoS_001	Resource supply
002	DemoS_002	More demand options and multiple supply curves
003	DemoS_003	Power sector: basics
004	DemoS_004	Power sector: sophistication
005	DemoS_005	2-region model with endogenous trade: compact approach
006	DemoS_006	Multi-region with separate regional templates
007	DemoS_007	Adding complexity
008	DemoS_008	Split Base-Year (B-Y) templates by sector: demands by sector
009	DemoS_009	SubRES sophistication (CHP, district heating) and Trans files
010	DemoS_010	Demand projections and elastic demand
011	DemoS_011	Linking input templates and VEDA-BE sets
012	DemoS_012	More modelling techniques

3.1 DemoS_001 - Resource supply

Description. This is the first step and therefore represents a very simple model that serves as the starting point for the development of a more complex model: it includes a single supply curve and a single demand for one commodity in a single region over two time periods.

Objective. The objective is to introduce examples of how to implement in VEDA-FE templates the most basic types of energy commodities and processes that are normally part of a typical TIMES model, along with their respective attributes: a three-step supply curve, an import and an export option, one generic demand and one demand process for one energy commodity (i.e. coal).

This first demo is used also to introduce the SysSettings workbook, the base year template (or VT template), and how to use the most common VEDA-FE tables.

Attributes introduced[2]:		Files created
G_DYEAR	EFF	SysSettings
Discount	AFA	VT_REG_PRI_v01
YRFR	INVCOST	
CUM	FIXOM	
COST	LIFE	
ACT_BND	DEMAND	

The first step model is built using only two files: the default SysSettings file and one B-Y Template (VT_REG_PRI_V01). The base year transformation file (BY_Trans) is created by default; it is empty at this stage. Figure 16 shows the VEDA-FE Navigator (see Section 2.2) for the DemoS_001. This is the first window you will see when you switch from an other model to the DemoS_001.

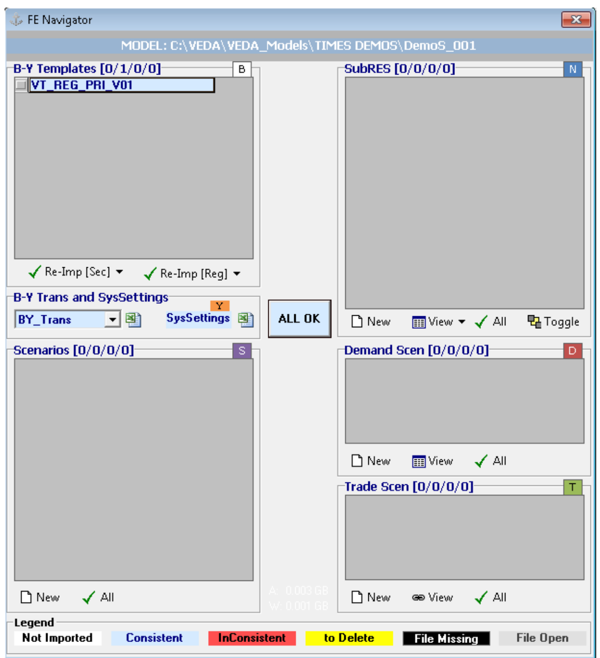


Figure 16. The files included in DemoS_001

The reference energy system (RES) of this first demo can be viewed in VEDA-FE (see Section 2.4.2 for more information), and it is shown in Figure 17. The RES shows an energy service demand called TPSCOA satisfied by an end-use demand device called DTPSCOA, which uses as its input the commodity called COA. The COA commodity can be also exogenously exported outside the model boundary with the export technology called EXPCOA1.

[2] The meaning of all the attributes, along with their qualifier indexes, as said above can be found in VEDA-FE, Advanced Functions menu, Attributes Master (Figure 14).

The production of the COA commodity is based on one import technology (IMPCOA1) and on a three step local supply curve with the technologies MINCOA1, MINCOA2 and MINCOA3.

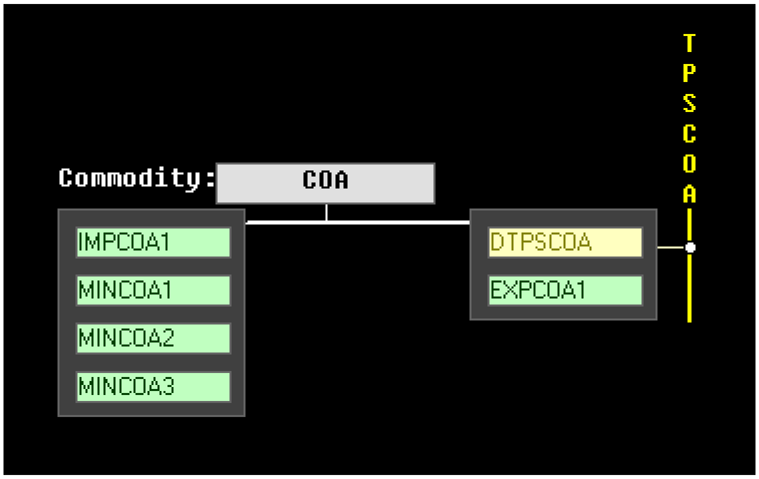


Figure 17. Reference energy system DemoS_001

The next two sections explain how this TIMES model for delivering the commodity TPSCOA at the minimum cost is built in VEDA-FE sheet by sheet for the two templates of this first demo.

3.1.1 SysSetting template

This file is used to declare the very basic structure of any VEDA-TIMES model, including its regions, time slices, start year, etc. It also contains some settings for the synchronization process and can include some additional information. In this example, this file contains the following sheets:

- Region-Time slices
- TimePeriods
- Import Settings
- Interpol_Extrapol_Defaults
- Constants
- Defaults
- Commodity Group. (This sheet is not used in the basic Demos. In general it can be used to build user commodity groups.)

3.1.1.1 <u>Region-Time slices</u>

This sheet contains two tables (Figure 18):

- ~BookRegions_Map is used to define
  1. The workbook name (here, REG), which needs to be the same for each B-Y Template of a region.
  2. The list of model region names (REG1). In this first step, there is only one region and one file.

- ~TimeSlices is used to define the time-slice resolution for the model at different hierarchical levels: SEASON, WEEKLY and DAYNITE. In this first step, there is only one time slice defined by the user for the seasonal level and called ANNUAL.

~BookRegions_Map	
BookName	Region
REG	REG1

~TimeSlices		
Season	Weekly	DayNite
ANNUAL		

Figure 18. Regions and time slices definition in the SysSettings file for DemoS_001

3.1.1.2 <u>TimePeriods sheet</u>

This sheet contains three tables (Figure 19):

- ~StartYear is used to define the start year of the model (2005 for this example and all the other steps).
- ~ActivePDef is used to select the set of active periods (Pdef-1, by default) from all those defined in the following table.
- ~TimePeriods is used to specify period definitions by specifying the number of years for each period. In this step, only a single period definition has been created (Pdef-1), which contains 1 year for the first period (start year) and 2 years for the second period.

~StartYear
2005

~ActivePDef
Pdef-1

~TimePeriods
Pdef-1
1
2

Figure 19. Start year and time period definition in the SysSettings file

3.1.1.3 <u>Import Settings sheet</u>

This sheet contains one table (Figure 20):

- ~ImpSettings is used to declare some settings for the synchronization process (1= active; 0=non active).
  - Check #DIV/0 and #REF errors in Templates – VEDA will produce a log after the import process identifying errors made by the user.
  - Dummy Imports – These backstop dummy processes can be introduced in the model automatically by VEDA in order to avoid infeasibilities that may arise

when there is not enough energy carrier produced or when a demand cannot be supplied. These aid in the model debugging process.

- Vintage Bounds - VEDA can automatically generate bounds to prohibit investments in processes when a newer vintage becomes available, assuming that the last two characters of the process name are used for the first year of availability.
- DumVarforUC – This dummy variable option can be introduced in the model automatically by VEDA for each User Constraint in order to avoid infeasibilities due to a user constraint. These aid in the model debugging process.

~ImpSettings

Option	Value
Check #DIV/0 and #REF errors in Templates	1
Create Dummy Imports for Energy and Material Commodities	1
Create Dummy Imports for Demands	1
Generate Vintage Bounds	0
DumVarforUC	0

Figure 20. Import settings in the SysSettings file

3.1.1.4 <u>Interpol_Extrapol_Defaults sheet</u>

This sheet normally contains two tables, one for setting user interpolation rules applied to all the other files unless the user specifies new rules in other templates to overwrite this information, and one for setting the default prices of dummy import processes. There is only the second table in the current version (Figure 21).

- ~TFM_UPD (transformation update table) is a transformation table used to update pre-existing data in a rule-based manner. In this example, it sets default prices (ACTCOST) for the backstop dummy processes for energy commodities (processes with names matching IMP*Z – dummy IMPort processes ending with "Z") and demands (IMPDEMZ - a dummy IMPDEMZ process that can feed any demand). These costs should be a few orders of magnitude higher than real import costs in your model in order to ensure that these processes only become active when real fuel supplies are insufficient or unavailable.
- More information about this type of table is available in Section 2.3.7.

~TFM_UPD

TimeSlice	LimType	Attribute	Year	Other_Inde	AllRegions	REG1	REG2	Pset_Set	Pset_PN	Pset_PD
		ACTCOST			2222			IRE	IMP*Z	
		ACTCOST			8888			IRE	IMPDEMZ	

Figure 21. Dummy import prices in the SysSettings file

3.1.1.5 <u>Constants sheet</u>

This sheet contains one table (Figure 22):

- ~TFM_INS is a transformation table used to insert new attributes and values in a rule-based manner. In this first step, it is used to declare three new TIMES attributes.

- G_DYEAR - discounting year; this is a user input and in this example is 2005.
- DISCOUNT - overall discount rate for the energy system; this is a user input and in this example is 5% and is constant for the entire modelling horizon. The same rate is used for depreciation of investments.
- YRFR - fraction of year for each time slice; this is a user input and in this example is 100% for the single ANNUAL time slice.

- More information about this type of table is available in Section 2.3.7.

~TFM_INS					
TimeSlice	LimType	Attribute	AllRegions	REG1	Cset_CN
		G_DYEAR	2005		
		Discount	0.05		
ANNUAL		YRFR	1.00		

Figure 22. Constant declarations in the SysSettings file

3.1.1.6 Defaults sheet

This sheet contains two tables (Figure 23):

- ~Currencies is used to define a default currency for the whole model; this is a user input. In this example the default unit is million 2005 euros (MEuro05). It is important to note that for TIMES this is just a label called MEuro05. It is the user's responsibility to be consistent with costs and units in the model.
- ~DefUnits is used to define units for activity, capacity and commodity for each sector in the model: petajoules (PJ) and petajoules per year (Pja) in this case. Again, it is the user's responsibility to ensure consistency in the units used in any TIMES model. It is possible to use any units, but it is important to be coherent across the model.

~Currencies
Currency
MEuro05

~DefUnits	
Option	PRI
Process_ActUnit	PJ
Process_CapUnit	Pja
Commodity_Unit	PJ

Figure 23. Default declarations in the SysSettings file

3.1.2 B-Y Template

The B-Y templates are used to set up the base structure of the model, and in principle it is possible to build a full model using just B-Y templates. This is the approach used for this first example. Later when the model grows to include more commodities, technologies, sectors, regions, and additional information to run different scenarios, we will demonstrate the flexibility and modularity of VEDA-FE using different types of workbooks to input information.

In this first example the B-Y Template is used to set up the base-year process stock and the base-year end-use demand levels, such that the overall energy flows reflect the energy balance.

3.1.2.1 RES&OBJ sheet

This sheet contains some pictures showing the normal completion of a run in VEDA-FE with the value of the objective function and the same objective function in the VEDA-BE table. It is also showing the reference energy system of this model step using the VEDA-FE feature Go-To RES described in Section 2.4.2.

3.1.2.2 EnergyBalance sheet

This sheet contains the energy balance at the model start year (2005) for REG1 (Figure 24). The energy balance in itself is not imported into the model; the table is not identified with any VEDA table header (cell starting with the character "~"). However, it allows the user to calibrate the model start year with appropriate historical energy flows. A typical energy balance comprises two dimensions:

- Different types of energy commodities in columns. In this simple example, the different types of energies are partially aggregated in categories (e.g. solid fuels, renewable energies, etc.). The first row of the table includes codes defined by the modeller that are used to name the energy commodities in the model.
- Steps of the whole supply-demand chain in rows. This simple example shows three main sections: primary energy supply, energy conversion and final energy consumption. For each energy commodity, the primary energy supply minus the energy used for conversion yield the remainder for final energy consumption. The first column of the table includes codes defined by the modeller that are used to name energy processes in a uniform manner in the model.

		COA	GAS	OIL	NUC	RNW	SLU	HET	ELC	
		Solid Fuels	Natural Gas	Crude Oil	Nuclear Energy	Renewable Energies	Industrial Wastes	Derived Heat	Electricity	Total
	PRIMARY									
MIN	Domestic Supply	8098	7899	5379	10775	5027	0	0	0	**37178**
IMP	Imports	6463	13292	39960	0	113	0	0	1168	**60995**
EXP	Exports	-1147	-2516	-14831	0	-72	0	0	-1127	**-19693**
TPS	**Total Primary Supply**	13414	**18675**	**30508**	**10775**	**5067**	**0**	**0**	**41**	**78480**
	CONVERSION									
ESC	Energy Sector Consumption	-58	-793	-1849	0	-4	-2	0	0	**-2705**
ELC	Electricity Plants	-9598	-5636	-1225	-10775	-1256	-33	1738	11581	**-15204**
HPL	Heat Plants	-161	-301	-50	0	-140	-2	659	0	**5**
REF	Petroleum Refineries			-31736						**-31736**
	Total Conversion	**-9817**	**-6730**	**-34859**	**-10775**	**-1400**	**-36**	**2396**	**11581**	**-49640**
	FINAL									
RSD	Residential	357	5160	2289	0	1294	0	865	2872	**12837**
COM	Commercial	57	1752	855	0	67	1	255	2527	**5514**
IND	Industry	1897	4437	2016	0	722	117	634	4088	**13911**
AGR	Agriculture	44	201	797	0	63	0	16	19	**1141**
TRA	Transport	1	21	14851	0	131	0	0	266	**15270**
OTH	Other	1189	0	393	0	1390	0	627	650	**4249**
NEN	Non Energy	52	634	4073		0	0	0	0	**4759**
BNK	Bunkers	0	0	2111		0	0	0	0	**2111**
TFC	**Total Final Consumption**	**3597**	**12205**	**27385**	**0**	**3667**	**118**	**2396**	**10423**	**59791**

Data used in the templa te to buld the model

	COA
Domestic Supply Curve Share - Step 1	75%
Domestic Supply Curve Share - Step 2	25%

Figure 24. Initial energy balance at start year 2005 for REG1 – Covered in DemoS_001

The portion of the energy balance that is developed in this first step model is identified using a different color (orange): primary supply of solid fuels (COA).

A greater level of disaggregation can be added along both commodity and sector dimensions using additional user assumptions as data sources. In this example, shares are provided below the energy balance table to split the total domestic production of solid fuels (COA) into more than one step. This way, it is possible to set up in the model a supply curve defined by the maximum production and cost of each step.

3.1.2.3 Pri_COA

This sheet shows how to declare commodities and processes (in their respective declaration tables) and to describe specific supply processes (in a flexible import table): primary supply of solid fuels (COA) in this example.

In any TIMES model, all commodities and processes in the model need to be declared once in commodity tables (identified with ~FI_Comm) and process tables (identified with ~FI_Process) with a structure as explained in Sections 2.3.4 and 2.3.5 and shown in Figure 25 and Figure 26.

~FI_Comm								
Csets	Region	CommName	CommDesc	Unit	LimType	CTSLvl	PeakTS	Ctype
*Commodity Set Membership	Region Name	Commodity Name	Commodity Description	Unit	Sense of the Balance EQN.	Timeslice Level	Peak Monitoring	Electricity Indicator
NRG		COA	Solid Fuels	PJ				

Figure 25. A typical commodity declaration table

~FI_Process								
Sets	Region	TechName	TechDesc	Tact	Tcap	Tslvl	PrimaryCG	Vintage
*Process Set Membership	Region Name	Technology Name	Technology Description	Activity Unit	Capacity Unit	TimeSlice level of Process Activity	Primary Commodity Group	Vintage Tracking
*								
MIN		MINCOA1	Domestic Supply of Solid Fuels Step 1	PJ				
		MINCOA2	Domestic Supply of Solid Fuels Step 2	PJ				
		MINCOA3	Domestic Supply of Solid Fuels Step 3	PJ				
IMP		IMPCOA1	Import of Solid Fuels Step 1	PJ				
EXP		EXPCOA1	Export of Solid Fuels Step 1	PJ				

Figure 26. A typical process declaration table

Unlike the tables used to declare commodities and processes, the tables used to describe specific processes are very flexible (~FI_T). They are built using first **Row ID column headers** before and below the ~FI_T tag to identify the process names (TechName), descriptions (TechDesc), commodity inputs (Comm-IN), and commodity outputs (Comm-OUT), as well as the years of data (Year) when relevant. Then **Data column headers** after the ~FI_T are used to describe these processes. The number and arrangement of rows and columns is totally flexible in these tables. More information about the ~FI_T tables is available in Section2.3.6.

In the first model step, a flexible import table is used to describe the primary supply options for COA (Figure 27):

- A 3-step domestic coal supply curve through three mining processes (MINCOA*), each characterized with the cumulative amount of resources available over the modelling horizon (CUM), the annual cost per unit of energy (COST) and a bound on the annual production (ACT_BND) for the start year 2005 and the following period 2006. Bounds need to be combined with the LimType (UP), which is indicated in a specific column in this example. When not specified, it is UP by default (see Attribute Master Table, Section 2.4.4).

- Import and export options are characterized with the COST and ACT_BND attributes.

				~FI_T			
TechName	**Comm-IN**	**Comm-OUT**	**Year**	**LimType**	**CUM**	**COST**	**ACT_BND**
*Technology Name	Input Commodity	Output Commodity			Reserves Cumulative Value	Cost	Annual Production Bound
*Units					PJ	M€2005/PJ	PJ
MINCOA1		COA	2005	UP	80000	2.00	6074
			2006	UP			6074
MINCOA2		COA	2005	UP	160000	2.50	2025
			2006	UP			2025
MINCOA3		COA			320000	3.00	
IMPCOA1		COA				2.75	
EXPCOA1	COA		2005	UP		2.75	1147
			2006	UP			1147

*Blue cells are linked to the energy balance.

Figure 27. Description of supply options in a flexible table

3.1.2.4 DemTechs_TPS

This sheet shows how to declare commodities and processes (in their respective tables) and to describe specific demand processes (in a flexible import table): a demand process to deliver the total primary supply coal demand, in this example.

A new DEM commodity (TPSCOA -Demand Total Primary Supply – COA) and a new DMD process (DTPSCOA – Demand technology Total Primary Supply – COA) are declared in the commodity and process tables (Figure 28), as described in the previous section.

~FI_Comm								
Csets	**Region**	**CommName**	**CommDesc**	**Unit**	**LimType**	**CTSLvl**	**PeakTS**	**Ctype**
*Commodity Set Membership	Region Name	Commodity Name	Commodity Description	Unit	Sense of the Balance EQN.	Timeslice Level	Peak Monitoring	Electricity Indicator
DEM		TPSCOA	Demand Total Primary Supply - COA	PJ				

~FI_Process								
Sets	**Region**	**TechName**	**TechDesc**	**Tact**	**Tcap**	**Tslvl**	**PrimaryCG**	**Vintage**
*Process Set Membership	Region Name	Technology Name	Technology Description	Activity Unit	Capacity Unit	TimeSlice level of Process Activity	Primary Commodity Group	Vintage Tracking
*								
DMD		DTPSCOA	Demand Technology Total Primary Supply - COA	PJ	PJa			

Figure 28. Declaration of demand commodities and processes

A flexible import table is used to describe the demand option for total solid fuels (Figure 29):

- A demand process for the total primary supply of COA (DTPSCOA) is characterized with an efficiency (EFF), an annual availability factor (AFA), an investment cost (INVCOST), a fixed operation and maintenance cost (FIXOM), and a technical lifetime (LIFE). By default this technical lifetime is also used as the economic lifetime, unless a specific economic lifetime (ELIFE) is defined.

		~FI_T						
TechName	**Comm-IN**	**Comm-OUT**	**STOCK**	**EFF**	**AFA**	**INVCOST**	**FIXOM**	**LIFE**
*Technology Name	Input Commodity	Output Commodity	Existing Installed Capacity	Efficiency	Utilisation Factor	Invesctment Cost	Fixed O&M Cost	Lifetime
*Units			PJa			M€2005/PJ	M€2005/PJa	Years
DTPSCOA	COA	TPSCOA		1.00	0.95	10	0.20	20

Figure 29. Description of a simple demand processes

3.1.2.5 Demands

This sheet is used to specify the demand (DEMAND) value for the TPSCOA at the base year 2005 (Figure 30). This value comes from the energy balance and represents the total final COA consumption and the total consumed for energy conversion. This demand is constant over the time horizon of the analysis due to the default interpolation/extrapolation applied to the attribute Demand. The future values can be changed by specifying new inputs for the future years/periods.

	~FI_T		
Attribute	**CommName**	***Unit**	**2005**
*	Demand Commodity Name	Demand Unit	Demand Value
*Units			PJ
Demand	TPSCOA	PJ	13414

*Blue cells are linked to the energy balance. Here, the demand value is equivalent to the sum of Total Conversion plus Total Final consumption.

Figure 30. Definition of base year demand values

3.1.3 Solving the model

The model is solved via the FE Case manager (**Basic Functions, Case Manager**), explained more in detail in Section 2.4.5.

For all step models, all cases (runs) are pre-defined by default (Figure 31) with a name and a description (here, DemoS_001; Demo Step 001), the components to be included in the run (BASE, SysSettings), the Regions (REG1), the Ending Year (2006), and the Period Defs (Pdef-1). It is important to note that the BASE component represents all the base year information included in all B-Y Templates together (only VT_REG_PRI_V01 in this example).

The optimizer options (**CPLEX button**) and the model variants (**Control Panel**) are also set by default. The model can be launched by clicking the **SOLVE** button. The model will be solved using the TIMES source code indicated under **GAMS Source Code folder** and the results files stored in the folder indicated below **GAMS Work folder**.

3.1.4 Results analysis in VEDA-BE

The results of a model run in VEDA-FE can be imported into VEDA-BE through the VEDA-BE menu command **Results, Import/Archive**.

A results database distributed with the Demo models called **DemoS_VBE** already contains pre-defined tables as well as commodity/process sets and all step runs described in this manual. This database should be pasted into the VEDA-BE/Databases folder. Then it can be opened in VEDA-BE by selecting **Open Database** from the **File** menu and browsing to the VEDA-BE/Databases/ DemoS_VBE folder.

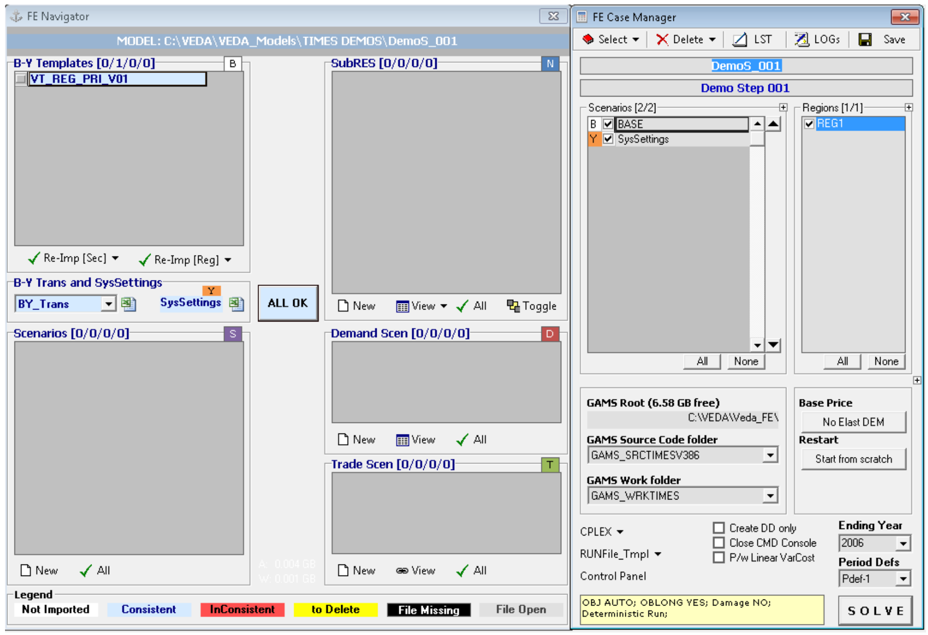


Figure 31. VEDA-FE Case Manager for submitting model runs

The list of pre-defined tables can be seen under **Table definition** at the top left of the main window. To view a particular table, scroll down/up the list and select it, then click the **View Table(s)** button. The table will open with a pre-defined layout than can be modified in a very flexible manner. Not all of the tables can be used for the first demo steps, in which only few results and information will be available. If a VEDA-BE table is inconsistent or empty you will get a pop up message saying that table is empty.

For more information on the capabilities and use of VEDA-BE, see Part V of the TIMES documentation.

The main VEDA-BE tables that can be checked for the first DemoS are:

- __Check Dummy Imports (Figure 32)

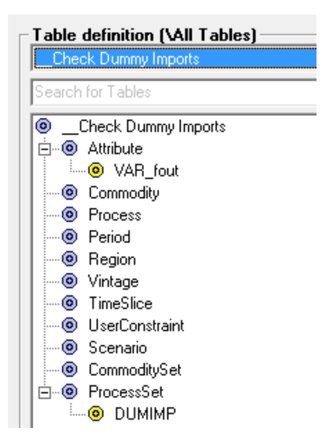


Figure 32. __Check Dummy Imports table in VEDA-BE

- In an healthy model this table should be empty. If not, it means the model has some infeasibilities and is using some dummy technologies (built by default in VEDA-FE) to satisfy the commodity/demand production.
- This table is built by selecting the attribute VAR_FOUT and the ProcessSet DUMIMP (this is a user-defined process set).

- _SysCost
  - This table (Figure 33), built selecting the attribute Reg_Obj, shows the total system cost discounted to the G_DYEAR defined in the SysSettings file (in this example 2005). Figure 34 shows the total system cost in million euros for the model run to 2006, based on two periods (2005 and 2006) for a total of three years.

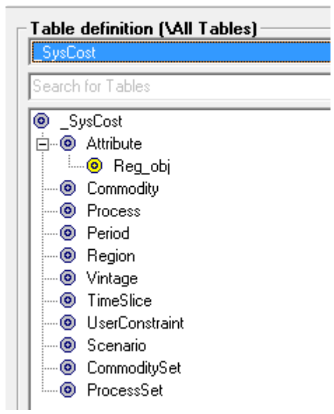


Figure 33. _SysCost table in VEDA-BE

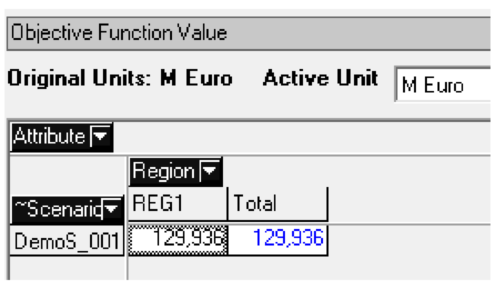


Figure 34. Total system cost in DemoS_001

  - The Scenario label shows the scenario name (DemoS_001) for the run we are viewing, while under the column Region we see the region name (REG1) and the value of the objective function. The column Total is shows the total by row (over regions). In this case, we only have the single region REG1, so the value is the same.
  - The _SysCost table provides a key model run indicator. In TIMES models, the Objective-Function is to minimize the total discounted cost of the system, properly augmented by the 'cost' of lost demand (when using the elastic demand features). See Parts I and II of the TIMES documentation for more on the model objective function.

- All costs
    - This table can be used to show the undiscounted cost elements of the model solution (Figure 35).

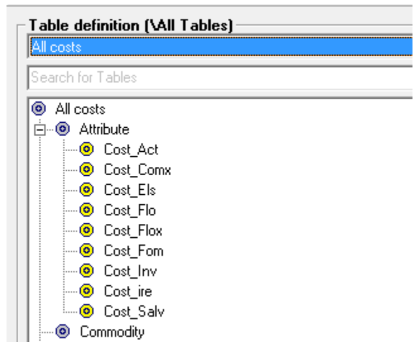


Figure 35. All costs table in VEDA-BE

    - The cost elements, each an individual attribute selected in the table definition, comprise capital costs for investing in and/or dismantling processes (Cost_Inv), fixed O&M costs (Cost_Fom), activity costs (Cost_Act), flow costs including import and export prices (Cost_Flo), implied costs of endogenous trade (Cost_ire), taxes and subsidies (Cost_Flox, Cost_Comx), salvage value of processes and commodities at the end of the planning horizon (Cost_Salv), and welfare loss resulting from reduced end-use demands (Cost_Els).
    - The undiscounted cost elements (in million euros) that are part of the solution for this first step for REG1 are shown below (Figure 36).

All costs

All system costs (activity, flow, investments and salvage)

Original Units: M Euro　Active Unit: M Euro　Data values filter:

Region | *Vintage* | *UserConstraint* | *Commodity* | *Process*

~Scenario~	Attribute	-	2005	2006
DemoS_001	Cost_Flo [Annual flow costs (including import/export prices)]		31,827	31,827
	Cost_Fom [Annual fixed operating and maintenance costs]		2,824	2,824
	Cost_Inv [Annual investment costs]		10,791	10,791
	Cost_Salv [Salvage values of capacities at EOH+1]	110,345		

Figure 36. All system costs results by element

    - The attribute column in this case shows both the attribute name and description, while the Period columns show the value of each attribute in each model period, except the salvage value (Cost_Salv), which does not take a period index.
- Demands (Figure 37)
    - This table is used to show the energy service demand(s). In this case there is only the single demand called TPSCOA, which is in PJ (Figure 38).

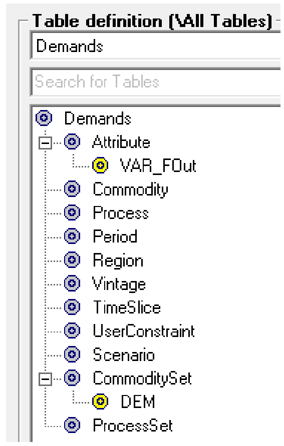


Figure 37. Demands table in VEDA-BE

- The Demands table shows, from left to right, for the scenario DemoS_001, region REG1, process (or technology) DTPSCOA, a flow out (Var_FOut – production or output from the process) for the commodity Demand Total Primary Supply – COA (TPSCOA), the values for the periods 2005 and 2006.

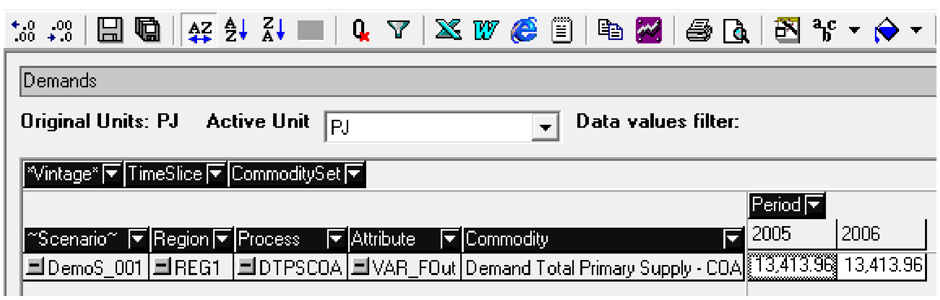


Figure 38. TPSCOA demand

- Fuel Supply (Figure 39)
  - This table is built selecting the attribute VAR_FOut (flow out) and the process set IRE (that includes all the process defined in ~FI_PROCESS tables as MIN, IMP and EXP). In other words, this table can be used to check the output from all the processes that belong to import and mining sets. The export process is characterised with an input and not an output, so it not possible to check the behavior of the export process by selecting only VAR_FOut.
  - The COA demand is met in a significant proportion with imports (6,462.67 PJ) and the rest with domestic resources through the first two steps of the supply curve. (The third step is not used, because it has higher COST than the imports, see Figure 40.) The demand and supply balance of COA is constant between 2005 and 2006, as described above in Section 3.1.2.5.

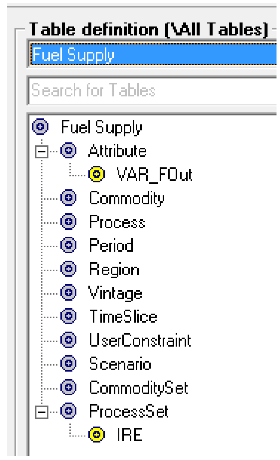
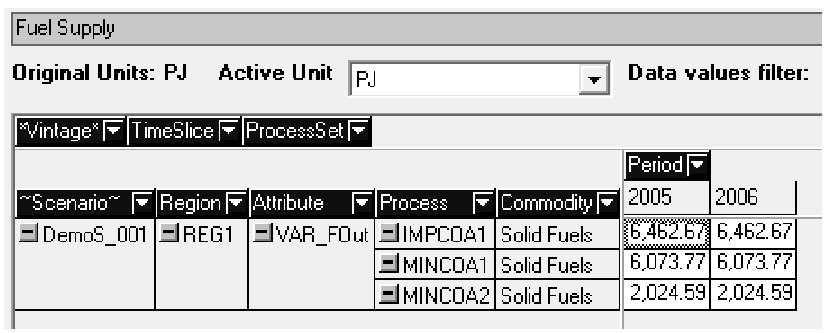


Figure 39. Fuel Supply table in VEDA-BE

- In this example the marginal technology, that is, the technology that would produce the next additional unit of the COA commodity, is the import technology. This information will be reflected in the commodity marginal price for COA, which will be equal to the production cost of the COA commodity from the marginal technology.



~Scenario~	Region	Attribute	Process	Commodity	2005	2006
DemoS_001	REG1	VAR_FOut	IMPCOA1	Solid Fuels	6,462.67	6,462.67
			MINCOA1	Solid Fuels	6,073.77	6,073.77
			MINCOA2	Solid Fuels	2,024.59	2,024.59

Figure 40. Fuel Supply results by process and period

- Prices_All
  - This table (Figure 41), built selecting the attribute EQ_CombalM, can be used for showing commodities' marginal prices in the run.

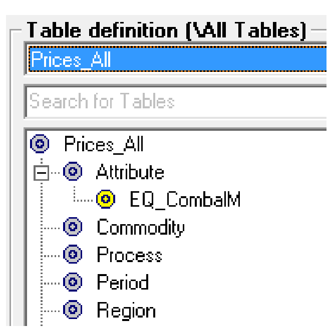


Figure 41. Marginal prices table in VEDA-BE

- As noted above, the marginal price of COA (solid fuels) is the same as the production cost from the marginal technology (import of solid fuels). In this example, it is 2.75 MEuro/PJ in both periods (Figure 42). The marginal price of TPSCOA (Demand Total Primary Supply – COA) in 2005 depends on the new capacity investment that must happen in that year to serve the demand. The marginal price for 2005 can be calculated by taking in account the marginal prices of the solid fuels commodity, the investment cost of the demand technology, the operating cost for the demand technology, and finally the salvage cost. In 2006 there isn't any new investment, so the marginal price will be only a function of the fuel cost.

Attribute

~Scenario~	Region	Commodity	TimeSlice	Period 2005	2006
DemoS_001	REG1	Demand Total Primary Supply - COA	ANNUAL	5.65	2.75
		Solid Fuels	ANNUAL	2.75	2.75

Figure 42. Marginal prices results for DemoS_001

3.2 DemoS_002 - More demand options and multiple supply curves

Description. The second step model includes a greater number of supply, demand, import and export options for additional commodities in a single region over two time periods.

Objective. The objective is to show how to expand the model with more examples of commodities (energy and emissions) and of typical processes along with their respective attributes, including emission coefficients. On the supply side, it includes more three-step supply curves (e.g., for oil & gas in addition to coal), extraction processes, and import and export options, as well as the introduction of new sector fuel processes (processes used to change fuel names into sectoral commodity names). The demand side is also expanded with the presentation of two demands for energy services (residential and transportation) and corresponding end-use devices in each sector. Emission commodities (e.g. CO_2) and emission tracking are also introduced at the end-use device level in both the residential and transport sectors.

Attributes introduced:	Files updated
STOCK ENV_ACT START	VT_REG_PRI_v02

Files. The second step model is built by modifying the B-Y Template (VT_REG_PRI_V02) to add processes as well as energy and emission commodities. The SysSettings file is the same as in the DemoS_001.

3.2.1 B-Y Templates

3.2.1.1 EnergyBalance sheet

The energy balance is the same as in the first step although a larger portion is covered in this second step model (Figure 43). In addition to the primary supply of solid fuels (COA), the model covers the primary supply of natural gas (GAS) and crude oil (OIL) as well as the demand for GAS and OIL in the residential and transportation sectors (rather than for the aggregated primary supply as for COA).

A higher degree of disaggregation is also provided. On the supply side, the same level of disaggregation as for COA is provided for GAS and OIL, with shares to split the total domestic production in more than one step. On the demand side, fuel consumption is split by sector and by end use in the residential sector (space heating, appliances, and other). GAS is allocated at 100% to the Other end use in the residential sector and OIL at 100% to the single end use D1 in the transportation sector.

		COA	GAS	OIL	NUC	RNW	SLU	HET	ELC	
		Solid Fuels	Natural Gas	Crude Oil	Nuclear Energy	Renewable Energies	Industrial Wastes	Derived Heat	Electricity	Total
	PRIMARY									
MIN	Domestic Supply	8098	7899	5379	10775	5027	0	0	0	37178
IMP	Imports	6463	13292	39960	0	113	0	0	1168	60995
EXP	Exports	-1147	-2516	-14831	0	-72	0	0	-1127	-19693
TPS	Total Primary Supply	13414	18675	30508	10775	5067	0	0	41	78480
	CONVERSION									
ESC	Energy Sector Consumption	-58	-793	-1849	0	-4	-2	0	0	-2705
ELC	Electricity Plants	-9598	-5636	-1225	-10775	-1256	-33	1738	11581	-15203
HPL	Heat Plants	-161	-301	-50	0	-140	-2	659	0	5
REF	Petroleum Refineries			-31736						-31736
	Total Conversion	-9817	-6730	-34859	-10775	-1400	-36	2396	11581	-49640
	FINAL									
RSD	Residential	357	5160	2289	0	1294	0	865	2872	12837
COM	Commercial	57	1752	855	0	67	1	255	2527	5514
IND	Industry	1897	4437	2016	0	722	117	634	4088	13911
AGR	Agriculture	44	201	797	0	63	0	16	19	1141
TRA	Transport	1	21	14851	0	131	0	0	266	15270
OTH	Other	1189	0	393	0	1390	0	627	650	4249
NEN	Non Energy	52	634	4073		0	0	0	0	4759
BNK	Bunkers	0	0	2111		0	0	0	0	2111
TFC	Total Final Consumption	3597	12205	27385	0	3667	118	2396	10423	59791

Data used in the template to buld the model

	COA	GAS	OIL
Domestic Supply Curve Share - Step 1	75%	50%	80%
Domestic Supply Curve Share - Step 2	25%	50%	20%

Sector	Break-out by end-use	Solid Fuels	Natural Gas	Crude oil	Nuclear Energy	Renewable Energies	Industrial Wastes	Derived Heat	Electricity	
RSD	SH									Space Heating
RSD	AP									Appliancens
RSD	OT		1							Other
COM	D1									Demand 1
COM	D6									Demand 6
TRA	D1			1						Demand 1

Figure 43. Energy balance at start year 2005 for REG1 – Covered in DemoS_002

3.2.1.2 Pri_COA/GAS/OIL sheets

These new Pri_GAS and the Pri_OIL sheets have exactly the same structure as the Pri_COA sheet (which has not been modified from the first step) including:

- A commodity table to declare additional energy commodities (NRG): GAS - Natural gas (PJ) and OIL - Crude oil (PJ).
- A process table to declare additional supply options for GAS and OIL: mining processes (MINGAS* and MINOIL*), import processes (IMPGAS1, IMPOIL1), and export processes (EXPGAS1, EXPOIL1).
- A flexible import table to describe the primary supply options for GAS and OIL: 3-step domestic supply curves through three mining processes, as well as import and export options. All are characterized with the same attributes.

3.2.1.3 Sector_Fuels sheet

This is a new sheet that is used to construct sector fuel processes (FTE-*), which produce sector fuels from primary fuels, e.g.: GAS becomes RSDGAS and OIL becomes TRAOIL in this example (Figure 44). This is done to make it easy to track fuel consumption at the sectoral level as well as to add sectoral emissions (which could be constrained separately). These technologies can be also used to add additional information on the sectoral commodities, for example additional costs to simulate a sectoral tariff for GAS or an investment cost to simulate new investments in infrastructure and so on. The same approach is used to declare the new commodities and processes in their respective tables.

		~FI_T			
TechName	Comm-IN	Comm-OUT	STOCK	EFF	LIFE
*Technology Name	Input Commodity	Output Commodity	Existing Installed Capacity	Efficiency	Lifetime
*Units			PJa		Years
FTE-RSDGAS	GAS	RSDGAS		1.00	30
FTE-TRAOIL	OIL	TRAOIL		1.00	30

Figure 44. Introduction of sector fuel processes

3.2.1.4 DemTechs_RSD and DemTechs_TRA sheets

Demand processes (DMD) are introduced in these sheets (Figure 45). They consume an energy commodity (RSDGAS, TRAOIL) to produce directly the energy service commodity: residential–other (DROT) and transport (DTD1) in this example. In both sectors, there are existing (ROTEGAS and TOTEOIL) and new processes (ROTNGAS and TOTNOIL).

- The existing processes are characterized with their existing installed capacity (STOCK), corresponding in this case to the energy consumption required to produce these energy services in the base year as given by the energy balance and the additional fuel split assumptions. They also have an efficiency (EFF), an annual availability factor (AFA) and a life time (LIFE).
- Existing processes characterised in VEDA B-Y Templates with a base year STOCK can not increase their capacity endogenously through new investment because when synchronizing the templates, by default VEDA-FE inserts the attribute NCAP_BND with interpolation/extrapolation rule number 2, setting an upper bound of EPS (epsilon, or effectively zero) for all years. (For more information on interpolation/extrapolation see

Table 8 in Section 3.3.2.2) New technologies thus are needed to replace the existing capacity as it retires or increase the amount of capacity available after the base year.

- The new processes do not have an existing installed capacity, but they are available in the database to be invested in to replace the existing ones and meet the demand for energy services. They are characterized with an investment cost (INVCOST), a fixed operation and maintenance cost (FIXOM), and the year in which they become available (START). The model can invest in these new technologies only beginning in that START year.
- Finally, emission commodities (ENV) are also introduced along with these processes: CO2 emissions in the residential (RSDCO2) and the transport (TRACO2) sectors in this example (in kt). An emission coefficient (ENV_ACT in kt/PJ_{output}) is provided for each process based on the technology output. It is also possible to define emissions coefficients based on fuel input (see Section 3.7.2.7).

		~FI_T								
TechName	Comm-IN	Comm-OUT	STOCK	EFF	AFA	INVCOST	FIXOM	LIFE	START	ENV_ACT
*Technology Name	Input Commodity	Output Commodity	Existing Installed Capacity	Efficiency	Utilisation Factor	Invesctment Cost	Fixed O&M Cost	Lifetime	Start Year	Activity Emission Coefficient
*Units			PJa			M€2005/PJ	M€2005/PJa	Years	Year	kt/PJ
ROTEGAS	RSDGAS	DROT	5486	1.00	0.95		0.24	10		
		RSDCO2								56.1
ROTNGAS	RSDGAS	DROT		1.20	0.95	12	0.24	20	2006	
		RSDCO2								46.8

		~FI_T								
TechName	Comm-IN	Comm-OUT	STOCK	EFF	AFA	INVCOST	FIXOM	LIFE	START	ENV_ACT
*Technology Name	Input Commodity	Output Commodity	Existing Installed Capacity	Efficiency	Utilisation Factor	Invesctment Cost	Fixed O&M Cost	Lifetime	Start Year	Activity Emission Coefficient
*Units			PJa			M€2005/PJ	M€2005/PJa	Years	Year	kt/PJ
TOTEOIL	TRAOIL	DTD1	16666	1.00	0.90		0.20	10		
		TRACO2								65
TOTNOIL	TRAOIL	DTD1		1.10	0.90	10	0.20	15	2006	
		TRACO2								59

Figure 45. End-use demand processes

3.2.1.5 Demands sheet

The demand table is expanded to include the demand for the new energy services created at this step: residential–other (DROT) and transport (DTD1). The 2005 values come from the energy balance sheet and then will be constant, as explained in Section 3.1.2.5, until new data is input for future years.

3.2.2 Results

There are more demands for energy services (Figure 46) and fuel supply options (Figure 47) in this second step model compared with the first step. Also, a new piece of information available at this second step is CO2 emissions by sector (Figure 48), which are computed from the input coefficients provided for each process and the activity of each process. These three tables can be viewed in the same way as explained for DemoS_001, and if results for both DemoS_001 and DemoS_002 have been imported, then it will be possible to see and compare results for the two scenarios.The main findings from the results analysis are:

- The domestic demand for transportation (DTC1) represents the major proportion (44%) of total domestic demand for energy. This sector relies on oil and also accounts for the largest part of the CO2 emissions (TRACO2), although no coefficient was provided for solid fuels combustion emissions.

Demands

Original Units: PJ **Active Unit** PJ **Data values filter:**

Attribute | *Vintage* | TimeSlice | CommoditySet

~Scenario~	Region	Commodity	Process	2005	2006
DemoS_001	REG1	TPSCOA [Demand Total Primary Supply - COA]	DTPSCOA	13,414	13,414
			Total	13,414	13,414
DemoS_002	REG1	DROT [Demand Residential Sector - Other]	ROTEGAS	5,160	4,690
			ROTNGAS		470
			Total	5,160	5,160
		DTD1 [Demand Transport Sector - Demand 1]	TOTEOIL	14,851	13,500
			TOTNOIL		1,351
			Total	14,851	14,851
		TPSCOA [Demand Total Primary Supply - COA]	DTPSCOA	13,414	13,414
			Total	13,414	13,414

Figure 46. Results - Demands table for DemoS_002

Fuel Supply

Original Units: PJ **Active Unit** PJ **Data values filter:**

Attribute | *Vintage* | TimeSlice | ProcessSet

~Scenario~	Region	Commodity	Process	2005	2006
DemoS_001	REG1	COA [Solid Fuels]	IMPCOA1 [Import of Solid Fuels Step 1]	6,463	6,463
			MINCOA1 [Domestic Supply of Solid Fuels Step 1]	6,074	6,074
			MINCOA2 [Domestic Supply of Solid Fuels Step 2]	2,025	2,025
			Total	14,561	14,561
DemoS_002	REG1	COA [Solid Fuels]	IMPCOA1 [Import of Solid Fuels Step 1]	6,463	6,463
			MINCOA1 [Domestic Supply of Solid Fuels Step 1]	6,074	6,074
			MINCOA2 [Domestic Supply of Solid Fuels Step 2]	2,025	2,025
			Total	14,561	14,561
		GAS [Natural Gas]	MINGAS1 [Domestic Supply of Natural Gas Step 1]	3,950	3,950
			MINGAS2 [Domestic Supply of Natural Gas Step 2]	3,726	3,648
			Total	7,676	7,598
		OIL [Crude Oil]	IMPOIL1 [Import of Crude Oil Step 1]	24,303	2,418
			MINOIL1 [Domestic Supply of Crude Oil Step 1]	4,303	9,849
			MINOIL2 [Domestic Supply of Crude Oil Step 2]	1,076	2,462
			Total	29,682	14,728

Figure 47. Results – Fuel Supply table for DemoS_002

- The demand for residential–other (DROT) and transportation (DTC1) is first fully satisfied with the existing demand processes (ROTEGAS and TOTEOIL) in the base year 2005, but the new demand processes (ROTNGAS and TOTNOIL) start penetrating in 2006. The new processes are more efficient and require less energy to satisfy the demand. The existing processes satisfy less demand in 2006 because their STOCK in 2006 is lower than in 2005. The STOCK decreases between the base year value and zero linearly over the technical LIFE. For example, for ROTEGAS the base (2005) stock is 5486 PJ and will be zero in 2015 (because the residual technical life is 10 years). The stock value between 2005 and 2015 is linearly interpolated between 5486 PJ and 0 PJ.
- A large proportion of the oil imported in 2005 is destined to export markets (exports reach their upper limit because the export price is no higher than that of the marginal oil supply, the import price), while in 2006 the demand from export markets decreases to

zero and more oil is produced domestically to meet the domestic demand for transportation oil.

Emissions by Sector

Original Units: Kt | Active Unit: Kt | Data values filter:

Attribute | *Process* | *Vintage* | TimeSlice | CommoditySet

~Scenario~	Region	Commodity	2005	2006
DemoS_002	REG1	RSDCO2 [Residential Carbon dioxide]	289,464	285,074
		TRACO2 [Transport Carbon dioxide]	965,331	957,345
		Total	1,254,796	1,242,419

Figure 48. Results – Emissions by Sector table for DemoS_002

Objective-Function = 496 637 M euros (see the _SysCost table in VEDA-BE).

All the system cost components can be seen from the VEDA-BE table **All costs**. As the model includes different types of energy commodities, it is relevant to have a look at their respective marginal prices (Figure 49). Marginal prices of oil are the highest due to higher production costs and import prices. Marginal (shadow) prices for process activity (Figure 50) allow us to understand why the third step of the supply curve for fossil fuels (MINCOA3, MINGAS3, MINOIL3) are not part of the optimal solution, as they are more expensive. For example the VAR_ActM for MINCOA1 is -0.75. This means that if we relax the upper activity bound of this technology of by GJ than the objective function will decrease by 0.75 euros, while forcing the production of 1 GJ from MINCOA3 will increase the objective function by 0.25 euros.

In TIMES, the shadow prices of commodities play a very important diagnostic role. If some shadow price is clearly out of line (i.e., if it seems much too small or too large compared to anticipated market prices), this indicates that the database may contain some errors. For instance, if the shadow price of a commodity is zero and the quantity supplied is non zero, as pointed out by the second theorem of Linear Programming, it means that there is more supply than demand for that commodity. The examination of shadow prices is just as important as the analysis of the quantities produced and consumed of each commodity and of the technological investments.

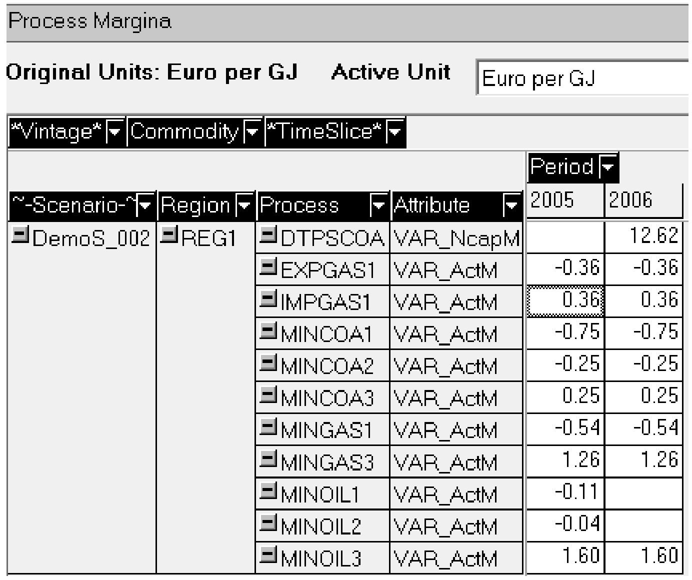
Energy Prices

Original Units: Euro per GJ | Active Unit: Euro per GJ | Data values

Attribute | CommoditySet

~Scenario~	Region	Commodity	TimeSlice	2005	2006
DemoS_001	REG1	COA [Solid Fuels]	ANNUAL	2.75	2.75
DemoS_002	REG1	COA [Solid Fuels]	ANNUAL	2.75	2.75
		GAS [Natural Gas]	ANNUAL	4.14	4.14
		OIL [Crude Oil]	ANNUAL	8.00	8.00
		RSDGAS [Residential Natural Gas]	ANNUAL	4.14	4.14
		TRAOIL [Transport Crude Oil]	ANNUAL	8.00	8.00

Figure 49. Results – Prices_Energy table for DemoS_002



Process Margina

Original Units: Euro per GJ   Active Unit: Euro per GJ

Vintage | Commodity | *TimeSlice*

~-Scenario-~	Region	Process	Attribute	2005	2006
DemoS_002	REG1	DTPSCOA	VAR_NcapM		12.62
		EXPGAS1	VAR_ActM	-0.36	-0.36
		IMPGAS1	VAR_ActM	0.36	0.36
		MINCOA1	VAR_ActM	-0.75	-0.75
		MINCOA2	VAR_ActM	-0.25	-0.25
		MINCOA3	VAR_ActM	0.25	0.25
		MINGAS1	VAR_ActM	-0.54	-0.54
		MINGAS3	VAR_ActM	1.26	1.26
		MINOIL1	VAR_ActM	-0.11	
		MINOIL2	VAR_ActM	-0.04	
		MINOIL3	VAR_ActM	1.60	1.60

Figure 50. Results – marginal process activity prices in DemoS_002

3.3 DemoS_003 - Power sector: basics

Description. The third step model demonstrates the modelling of a simple power sector in a single region over more than two time periods. From the base year of 2005, the time horizon is expanded from 2006 to 2020.

Objective. The objective is to show how to model a typical power sector with different types of power plants (e.g., thermal, nuclear and renewable) along with their respective attributes and the transmission efficiency of the network. Other objectives are to add more time periods, to show how to project future demands (e.g. constant or growing), and to explain the powerful interpolation/extrapolation rules existing in VEDA-TIMES, as well as the difference between model years and data years.

Attributes introduced:	Files updated
COM_IE	SysSettings
CAP2ACT	VT_REG_PRI_v03

Files. The third step model is built by modifying:

1. the SysSettings file to add more time periods and declare the transmission efficiency of the electricity network.
2. the B-Y Template (VT_REG_PRI_V03) to model the power sector and insert interpolation/extrapolation rules.

3.3.1 SysSettings file

3.3.1.1 <u>TimePeriods sheet</u>

The ~TimePeriods table is used to extend the time horizon of the model by adding three active periods of five years each (Figure 51). These specifications are saved as a new time period definition (Pdef-5). The time horizon is extended to 2020, with the milestones years being 2005, 2006, 2010, 2015 and 2020.

~TimePeriods	
Pdef-1	Pdef-5
1	1
2	2
	5
	5
	5

Figure 51. New time periods definition in the SysSettings file

The changes to the period definitions can also be seen within VEDA-FE, by selecting **MileStone Years** from the **Advanced Functions** menu, as shown in Figure 52. In addition to showing the currently selected definitions, the MileStone years tool can be used to modify the definition or add a new set of definitions in an easy way. Input desired period lengths in the yellow area, adding new periods below the currently defined ones as desired. These changes will be reflected in the period specifications shown on the right. You may then choose to **Save** and overwrite the previous definition, or enter a new name in the dropdown menu in the lower left hand corner of the form to create a new set. These changes will then be reflected in the SysSettings file.

BaseYear							
2005			1	2	3	4	5
PeriodLength	Start		2005	2006	2008	2013	2018
1	Mid		2005	2006	2010	2015	2020
2	End		2005	2007	2012	2017	2022
5	Lnth		1	2	5	5	5
5							
5							

Figure 52. Milestones years from the new time period definition

With the introduction of the interpolation/extrapolation rules, it is possible to run the model on a longer time horizon without having to declare data values for all periods up to 2020.

3.3.1.2 Constants sheet

The transformation table is also used to insert a new constant in the model: the transmission efficiency (COM_IE) for the electricity (ELC) commodity in REG1 (Figure 53).

~TFM_INS					
TimeSlice	LimType	Attribute	AllRegions	REG1	Cset_CN
		G_DYEAR	2005		
		Discount	0.05		
ANNUAL		YRFR	1.00		
		COM_IE		0.90	ELC

Figure 53. New constant declarations in the SysSettings file

3.3.2 B-Y Templates

3.3.2.1 EnergyBalance sheet

The energy balance is the same as in the second step although a larger portion of it is covered in this third step model (Figure 54). The energy used for conversion into electricity and the total electricity generation are now included.

		COA	GAS	OIL	NUC	RNW	SLU	HET	ELC	
		Solid Fuels	Natural Gas	Crude Oil	Nuclear Energy	Renewable Energies	Industrial Wastes	Derived Heat	Electricity	Total
	PRIMARY									
MIN	Domestic Supply	8098	7899	5379	10775	5027	0	0	0	**37178**
IMP	Imports	6463	13292	39960	0	113	0	0	1168	**60995**
EXP	Exports	-1147	-2516	-14831	0	-72	0	0	-1127	**-19693**
TPS	**Total Primary Supply**	**13414**	**18675**	**30508**	**10775**	**5067**	**0**	**0**	**41**	**78480**
	CONVERSION									
ESC	Energy Sector Consumption	-58	-793	-1849	0	-4	-2	0	0	**-2705**
ELC	Electricity Plants	-9598	-5636	-1225	-10775	-1256	-33	1738	11581	**-15203**
HPL	Heat Plants	-161	-301	-50	0	-140	-2	659	0	**5**
REF	Petroleum Refineries			-31736						**-31736**
	Total Conversion	**-9817**	**-6730**	**-34859**	**-10775**	**-1400**	**-36**	**2396**	**11581**	**-49640**
	FINAL									
RSD	Residential	357	5160	2289	0	1294	0	865	2872	**12837**
COM	Commercial	57	1752	855	0	67	1	255	2527	**5514**
IND	Industry	1897	4437	2016	0	722	117	634	4088	**13911**
AGR	Agriculture	44	201	797	0	63	0	16	19	**1141**
TRA	Transport	1	21	14851	0	131	0	0	266	**15270**
OTH	Other	1189	0	393	0	1390	0	627	650	**4249**
NEN	Non Energy	52	634	4073		0	0	0	0	**4759**
BNK	Bunkers	0	0	2111		0	0	0	0	**2111**
TFC	**Total Final Consumption**	3597	**12205**	**27385**	**0**	**3667**	**118**	**2396**	10423	**59791**
	Data used in the template to buld the model									

Figure 54. Energy balance at start year 2005 for REG1 – Covered in DemoS_003

3.3.2.2 Pri_COA/GAS/OIL sheets

These sheets were all modified in a similar way to show the use of interpolation/extrapolation rules in VEDA-TIMES (Figure 55). With the introduction of the interpolation/extrapolation rules, it is possible to run the model for a longer time horizon without having to declare data values for all periods up to 2020.

To activate an interpolation/extrapolation (I/E) rule for a specific process, insert a data row and write a "0" as the Year. In this example, an interpolation/extrapolation rule will be enabled for the processes MINCOA1, MONCOA2 and EXPCOA1. Then, an interpolation/extrapolation code is indicated under the attribute. In this example, option 5 will be applied to the activity bound (ACT_BND) of these processes. The option codes for the interpolation/extrapolation rules are presented in Table 8. The code 5 means full interpolation and forward extrapolation of the attribute.

In this example, MINCOA1 has an activity bound of 6074 PJ in the year 2005, and due to the I/E rule, the 2005 value is kept constant over the time horizon. Just remember that the ACT_BND is not I/E by default, so when no I/E rule is explicitly specified in the template, the bound will be applied only to the periods defined in the year column.

Default interpolation/extrapolation mechanisms are embedded in the TIMES code itself (for more information see Section 3.1.1 of Part II of the TIMES documentation). It is also useful to check the Attribute Master table in VEDA-FE (see Section 2.4.4) for more information about which attributes are interpolated/extrapolated by default and which are not.

				~FI_T			
TechName	Comm-IN	Comm-OUT	Year	LimType	CUM	COST	ACT_BND
*Technology Name	Input Commodity	Output Commodity			Reserves Cumulative Value	Cost	Annual Production Bound
*Units					PJ	M€2005/PJ	PJ
MINCOA1		COA	2005		80000	2.00	6074
			0				5
MINCOA2		COA	2005		160000	2.50	2025
			0				5
MINCOA3		COA			320000	3.00	
IMPCOA1		COA				2.75	
EXPCOA1	COA		2005	UP		2.75	1147
			0	UP			5

Figure 55. PRI_COA sheet with interpolation/extrapolation rules

Table 8. Interpolation/extrapolation codes in TIMES

Option code	Action	Applies to
0 (or none)	Interpolation and extrapolation of data in the default way as predefined in TIMES (see below)	All
< 0	No interpolation or extrapolation of data (only valid for non-cost parameters).	All
1	Interpolation between data points but no extrapolation.	All
2	Interpolation between data points entered, and filling-in all points outside the interpolation window with the EPS value.	All
3	Forced interpolation and both forward and backward extrapolation throughout the time horizon.	All
4	Interpolation and backward extrapolation	All
5	Interpolation and forward extrapolation	All
10	Migrated interpolation/extrapolation within periods	Bounds, RHS
11	Interpolation migrated at end-points, no extrapolation	Bounds, RHS
12	Interpolation migrated at ends, extrapolation with EPS	Bounds, RHS
14	Interpolation migrated at end, backward extrapolation	Bounds, RHS
15	Interpolation migrated at start, forward extrapolation	Bounds, RHS
YEAR (≥ 1000)	Log-linear interpolation beyond the specified YEAR, and both forward and backward extrapolation outside the interpolation window.	All

3.3.2.3 Pri_RNW and Pri_NUC sheets

As with supply curves for fossil fuels, mining processes are created for the uranium resources and the renewable potential (Figure 56). They are considered unlimited and at no cost in this simple example.

				~FI_T			
TechName	Comm-IN	Comm-OUT	Year	LimType	CUM	COST	ACT_BND
*Technology Name	Input Commodity	Output Commodity			Reserves Cumulative Value	Cost	Annual Production Bound
*Units					PJ	M€2005/PJ	PJ
MINRNW1		RNW					

				~FI_T			
TechName	Comm-IN	Comm-OUT	Year	LimType	CUM	COST	ACT_BND
*Technology Name	Input Commodity	Output Commodity			Reserves Cumulative Value	Cost	Annual Production Bound
*Units					PJ	M€2005/PJ	PJ
MINNUC1		NUC					

Figure 56. Description of new supply options

3.3.2.4 <u>Sector_Fuels sheet</u>

Additional sector fuel processes (FTE-*) are defined and characterized in this sheet, namely to produce the electricity sector fuels from primary fuels, including fossil fuels (e.g. COA to ELCCOA) and other sources (e.g. NUC to ELCNUC). The same approach is used to declare the new commodities and processes in their respective tables.

3.3.2.5 <u>Con_ELC sheet</u>

A series of processes are created to represent different types of power plants (Figure 57). These are conversion processes that consume electricity sector fuels (ELCGAS, ELCNUC, etc.) to produce electricity (ELC).

- The existing processes are characterized with their existing installed capacity (STOCK) in GW (calculated from the information given in the energy balance in terms of energy consumption for electricity production and technical attribute values). They also have an efficiency (EFF), an annual availability factor (AFA), fixed and variable O&M costs (FIXOM, VAROM), a life time (LIFE), and a CO2 emission coefficient (ENV_ACT).
- By default, all attribute values apply to the base year 2005 when not specified. It is possible to declare any attribute values for future years using the command "~" followed by the year, as for the installed capacity attribute in this case (STOCK~2030). By default, an existing installed capacity (STOCK) decreases to zero at the end of its lifetime (e.g., after 30 years for ELCTECOA00). By specifying an installed capacity value for 2030, as for ELCTENUC00, a new retirement profile is defined (constant in this example), and it is not necessary to specify a life duration.
- The new processes do not have an existing installed capacity, but they are available in the database to be invested in to replace the existing ones and meet the demand for electricity. They are characterized in addition with an investment cost (INVCOST) as well as the year where they become available (START).
- A new attribute is introduced (CAP2ACT) allowing the conversion between the process capacity and activity units. In this example a coefficient of 31.536 PJ/GW is needed (1GW * 365 days * 24 hours = 8760 GWh = 31.536 PJ). When not specified and when both capacity and activity are tracked in the same unit, the CAP2ACT is equal to 1.

The same approach is used to declare the new commodities and processes in their respective tables (Figure 58) including the declaration of existing and new power plants as ELE processes. The process names follow a convention where T=thermal, C=CHP, R=Renewable, N=Nuclear.

		~FI_T											
TechName	Comm-IN	Comm-OUT	STOCK	STOCK~2030	EFF	AFA	INVCOST	FIXOM	VAROM	LIFE	START	ENV_ACT	CAP2ACT
*Technology Name	Input Commodity	Output Commodity	Existing Installed Capacity	Retirement Capacity	Efficiency	Utilisation Factor	Invesctment Cost	Fixed O&M Cost	Variable O&M Cost	Lifetime		Activity Emission Coefficient	Capacity to Activity Factor
*Units			GW	GW			M€2005/GW	M€2005/GW	M€2005/PJ	Years		kt	PJ/GW
ELCTECOA00	ELCCOA	ELC	137		0.38	0.85		40.00	0.50	30			31.536
		ELCCO2										260	
ELCTEGAS00	ELCGAS	ELC	104		0.49	0.85		35.00	0.40	20			31.536
		ELCCO2										114	
ELCTEOIL00	ELCOIL	ELC	11		0.25	0.85		20.00	0.20	30			31.536
		ELCCO2										306	
ELCRERNW00	ELCRNW	ELC	88	88	1.00	0.45		70.00					31.536
ELCTENUC00	ELCNUC	ELC	125	125	0.33	0.90		38.00	0.27				31.536
ELCTNCOA00	ELCCOA	ELC			0.42	0.85	1650	35.00	0.40	40	2006		31.536
		ELCCO2										238	
ELCTNGAS00	ELCGAS	ELC			0.52	0.85	750	30.00	0.35	30	2006		31.536
		ELCCO2										108	
ELCTNOIL00	ELCOIL	ELC			0.30	0.85	250	15.00	0.20	40	2006		31.536
		ELCCO2										255	

Figure 57. Existing and new power plants

~FI_Comm								
Csets	Region	CommName	CommDesc	Unit	LimType	CTSLvl	PeakTS	Ctype
*Commodity Set Membership	Region Name	Commodity Name	Commodity Description	Unit	Sense of the Balance EQN.	Timeslice Level	Peak Monitoring	Electricity Indicator
NRG		ELC	Electricity	PJ				ELC
ENV		ELCCO2	Electricity Plants Carbon dioxide	kt				

~FI_Process								
Sets	Region	TechName	TechDesc	Tact	Tcap	Tslvl	PrimaryCG	Vintage
*Process Set Membership	Region Name	Technology Name	Technology Description	Activity Unit	Capacity Unit	TimeSlice level of Process Activity	Primary Commodity Group	Vintage Tracking
*								
ELE		ELCTECOA00	Power Plants Existing00 - Solid Fuels	PJ	GW			
		ELCTEGAS00	Power Plants Existing00 - Natural Gas	PJ	GW			
		ELCTEOIL00	Power Plants Existing00 - Crude Oil	PJ	GW			
		ELCRERNW00	Power Plants Existing00 - Renewable Energies	PJ	GW			
		ELCTENUC00	Power Plants Existing00 - Nuclear Energy	PJ	GW			
		ELCTNCOA00	Power Plants New00 - Solid Fuels	PJ	GW			
		ELCTNGAS00	Power Plants New00 - Natural Gas	PJ	GW			
		ELCTNOIL00	Power Plants New00 - Crude Oil	PJ	GW			

Figure 58. Declaration of electricity commodities and processes

3.3.2.6 DemTechs_ELC sheet

The total demand for electricity (ELC) is modelled in a simplistic manner as for solids fuels (COA). A flexible table is used to describe the demand device for electricity (Figure 59):

- A process for the total demand of ELC (DTPSELC) is characterized with an efficiency (EFF), an annual availability factor (AFA), an investment cost (INVCOST) a fixed operation and maintenance cost (FIXOM), and a life time (LIFE).

		~FI_T						
TechName	Comm-IN	Comm-OUT	STOCK	EFF	AFA	INVCOST	FIXOM	LIFE
*Technology Name	Input Commodity	Output Commodity	Existing Installed Capacity	Efficiency	Utilisation Factor	Invesctment Cost	Fixed O&M Cost	Lifetime
*Units			PJa			M€2005/PJ	M€2005/PJa	Years
DTPSELC	ELC	TPSELC		1.00	0.95	10	0.20	20

Figure 59. Description of a simple electricity demand processes

3.3.2.7 Demands

The end-use demand table is expanded to include the demand for electricity (TPSELC) in the base year as well as for future years (Figure 60). While the demand for other fuels or for energy services will be kept constant over time (extrapolated at a constant level by default), the demand for electricity is set up to increase by an annual growth rate of 1% through 2020.

	~FI_T							
Attribute	CommName	*Unit	2005	2006	2010	2015	2020	
*	Demand Commodity Name	Demand Unit	Demand Value					Demand Driver (annual growth)
*Units			PJ					
Demand	TPSCOA	PJ	3597					
Demand	DROT	PJ	5160					
Demand	DTD1	PJ	14851					
Demand	TPSELC	PJ	10423	10527	10955	11513	12101	1%

Figure 60. Definition of base year and future years demand values

3.3.3 Results

The demands for energy and energy services are extended to the 2020 horizon (Figure 61), increasing by 1% per year (TPSELC) or remaining constant (all others). The effects of the interpolation/extrapolation rules applied on the activity bound of certain supply processes can be seen below (

Figure 62). The activity of the first two mining processes (first two steps of the domestic supply curves) for fossil fuels (COA, GAS, OIL) is controlled by the annual activity bound (set constant for each period by the interpolation rule) and the cumulative bound (CUM). The combination of these two conditions leads to a significant increase in imports to meet the growing demand for energy. Exports are also kept constant using the same interpolation/extrapolation rules. More primary supply options exist now with the addition of the electric fuels such as nuclear and renewables.

Results from the new electricity sector are introduced (Figure 63 and Figure 64). The total generating installed capacity increases from 466.3 GW in 2005 to 541.6 GW in 2020. Most of this increase is coming from new coal-fired power plants (ELCTNCOA00), the most expensive process but the least expensive fuel. The installed capacity of nuclear and renewable power plants remain constant as specified in the B-Y Template. Electricity production is coming mainly from fossil fuels (64%), with a smaller contribution from nuclear (26%) and renewables (9%). The oil plants are working only in the base year, as calibrated to the energy balance, because the fuel is too expensive compared to the other available options.

Demands

Original Units: PJ **Active Unit** PJ **Data values filter:**

Attribute | *Process* | *Vintage* | TimeSlice | CommoditySet

Region	~-Scenario-~	Commodity	2005	2006	2010	2015	2020
REG1	DemoS_002	DROT [Demand Residential Sector - Other]	5,160	5,160			
		DTD1 [Demand Transport Sector - Demand 1]	14,851	14,851			
		TPSCOA [Demand Total Primary Supply - COA]	13,414	13,414			
	DemoS_003	DROT [Demand Residential Sector - Other]	5,160	5,160	5,160	5,160	5,160
		DTD1 [Demand Transport Sector - Demand 1]	14,851	14,851	14,851	14,851	14,851
		TPSCOA [Demand Total Primary Supply - COA]	3,597	3,597	3,597	3,597	3,597
		TPSELC [Demand Total Primary Supply - ELC]	10,423	10,527	10,955	11,513	12,101

Figure 61. Results – demand for energy services in DemoS_003

Fuel Supply

Original Units: PJ **Active Unit** PJ **Data values filter:**

Attribute | *Vintage* | TimeSlice | ProcessSet

~-Scenario-~	Region	Commodity	Process	2005	2006	2010	2015	2020
DemoS_003	REG1	COA [Solid Fuels]	IMPCOA1	6,244	7,551	9,895	12,890	21,826
			MINCOA1	6,074	6,074	6,074	6,074	208
			MINCOA2	2,025	2,025	2,025	2,025	2,025
		GAS [Natural Gas]	IMPGAS1	5,412	5,052	9,217	9,634	8,225
			MINGAS1	3,950	3,950	630		
			MINGAS2	3,950	3,950	1,630		
		NUC [Nuclear Energy]	MINNUC1	10,775	10,775	10,775	10,775	10,775
		OIL [Crude Oil]	IMPOIL1	25,528	24,181	26,241	28,332	28,332
			MINOIL1	4,303	4,303	2,218		
			MINOIL2	1,076	1,076	555		
		RNW [Renewable Energies]	MINRNW1	1,256	1,256	1,256	1,256	1,256

Figure 62. Results – fuel supply options in DemoS_003

ELC plants capacity and new capacity

Original Units: GW **Active Unit** GW **Data values filter:**

Attribute | *Vintage*

~Scenario~	Region	ProcessSet	Process	2005	2006	2010	2015	2020
DemoS_003	REG1	ELECOA [Coal Power Plants]	ELCTECOA00	137	133	115	92	69
			ELCTNCOA00		26	82	154	227
		ELEGAS [Gas Power Plants]	ELCTEGAS00	104	98	78	52	26
		ELENUC [Nuclear Power Plants]	ELCTENUC00	125	125	125	125	125
		ELEOIL [Oil Power Plants]	ELCTEOIL00	11	11	10	8	6
		ELERNW [Renewable Power Plants]	ELCRERNW00	88	88	88	88	88
	Total			466	482	498	519	542

Figure 63. Results – electricity capacity in DemoS_003

ELC Plants Production

Original Units: PJ   Active Unit: Billion Kwh   Data values filter:

Attribute | *Process* | *Vintage* | TimeSlice

~Scenario~	Region	ProcessSet	2005	2006	2010	2015	2020
DemoS_003	REG1	ELECOA [Coal Power Plants]	1,024	1,180	1,466	1,831	2,205
		ELEGAS [Gas Power Plants]	772	733	579	386	193
		ELENUC [Nuclear Power Plants]	988	988	988	988	988
		ELEOIL [Oil Power Plants]	85				
		ELERNW [Renewable Power Plants]	349	349	349	349	349
		Total	3,217	3,249	3,381	3,554	3,735

Figure 64. Results – electricity activity in DemoS_003

Objective-Function = 3,185,019 M euros (see the _SysCost table in VEDA-BE). This cost is significantly higher compared to the optimal cost obtained with DemoS_002 because of the addition of the electricity sector. All the system cost components can be seen in the VEDA-BE table **All costs**, as well as the marginal fuel prices in **Price_Energy** and the process activity in **Process Marginals**.

3.4 DemoS_004 - Power sector: sophistication

Description. The fourth step model expands the modelling to a more sophisticated power sector in the same single region over the 2020 horizon.

Objective. The objective is to introduce the concepts of time slices, peak, and peak reserve capacity. Time slices are added to the model to adequately capture the timing of the electricity demand, and the peak reserve capacity requirement is illustrated through scenario variants, with and without peak reserve capacity factor. This step model is also used to show how interpolation/extrapolation specifications can be moved to the SysSettings file and applied to all instances of an attribute in the model using a single declaration.

Attributes introduced:	Files updated
PEAK	SysSettings
COM_FR	VT_REG_PRI_v04
COM_PEAK	Files created
COM_PKRSV	Scen_Peak_RSV
COM_PKFLX	Scen_Peak_RSV-FLX

Files. The forth step model is built:

1. by modifying the SysSettings file to add new time slices and to insert default interpolation/extrapolation options;
2. by modifying the B-Y Template (VT_REG_PRI_V04) to declare the contribution of power plants to the peak and add the load curve of electricity demand;
3. by creating scenario files to illustrate the peak reserve capacity requirement (Figure 65).

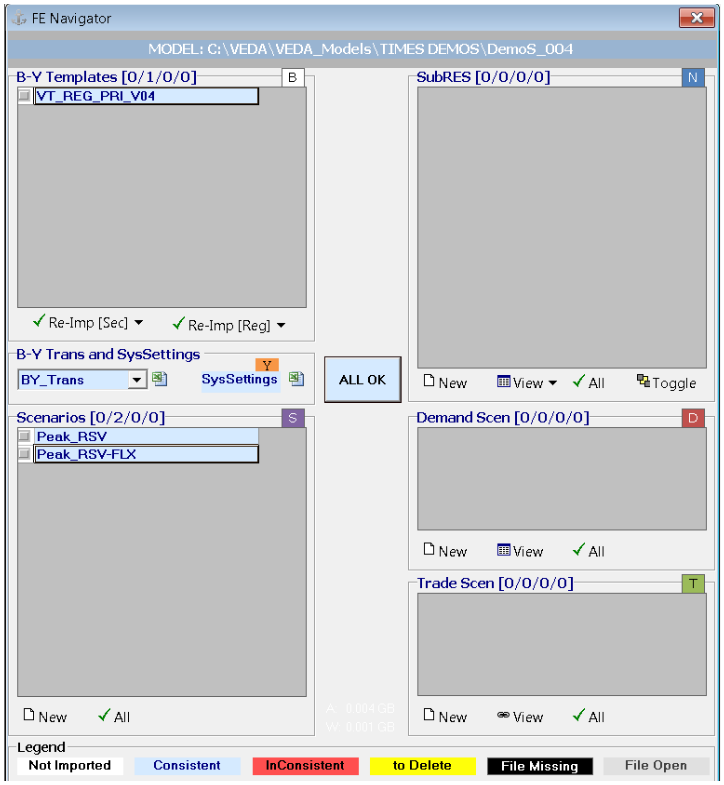


Figure 65. The files included in DemoS_004

3.4.1 SysSettings file

3.4.1.1 Region-Time Slices

The ~TimeSlices table is used to create four time slices (Figure 66) and replace the previous single ANNUAL time slice. There are four time slices combining two seasons (W- Winter and S-Summer) and two intraday periods or day-night periods (D- Day and N- Night).

~TimeSlices		
Season	Weekly	DayNite
S		D
W		N

Figure 66. New time slices definition in the SysSettings file

3.4.1.2 Interpol_Extrapol_Defaults

A table is added for setting the default interpolation/extrapolation rules (Figure 67). A transformation table used to update pre-existing data (~TFM_UPD) in a rule-based manner, it sets the default interpolation/extrapolation rule, indicated by the 0 in the Year column, for the attribute defined in the Attribute column and all the processes defined in the model. In this case, this is the same interpolation/extrapolation rule used for each of the supply processes (see Figure 30) in the B-Y Template. It is now moved into the SysSettings file and applied to the activity bound (ACT_BND) of all processes at once.

~TFM_UPD					
TimeSlice	LimType	Attribute	Year	AllRegions	Pset_PN
	UP	ACT_BND	0	5	

Figure 67. Default table for interpolation/extrapolation rules in the SysSettings file

3.4.1.3 Constants

The existing transformation table is also used to insert new constants in the model: fractions of year for the new time slices (YRFR) replace the single ANNUAL time slice (100%) as declared in the previous steps (Figure 68). The timeslice name is identified in the first column (TimeSlice), while their fractions (for the attribute called YRFR) over one year are declared for AllRegions as for the other constants of the model. The fraction values, as with any other input in the model, are the user's responsibility. In this case, it is important that they sum to 100%.

~TFM_INS					
TimeSlice	LimType	Attribute	AllRegions	REG1	Cset_CN
		G_DYEAR	2005		
		Discount	0.05		
SD		YRFR	0.25		
SN		YRFR	0.23		
WD		YRFR	0.25		
WN		YRFR	0.27		
		COM_IE		0.90	ELC

Figure 68. New time slice declarations in the SysSettings file

3.4.2 B-Y Templates

3.4.2.1 Con_ELC

A new attribute is declared for all existing and new processes representing power plants (Figure 69):

- Their contribution to peak (Peak), i.e., the fraction of a process's capacity that is considered to be secure and thus will most likely be available to contribute to the peak (and reserve capacity) load in the highest demand time-slice of a year for a commodity (electricity or heat only). In this case, the capacity contribution of all thermal and nuclear power plants is 100%, while the capacity contribution of the renewable power plant is 50%. Indeed, many types of supply processes can be regarded as predictably available with their entire capacity contributing during the peak and thus have a peak coefficient equal to 1 (100%), whereas others (such as wind turbines or solar plants) are attributed a peak coefficient less than 1 (100%), since they are on average only fractionally available at peak. (E.g., a wind turbine typically has a peak coefficient of 0.25 or 0.3 maximum).

Another important change to mention is the start year of one new process (ELCTNOIL00) that can be installed from the 2005 base year to cover the additional capacity needed for the reserve equation (5%), as defined in the scenario files.

		~FI_T							
TechName	Comm-IN	Comm-OUT	STOCK	STOCK~2030	(...)	START	ENV_ACT	CAP2ACT	Peak
*Technology Name	Input Commodity	Output Commodity	Existing Installed Capacity	Retirement Capacity			Emission Coefficient	Capacity to Activity Factor	% contribution to PEAK
*Units			GW	GW			kt	PJ/GW	
ELCTECOA00	ELCCOA	ELC	137					31.536	1.00
		ELCCO2					260		
ELCTEGAS00	ELCGAS	ELC	104					31.536	1.00
		ELCCO2					114		
ELCTEOIL00	ELCOIL	ELC	11					31.536	1.00
		ELCCO2					306		
ELCRERNW00	ELCRNW	ELC	88	88				31.536	0.50
ELCTENUC00	ELCNUC	ELC	125	125				31.536	1.00
ELCTNCOA00	ELCCOA	ELC				2006		31.536	1.00
		ELCCO2					238		
ELCTNGAS00	ELCGAS	ELC				2006		31.536	1.00
		ELCCO2					108		
ELCTNOIL00	ELCOIL	ELC				2005		31.536	1.00
		ELCCO2					255		

Figure 69. Peak contribution for different types of power plants

Additional information is required to complete the declaration of the electricity commodity and processes in their respective tables (Figure 70 and Figure 71). Along with the new time slices, it is possible to specify the tracking level of the electricity commodity (ELC) in the **CTSLvl** column: DAYNITE. (When not specified, as in the previous step, the default is ANNUAL.) **PeakTS (**peak time slice monitoring**)** directs TIMES to generate the peak equation for the specified time slices. It is possible to declare any of the time slices defined in the SysSettings file, or ANNUAL (the default) to generate the peaking equation for all time slices. Since it is left blank here, the peak equation will be generated in all time slices once it has been requested using COM_Peak (see Section 3.4.3.1). Finally, it is important that the user enter ELC in the **Ctype** column when declaring an electricity commodity that may be produced by combined heat and power (CHP) plants, as this commodity will be in DemoS_009.

For the electricity processes, the process table is used to define the time slice level of operation in the **Tslvl** column (Figure 71). For example, the coal-fired and the nuclear power plants are defined at the SEASON time slice level, meaning that their operational level does not vary across DAYNITE time slices. (When not specified, the default is based on the Sets declaration: DAYNITE (for ELE), SEASON (for CHP and HPL) ANNUAL (for all others).)

~FI_Comm								
Csets	Region	CommName	CommDesc	Unit	LimType	CTSLvl	PeakTS	Ctype
*Commodity Set Membership	Region Name	Commodity Name	Commodity Description	Unit	Sense of the Balance EQN.	Timeslice Level	Peak Monitoring	Electricity Indicator
NRG		ELC	Electricity	PJ		DAYNITE		ELC
ENV		ELCCO2	Electricity Plants Carbon dioxide	kt				

Figure 70. Declaration of time slice level for electricity commodity

~FI_Process								
Sets	Region	TechName	TechDesc	Tact	Tcap	Tslvl	PrimaryCG	Vintage
*Process Set Membership	Region Name	Technology Name	Technology Description	Activity Unit	Capacity Unit	TimeSlice level of Process Activity	Commodity Group	Vintage Tracking
*								
ELE		ELCTECOA00	Power Plants Existing00 - Solid Fuels	PJ	GW	SEASON		
		ELCTEGAS00	Power Plants Existing00 - Natural Gas	PJ	GW			
		ELCTEOIL00	Power Plants Existing00 - Crude Oil	PJ	GW			
		ELCRERNW00	Power Plants Existing00 - Renewable Energies	PJ	GW			
		ELCTENUC00	Power Plants Existing00 - Nuclear Energy	PJ	GW	SEASON		
		ELCTNCOA00	Power Plants New00 - Solid Fuels	PJ	GW	SEASON		
		ELCTNGAS00	Power Plants New00 - Natural Gas	PJ	GW			
		ELCTNOIL00	Power Plants New00 - Crude Oil	PJ	GW			

Figure 71. Declaration of time slice operational level for processes

3.4.2.2 Pri_COA/GAS/OIL

These sheets were all modified back to remove the interpolation/extrapolation rules: the flag to activate an interpolation/extrapolation rule (additional rows with a "0" as the Year) and the rule code in the attribute column.

3.4.2.3 Demands

A table is added to define the load curve of the demand for electricity (TPSELC) in the base year, which will also apply for future years (Figure 72). The attribute (COM_FR) is introduced to declare the fraction of the electricity demand occurring in each time slice.

		~FI_T	
Attribute	CommName	Timeslices	2005
*	Demand Commodity Name		
*Units			
COM_FR	TPSELC	SD	0.30
COM_FR	TPSELC	SN	0.20
COM_FR	TPSELC	WD	0.27
COM_FR	TPSELC	WN	0.23

Figure 72. Definition of load curve for the electricity demand

The TPSELC commodity is the demand commodity produced by a demand technology (end-use technology) called DTPSELC (Figure 73) and defined in the sheet DemTechs_ELC. This technology takes as input the ELC commodity that will be consumed by timeslice as defined by the COM_FR attribute for TPSELC.

		~FI_T						
TechName	Comm-IN	Comm-OUT	STOCK	EFF	AFA	INVCOST	FIXOM	LIFE
*Technology Name	Input Commodity	Output Commodity	Existing Installed Capacity	Efficiency	Utilisation Factor	Invesctment Cost	Fixed O&M Cost	Lifetime
*Units			PJa			M€2005/PJ	M€2005/PJa	Years
DTPSELC	ELC	TPSELC		1.00	0.95	10	0.20	20

Figure 73. Demand technology producing DTPSELC

3.4.3 Scenario files

3.4.3.1 Scen_Peak_RSV and Scen_Peak_RSV-FLX

Two scenario files are created to insert new information in the RES that can be retained or not in the configuration of the model at the time of solving the model (see Section 2.4.5). A transformation table **~TFM_INS** is used to declare new attributes (Figure 74):

- COM_Peak - Specify that the peaking equation will be generated for the ELC commodity.
- COM_PKRSV - Declare the capacity fraction (%) that is required for the peak reserve. This is the option used in the first scenario file (Peak_RSV).
- COM_PKFLX - Declare the fraction (%) by which the actual peak demand exceeds the average calculated demand, by time slice. This is the option used in the second scenario file (Peak_RSV- FLX) for the Summer-Day time slice (SD), although in practice COM_PKFLX is typically used alongside COM_PKRSV.

The TIMES peak equation allows the user to require that the total capacity of all processes producing a commodity at each time period and in each region exceed, by a certain percentage, the average demand in the time-slice when the highest demand occurs. This peak reserve factor (COM_PKRSV) insures against several contingencies, such as possible commodity shortfall due to uncertainty regarding its supply (e.g. water availability in a reservoir), unplanned equipment down time, and random peak demand that exceeds the average demand during the time-slice when the peak occurs. This constraint is therefore akin to a safety margin to protect against random events not explicitly represented in the model. Optionally, COM_PKFLX can be used to reflect the fact that the actual system peak demand is greater than the average demand in the model's peak slice, allowing COM_PKRSV to represent a more typical utility reserve margin.

~TFM_INS															
TimeSlice	LimType	Attribute	Year	Attrib_Cond	Val_Cond	AllRegions	REG1	Pset_Set	Pset_PN	Pset_PD	Pset_CI	Pset_CO	Cset_Set	Cset_CN	Cset_CD
		COM_PEAK					1.00							ELC	
		COM_PKRSV	2005				5%							ELC	
		COM_PKRSV	2020				20%							ELC	

~TFM_INS															
TimeSlice	LimType	Attribute	Year	Attrib_Cond	Val_Cond	AllRegions	REG1	Pset_Set	Pset_PN	Pset_PD	Pset_CI	Pset_CO	Cset_Set	Cset_CN	Cset_CD
		COM_PEAK					1.00							ELC	
		COM_PKRSV												ELC	
SD		COM_PKFLX	2005				5%							ELC	
SD		COM_PKFLX	2020				20%							ELC	

Figure 74. Declaration of the peak reserve in a scenario file

3.4.4 Results

Three cases are solved with this step model, with a different selection of scenario files (Figure 75): the DemoS_004 case is solved using only the two components (BASE, SysSettings), while the DemoS_004a case is solved adding one scenario file (Peak_RSV), and the DemoS_004b case is solved adding the other scenario file (Peak_RSV-FLX). The different cases can be loaded in the FE Case Manager using the **Select** menu. Choosing the **Single** option will solve each case individually, while choosing the **Batch** option will launch multiple cases simultaneously (i.e., the cases will be launched automatically by VEDA-FE one after the other).

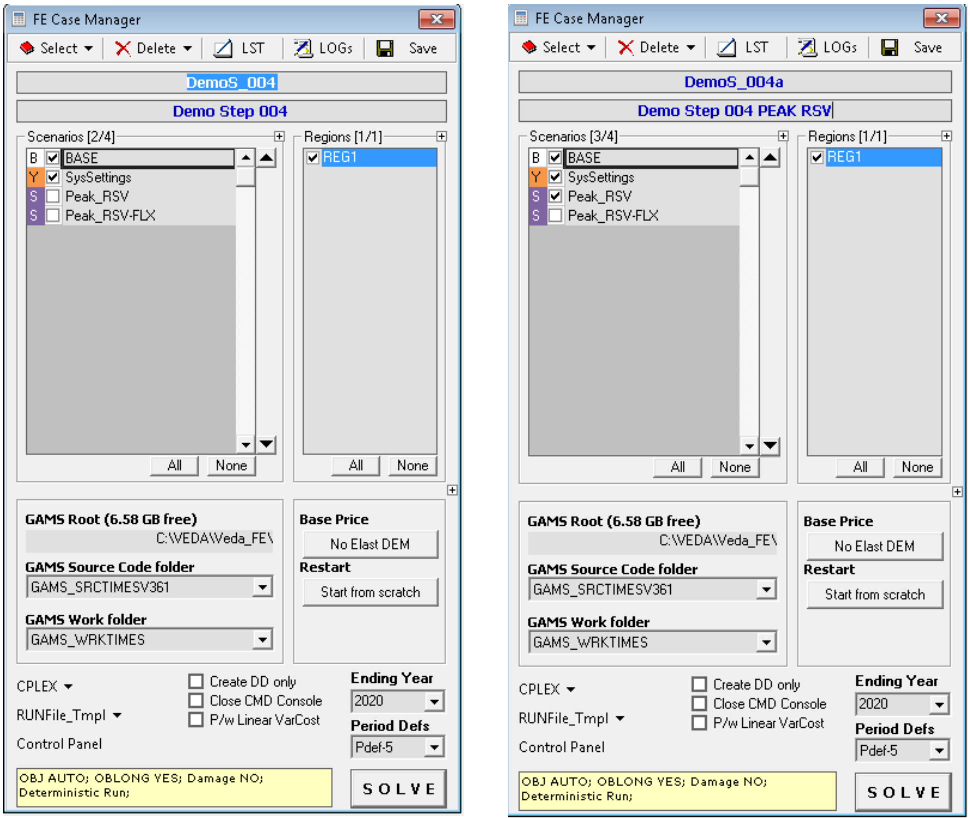


Figure 75. Solving different cases using different scenario files

The impacts of the improvements made in the electricity sector on the electricity generating capacity are shown in Figure 76, namely.

- The effect of adding new time slices and of specifying the seasonal operational level for the coal-fired power plant in DemoS_004, compared with DemoS_003: there is a switch from coal-fired generation to natural gas-fired generation due to its greater flexibility (time slice level DAYNITE for gas, as opposed to SEASON for coal) to satisfy the electricity demand. The additional natural gas supply is coming from import sources.
- The effect of declaring a peak reserve factor on the total capacity in DemoS_004a, compared with DemoS_004: there is additional capacity required that is coming from oil-fired power plants as new power plants are available from 2005. The total capacity in DemoS_004a is increasing from 507 GW in 2005 to 659 GW in 2020 (compared with 466 GW to 542 GW without the peak reserve requirement).
- There is no effect on the generating capacity in DemoS_004b, compared with DemoS_004a.

The electricity price varies across years and time slices (Figure 77).

ELC plants capacity and new capacity

Original Units: GW   Active Unit: GW   Data values filter:

Attribute | *Process* | *Vintage*

Region	~-Scenario-~	ProcessSet	2005	2006	2010	2015	2020
REG1	DemoS_003	Coal Power Plants	137	158	197	246	296
		Gas Power Plants	104	98	78	52	26
		Nuclear Power Plants	125	125	125	125	125
		Oil Power Plants	11	11	10	8	6
		Renewable Power Plants	88	88	88	88	88
		Total	466	482	498	519	542
	DemoS_004	Coal Power Plants	137	158	184	189	194
		Gas Power Plants	104	98	90	108	128
		Nuclear Power Plants	125	125	125	125	125
		Oil Power Plants	11	11	10	8	6
		Renewable Power Plants	88	88	88	88	88
		Total	466	482	498	519	542
	DemoS_004a	Coal Power Plants	137	158	184	189	194
		Gas Power Plants	104	98	90	108	128
		Nuclear Power Plants	125	125	125	125	125
		Oil Power Plants	53	52	66	93	123
		Renewable Power Plants	88	88	88	88	88
		Total	507	523	554	605	659

Figure 76. Results – electricity generation capacity in DemoS_004

Energy Prices

Original Units: Euro per GJ   Active Unit: Euro per GJ   Data values filter:

Attribute | CommoditySet

~-Scenario-~	Region	-Commodity-	TimeSlice	2005	2006	2010	2015	2020
DemoS_004	REG1	Electricity	SD	35.78	12.97	14.05	14.05	14.05
			SN	35.78	12.97	11.79	11.79	11.79
			WD	35.78	12.97	14.24	14.24	14.24
			WN	35.78	12.97	11.79	11.79	11.79
DemoS_004a	REG1	Electricity	SD	29.85	12.97	12.85	12.85	12.85
			SN	29.85	12.97	10.59	10.59	10.59
			WD	29.85	12.97	13.05	13.05	13.05
			WN	29.85	12.97	10.59	10.59	10.59

Figure 77. Results – electricity price by time slice in DemoS_004

Other interesting results to show are related to the peak contribution specifically (Figure 78). The peak equation expresses that the available capacity must exceed demand for the electricity (ELC) commodity in any time slice by a certain margin, so the dual value of the peak equation describes the premium consumers have to pay in addition to the commodity price (dual value of EQ_COMBAL) during the peak time slice (SD in this case) to ensure adequate system capacity. The peak marginal is similar, though not identical, when using COM_PKRSV and COM_PKFLX, owing to the differences in how they are applied in the TIMES equations.

`Peak Equation

Original Units: **Active Unit** **Data values filter:**

~Scenario~	Region	Attribute	Commodity	TimeSlice	2005	2006	2010	2015	2020
DemoS_004a	REG1	EQ_Peak	Electricity	SD	-2,848.96	-2,712.32	-2,392.62	-1,975.97	-1,594.03
				SN	-1,828.90	-1,695.27	-1,368.66	-942.87	-546.86
				WD	-2,536.59	-2,397.01	-2,065.00	-1,632.25	-1,233.34
				WN	-2,095.53	-1,937.20	-1,549.19	-1,043.34	-572.45
		EQ_PeakM	Electricity	SD	12.23		4.48	4.69	4.89
DemoS_004b	REG1	EQ_Peak	Electricity	SD	-2,991.40	-2,875.05	-2,631.88	-2,272.36	-1,912.84
				SN	-1,816.11	-1,670.66	-1,286.43	-738.90	-172.20
				WD	-2,522.71	-2,370.29	-1,975.73	-1,410.80	-826.57
				WN	-2,080.44	-1,908.16	-1,452.15	-802.63	-130.31
		EQ_PeakM	Electricity	SD	11.65		4.07	4.07	4.07

Figure 78. Results – Dual values of the peak equations in DemoS_004

Objective-Function = 3,187,361 M euros (see the _SysCost table in VEDA-BE). This cost is only slightly higher with the peak reserve requirement and the additional investments in generating capacity: 3,211,296 M euros.

3.5 DemoS_005 - 2-region model with endogenous trade: compact approach

Description. At the fifth step, the model evolves from being a single region model to become a compact multi-regional model (2 or more regions in the same set of B-Y Templates). This approach is relevant when all the model regions are under the control of a single individual.

Objective. The objective is to create the multi-regional model framework typical to larger or more complex models, namely the trade matrix that allows the modelling of energy trade movements (uni-directional or bi-directional trade between two regions). Another objective is to demonstrate how to limit emissions from a sector in a particular region or from the entire energy system of all regions through emission bounds or user constraints. Scenario variants illustrate the impact of a cap on CO_2 emissions from the electricity sector only and of a cross-region user constraint on the total CO_2 emissions from the transport and electricity sectors.

Attributes introduced: COM_BNDNET UC_RHSRTS UC_COMNET	Files updated SysSettings VT_REG_PRI_v05 Files created Scen_TRADE_PARAM Scen_ELC_CO2_BOUND Scen_UC_CO2BND Files removed Scen_Peak_RSV-FLX

Files. The fifth step model is built:

1. by modifying the SysSettings file to add one region;
2. by modifying the B-Y Template (VT_REG_PRI_V05) to disaggregate the energy balance between two regions and to regionalize some process attributes;

3. by creating trade files to capture the trade movements between the two regions;
4. by creating more scenario files to limit GHG emissions (Figure 79).

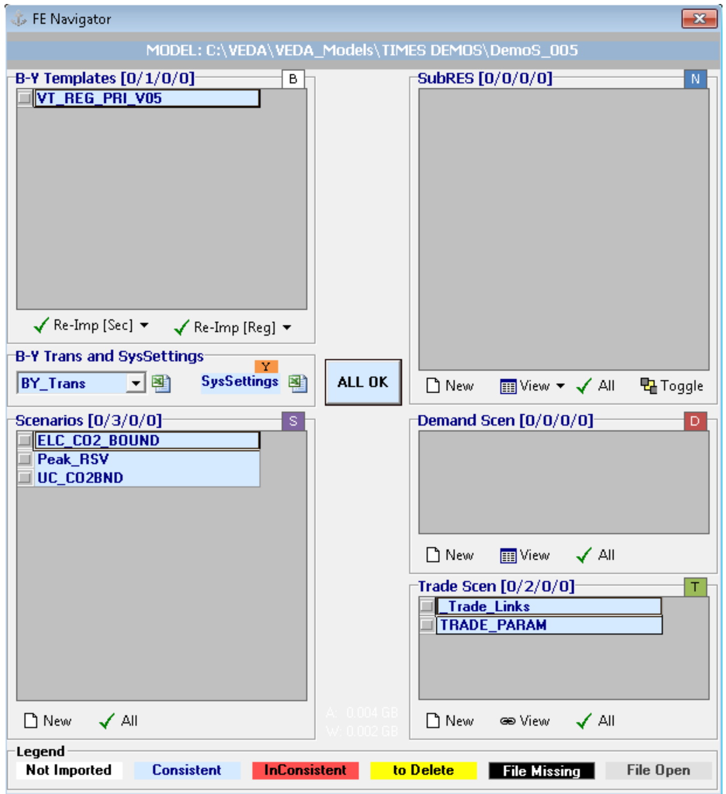


Figure 79. The files included in DemoS_005

3.5.1 SysSettings file

3.5.1.1 Region-Time Slices

The ~BookRegions_Map table is used to create one additional region: REG2 (Figure 80) in the same workbook (REG).

~BookRegions_Map	
BookName	**Region**
REG	REG1
	REG2

Figure 80. New region definition in the SysSettings file

3.5.2 B-Y Templates

3.5.2.1 EnergyBalance, EB1, EB2

The energy balance is disaggregated between two regions (Figure 81) using shares on production, conversion, and final consumption of various energy commodities: REG1 becomes producer and consumer of solid fuels (100%), crude oil (30%) and renewable energies (100%), while REG2 becomes producer and consumer of natural gas (100%), crude oil (70%), and nuclear energy (100%). The same portion of the energy balance as in the fourth step is used in this fifth step model.

		COA	GAS	OIL	NUC	RNW	SLU	HET	ELC	
	REG1	Solid Fuels	Natural Gas	Crude Oil	Nuclear Energy	Renewable Energies	Industrial Wastes	Derived Heat	Electricity	Total
	PRIMARY									
MIN	Domestic Supply	8098	0	1614	0	5027	0	0	0	14739
IMP	Imports	6463	0	11988	0	113	0	0	584	19148
EXP	Exports	-1147	0	-4449	0	-72	0	0	-563	-6232
TPS	Total Primary Supply	13414	0	9152	0	5067	0	0	20	27654
	CONVERSION									
ESC	Energy Sector Consumption	-58	0	-555	0	-4	-1	0	0	-617
ELC	Electricity Plants	-9598	0	-367	0	-1256	-16	869	5791	-4578
HPL	Heat Plants	-161	0	-15	0	-140	-1	329	0	12
REF	Petroleum Refineries	0	0	-9521	0	0	0	0	0	-9521
	Total Conversion	-9817	0	-10458	0	-1400	-18	1198	5791	-14704
	FINAL									
RSD	Residential	357	0	687	0	1294	0	433	1436	4206
COM	Commercial	57	0	256	0	67	1	127	1264	1772
IND	Industry	1897	0	605	0	722	59	317	2044	5643
AGR	Agriculture	44	0	239	0	63	0	8	10	364
TRA	Transport	1	0	4455	0	131	0	0	133	4720
OTH	Other	1189	0	118	0	1390	0	314	325	3336
NEN	Non Energy	52	0	1222	0	0	0	0	0	1274
BNK	Bunkers	0	0	633	0	0	0	0	0	633
TFC	Total Final Consumption	3597	0	8215	0	3667	59	1198	5211	21948

		COA	GAS	OIL	NUC	RNW	SLU	HET	ELC	
	REG2	Solid Fuels	Natural Gas	Crude Oil	Nuclear Energy	Renewable Energies	Industrial Wastes	Derived Heat	Electricity	Total
	PRIMARY									
MIN	Domestic Supply	0	7899	3765	10775	0	0	0	0	22440
IMP	Imports	0	13292	27972	0	0	0	0	584	41848
EXP	Exports	0	-2516	-10381	0	0	0	0	-563	-13461
TPS	Total Primary Supply	0	18675	21355	10775	0	0	0	20	50826
	CONVERSION									
ESC	Energy Sector Consumption	0	-793	-1294	0	0	-1	0	0	-2088
ELC	Electricity Plants	0	-5636	-857	-10775	0	-16	869	5791	-10625
HPL	Heat Plants	0	-301	-35	0	0	-1	329	0	-7
REF	Petroleum Refineries	0	0	-22216	0	0	0	0	0	-22216
	Total Conversion	0	-6730	-24402	-10775	0	-18	1198	5791	-34936
	FINAL									
RSD	Residential	0	5160	1603	0	0	0	433	1436	8631
COM	Commercial	0	1752	598	0	0	1	127	1264	3742
IND	Industry	0	4437	1411	0	0	59	317	2044	8268
AGR	Agriculture	0	201	558	0	0	0	8	10	777
TRA	Transport	0	21	10396	0	0	0	0	133	10550
OTH	Other	0	0	275	0	0	0	314	325	913
NEN	Non Energy	0	634	2851	0	0	0	0	0	3485
BNK	Bunkers	0	0	1478	0	0	0	0	0	1478
TFC	Total Final Consumption	0	12205	19169	0	0	59	1198	5211	37843

Figure 81. Energy balance at start year 2005 for REG1 & REG 2–Covered in DemoS_005

3.5.2.2 <u>Pri_COA/GAS/OIL</u>

These sheets are updated to include two regions and to regionalize some process attributes. There are several ways of accounting for the regionalization of some attributes. For instance, it is possible to insert a **Region** column on the left side of any **~FI_T** table and to indicate in which region(s) the process is available (Figure 82). A process can be available in only one region (e.g. MINGAS* and IMPGAS1) or in several regions (EXPGAS1). In this later case, different rows can be inserted to declare different values for some of the attributes (ACT_BND of EXPGAS1);

the values that remain on the initial row will apply to all regions (COST of EXPGAS1). The additional rows approach is mainly used when all attributes of a process vary across regions.

In the process table (~FI_ Process), the region where each process is available can be specified (Figure 83): MINGAS* and IMPGAS1 processes exist only in REG2, while the EXPGAS1 process exists in both regions (by default, when the **Region** column is empty, it applies to all regions). Comma-separated entries are also allowed, for instance, when a process exists in more than one region but not in all regions.

			~FI_T			
Region	**TechName**	**Comm-IN**	**Comm-OUT**	**CUM**	**COST**	**ACT_BND**
Region Name	*Technology Name	Input Commodity	Output Commodity	Reserves Cumulative Value	Cost	Annual Production Bound
	*Units			PJ	M€2005/PJ	PJ
REG2	MINGAS1		GAS	15000	3.60	3950
REG2	MINGAS2		GAS	20000	4.14	3950
REG2	MINGAS3		GAS	30000	5.40	
REG2	IMPGAS1		GAS		4.50	
	EXPGAS1	GAS			4.50	
REG1						2516
REG2						2516

Figure 82. Regionalization of process attributes using additional rows

~FI_Process								
Sets	**Region**	**TechName**	**TechDesc**	**Tact**	**Tcap**	**Tslvl**	**PrimaryCG**	**Vintage**
*Process Set Membership	Region Name	Technology Name	Technology Description	Activity Unit	Capacity Unit	TimeSlice level of Process Activity	Primary Commodity Group	Vintage Tracking
*								
MIN	REG2	MINGAS1	Domestic Supply of Natural Gas Step 1	PJ				
	REG2	MINGAS2	Domestic Supply of Natural Gas Step 2	PJ				
	REG2	MINGAS3	Domestic Supply of Natural Gas Step 3	PJ				
IMP	REG2	IMPGAS1	Import of Natural Gas Step 1	PJ				
EXP		EXPGAS1	Export of Natural Gas Step 1	PJ				

Figure 83. Region specification in the default process table

3.5.2.3 <u>Con_ELC</u>

This sheet is also updated to include two regions and to regionalize some process attributes. However, a different approach is used (Figure 84): columns are inserted (duplicated) only for those attributes that vary across regions: the STOCK attribute in this example. As for the year, the regions are identified using the " ~ " command after the attribute. The additional columns approach is mainly used when only few attributes of a process vary across regions.

The column approach is also used in the following sheets, namely for the STOCK attribute: Sector_Fuels, DemTechs_TPS, DemTechs_ELC, DemTechs_RSD and DemTechs_TRA. The row approach is used in the Demand sheet.

3.5.3 Trade files

Two trade files are created to model the energy trade movements between the two regions.

		~FI_T						
TechName	**Comm-IN**	**Comm-OUT**	**STOCK~REG1**	**STOCK~REG2**	**STOCK~REG1~2030**	**STOCK~REG2~2030**	**EFF**	**(...)**
*Technology Name	Input Commodity	Output Commodity	Existing Installed	Existing Installed	Retirement Capacity	Retirement Capacity	Efficiency	
*Units			GW	GW	GW	GW		
ELCTECOA00	ELCCOA	ELC	137	0			0.38	
		ELCCO2						
ELCTEGAS00	ELCGAS	ELC	0	104			0.49	
		ELCCO2						
ELCTEOIL00	ELCOIL	ELC	3	8			0.25	
		ELCCO2						
ELCRERNW00	ELCRNW	ELC	88	0	88	0	1.00	
ELCTENUC00	ELCNUC	ELC	0	125	0	125	0.33	
ELCTNCOA00	ELCCOA	ELC					0.42	
		ELCCO2						
ELCTNGAS00	ELCGAS	ELC					0.52	
		ELCCO2						
ELCTNOIL00	ELCOIL	ELC					0.30	
		ELCCO2						

Figure 84. Regionalization of process attributes using additional columns

3.5.3.1 Scen_Trade_Links

The ~ TradeLinks tables are used to declare the traded commodities and their links between regions (Figure 85): either bilateral links between regions (e.g. ELC trade between REG 1 (importer/exporter) and REG2 (importer/exporter) or unilateral links between regions (e.g. GAS trade between REG 1 (importer) and REG2 (exporter). For each link declared (1=active links), VEDA-FE will automatically create an IRE (inter-regional trade) process to which attributes may then be associated (e.g., bounds, investment costs, etc.). The naming convention for IRE processes is:

- Bilateral trade: TB_<fuel name>_<exporter region>_<importer region>_<01> (e.g. TB_ELC_REG1_REG2_01)
- Unilateral trade: TU_<fuel name>_<exporter region>_<importer region>_<01> (e.g. TU_GAS_REG2_REG1_01)

~TradeLinks		
ELC	REG1	REG2
REG1		1
REG2	1	

~TradeLinks		
GAS	REG1	REG2
REG1		
REG2	1	

Figure 85. Examples of trade matrix for bilateral and unilateral links

3.5.3.2 Scen_Trade_Param

In this file, a transformation table **~TFM_INS** is used to insert new attributes for trade processes (Figure 86), for example: an investment cost (INVCOST) for all unilateral trade processes (TU_*). Trade processes are created automatically after the user declares unilateral or bilateral links between regions in the **_Trade_Links** file.

~TFM_INS																	
TimeSlice	LimType	Attribute	Year	Attrib_Cond	Val_Cond	AllRegions	REG1	REG2	Pset_Set	Pset_PN	Pset_PD	Pset_CI	Pset_CO	Cset_Set	Cset_CN	Cset_CD
		INVCOST				10				TU_*						

Figure 86. Declaration of attributes for IRE processes

3.5.4 Scenario files

Two more scenario files are created to insert new information in the RES that can be retained or not in the configuration of the model at the time of solving the model. Of the previous scenario files, only the Scen_Peak_RSV file is retained for further analysis.

3.5.4.1 Scen_ELC_CO2_Bound

This file is used to introduce a bound (limit) on the CO2 emissions from the power sector in REG1. A transformation table ~TFM_INS is used (Figure 87) to declare an upper bound on annual emissions (Attribute = COM_BNDNET; LimType = UP), on the CO2 emissions from the electricity sector only (ELCCO2) in REG1. In this example the upper bound is calculated as a percentage reduction target from the power sector CO2 emissions in a reference scenario for 2010 (10% = 993,548 kt) and 2020 (20% = 1,017,340 kt). It is necessary to run the step model without any limit on emissions first to get the reference emission trajectory (run DemoS_005) and to calculate the bounds as a reduction target from the reference emissions. An interpolation rule is used with the "0" flag in the Year column and the interpolation/extrapolation option in the region column where the bounds are declared. The code 5 means full interpolation and forward extrapolation.

~TFM_INS														
TimeSlice	LimType	Attribute	Year	AllRegions	REG1	REG2	Pset_Set	Pset_PN	Pset_PD	Pset_CI	Pset_CO	Cset_Set	Cset_CN	Cset_CD
	UP	COM_BNDNET	2010		993548								ELCCO2	
	UP	COM_BNDNET	2020		1017340								ELCCO2	
	UP	COM_BNDNET	0		5								ELCCO2	

Figure 87. Declaration of emission bounds for the power sector

3.5.4.2 Scen_UCCO2_BND – user constraint

This file shows another way used to introduce bounds (limits) on the CO2 emissions from both the power and the transportation sectors in each region (REG1 and REG2). The idea is to build a user constraint (Figure 88) that specifies the maximum amount of emissions in a specific year for the sum of TRACO2 and ELCCO2 emission commodities.

These upper bounds (or limits) are again calculated as a percentage reduction target from the CO2 emissions (sum in kt) of the power and the transportation sector in a reference scenario for 2010 (10%) and 2020 (20%). It is necessary to run the step model without any limit on emissions first to get the reference emission trajectory (run DemoS_005) and to calculate the bounds as a reduction target from the reference emissions.

~UC_Sets: R_E: AllRegions													
~UC_Sets: T_E:													
								~UC_T:UC_RHSRTS					
UC_N	Pset_Set	Pset_PN	Pset_CI	Pset_CO	Cset_CN	Attribute	Year	LimType	UC_COMNET	REG1	REG2	UC_RHSRTS~0	UC_Desc
AU_CO2_BND					TRACO2,ELCCO2		2010	UP	1	1142284	1142284	5	CO2 Bound Constraint
					TRACO2,ELCCO2		2020	UP	1	1227958	1053944		

Figure 88. Declaration of emission bounds using a user constraint

The UC scenario template is set up as described in Section 2.3.8. The sets declarations above the table indicate:

- ~UC_Sets: R_E: AllRegions: The constraints are to be applied to all regions in the model, individually (E=each). That is, the bounds imposed for REG1 and REG2 are separate, and there is no emissions trading between regions.
- ~UC_Sets: T_E: The constraints are imposed to each time period individually. There is no banking or borrowing between periods.

The table level declaration following the table tag (~UC_T:**UC_RHSRTS**) indicates that any column without an index will be interpreted as the right hand side of the constraint, in this case, the indicated bounds in REG1 and REG2 in the given years. This right hand side bounds 1 times the net production (UC_COMNET) of the sum of TRACO2 and ELCCO2. The interpolation/extrapolation option 5 indicates full interpolation and forward extrapolation.

3.5.5 Results

Three cases are solved with this step model, with a different selection of scenario files: the DemoS_005 case is solved without any limit on CO2 emissions and using only the three main components (BASE, TRADE_PARAM, SysSettings), while the DemoS_005a case is solved adding one scenario file (ELC_CO2_BOUND) to put a limit on CO2 emissions from the REG1 power sector, and the DemoS_005b case is solved adding the other scenario file (UC_CO2_BND) to put a limit on both the power and the transportation sectors in both regions.

A first sample of results shows the different configuration of the energy supply systems in the two regions (Figure 89). As mentioned earlier, the REG1 becomes the main provider of solid fuels, renewable energies and some crude oil (from both domestic production and imports). REG1 is also getting electricity from REG2. REG2 becomes the main provider of natural gas, nuclear energy and some crude oil (from both domestic production and imports).

Fuel Supply

Original Units: PJ Active Unit PJ Data values filter:

Attribute | *Process* | *Vintage* | *TimeSlice* | ProcessSet

~Scenario~	Region	Commodity	2005	2006	2010	2015	2020
DemoS_004a	REG1	Crude Oil	30,702	29,559	29,014	28,332	28,332
		Natural Gas	13,312	12,952	12,116	12,552	13,470
		Nuclear Energy	10,775	10,775	10,775	10,775	10,775
		Renewable Energies	1,256	1,256	1,256	1,256	1,256
		Solid Fuels	14,342	15,650	17,203	17,376	17,564
		Total	70,387	70,191	70,363	70,290	71,397
DemoS_005	REG1	Crude Oil	9,155	8,881	8,772	8,636	8,500
		Electricity	774	837	866	904	955
		Renewable Energies	1,256	1,256	1,256	1,256	1,256
		Solid Fuels	14,342	14,481	14,868	15,380	15,899
		Total	25,527	25,455	25,762	26,175	26,609
	REG2	Crude Oil	21,027	20,723	20,469	20,150	19,832
		Natural Gas	13,118	13,517	14,226	15,220	16,371
		Nuclear Energy	10,775	10,775	10,775	10,775	10,775
		Total	44,920	45,015	45,469	46,145	46,978

Figure 89. Results – fuel supply options for both regions in DemoS_005

A second sample of results shows the evolution of the emissions in the different sectors of the two regions (Figure 90):

- Emissions from the power and the transportation sectors as projected in the DemoS_005 case were used to compute the emissions limits in the other two cases.
- A limit on the CO2 from the power sector in REG1 (DemoS_005a) leads to a lower electricity production from solid fuels, and an emission increase in REG2, which produces more electricity from natural gas to supply REG1 (Figure 91).
- With a limit on the CO2 from both the power and the transportation sector in REG1 and in REG2 (DemoS_005b), all the emission reductions are coming from the power sector in both regions. Emissions from the transportation sector are not affected compared with the reference case (DemoS_005) meaning that the power sector of both regions could provide enough reduction options at a lower cost to meet the target. Because there is no trading in emissions between regions, REG2 must cut back on its electricity generation from natural gas, and it begins importing natural gas-fired electricity from REG1, which in turn imports natural gas from REG2 (Figure 91).

Emissions by Sector

Original Units: Kt **Active Unit** Kt **Data values filter:**

Attribute | *Process* | *Vintage* | *TimeSlice* | CommoditySet

~-Scenario-~	Region	Commodity	2005	2006	2010	2015	2020
DemoS_005	REG1	Electricity Plants Carbon dioxide	977,034	971,777	1,010,342	1,061,453	1,113,287
		Transport Carbon dioxide	289,599	288,090	280,999	272,136	263,272
	REG2	Electricity Plants Carbon dioxide	324,377	329,599	379,121	447,078	523,824
		Residential Carbon dioxide	289,464	287,511	277,765	265,584	253,402
		Transport Carbon dioxide	675,732	672,210	655,665	634,983	614,302
	Total		2,556,206	2,549,186	2,603,892	2,681,233	2,768,086
DemoS_005a	REG1	Electricity Plants Carbon dioxide	977,034	971,777	993,548	1,005,444	1,017,340
		Transport Carbon dioxide	289,599	288,090	280,999	272,136	263,272
	REG2	Electricity Plants Carbon dioxide	324,377	329,599	387,211	473,946	569,433
		Residential Carbon dioxide	289,464	287,511	277,765	265,584	253,402
		Transport Carbon dioxide	675,732	672,210	655,665	634,983	614,302
	Total		2,556,206	2,549,186	2,595,188	2,652,092	2,717,749
DemoS_005b	REG1	Electricity Plants Carbon dioxide	977,034	971,777	861,284	912,985	964,686
		Transport Carbon dioxide	289,599	288,090	280,999	272,136	263,272
	REG2	Electricity Plants Carbon dioxide	324,377	329,599	450,923	463,131	439,643
		Residential Carbon dioxide	289,464	287,511	277,765	265,584	253,402
		Transport Carbon dioxide	675,732	672,210	655,665	634,983	614,302
	Total		2,556,206	2,549,186	2,526,636	2,548,818	2,535,304

Figure 90. Results – emissions by sector and by region in DemoS_005

Finally, the marginal price of CO2 (i.e. the price to pay in euros to reduce the last ton of CO2 to meet the reduction targets) in both scenarios with limits on emissions is particularly relevant and represents the level of tax that would be necessary to achieve the reduction targets that are prescribed in the scenario files (Figure 92).

Electricity endogenous trade

Original Units: PJ **Active Unit** PJ **Data values filter:**

Vintage | *TimeSlice*

~Scenario~	Commodity	Region	Attribute	Process	2005	2006	2010	2015	2020
DemoS_005	ELC	REG1	VAR_FOut	TB_ELC_REG1_REG2_01	774	837	866	904	955
		REG2	VAR_FIn	TB_ELC_REG1_REG2_01	774	837	866	904	955
DemoS_005a	ELC	REG1	VAR_FOut	TB_ELC_REG1_REG2_01	774	837	937	1,140	1,358
		REG2	VAR_FIn	TB_ELC_REG1_REG2_01	774	837	937	1,140	1,358
DemoS_005b	ELC	REG1	VAR_FIn	TB_ELC_REG1_REG2_01					208
			VAR_FOut	TB_ELC_REG1_REG2_01	774	837	1,494	1,042	418
		REG2	VAR_FIn	TB_ELC_REG1_REG2_01	774	837	1,494	1,042	418
			VAR_FOut	TB_ELC_REG1_REG2_01					208

Endogenous gas trade

Original Units: PJ **Active Unit** PJ **Data values filter:**

Vintage | TimeSlice

~Scenario~	Commodity	Region	Attribute	Process	2015	2020
DemoS_005b	GAS	REG1	VAR_FOut	TU_GAS_REG2_REG1_01	1,714	4,907
		REG2	VAR_FIn	TU_GAS_REG2_REG1_01	1,714	4,907

Figure 91. Results – endogenous trades in DemoS_005

CO2 Prices

Original Units: MEuro per kton **Active Unit** MEuro per kton **Data values filter:**

Attribute | TimeSlice | CommoditySet

~Scenario~	Region	Commodity	2010	2015	2020
DemoS_005a	REG1	Electricity Plants Carbon dioxide	-0.0026	-0.0026	-0.0032
DemoS_005b	REG1	Electricity Plants Carbon dioxide	-0.0026	-0.0380	-0.0380
		Transport Carbon dioxide	-0.0026	-0.0380	-0.0380
	REG2	Electricity Plants Carbon dioxide		-0.0724	-0.0878
		Transport Carbon dioxide		-0.0724	-0.0878

Figure 92. Results – emissions by sector and by region in DemoS_005

Objective-Function = 3,204,949 M euros (see the _SysCost table in VEDA-BE) with 1,225,688 M euros for REG1 and 1,979,261 M euros for REG2. This cost is less than 0.1% higher with the emission limits for the power sector (3,206,161 M euros) and 1.4% higher with the emission limits for the power and the transportation sectors (3,250,281 M euros). More details about the impacts of the emission limits on the different cost components of the system in each region are shown below (Figure 93).

All system costs (activity, flow, investments and salvage)

Original Units: M Euro **Active Unit** M Euro **Data values filter:**

Process | *Vintage* | *UserConstraint* | *Commodity*

Period

~-Scenario-~	Region	Attribute	-	2005	2006	2010	2015	2020
DemoS_005	REG1	Cost_Act		1,858	1,859	1,893	1,940	1,989
		Cost_Flo		66,600	64,792	66,083	67,572	72,308
		Cost_Fom		14,313	14,478	15,134	15,990	16,873
		Cost_Inv		7,730	8,720	12,666	17,667	22,811
		Cost_Salv	84,969					
		Cost_ire		10,401	8,644	8,936	9,289	9,864
	REG2	Cost_Act		2,045	2,104	2,247	2,445	2,673
		Cost_Flo		122,596	121,957	129,502	135,317	137,951
		Cost_Fom		9,645	10,201	11,651	13,544	15,519
		Cost_Inv		4,192	5,915	12,017	19,793	27,976
		Cost_Salv	81,152					
		Cost_ire		-10,401	-8,644	-8,936	-9,289	-9,864
DemoS_005b	REG1	Cost_Act		1,858	1,859	1,642	1,841	2,169
		Cost_Flo		66,600	64,792	61,976	60,832	60,628
		Cost_Fom		14,313	14,478	14,366	15,686	17,498
		Cost_Inv		7,730	8,720	10,570	17,848	27,283
		Cost_Salv	78,311					
		Cost_ire		10,401	8,644	16,812	29,441	30,616
	REG2	Cost_Act		2,045	2,104	2,483	2,499	2,395
		Cost_Flo		122,596	121,957	135,261	144,316	153,281
		Cost_Fom		9,645	10,201	12,284	13,617	14,726
		Cost_Inv		4,192	5,915	12,996	22,018	32,800
		Cost_Salv	80,071					
		Cost_ire		-10,401	-8,644	-16,812	-29,441	-30,616

Figure 93. Results – emissions by sector and by region in DemoS_005

3.6 DemoS_006 - Multi-region with separate regional templates

Description. At the sixth step, the configuration of the multi-regional model developed previously shifts from a single set of B-Y Templates for all regions to a separate sets of B-Y Templates for each region. This approach is relevant when the model regions are under the control of more than one individual.

Objective. The objective is again to create the multi-regional model framework typical to larger or more complex models, with the trade matrix and limits on emissions of all regions, but additionally to introduce the concept of technology repositories (i.e., SubRES) that include a number of new processes (in competition) that are available in the database to replace the existing ones at the end of their lifetime or to meet an increasing demand.

The motivation behind these repositories is mainly to avoid repeating the new process specifications for each region; all attributes specifications apply to all regions unless a transformation file is used to regionalize some values when necessary.

Simultaneously, the role of the vintage feature is illustrated to handle processes for which characteristics change over time (other than investment cost) when new capacity is built. As in step 5, the scenario variants illustrate the impact of a cap on CO_2 emissions from the electricity sector only and of a cross-region user constraint on the total CO_2 emissions from the transport and electricity sectors.

Attributes introduced:	Files updated
N.A.	SysSettings

	Files created SubRES_NewTechs VT_REG1_PRI_v06 VT_REG2_PRI_v06 Files replaced VT_REG1_PRI_v05

Files. The sixth step model is built 1) by modifying the SysSettings file to add one B-Y Template, 2) by replacing the B-Y Template (VT_REG_PRI_V05) by two B-Y Template (VT_REG1_PRI_v06, VT_REG2_PRI_v06) to disaggregate the energy balance between two regions in two separate files, and 3) by creating a SubRES file to add new processes to the model (Figure 94).

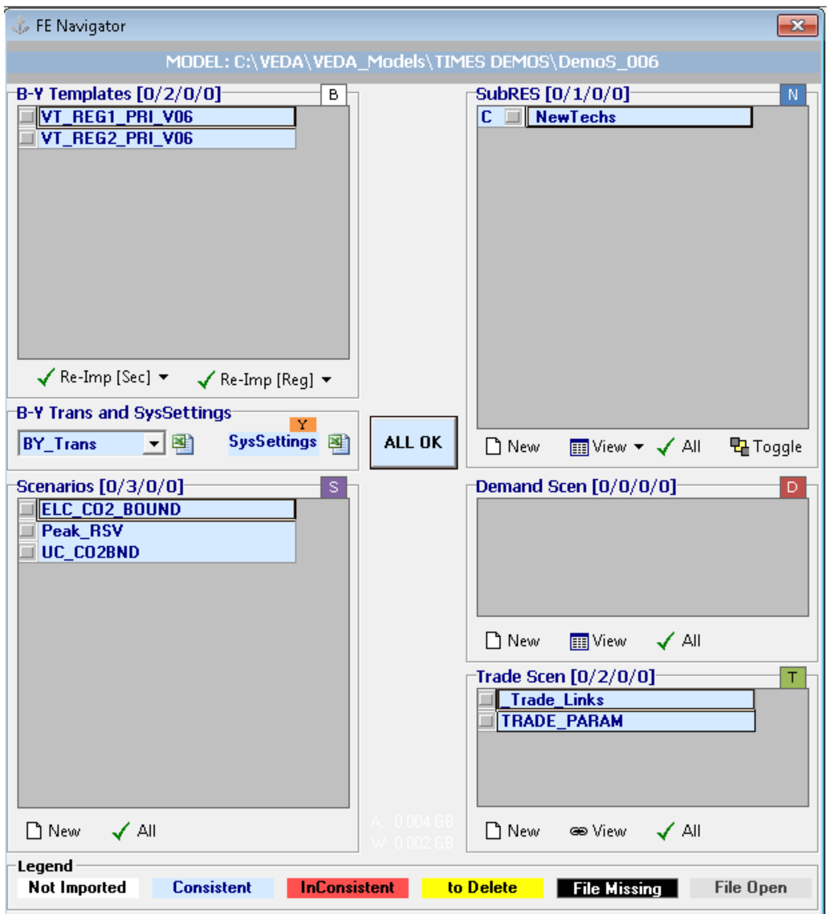


Figure 94. The files included in DemoS_006

3.6.1 SysSettings file

3.6.1.1 <u>Region-Time Slices</u>

The ~BookRegions_Map table is used to create one additional workbook: one for each region REG1 and REG2 (Figure 95).

~BookRegions_Map	
BookName	Region
REG1	REG1
REG2	REG2

Figure 95. New workbook name definitions in the SysSettings file

3.6.2 B-Y Templates

The structure of the two B-Y Templates (VT_REG1_PRI_v06 and VT_REG2_PRI_v06) is identical to the structure of the B-Y Template of the fourth step model and uses the same energy balances defined in the fifth step model for REG1 and REG2 respectively. There is no change to report, except that new power plants are moved from the B-Y Template to the new process repository.

3.6.3 SubRES_NewTechs

Two files are created to add new processes in the model, the SubRES and SubRES_Trans files. The SubRES file is a repository of new processes available for all regions. In the SubRES, by default, all attribute specifications apply to all regions. This approach is convenient for models with multiple regions because a single set of declarations can be made for all regions. The SubRES file includes one sheet for each sector: PRI_ELC, PRI_RSD, PRI_TRA, PRI_FuelSec. (Due to the way SubRES are processed in VEDA-FE, it is required that the name of each sheet start with a valid name of one of the model sectors, as defined in the names of the B-Y templates. In this case, PRI is the only such model sector, and so all sheets in the SubRES template begin with PRI_.)

With this approach, the B-Y Templates now include only processes with existing capacity in the base year 2005, and all new processes are defined in the SubRES. Duplicate definition should be avoided. The new power plants are now declared in this file without any regional specification (Figure 96). Other new processes are created in the other sheets following the same rules: new processes do not have an existing installed capacity, but they are characterized with an investment cost (INVCOST) as well as the year where they become available (START).

The role of the vintage feature is illustrated to handle processes for which characteristics other than investment cost change over time when new capacity is built., In this example, the new gas-fired power plant (ELCTNGAS00) has its efficiency and emission coefficient evolving between 2006 and 2020. The process ELCTNGAS00 is vintaged (Vintage=Yes) in the ~FI_Process table (Figure 97).

			~FI_T										
TechName	Comm-IN	Comm-OUT	Year	START	EFF	AFA	INVCOST	FIXOM	VAROM	LIFE	ENV_ACT	CAP2ACT	Peak
*Technology Name	Input Commodity	Output Commodity			Efficiency	Utilisation Factor	Invesctment Cost	Fixed O&M Cost	Variable O&M Cost	Lifetime	Activity Emission Coefficient	Capacity to Activity Factor	% contribution to PEAK
*Units							M€/GW	M€/PJa	M€/PJ	Years	kt	(Act Unit/Cap Unit)	
ELCTNCOA00	ELCCOA	ELC		2006	0.42	0.85	1650	35.00	0.40	40		31.536	1.00
		ELCCO2									238		
ELCTNOIL00	ELCOIL	ELC		2005	0.30	0.85	250	15.00	0.20	40		31.536	1.00
		ELCCO2									187		
ELCTNGAS00	ELCGAS	ELC		2006		0.85	750	30.00	0.35	30		31.536	1.00
		ELCCO2	2006		0.50						153		
		ELCCO2	2010		0.51						150		
		ELCCO2	2015		0.52						147		
		ELCCO2	2020		0.55						139		

Figure 96. Example of new processes in the SubRES file

~FI_Process

Sets	Region	TechName	TechDesc	Tact	Tcap	Tslvl	PrimaryCG	Vintage
*Process Set Membership	Region Name	Technology Name	Technology Description	Activity Unit	Capacity Unit	TimeSlice level of Process Activity	Primary Commodity Group	Vintage Tracking
ELE		ELCTNCOA00	Power Plants Existing00 - Solid Fuels	PJ	GW	SEASON		
		ELCTNGAS00	Power Plants Existing00 - Natural Gas	PJ	GW			Yes
		ELCTNOIL00	Power Plants Existing00 - Crude oil and Petroleum Products	PJ	GW			

Figure 97. Example of a new process with vintage tracking in the SubRES file

3.6.3.1 <u>SubRES_NewTechs_Trans</u>

For each SubRES_<user-name> file, there is an associated SubRES_<user-name>_Trans file. The transformation files contain the mapping and transformation operations that control the inheritance (or not) of new processes into the various regions of the model, as well as to change any process characteristics, such as investment costs, by region. In this example, the file is empty, so all new processes in the SubRES are available in both regions with identical characteristics.

3.6.4 Results

The results are very similar to those obtained with the previous step model since most of the changes occurred in the way the information is structured in different files rather than in the energy system itself. However, the impact of the vintage feature for the new gas-fired power plants is illustrated (Figure 98).

ELC Plants Production

Original Units: PJ Active Unit Billion Kwh Data values filter:

Attribute | *TimeSlice*

Region	ProcessSet	-Process-	~Scenario~	Vintage	2006	2010	2015	2020
REG2	Gas Power Plants	ELCTNGAS00	DemoS_005	2006	133			
				2010		436		
				2015			825	
				2020				1,224
				Total	133	436	825	1,224
			DemoS_006	2006	10	10	10	10
				2010		235	235	237
				2015			405	417
				2020				560
				Total	10	245	650	1,224

Figure 98. Results – fuel supply options for both regions in DemoS_005

Objective-Function = 3,205,281 M euros (see the _SysCost table in VEDA-BE) with 1,293,017 M euros for REG1 and 1,912,264 M euros for REG2. These costs are similar to those computed with the previous step model DemoS_005.

3.7 DemoS_007 – Adding complexity

Description. The seventh step model is enhanced to capture more components of the energy balance, leading to a more comprehensive representation of the RES with more complex processes.

Objectives. The objective is to show how to model a more comprehensive RES covering more details of the energy balance with more complex processes along its two dimensions: number of commodities and the number of transformation steps in the whole supply-demand chain. In this step refined petroleum products are broken out into different commodities (e.g., gasoline, diesel, heavy fuel, etc.) to better describe the transport sector, where different types of vehicles are introduced. This enhancement of the RES requires the modelling of additional and more complex processes (e.g., refineries and dual demand cars) and the need to introduce the primary commodity group (PCG) concept.

Several more techniques are also introduced in this step:

- We present an easier way to account for combustion-based emissions, by directly linking emission coefficients with each unit of fuel burnt.
- We illustrate how to build end-use demand projections starting from base year values and different growth rates. This is done using the fill table feature to grab base year information from the initial files (e.g. B-Y Templates).
- We show how to build a user constraint that specific the minimum (or maximum) annual growth rate for a set of processes using the CAP, GROWTH attribute.
- Finally, we demonstrate how to use the elastic demand feature of TIMES, including how to generate the file containing the demand prices for base scenarios and how to use these prices for the constrained scenarios.

Attributes introduced:	Files updated
Share ACTFLO COM_VOC COM_STEP COM_ELAST UC_CAP	SysSettings VT_REG1_PRI_v07 VT_REG2_PRI_v07 SubRES_NewTechs Files created Scen_DemProj_DTCAR Scen_Refinery Scen_ElasticDem Scen_TRA_CO2_BOUND Scen_UC Growth

Files. The seventh step model is built:

1. by modifying the SysSettings file to add interpolation rules;
2. by modifying the two B-Y Template (VT_REG1_PRI_v07, VT_REG2_PRI_v07) and the SubRES file (SubRES_NewTechs) to add more commodities, more complex processes, and emission coefficients, and to introduce the PCG concept;
3. by creating a scenario file to project demand from base year values;
4. by creating a scenario file to update refinery attributes;
5. by creating a scenario file to include price-elasticities for demands;
6. by creating a scenario file with a limit on emissions from the transportation sector;
7. by creating a scenario file with a user constraint on growth rates of new cars (Figure 99).

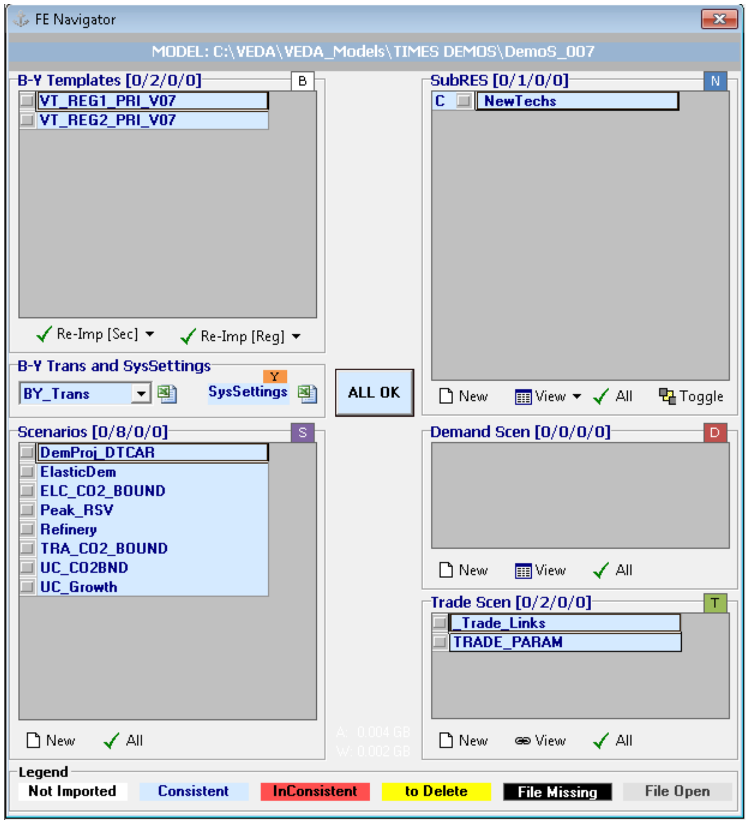


Figure 99. The files included in DemoS_007

3.7.1 SysSettings file

3.7.1.1 Interpol_Extrapol_Defaults

More interpolation/extrapolation rules are added to the transformation table (Figure 100). The same interpolation/extrapolation rule (number 5) is also used for the maximum input shares (Share-I) and the maximum output shares (Share-O) of all processes at once. These new attributes are defined in the next section.

~TFM_UPD					
TimeSlice	LimType	Attribute	Year	AllRegions	Pset_PN
	UP	ACT_BND	0	5	
	UP	Share-O	0	5	
	UP	Share-I	0	5	

Figure 100. Updated table for interpolation/extrapolation rules in the SysSettings file

3.7.2 B-Y Templates

3.7.2.1 EnergyBalance

At this step, the energy balance is disaggregated and includes a larger number of commodities. The crude oil category is disaggregated to track all refined products independently (Figure 101) to better describe the transport sector where different types of cars are introduced. A larger portion of the energy balance is covered in terms of the number of commodities and also of the number of transformation steps in the whole supply-demand chain, with the addition of the refining step.

	REG2	COA Solid Fuels	GAS Natural Gas	OIL Crude oil	DSL Diesel oil	KER Kerosenes	LPG LPG	GSL Motor spirit	NAP Naphtha	HFO Heavy Fuel Oil	OPP Other Petroleum Products	NUC Nuclear Energy	RNW Renewable Energies	SLU Industrial Wastes	HET Derived Heat	ELC Electricity	Total
	PRIMARY																
MIN	Domestic Supply	0	7899	3761	0	0	0	0	0	0	0	10775	0	0	0	0	**22435**
IMP	Imports	0	13292	19354	3087	847	457	924	956	1511	836	0	0	0	0	584	**41848**
EXP	Exports	0	-2516	-2308	-2356	-414	-272	-2101	-561	-1735	-634	0	0	0	0	-563	**-13461**
TPS	**Total Primary Supply**	**0**	**18675**	**20807**	**730**	**433**	**184**	**-1177**	**395**	**-224**	**202**	**10775**	**0**	**0**	**0**	**20**	**50822**
	CONVERSION																
ESC	Energy Sector Consumption	0	-793	0	-23	0	-740	-230	-1	-288	0	0	0	-1	0	0	**-2076**
ELC	Electricity Plants	0	-5636	0	-42	0	-33	0	0	-735	-47	-10775	0	-16	869	5791	**-10625**
HPL	Heat Plants	0	-301	0	-11	0	0	0	0	-21	-2	0	0	-1	329	0	**-7**
REF	Petroleum Refineries	0	0	-22216	7982	1357	1521	4697	1358	3199	1820	0	0	0	0	0	**-281**
	Total Conversion	**0**	**-6730**	**-22216**	**7906**	**1357**	**747**	**4467**	**1358**	**2155**	**1771**	(Ctrl)	**0**	**-18**	**1198**	**5791**	**-12990**
	FINAL																
RSD	Residential	0	5160		1207	102	266	4	0	22	1	0	0	0	433	1436	**8631**
COM	Commercial	0	1752		516	2	44	8	0	27	0	0	0	1	127	1264	**3742**
IND	Industry	0	4437		418	51	200	11	62	400	268	0	0	59	317	2044	**8267**
AGR	Agriculture	0	201		513	1	23	2	0	19	0	0	0	0	8	10	**777**
TRA	Transport	0	21		5399	1467	132	3352	0	47	0	0	0	0	0	133	**10550**
OTH	Other	0	0		0	0	0	0	0	0	0	0	0	0	314	325	**639**
NEN	Non Energy	0	634		107	7	280	4	1259	73	1121	0	0	0	0	0	**3485**
BNK	Bunkers	0	0		206	0	0	0	0	1263	9	0	0	0	0	0	**1478**
TFC	**Total Final Consumption**	0	**12205**		**8366**	**1629**	**945**	**3382**	**1321**	**1851**	**1400**	**0**	**0**	**59**	**1198**	5211	**37568**

Figure 101. Disaggregated energy balance at start year 2005 for REG2 – Covered in DemoS_007

3.7.2.2 <u>Con_REF – primary commodity group definition</u>

A flexible refinery (REFEOIL00) is introduced in this sheet (Figure 102) to convert crude oil (OIL) into refined products (DSL, KER, LPG, GSL, etc.) that will be used in the transportation sector.

- The existing refinery is characterized with an efficiency (EFF) and an annual activity bound (ACT_BND) equivalent to the sum of the refined products produced at base year 2005 as given in the energy balance. In this example the efficiency is represented by the ratio of the crude oil in input to the refinery on the sum of the petroleum products in output. For this reason we get an efficiency greater than 1. This behaviour depends on the definition of the commodity group of a technology (see below for more details).
- This more complex process with multiple outputs commodities is also characterized with a new attribute: the maximum share for each commodity output in the total production (Share-O~UP). In this example, the maximum shares for all outputs sum to 100%, meaning that they are equivalent to fixed shares. It would be possible to have a sum of maximum shares greater than 100%, leaving some flexibility to the model to optimize the output mix.

The same approach is used to declare the new commodities and processes in their definition tables, where the refinery is declared as a PRE process, and the concept of Primary Commodity Group (PCG) is introduced (Figure 103). The activity of a standard process is equal to the sum of the commodity flow(s) on either the input side or the output side of a process, as defined by the PCG. The activity of a process is limited by the available capacity, so that the activity variable establishes a link between the installed capacity of a process and the maximum possible commodity flows entering or leaving the process during a year or a subdivision of a year.

		~FI_T			
TechName	**Comm-IN**	**Comm-OUT**	**Share-O~UP**	**EFF**	**ACT_BND**
*Technology Name	Input Commodity	Output Commodity	Output Share	Efficiency	Activity Bound
*Units			Pja		
REFEOIL00	OIL	DSL	36%	1.01	9400
		KER	6%		
		LPG	7%		
		GSL	21%		
		NAP	6%		
		HFO	15%		
		OPP	8%		

Figure 102. Refinery

In a simple process, one consuming a single commodity and producing a single commodity, the modeler simply chooses one of these two flows to define the activity, and thereby the process normalization (input or output). In complex processes, with several commodities (perhaps of different types) as inputs and/or outputs, the definition of the activity variable requires designation of the PCG to serve as the activity-defining group. The PCG is defined as a subset of the commodities of the same nature entering or leaving a process. For instance, the PCG may be the group of energy carriers, or the group of materials of a given type, on either the input or output side of the process. More about PCGs and their use can be found in Section 2.2.1 of Part II of the TIMES documentation.

VEDA-FE establishes default PCGs for any process involving multiple inputs and/or outputs, based upon the assumption first that all processes are output normalized and then according to the commodities' nature. In case of different commodity types on the output (or input) side, the default PCG is based on the following order:

- DEM
- MAT
- NRG
- ENV
- FIN

However, in some cases it is desirable/necessary to override these defaults, for instance to normalize a process with energy commodities inputs (NRGI) as for the refinery in this example. Indeed, the activity of a refinery is usually characterized based on the barrels of crude oil consumed.

~FI_Process								
Sets	**Region**	**TechName**	**TechDesc**	**Tact**	**Tcap**	**Tslvl**	**PrimaryCG**	**Vintage**
*Process Set Membership	Region Name	Technology Name	Technology Description	Activity Unit	Capacity Unit	TimeSlice level of Process Activity	Primary Commodity Group	Vintage Tracking
*								
PRE		REFEOIL00	Refinery Existing00	PJ	Pja		NRGI	

Figure 103. Overwrite default PCG for the refinery

3.7.2.3 Pri_PP

Import and export options for all refined petroleum products were added in this sheet; they are characterized with the COST and ACT_BND attributes as for any other primary fuels (solid fuels, natural gas, crude oil) (Figure 104). Note that by convention, the export prices are generally be slightly less than import prices, to avoid the model importing just to export.

3.7.2.4 Sector_Fuels

Additional sector fuel processes (FTE-*) are defined and characterized in this sheet (Figure 105), namely to produce the transportation sector fuels from primary refined products (e.g. GSL to TRAGSL). It is not always relevant to keep track of all primary fuels in a sector; multiple primary fuels can be aggregated into a single sector fuel in this case. In this example, several refined products are aggregated into a single electricity sector fuel (via FTE-ELCOIL). When more than one primary fuel are used to create one sector fuel, the shares of input fuels (Share-I~UP) need to be provided. As with Share-O, the maximum input shares may sum to greater than 100%, if desired, to provide some process flexibility.

				~FI_T			
TechName	Comm-IN	Comm-OUT	Year	LimType	CUM	COST	ACT_BND
*Technology Name	Input Commodity	Output Commodity			Reserves Cumulative Value	Cost	Annual Production Bound
*Units					PJ	M€2005/PJ	PJ
IMPDSL1		DSL				10.40	
IMPKER1		KER				11.20	
IMPLPG1		LPG				8.80	
IMPGSL1		GSL				11.20	
IMPNAP1		NAP				8.40	
IMPHFO1		HFO				8.40	
IMPOPP1		OPP				8.40	
EXPDSL1	DSL					10.30	1010
EXPKER1	KER					11.09	177
EXPLPG1	LPG					8.71	117
EXPGSL1	GSL					11.09	900
EXPNAP1	NAP					8.32	241
EXPHFO1	HFO					8.32	744
EXPOPP1	OPP					8.32	272

Figure 104. Imports and exports of refined petroleum products

		~FI_T				
TechName	Comm-IN	Comm-OUT	Share-I~UP	STOCK	EFF	LIFE
*Technology Name	Input Commodity	Output Commodity	Input Share	Existing Installed Capacity	Efficiency	Lifetime
*Units				PJa		Years
FTE-RSDGAS	GAS	RSDGAS			1.00	50
FTE-TRADSL	DSL	TRADSL			1.00	50
FTE-TRAKER	KER	TRAKER			1.00	50
FTE-TRALPG	LPG	TRALPG			1.00	50
FTE-TRAGSL	GSL	TRAGSL			1.00	50
FTE-TRAHFO	HFO	TRAHFO			1.00	50
FTE-TRAELC	ELC	TRAELC			1.00	50
FTE-TRAGAS	GAS	TRAGAS			1.00	50
FTE-ELCCOA	COA	ELCCOA			1.00	50
FTE-ELCGAS	GAS	ELCGAS			1.00	50
FTE-ELCOIL	DSL	ELCOIL	5%		1.00	50
	LPG		4%			
	HFO		86%			
	OPP		5%			
FTE-ELCRNW	RNW	ELCRNW			1.00	50
FTE-ELCNUC	NUC	ELCNUC			1.00	50

Figure 105. Additional sector fuel processes with multiple inputs

3.7.2.5 DemTechs_TRA

The single demand process consuming an energy commodity (TRAOIL) and producing directly the transport demand commodity (DTD1) is replaced with more sophisticated processes representing cars and characterized with non-energy units (Figure 106). The declaration of these processes is shown below (Figure 107): their activity units are in billions passengers-kilometres (BpK) rather than PJ, and their capacity units are in thousands of units (000_units) rather than PJa.

- The existing processes are characterized with their existing installed capacity (STOCK) in thousands of car units (000_units) as indicated above. The stock values correspond to the amount of fuel consumption (e.g. TRADSL) required to produce the transportation demand (DTCAR) as given by the energy balance and taking into account the efficiency (EFF), the annual availability factor (AFA) and the conversion between capacity unit and activity unit (CAP2ACT).
- The efficiency (EFF) is specified in terms of billions of vehicle-kilometres per petajoule (BVkm/PJ), and can be interpreted as the number of kilometres a vehicle can travel with 1 PJ of energy.
- The annual availability factor (AFA) represents the average thousand kilometres ('000 km) a car is traveling each year.
- A new attribute is introduced to capture the relation between the process activity and the commodity flow (ACTFLO), the commodity being the output demand, in terms of passengers per car unit (Passenger/Car). This TIMES parameter requires an additional index that is the specification of the commodity group: DEMO (demand out) in this example.
- The life time (LIFE) is specified in number of years as for the other processes.
- The conversion factor between capacity unit and activity unit (CAP2ACT) is not equal to 1 because the units are different: the activity is in billion vehicle-kilometres, the stock is in thousands of units (000_units or vehicles) and the utilization factor (AFA) is in thousand kilometres per vehicle. The CAP2ACT is translating mvkm into bvkm.

		~FI_T								
TechName	Comm-IN	Comm-OUT	STOCK	EFF	AFA	ACTFLO~DEMO	INVCOST	FIXOM	LIFE	CAP2ACT
*Technology Name	Input Commodity	Output Commodity	Existing Installed	Efficiency	Utilisation Factor	Activity to Flo	Invesotment Cost	Fixed O&M Cost	Lifetime	
*Units			000_Units	BV*km/PJ	'000 km	Passenger/Car	MI2005/000_Units	MI2005/000_Unitsa	Years	bvkm/mvkm
TCAREDSL	TRADSL	DTCAR	58069	0.41	17	1.25		0.16	10	0.001
TCARELPG	TRALPG	DTCAR	1550	0.38	14	1.25		0.16	10	0.001
TCAREGSL	TRAGSL	DTCAR	50466	0.40	12	1.25		0.15	10	0.001
TCAREGAS	TRAGAS	DTCAR	0	0.38	14	1.25		0.16	10	0.001

Figure 106. More complex processes in the transportation sector

~FI_Process								
Sets	Region	TechName	TechDesc	Tact	Tcap	Tslvl	PrimaryCG	Vintage
*Process Set Membership	Region Name	Technology Name	Technology Description	Activity Unit	Capacity Unit	TimeSlice level of Process	Primary Commodity	Vintage Tracking
*								
DMD		TCAREDSL	Demand Technologies Transport Sector - Existing Cars - Diesel oil	BPkm	000_Units		DEMO	
		TCARELPG	Demand Technologies Transport Sector - Existing Cars - LPG	BPkm	000_Units		DEMO	
		TCAREGSL	Demand Technologies Transport Sector - Existing Cars - Motor spirit	BPkm	000_Units		DEMO	
		TCAREGAS	Demand Technologies Transport Sector - Existing Cars - Natural Gas	BPkm	000_Units		DEMO	

Figure 107. Declaration of more processes in the transportation sector

3.7.2.6 Demands

The demand for transportation by cars is updated and declared in the right units and correspond to the sum of billion passengers-kilometres (Bpass*km) for all types of cars (Figure 108):

- Demand (Bpass*km) = STOCK (000_units) * AFA (000_vehiclekm/unit) * ACTFLO~DEMO (Passengers/vehicle)* CAP2ACT(0.001bvkm/mvkm)

	~FI_T						
Attribute	CommName	*Unit	2005	2006	2010	2015	2020
*	Demand Commodity Name	Demand Unit	Demand Value				
*Units			PJ				
Demand	TPSCOA	PJ	3597				
Demand	DROT	PJ	0				
Demand	DTCAR	Bpass*km	1950				
Demand	TPSELC	PJ	5211	5264	5477	5757	6050

Figure 108. Demand for transportation by car in physical units

3.7.2.7 Emi

A new sheet is added to introduce a comprehensive and convenient approach to account for combustion emissions by sector. Indeed, the easiest way to account for combustion emissions is to directly associate the fuel-based emission coefficients with fuel consumption throughout the whole energy system.

A new ~COMEMI table is added (Figure 109) to define fuel-based emission coefficients instead of defining emission coefficients for each process in all ~FI_T tables. The special tag ~COMEMI is used to link emissions to commodity consumption through special processing in the VEDA-FE SYNC process. (The VEDA-TIMES parameters VDA-EMCB and FLO-EMIS provide alternative ways to declare consumption-linked emissions. See Part II of the TIMES documentation for more on the use of these parameters.)

In this example, emissions of TRACO2 are associated with six fuels (LPG, gasoline, kerosene, diesel, heavy fuel oil, natural gas,) for which a coefficient (kt/PJ) is provided. These coefficients are applied to all the fuel consumption by all the individual processes in the transportation sector.

~COMEMI						
CommName	TRALPG	TRAGSL	TRAKER	TRADSL	TRAHFO	TRAGAS
*Units	kt/PJ	kt/PJ	kt/PJ	kt/PJ	kt/PJ	kt/PJ
TRACO2	65.00	72.00	74.00	74.00	78.00	56.00

Figure 109. Combustion emissions from the transportation sector

3.7.3 SubRES_NewTechs

3.7.3.1 PRI_TRA

This sheet is updated to model the new cars using the same approach as described above for the existing cars.

3.7.4 Scenario files

Several scenario files are created at this seventh step.

3.7.4.1 Scen_DemProj_DTCAR

This scenario file is created to project transport demand using a fill table to grab base year values from B-Y templates (Figure 110). The **~TFM_FILL** table (see section 2.3.3 for more information) is a feature allowing a template to collect information from other templates. In this example, the table is collecting the base year values (YEAR=2005) from the B-Y templates (Scenario = BASE) for the transportation demand (Attribute=Demand) by cars (commodity = DTCAR). VEDA-FE fills in the REG1 and REG2 values in the blue highlighted cells each time the template is SYNCed.

~TFM_FILL								
Operation_Sum_Avg_Count	Scenario	TimeSlice	LimType	Attribute	Year	REG1	REG2	Cset_CN
A	BASE			Demand	2005	1950.24	4560.75	DTCAR

Figure 110. Grab base year demand values from B-Y templates

The DTCAR demand is then projected to 2020 in the **~TFM_INS** table using the base year values and some multipliers (2% for REG1 and 3% for REG2) defined by the user (Figure 111).

~TFM_INS							Demand Driver (annual growth)	
TimeSlice	LimType	Attribute	Year	REG1	REG2	Cset_CN	Reg1	Reg2
		Demand	2006	1989.2	2008.7	DTCAR	2%	3%
		Demand	2010	2153.2	2260.9	DTCAR		
		Demand	2015	2377.3	2621.0	DTCAR		
		Demand	2020	2624.8	3038.4	DTCAR		

Figure 111. Using base year values to project end-use demands

3.7.4.2 Scen_Refinery

This scenario file is created to update refinery attributes, again using a fill table to grab information from B-Y templates (Figure 112). In this example, the table is collecting the base year values (YEAR=2005) from the B-Y templates (Scenario = BASE) for the activity production bound (Attribute=ACT_BND) of the refinery (process = REFEOIL00).

~TFM_FILL								
Operation	Scenario	TimeSlice	LimType	Attribute	Year	REG1	REG2	Pset_PN
A	BASE			ACT_BND	2005	9400.42	21934.32	REFEOIL00

Figure 112. Grab base year attribute values from B-Y templates

The activity production is then projected to 2020 in the ~TFM_INS table using the base year values and some relaxation factors (25% for REG1 and 30% for REG2) defined by the user (Figure 113). In addition, the maximum (UP) shares of the refinery outputs (Attribute=SHARE-O) are all updated to 50%, creating flexibility for the model to optimize the mix of refined products (DSL, KER, LPG, etc.).

~TFM_INS																
TimeSlice	LimType	Attribute	Year	Other_Indexes	AllRegions	REG1	REG2	Pset_Set	Pset_PN	Pset_PD	Pset_CI	Pset_CO	Cset_Set	Cset_CN	Cset_CD	
	UP	Share-O	2020	NRGO		50%	50%		REFEOIL00					DSL		
	UP	Share-O	2020	NRGO		50%	50%		REFEOIL00					KER		
	UP	Share-O	2020	NRGO		50%	50%		REFEOIL00					LPG		
	UP	Share-O	2020	NRGO		50%	50%		REFEOIL00					GSL		
	UP	Share-O	2020	NRGO		50%	50%		REFEOIL00					NAP		
	UP	Share-O	2020	NRGO		50%	50%		REFEOIL00					HFO		
	UP	Share-O	2020	NRGO		50%	50%		REFEOIL00					OPP		
	UP	ACT_BND	2020			11751	28515		REFEOIL00							

Figure 113. Using base year values to update refinery attributes

3.7.4.3 Scen_TRA_CO2_BOUND

This file is used to introduce bounds (limits) on the CO2 emissions from the transportation sector in REG1 and REG2. A transformation table ~TFM_INS is used (Figure 114) to declare upper bounds on annual emissions (Attribute = COM_BNDNET; LimType = UP), on the CO2 emissions from the transportation sector only (TRACO2) in REG1 and REG2. These upper bounds are calculated as percentage reduction targets from the transportation sector CO2 emissions in a reference scenario for 2010 (10%) and 2020 (20%). It is necessary to run the step model without any limit on emissions first to get the reference emission trajectory (run DemoS_007) and then calculate the bounds as a reduction targets from the reference emissions. An interpolation rule is used with the "0" flag in the Year column and the interpolation/extrapolation option in the region column where the bounds are declared; the code 5 means full interpolation and forward extrapolation.

~TFM_INS															
TimeSlice	LimType	Attribute	Year	AllRegions	REG1	REG2	Pset_Set	Pset_PN	Pset_PD	Pset_CI	Pset_CO	Cset_Set	Cset_CN	Cset_CD	
	UP	COM_BNDNET	2010		279594	293300							TRACO2		
	UP	COM_BNDNET	2020		303192	350973							TRACO2		
	UP	COM_BNDNET	0		5	5							TRACO2		

Figure 114. Declaration of emission bounds for the transportation sector

3.7.4.4 Scen_UC Growth

This file shows another type of user constraint that specifies the maximum (or minimum) annual growth rate for a set of processes using the CAP, GROWTH attribute (Figure 115). (See Section 2.3.8 for more on user constraints.)

This user constraint imposes a maximum capacity (defined by UC_CAP) growth rate (CAP,GROWTH) of 1% per year (value in the column UC_CAP) for cars consuming TRADSL (these cars are identified using the two columns PSET_CO and PSET_CI). This constraint also provides a seed value of 1 (column UC_RHSRTS) to enable the capacity growth to start in case the existing capacity of diesel cars is zero.

~UC_Sets: R_E: AllRegions											
~UC_Sets: T_SUC:											
							~UC_T				
UC_N	Pset_Set	Pset_PN	Pset_CI	Pset_CO	UC_ATTR	Year	LimType	UC_CAP	UC_CAP~RHS	UC_RHSRTS	UC_RHSRTS~0
UC_GrowthOfNewCars			TRADSL	DTCAR	CAP, GROWTH		LO	1.01	1	-1	5

Figure 115. Specifying growth rates with a user constraint

3.7.4.5 Scen_ElasticDem

This file is used to introduce price-elasticities for end-use demands (Figure 116), so that demands can react to changes in their prices under a constrained energy system (e.g., under limits or tax on emissions, etc.). (See Section 4.2 of Part I of the TIMES documentation for more on the elastic demand formulation.)

In this example, price-elasticities are declared for the transportation demand by cars (DTCAR). Three attributes need to be declared:

- COM_ELAST: Elasticity of demand indicating how much the demand rises/falls in response to a unit change in the marginal cost of meeting a demand that is elastic.
- COM_VOC: Maximum possible variation of demand in both directions when using the elastic demand formulation (15% in this example).
- COM_STEP: Number of steps for the linear approximation of the demand curve (10 steps in this example).

~TFM_INS					
TimeSlice	LimType	Attribute	Year	Cset_CN	AllRegions
	UP,LO	COM_VOC	2006	DTCAR	0.15
	UP,LO	COM_VOC	0	DTCAR	5
	UP,LO	COM_STEP		DTCAR	10

~TFM_INS						
TimeSlice	LimType	Attribute	Year	Cset_CN	REG1	REG2
ANNUAL	LO	COM_ELAST	2006	DTCAR	-0.0330	-0.0330
ANNUAL	UP	COM_ELAST	2006	DTCAR	-0.0330	-0.0330
ANNUAL	LO	COM_ELAST	2020	DTCAR	-0.1500	-0.1500
ANNUAL	UP	COM_ELAST	2020	DTCAR	-0.0500	-0.0500

Figure 116. Declaring price-elasticities for end-use demands

In order to activate the elastic demand feature, there are few steps to follow:

- Generate a file with demand prices from a reference case, i.e. without any constraint or tax on emissions: in the Control Panel of the FE Case Manager, make sure the option “Write B Price for Elast Dem" is selected (Figure 117). This option is already selected in the DemoS_007.
- Solve a constrained case with price-elasticity:
    - Select the constrained scenarios you want to include in the model run (emission limits or taxes) as well as the elastic demand scenario.
    - In the FE Case Manager, click on **No Elast DEM** below Base Price and select the reference case that was run to get the demand base prices (see right side of Figure 118 where DemoS_007b is a constrained case run with elastic demands, while DemoS_007a on the left side is a constrained case run without elastic demands).

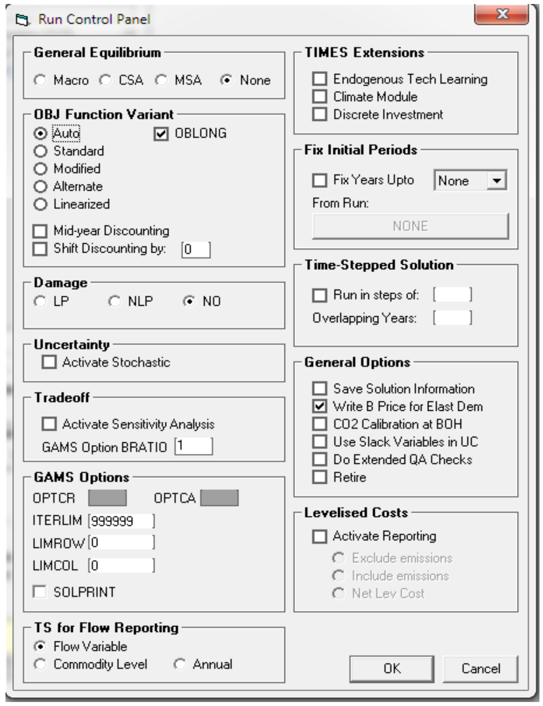


Figure 117. Write base prices for elastic demands

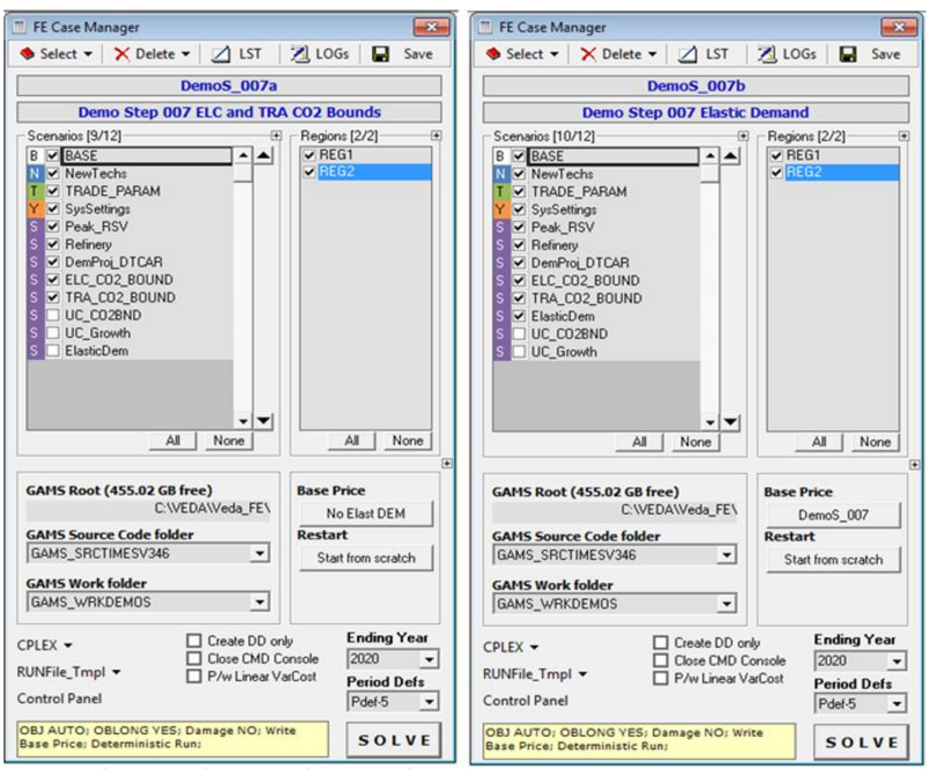


Figure 118. Activate the elastic demand in constrained runs

3.7.5 Results

The effect of price elasticities on the new projected demand for car transportation in thousand passengers-kilometres (kpass*km) to the 2020 horizon is visible (Figure 119) in the scenarios where it was activated (DemoS_007b and DemoS_007c). Demands are decreasing by about 9% in both regions, less than the maximum decrease of 15%, meaning than more cost-effective emission reduction options exist elsewhere in the system beyond that level.

The impacts of the emissions constraints and the growth rate constraint on the optimal process mix selected to meet the car transportation demand (kpass*km) is shown (Figure 120) for both regions together:

Demands

Original Units: Active Unit Data values filter:

Attribute | *Vintage* | TimeSlice | CommoditySet | *Process*

~-Scenario-~	-Commodity-	Region	2005	2006	2010	2015	2020
DemoS_007	Demand Transport Sector - Cars	REG1	1,950	1,989	2,153	2,377	2,625
		REG2	4,561	2,009	2,261	2,621	3,038
DemoS_007a	Demand Transport Sector - Cars	REG1	1,950	1,989	2,153	2,377	2,625
		REG2	4,561	2,009	2,261	2,621	3,038
DemoS_007b	Demand Transport Sector - Cars	REG1	1,950	1,989	2,056	2,235	2,389
		REG2	4,561	2,009	2,036	2,424	2,765
DemoS_007c	Demand Transport Sector - Cars	REG1	1,950	1,989	2,056	2,199	2,389
		REG2	4,561	2,009	2,036	2,424	2,765

Figure 119. Results - Effect of price elasticities for the car transportation demand in DemoS_007

Demands

Original Units: Active Unit Data values filter:

Attribute | *Vintage* | TimeSlice | CommoditySet | *Region*

~-Scenario-~	-Commodity-	Process	2005	2006	2010	2015	2020
DemoS_007	Demand Transport Sector - Cars	TCAREDSL	3,992	3,077	1,996		
		TCAREGAS	10	9	5		
		TCAREGSL	2,418	653	1,209		
		TCARELPG	90	24	26		
		TCARNDSL		234	1,178	4,998	5,663
		Total	6,511	3,998	4,414	4,998	5,663
DemoS_007a	Demand Transport Sector - Cars	TCAREDSL	3,992	3,077	1,752		
		TCAREGAS	10	9	5		
		TCAREGSL	2,418	653	1,209		
		TCARELPG	90	24	45		
		TCARNDSL		174	906	3,751	3,694
		TCARNELC			437	722	1,053
		TCARNGAS					245
		TCARNLPG		60	60	526	672
		Total	6,511	3,998	4,414	4,998	5,663
DemoS_007b	Demand Transport Sector - Cars	TCAREDSL	3,992	3,077	1,996		
		TCAREGAS	10	9	5		
		TCAREGSL	2,418	653	964		
		TCARELPG	90	24	45		
		TCARNDSL		174	906	3,751	3,694
		TCARNELC			115	382	543
		TCARNGAS					245
		TCARNLPG		60	60	526	672
		Total	6,511	3,998	4,092	4,659	5,153
DemoS_007c	Demand Transport Sector - Cars	TCAREDSL	3,992	3,077	1,996		
		TCAREGAS	10	9	5		
		TCAREGSL	2,418	653	964		
		TCARELPG	90	24	45		
		TCARNDSL		132	660	2,792	2,934
		TCARNELC			102	165	376
		TCARNGAS				934	1,148
		TCARNLPG		102	320	733	695
		Total	6,511	3,998	4,092	4,623	5,153

Figure 120. Results – Car transport process mix in DemoS_007

- In the reference case (DemoS_007), new diesel cars satisfy the entire demand for car transportation from 2015 and beyond. The output mix of the refinery is shown below (Figure 121).
- The limits on the transportation sector emissions (DemoS_007a) lead to a switch toward less polluting options such as electric, natural gas and LPG cars.
- The activation of elastic demand (DemoS_007b) leads to a reduction in the use of the most expensive option to meet demand – electric cars .
- The addition of a growth rate constraint on diesel cars (DemoS_007c) leads to a switch toward natural gas cars.

Refinery input and output

Original Units: PJ   Active Unit PJ   Data values filter:

Process | *Vintage* | TimeSlice | *Region*

~-Scenario-~	Attribute	Commodity	2005	2006	2010	2015	2020
DemoS_007	VAR_FIn	Crude Oil	21,002	16,000	18,172	17,907	16,544
		Total	21,002	16,000	18,172	17,907	16,544
	VAR_FOut	Diesel oil	9,074	7,684	7,303	9,513	8,167
		Heavy Fuel Oil	2,451	2,383	2,479	2,479	2,479
		Kerosenes	626	591	591	591	591
		LPG	654	440	443	389	389
		Motor spirit	6,223	2,992	5,419	3,001	3,001
		Naphtha	774	802	802	802	802
		Other Petroleum Products	933	906	906	906	906
		Total	20,737	15,798	17,942	17,680	16,335
DemoS_007c	VAR_FIn	Crude Oil	21,002	16,800	18,872	18,497	18,963
		Total	21,002	16,800	18,872	18,497	18,963
	VAR_FOut	Diesel oil	9,074	7,978	7,769	8,552	9,091
		Heavy Fuel Oil	2,451	2,479	2,479	2,479	2,479
		Kerosenes	626	591	591	591	591
		LPG	654	656	1,157	1,933	1,853
		Motor spirit	6,223	3,176	4,930	3,001	3,001
		Naphtha	774	802	802	802	802
		Other Petroleum Products	933	906	906	906	906
		Total	20,737	16,588	18,633	18,263	18,723

Figure 121. Results - Flexible refinery output in DemoS_007

Objective-Function = 5,484,966 M euros (see the _SysCost table in VEDA-BE) with 2,859,389 M euros for REG1 and 2,625,577 M euros for REG2. These costs are higher than those computed with the previous step model DemoS_006 because of the many components added to the RES. The total cost is 12% higher when emissions limits are imposed on the transportation sector (6,145,863 M euros), but only 7% higher with the activation of elastic demand as the model has more flexibility to reach the emissions targets (5,891,267 M euros). The addition of the growth rate constraint on diesel cars brings the system cost increase back up to 10% (6,025,956 M euros).

3.8 DemoS_008 - Split Base-Year (B-Y) templates by sector: demands by sector

Description. At the eighth step, the level of detail in the representation of the RES is expanded further, the base-year information is disaggregated into different B-Y Templates for each sector, and demands are projected through 2050. Each of these B-Y Templates utilizes only the relevant portion of the energy balance for its region and is linked to an additional single file containing the complete regional energy balances. This approach is convenient when different individuals work in parallel on different sectors. In addition, it encourages grouping of related commodities and processes, and as the size of a model grows it improves (and speeds up) the process of managing the model.

Objective. The objective is to give more examples on how to further expand the detail of the representation of the RES, in terms of the number of end-use demand segments and end-use devices as well as commodities. On the demand side, the idea is to cover the energy consumption by end-use in all sectors rather than by type of energy: agriculture (one end-use demand), commercial (three end-use demands), residential (three end-use demands), industrial (one end-use demands), and transport (two end-use demands). On the supply side, the idea is to break the renewables into more detail for wind, solar, hydro and biomass power. This enhancement of the RES requires the modelling of additional processes as well as the addition of emission coefficients for all sectors.

Another objective is to show how to impose a limit on power generation capacity: nuclear, for example. The scenario variants with nuclear maximum capacity, with different types of limits on emissions, and with and without the elastic demand feature, illustrate the impacts on the respective contribution of each sector to the target as well as on the electricity generation mix.

Attributes introduced:	Files updated
N.A.	SysSettings Scen_TRA_CO2_Bound Scen_ELC_CO2_Bound Scen_UC_CO2BND SubRES_NewTechs Files created VT_REG1_PRI_v08 VT_REG1_ELC_v08 VT_REG1_RCA_v08 VT_REG1_TRA_v08 VT_REG1_IND_v08 VT_REG2_PRI_v08 VT_REG2_RCA_v08 VT_REG2_ELC_v08 VT_REG2_TRA_v08 VT_REG2_IND_v08 Scen_UC_NUC_MaxCAP Files replaced VT_REG1_PRI_v07 VT_REG2_PRI_v07

Files. The eighth step model is built:

1. by modifying the SysSettings file to add more time periods;

2. by replacing the two B-Y Templates (VT_REG1_PRI_v07, VT_REG2_PRI_v07) by five B-Y Templates – one for each sector – in each region (VT_REG1_*_v08, VT_REG2_*_v08), and to add more energy commodities, energy processes, and emissions;
3. by completing the SubRES file;
4. by updating scenario files with limits on emissions;
5. by creating a scenario file with a user constraint on the maximum nuclear power capacity (Figure 122).

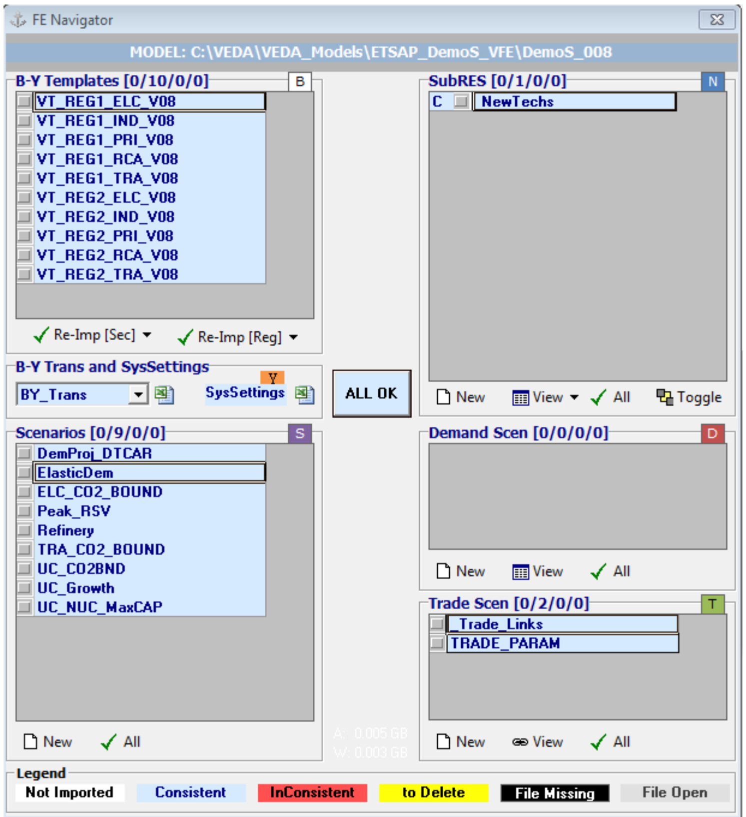


Figure 122. The files included in DemoS_008

3.8.1 SysSettings file

3.8.1.1 TimePeriods

The ~TimePeriods table is used to extend the time horizon of the model by adding six active periods of five years (Figure 123). These specifications are saved under a new time period definition (Pdef-11). The time horizon is extended to 2050 with the milestones years being 2005, 2006, 2010, 2015, 2020, 2025, 2030, 2035, 2040, 2045 and 2050. This can be seen in VEDA-FE, Advanced Functions menu, MileStone Years tab.

~TimePeriods		
Pdef-1	Pdef-5	Pdef-11
1	1	1
2	2	2
	5	5
	5	5
	5	5
		5
		5
		5
		5
		5
		5

Figure 123. New time periods definition in the SysSettings file

3.8.1.2 <u>Defaults</u>

The ~DefUnits table is used to specify the different default activity, capacity and commodity units for each sector in the model (Figure 124).

~DefUnits					
Option	PRI	ELC	IND	RCA	TRA
Process_ActUnit	PJ	PJ	PJ	PJ	kPk
Process_CapUnit	Pja	GW	GW	Pja	000_Units
Commodity_Unit	PJ	PJ	PJ	PJ	kPk

Figure 124. Default declarations in the SysSettings file

3.8.2 B-Y Template VT_REG*_PRI_V08

3.8.2.1 <u>EnergyBalance</u>

The energy balance is disaggregated further and includes a larger number of commodities. The renewable category is disaggregated to track several sources independently: biomass as well as hydro, wind, and solar energy (Figure 125). Moreover, the energy balances of both regions are now moved into a separate file (called EnergyBalance) and all B-Y Templates are linked to this file to grab the relevant sector data.

		COA	GAS	OIL	DSL	KER	LPG	(...)	NUC	BIO	HYD	WIN	SOL	SLU	HET	ELC	TOT
	REG1	Solid Fuels	Natural Gas	Crude Oil	Diesel oil	Kerosenes	LPG	(...)	Nuclear Energy	Biomass	Hydro power	Wind energy	Solar energy	Industrial Wastes	Derived Heat	Electricity	Total
	PRIMARY																
MIN	Domestic Supply	5264	3160	2686	0	0	0		4455	2262	503	264	126	0	0	0	18719
IMP	Imports	4201	5317	13824	2205	605	326		0	85	0	0	0	0	0	584	30166
EXP	Exports	-746	-1007	-1648	-1683	-295	-195		0	-54	0	0	0	0	0	-563	-9785
TPS	Total Primary Supply	8719	7470	14862	522	310	132	(...)	4455	2292	503	264	126	0	0	20	39100
	CONVERSION																
ESC	Energy Sector Consumption	-37	-317	0	-16	0	-529		0	-3	0	0	0	-1	0	0	-1275
ELC	Electricity Plants	-6239	-2254	0	-30	0	-24		-4455	-527	-503	-264	-68	-16	869	5791	-8279
HPL	Heat Plants	-105	-121	0	-8	0	0		0	-105	0	0	0	-1	329	0	-27
REF	Petroleum Refineries	0	0	-15868	5701	969	1086		0	0	0	0	0	0	0	0	-201
	Total Conversion	-6381	-2692	-15868	5647	969	533	(...)	-4455	-636	-503	-264	-68	-18	1198	5791	-9782
	FINAL																
RSD	Residential	232	2064		862	73	190		0	895	0	0	50	0	433	1436	6254
COM	Commercial	37	701		369	2	32		0	39	0	0	8	1	127	1264	2603
IND	Industry	1233	1775		299	36	143		0	541	0	0	0	59	317	2044	6976
AGR	Agriculture	29	80		367	0	16		0	47	0	0	0	0	8	10	573
TRA	Transport	0	8		3856	1048	94		0	121	0	0	0	0	0	133	7688
OTH	Other	773	0		0	0	0		0	0	0	0	0	0	314	325	1412
NEN	Non Energy	34	254		76	5	200		0	0	0	0	0	0	0	0	2324
BNK	Bunkers	0	0		147	0	0		0	0	0	0	0	0	0	0	1056
TFC	Total Final Consumption	2338	4882		5976	1164	675	(...)	0	1644	0	0	58	59	1198	5211	28886

* For purposes of clarity the energy balance is not presented totally and some columns are missing (for refined products).

Figure 125. Disaggregated energy balance at start year 2005 for REG1 – Covered in DemoS_008

3.8.2.2 Pri_COA, Pri_GAS, Pri_OIL, Pri_PP, Con_REF

The structure of these sheets have not changed, but the data is updated following a different commodity split between REG1 and REG2 in the energy balance.

3.8.2.3 Pri_RNW and Pri_NUC

Mining processes for the uranium resources and the new renewable potentials are characterized with a cost (Figure 126).

		~FI_T		
TechName	Comm-IN	Comm-OUT	COST	ACT_BND
*Technology Name	Input Commodity	Output Commodity	Cost	Annual Production Bound
*Units			M€2005/PJ	PJ
MINNUC1		NUC	0.25	

		~FI_T		
TechName	Comm-IN	Comm-OUT	COST	ACT_BND
*Technology Name	Input Commodity	Output Commodity	Cost	Annual Production Bound
*Units			M€2005/PJ	PJ
MINBIO1		BIO	4.05	
MINHYD1		HYD		
MINWIN1		WIN		
MINSOL1		SOL		

Figure 126. Description of new supply options for renewables

3.8.2.4 Pri_ELC

This sheet is created to capture the imports and exports of electricity (Figure 127). In the default process table, the operational level of these processes are declared as DAYNITE in the **Tslvl** column. Note that the ELC commodity is not declared in the default commodity table as it is already declared in the ELC B-Y Templates. Commodities need to be declared only once and then are available for all files (not only B-Y Templates).

		~FI_T		
TechName	Comm-IN	Comm-OUT	COST	ACT_BND
*Technology Name	Input Commodity	Output Commodity	Cost	Annual Production Bound
*Units			M€2005/PJ	PJ
IMPELC1		ELC	5.38	584
EXPELC1	ELC		6.00	563

Figure 127. Imports and exports options for electricity

3.8.3 B-Y Template VT_REG*_ELC_V08

3.8.3.1 Con_ELC

New power plants are added for each type of renewable energy (Figure 128) using the same approach as before. Their contribution to peak varies depending on the resources: 50% for hydro, 30% for wind, and 20% for solar. However, there is no emission coefficient associated with process anymore (in ~FI_T tables). All combustion emissions are tracked in a uniform manner at the sector level in a ~COMEMI table.

		~FI_T										
TechName	Comm-IN	Comm-OUT	STOCK	STOCK~2030	EFF	AFA	INVCOST	FIXOM	VAROM	LIFE	CAP2ACT	Peak
*Technology Name	Input Commodity	Output Commodity	Existing Installed Capacity	Retirement Capacity	Efficiency	Utilisation Factor	Invesctment Cost	Fixed O&M Cost	Variable O&M Cost	Lifetime	Capacity to Activity Factor	% contribution to PEAK
*Units			GW	GW			M€2005/GW	M€2005/GW	M€2005/PJ	Years	PJ/GW	
ELCTECOA00	ELCCOA	ELC	89		0.38	0.85		40.00	0.50	30	31.536	1.00
ELCTEGAS00	ELCGAS	ELC	41		0.49	0.85		35.00	0.40	20	31.536	1.00
ELCTEOIL00	ELCOIL	ELC	6		0.25	0.85		20.00	0.20	30	31.536	1.00
ELCNENUC00	ELCNUC	ELC	52	52	0.33	0.90		38.00	0.27		31.536	1.00
ELCREBIO00	ELCBIO	ELC	8		0.28	0.60		25	0.35	25	31.536	1.00
ELCREHYD00	ELCHYD	ELC	32		1.00	0.50		50	2.00	50	31.536	0.50
ELCREWIN00	ELCWIN	ELC	24		1.00	0.35		35	0.50	20	31.536	0.30
ELCRESOL00	ELCSOL	ELC	7		1.00	0.30		60		15	31.536	0.20

Figure 128. New power plants for renewable electricity generation

3.8.3.2 Emi

A similar sheet is added in all sectors with a ~COMEMI table used to define fuel-based emission coefficients associated with fuel consumption in each sector (Figure 129).

~COMEMI			
CommName	ELCCOA	ELCGAS	ELCOIL
*Units	kt/PJ	kt/PJ	kt/PJ
ELCCO2	95.00	56.10	76.40

Figure 129. Combustion emissions from the electricity sector

3.8.4 BY Template VT_REG*_IND_V08

3.8.4.1 DemTechs_IND

The energy consumed in the industrial sector is captured through a single generic process (Figure 130) consuming the mix of industrial fuels as given in the energy balance and producing one end-use demand (DIDM1). A relaxation factor is used for the maximum input shares in 2050 to give more flexibility to the model over time to optimize the fuel mix. However, the value of the relaxation factor should remain realistic since most fuel switches involve process switches as well.

					Relaxation factor			
		~FI_T			20%			
TechName	Comm-IN	Comm-OUT	STOCK	Share-I~UP	Share-I~2050~UP	EFF	AFA	LIFE
*Technology Name	Input Commodity	Output Commodity	Existing Installed Capacity	Input Share	Input Share	Efficiency	Utilisation Factor	Lifetime
*Units			PJa					Years
IDM1ETOT	INDCOA	DIDM1		19%	22%	1.00	0.95	30
	INDGAS			27%	32%			
	INDOIL			15%	18%			
	INDBIO			8%	10%			
	INDELC			31%	37%			

Figure 130. Multiple input shares process in the industrial sector

3.8.4.2 Emi

An emission commodity is created (Figure 131) and a ~COMEMI table is added in the Emi sheet to track all fuel-based emissions from the sector.

~FI_Comm								
Csets	Region	CommNam	CommDesc	Unit	LimType	CTSLvl	PeakTS	Ctype
*Commodity Set Membership	Region Name	Commodity Name	Commodity Description	Unit	Sense of the Balance EQN.	Timeslice Level	Peak Monitoring	Electricity Indicator
DEM		DIDM1	Demand Industry Sector - Demand 1	PJ				
ENV		INDCO2	Industry Carbon dioxide	kt				

Figure 131. New environmental commodity for industrial emissions

3.8.5 BY Template VT_REG*_RCA_V08

This B-Y Template includes the information related to three sectors: agriculture, commercial and residential.

3.8.5.1 DemTechs_AGR

The energy consumed in the agriculture sector is captured through a single generic process (as for the industrial sector) consuming the mix of agriculture fuels as given in the energy balance and producing one end-use demand (DAOT). A relaxation factor is also used for the maximum input shares in 2050 to give more flexibility to the model over time to optimize the fuel mix. However, the value of the relaxation factor should remain realistic since most fuel switches involve process switches as well.

3.8.5.2 DemTechs_RSD and DemTechs_COM

The energy consumed in the commercial and the residential sectors is modelled through specific processes (Figure 132). Multiple processes are in competition to satisfy each end-use demand (e.g., RSHE* to satisfy the DRSH demand). The existing processes are characterized with their existing installed capacity (STOCK) corresponding in this case to the energy consumption required to produce these energy services as given by the energy balance and the additional fuel split assumptions. The calculation of the existing stocks also takes into account availability factors (AFA) and are converted into GW using a capacity to activity factor (PRC_CAPACT equivalent to CAP2ACT). They also have an efficiency (EFF) and a life time (LIFE).

		~FI_T						
TechName	Comm-IN	Comm-OUT	STOCK	EFF	AFA	PRC_CAPACT	LIFE	Demand
*Technology Name	Input Commodity	Output Commodity	Existing Installed Capacity	Efficiency	Utilisation Factor	Capacity to Activity Factor	Lifetime	Production
*Units			GW			Capacity Unit/PJ	Years	
RSHECOA	RSDCOA	DRSH	0	0.85	0.30	31.536	15	0
RSHEGAS	RSDGAS	DRSH	165	0.90	0.30	31.536	15	1563
RSHEOIL	RSDOIL	DRSH	92	0.80	0.30	31.536	15	867
RSHEBIO	RSDBIO	DRSH	86	0.80	0.30	31.536	15	814
RSHESOL	RSDSOL	DRSH	5	1.00	0.30	31.536	15	51
RSHEELC	RSDELC	DRSH	15	0.95	0.30	31.536	15	145
RAPEELC	RSDELC	DRAP	4351	1.00	0.30	1.00	5	1305
ROTECOA	RSDCOA	DROT	780	1.00	0.30	1.00	10	234
ROTEGAS	RSDGAS	DROT	1737	1.00	0.30	1.00	10	521
ROTEOIL	RSDOIL	DROT	963	1.00	0.30	1.00	10	289
ROTEBIO	RSDBIO	DROT	301	1.00	0.30	1.00	10	90
ROTEELC	RSDELC	DROT	0	1.00	0.30	1.00	10	0

Figure 132. Existing processes in the residential sector

3.8.5.3 Demands

The demand table includes all end-use demands for energy services from the three sectors (Figure 133). The values come from the process sheets where the values are already computed in the pink column (Figure 132): STOCK*AFA*PRC_CAPACT. This sheet also includes the fractional shares of each end-use demand by time slice (Figure 134). These shares are relevant to capture the annual variation in the electricity (ELC) consumption levels and prices, the only commodity tracked at the time slice level. In this example, the annual variations are significant for those end-use demands affected by seasonal changes (e.g. space heating).

	~FI_T		
Attribute	CommName	*Unit	2005
*	Demand Commodity Name	Demand Unit	Demand Value
*Units			PJ
Demand	DRSH	PJ	3440
Demand	DRAP	PJ	1305
Demand	DROT	PJ	1135
Demand	DCSH	PJ	904
Demand	DCAP	PJ	1149
Demand	DCOT	PJ	447
Demand	DAOT	PJ	565

Figure 133. Demand for energy services in the RCA sectors

		~FI_T	
Attribute	CommName	Time:	2005
*	Demand Commodity Name		
*Units			
COM_FR	DRSH	SD	0.00
COM_FR	DRSH	SN	0.00
COM_FR	DRSH	WD	0.60
COM_FR	DRSH	WN	0.40
COM_FR	DRAP	SD	0.30
COM_FR	DRAP	SN	0.25
COM_FR	DRAP	WD	0.20
COM_FR	DRAP	WN	0.20
COM_FR	DROT	SD	0.25
COM_FR	DROT	SN	0.25
COM_FR	DROT	WD	0.25
COM_FR	DROT	WN	0.25
COM_FR	DCSH	SD	0.10
COM_FR	DCSH	SN	0.10
COM_FR	DCSH	WD	0.40
COM_FR	DCSH	WN	0.40
COM_FR	DCAP	SD	0.25
COM_FR	DCAP	SN	0.25
COM_FR	DCAP	WD	0.25
COM_FR	DCAP	WN	0.25
COM_FR	DCOT	SD	0.25
COM_FR	DCOT	SN	0.25
COM_FR	DCOT	WD	0.25
COM_FR	DCOT	WN	0.25

Figure 134. Fractional shares for RCA energy service demands

3.8.5.4 <u>Emi</u>

An emission commodity is created in all three sectors and three ~COMEMI tables are added in the Emi sheet to track all fuel-based emissions from each of the three sectors.

3.8.6 BY Template VT_REG*_TRA_V08

3.8.6.1 <u>DemTechs_TRA</u>

The energy consumed in the transportation sector is disaggregated into two end-use demands: transportation by cars and public transport. Consequently, more existing processes are included to satisfy the demand for the new public transport demand, and they are modelled using the same approach as for cars (Figure 135).

		~FI_T								
TechName	Comm-IN	Comm-OUT	STOCK	EFF	AFA	ACTFLO~DEMO	FIXOM	LIFE	CAP2ACT	CALIBRATION
*Technology Name	Input Commodity	Output Commodity	Existing Installed Capacity	Efficiency	Utilisation Factor	Activity to Flo	Fixed O&M Cost	Lifetime	Capacity to Activity Factor	Demand
*Units			000_Units	MVkm/PJ	'000 km	Passenger/Car	M€2005/000_Units	Years		kPass*km
TCAREGAS	TRAGAS	DTCAR	233	0.38	14	1.25	0.16	10	0.001	4
TCAREDSL	TRADSL	DTCAR	87103	0.41	17	1.25	0.16	10	0.001	1796
TCARELPG	TRALPG	DTCAR	2583	0.38	14	1.25	0.16	10	0.001	45
TCAREGSL	TRAGSL	DTCAR	84110	0.40	12	1.25	0.15	10	0.001	1209
TCAREBIO	TRABIO	DTCAR	3182	0.40	12	1.25	0.15	10	0.001	46
TCAREELC	TRAELC	DTCAR	0	0.40	12	1.25	0.15	10	0.001	0
TPUBEGAS	TRAGAS	DTPUB	0	0.10	50	15.00	0.24	30	0.001	0
TPUBEDSL	TRADSL	DTPUB	1168	0.15	50	15.00	0.24	30	0.001	876
TPUBELPG	TRALPG	DTPUB	0	0.10	50	15.00	0.24	30	0.001	0
TPUBEGSL	TRAGSL	DTPUB	0	0.15	20	15.00	0.23	30	0.001	0
TPUBEBIO	TRABIO	DTPUB	229	0.15	20	15.00	0.23	30	0.001	69
TPUBEELC	TRAELC	DTPUB	40	0.03	100	200.00	0.23	30	0.001	806

Figure 135. Existing processes in the transportation sector

3.8.6.2 <u>Demands</u>

The demand table includes both end-use demands (in Bpass-km) and the fractional shares of each end-use demand by time slice.

3.8.6.3 <u>Emi</u>

An emission commodity is created and a ~COMEMI table is added in the Emi sheet to track all fuel-based emissions from the sector.

3.8.7 SubRES_NewTechs

The structure of this file has not changed; this is a repository of new processes available for all the regions. The file includes one sheet for each sector: ELC, PRI, IND, RCA, TRA. (The sheet's names have changed and reflect each new sector's name).

The new process repository is completed with more new processes similarly as for the existing processes in the B-Y Templates, namely more processes for renewable power generation, public transport, and more energy services in the residential and commercial sectors (Figure 136).

3.8.7.1 <u>IEA-ETSAP_ETechDS</u>

This sheet contains a reference to the technology briefs (E-TechDS – Energy Technology Data Source) coordinated by the ETSAP-IEA. They are classified into two main categories:

energy supply technologies and energy demand technologies. They provide relevant data on the most important technical and economic attributes of numerous types of technologies.[3]

		~FI_T							
TechName	**Comm-IN**	**Comm-OUT**	**START**	**EFF**	**AFA**	**CAP2ACT**	**INVCOST**	**FIXOM**	**LIFE**
*Technology Name	Input Commodity	Output Commodity		Efficiency	Utilisation Factor	Capacity to Activity Factor	Invesctment Cost	Fixed O&M Cost	Lifetime
*Units						Capacity Unit/PJ	M€/Capacity Unit	M€/Capacity unit	Years
CSHNCOA1	COMCOA	DCSH	2006	0.88	0.30	31.536	400	10	20
CSHNGAS1	COMGAS	DCSH	2006	0.93	0.30	31.536	300	8	20
CSHNOIL1	COMOIL	DCSH	2006	0.83	0.30	31.536	250	6	20
CSHNBIO1	COMBIO	DCSH	2006	0.80	0.30	31.536	750	13	20
CSHNSOL1	COMSOL	DCSH	2006	1.00	0.30	31.536	1000	20	15
CSHNELC1	COMELC	DCSH	2006	0.96	0.30	31.536	400	10	20
CAPNELC1	COMELC	DCAP	2006	1.02	0.30	1.00	0.50		5
COTNCOA1	COMCOA	DCOT	2006	1.02	0.30	1.00	1.00		15
COTNGAS1	COMGAS	DCOT	2006	1.05	0.30	1.00	0.50		15
COTNOIL1	COMOIL	DCOT	2006	1.02	0.30	1.00	0.30		15
COTNBIO1	COMBIO	DCOT	2006	1.02	0.30	1.00	1.00		15
COTNELC1	COMELC	DCOT	2006	1.05	0.30	1.00	0.75		15
RSHNCOA1	RSDCOA	DRSH	2006	0.88	0.30	31.536	400	10	20
RSHNGAS1	RSDGAS	DRSH	2006	0.93	0.30	31.536	300	8	20
RSHNOIL1	RSDOIL	DRSH	2006	0.83	0.30	31.536	250	6	20
RSHNBIO1	RSDBIO	DRSH	2006	0.80	0.30	31.536	750	13	20
RSHNSOL1	RSDSOL	DRSH	2006	1.00	0.30	31.536	1000	20	15
RSHNELC1	RSDELC	DRSH	2006	0.96	0.30	31.536	400	10	20
RAPNELC1	RSDELC	DRAP	2006	1.02	0.30	1.00	0.50		5
ROTNCOA1	RSDCOA	DROT	2006	1.02	0.30	1.00	1.00		15
ROTNGAS1	RSDGAS	DROT	2006	1.05	0.30	1.00	0.50		15
ROTNOIL1	RSDOIL	DROT	2006	1.02	0.30	1.00	0.30		15
ROTNBIO1	RSDBIO	DROT	2006	1.02	0.30	1.00	1.00		15
ROTNELC1	RSDELC	DROT	2006	1.05	0.30	1.00	0.75		15

Figure 136. New processes in the residential and commercial sectors

3.8.8 Scenario files

3.8.8.1 Scen_UC_CO2BND

This user constraint is updated to introduce bounds (limits) on the CO2 emissions from all sectors in each region (REG1 and REG2). These upper bound are calculated as a percentage reduction target from the CO2 emissions (sum in kt) from all the sectors in a reference scenario for 2010 (10%) and 2020 (20%). It is necessary to run the step model without any limit on emissions first to get the reference emission trajectory (run DemoS_008) and to calculate the bounds as a reduction target from the reference emissions.

3.8.8.2 Scen_UC_NUC_MaxCAP

To build this scenario, a ~TFM_FILL table first collects information from the B-Y Templates for REG1 and REG2 (Figure 137): the installed capacity (STOCK) of the nuclear power plant (ELCNENUC00). These data are refreshed each time this file is synchronized (SYNC). Second, a user constraint is built to define an absolute upper limit on the total nuclear capacity by region (Figure 138). In 2015, the maximum capacity is fixed to the 2005 base year levels in both regions. Afterwards the capacity is kept constant for REG1 (using the interpolation rule

[3] http://www.iea-etsap.org/Energy_Technologies/Energy_Technology.asp

15=interpolation migrated at start, forward extrapolation), and in REG2 is limited to an additional 10% of the 2005 base year capacity in 2030 and an additional 50% in 2050.

~TFM_FILL									
Operation_Sum_Avg_Count	Scenario Name	TimeSlice	LimType	Attribute	Year	Other_Indexes	REG1	REG2	Pset_PN
A	BASE			STOCK			51.80	63.31	ELCNENUC00

Figure 137. Grab base information on nuclear power capacity

~UC_Sets: R_E: AllRegions													
~UC_Sets: T_E:													
								~UC_T:UC_RHSRT					
UC_N	Pset_Set	Pset_PN	Pset_CI	Pset_CO	Cset_CN	Attribute	Year	LimType	UC_CAP	REG1	REG2	UC_RHSRT~0	UC_Desc
AU_NUC_MaxCAP	ELE		ELCNUC				2015	UP	1	52	63	15	Max Nuclear Power Plants Capacity
	ELE		ELCNUC				2030	UP	1		70		
	ELE		ELCNUC				2050	UP	1		95		

Figure 138. Declare a maximum capacity for nuclear power plants with a user constraint

3.8.9 Results

The results for the electricity generation capacity (Figure 139) show the respective role of the new types of renewable power (biomass, hydro, wind and solar), the 2050 horizon, as well as the effects of the user constraint on nuclear capacity. Nuclear capacity remains constant for REG1 while it grows in REG2 up to the maximum bound in 2030, but not in 2050.

ELC plants capacity and new capacity

Original Units: GW Active Unit GW Data values filter:

Attribute *Process* *Vintage*

~Scenario~	Region	ProcessSet	2005	2006	2010	2015	2020	2025	2030	2035	2040	2045	2050
DemoS_007	REG1	Coal Power Plants	137	160	175	181	168						
		Oil Power Plants	50	51	63	79	95						
		Renewable Power Plants	88	88	88	88	88						
	REG2	Gas Power Plants	104	100	114	144	193						
		Nuclear Power Plants	125	125	125	125	125						
		Oil Power Plants	8	8	7	5	4						
DemoS_008	REG1	Biomass power plants	8	7	6	5	3	2					
		Coal Power Plants	89	86	74	81	84	94	92	86	86	86	86
		Gas Power Plants	41	39	31	21	18	8	8	8	8	8	
		Hydro power plants	32	31	29	26	22	19	16	13	10	6	3
		Nuclear Power Plants	52	52	52	52	52	52	52	52	52	52	52
		Oil Power Plants	6	6	5	4	10	10	11	14	14	14	14
		Solar/PV power plants	7	7	5	2							
		Wind Power Plants	24	23	18	12	6						
	REG2	Biomass power plants	3	2	2	2	1	1					
		Coal Power Plants	48	47	40	42	52	67	62	54	54	54	54
		Gas Power Plants	62	59	47	31	23	7	7	7	7	7	
		Hydro power plants	32	31	29	26	22	19	16	13	10	6	3
		Nuclear Power Plants	63	63	63	63	65	68	70	71	71	71	71
		Oil Power Plants	6	6	5	4	3	2	1				
		Solar/PV power plants	7	7	5	2							
		Wind Power Plants	44	42	33	22	11						

Figure 139. Results - Power generation capacity by fuel type in DemoS_008

The emissions by sector (in Mt) are presented (Figure 140) for both regions, where it is possible to see the contribution of each sector to reaching the reduction targets. In DemoS_008c, with a limit on the total emissions, the additional reductions are coming from the electricity sector (replacing coal-fired with gas-fired power plants), as well as from the residential and the commercial sectors (replacing solid fuels with renewable energies).

Emissions by Sector

Original Units: Kt **Active Unit** Mt **Data values filter:**

Attribute | *Process* | *Vintage* | *TimeSlice* | CommoditySet | *Region*

~-Scenario-~	Commodity	2005	2006	2010	2015	2020	2025	2030	2035	2040	2045	2050
DemoS_008	Agriculture Carbon dioxide	36	36	37	38	39	39	40	41	35	35	43
	Commercial Carbon dioxide	193	246	266	290	314	314	314	314	314	314	314
	Electricity Plants Carbon dioxide	1,049	962	932	956	981	1,045	988	893	889	877	852
	Industry Carbon dioxide	583	586	596	609	622	635	648	661	674	687	700
	Residential Carbon dioxide	563	701	784	887	990	990	990	990	990	990	990
	Transport Carbon dioxide	951	976	994	1,108	1,255	1,255	1,255	1,255	1,255	1,255	1,255
	Total	3,374	3,508	3,609	3,887	4,201	4,279	4,236	4,154	4,158	4,158	4,155
DemoS_008a	Agriculture Carbon dioxide	36	36	37	38	39	39	40	41	35	35	43
	Commercial Carbon dioxide	193	246	266	290	314	314	314	314	314	314	314
	Electricity Plants Carbon dioxide	1,049	962	925	962	866	907	850	755	752	739	804
	Industry Carbon dioxide	583	586	596	609	622	635	648	661	674	687	700
	Residential Carbon dioxide	563	701	784	887	990	990	990	990	990	990	990
	Transport Carbon dioxide	951	976	895	949	1,004	1,004	1,004	1,004	1,004	1,004	1,004
	Total	3,374	3,508	3,502	3,735	3,835	3,890	3,847	3,765	3,769	3,770	3,855
DemoS_008c	Agriculture Carbon dioxide	36	36	37	38	39	39	40	41	42	43	43
	Commercial Carbon dioxide	193	222	231	234	290	308	314	314	304	304	304
	Electricity Plants Carbon dioxide	1,049	962	864	876	784	686	601	480	466	408	376
	Industry Carbon dioxide	583	586	596	609	622	635	648	661	674	687	700
	Residential Carbon dioxide	563	608	665	757	913	926	933	949	936	954	938
	Transport Carbon dioxide	951	972	855	791	714	768	824	884	932	965	1,000
	Total	3,374	3,386	3,248	3,304	3,361	3,361	3,361	3,330	3,354	3,361	3,361

Figure 140. Results – Emissions by sector in DemoS_008

Objective-Function = 19,119,653 M euros (see the _SysCost table in VEDA-BE) with 9,068,703 M euros for REG1 and 10,050,950 M euros for REG2. These costs are again much higher to those computed in the previous step model DemoS_007 because of the expansion of the RES. The total cost is 4% higher with the emission limits for the electricity and the transportation sectors (19,358,261 M euros), and is only slightly reduced by the activation of the elastic demands (19,352,675 M euros). The additional user constraint on nuclear power increases the system cost by 11% (19,699,008 M euros).

3.9 DemoS_009 - SubRES sophistication (CHP, district heating) and Trans files

Description. At the ninth step, the model database is developed further by adding more SubRES with more complex processes. Because SubRES are used to add new processes in different sectors they can be considered as separate modules that can be included in model runs as part of the reference energy system or not. This approach is convenient when different individuals work in parallel on different sectors.

Objective. The objective is to give more examples of possible SubRES including more complex processes: one that introduces iron and steel production in the industrial sector, and one that introduces combined heat and power (CHP) processes, centralised heating plants, and heat exchanger + district heating network. Additional objectives include:

- To show how to use the BY Trans file to move or add data and reduce the size of tables in the B-Y Templates. Here we specify the availability factor by time slice for existing wind and solar processes and add an interpolation rule for new hydro capacity (NCAP_BND).
- To show how to use the transformation file associated with each SubRES to declare the availability or non-availability of each process in each region: new hydro power plants in this example.
- To give an example of a scenario used to insert/update information in the B-Y Templates and SubRES: the demands and the retirement profile for the iron and steel processes.
- To illustrate how to build a user constraint to limit the penetration of some processes, such as the district heating system between 2020 and 2050.

Attributes introduced:	Files updated
PASTI CEH CHPR UC_CAP UC_COMPRD UC_FLO	VT_REG1_ELC_V09 VT_REG2_ELC_V09 BY_Trans SubRES_NewTechs_Trans Files created SubRES_New-IND SubRES_New-CHP-DH Scen_IND_NewRes Scen_UC_DH_MinProd

Files. The ninth step model is built:

1. by modifying two B-Y Templates (VT_REG1_ELC_v09, VT_REG2_ELC_v09) to introduce past investment information;
2. by using the BY Transformation file (BY_Trans) to insert base year information (availability factor by time slice for existing wind and solar plants and interpolation rules);
3. by using a SubRES Transformation file (SubRES_NewTechs_Trans) to insert information for new processes (availability factor by time slice for new wind and solar plants) and to declare the availability or non-availability of each process in each region;
4. by building two new SubRES (one with an iron & steel sector; one with CHP processes and district heating);
5. by creating a scenario file to update information in the industrial sector;
6. by creating a scenario file with a user constraint on the minimum penetration of district heating in the residential sector (Figure 141).

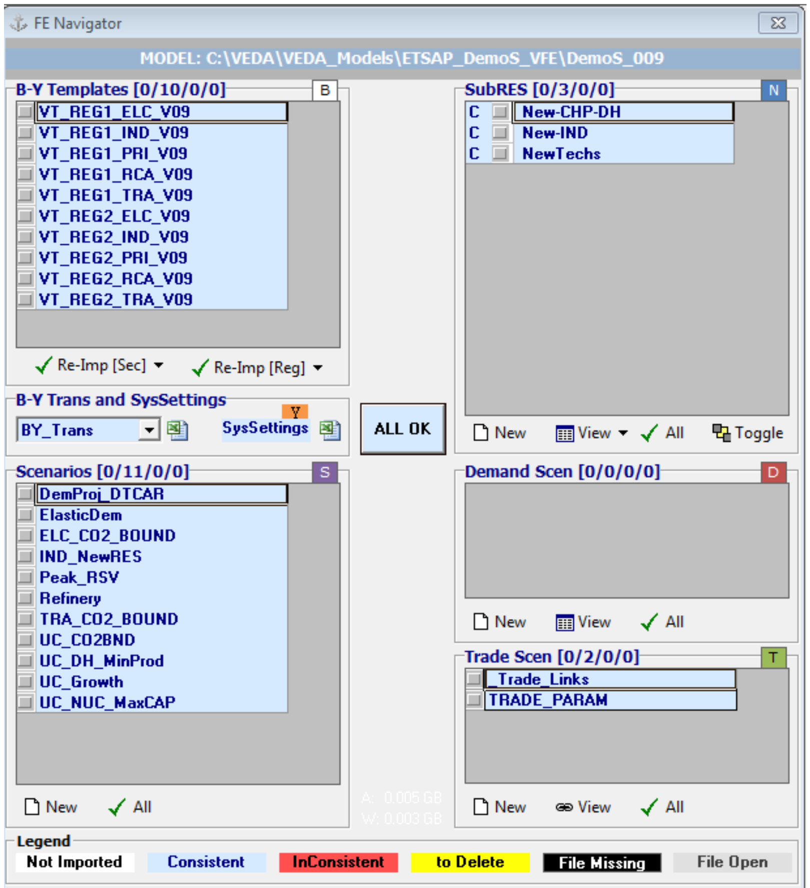


Figure 141. The files included in DemoS_009

3.9.1 B-Y Template VT_REG*_ELC_V09

The only B-Y Templates that are modified are the electricity ones (VT_REG1_ELC_V09 and VT_REG2_ELC_V09).

3.9.1.1 Con_ELC

The STOCK attribute for existing capacity can be replaced by another attribute (PASTI = past investments) to describe capacity installations that took place before the beginning of the model horizon (2005) and still exist during the modelling horizon. For any process, an arbitrary number of past investments may be specified to reflect the age structure in the existing capacity stock: the hydro power plants in this example (Figure 142). Each vintage of PASTI capacity will be constant until the end of its technical life, after which the capacity becomes zero in a single step. This allows a vintage-based retirement profile for the existing stock to be introduced into the model without the need to calculate and specify a STOCK in each future year.

		~FI_T				
TechName	Comm-IN	Comm-OUT	PASTI~1960	PASTI~1980	STOCK	STOCK~2030
*Technology Name	Input Commodity	Output Commodity	Past Investment	Past Investment	Existing Installed Capacity	Retirement Capacity
*Units			GW	GW	GW	GW
ELCTECOA00	ELCCOA	ELC			89	
ELCTEGAS00	ELCGAS	ELC			41	
ELCTEOIL00	ELCOIL	ELC			6	
ELCNENUC00	ELCNUC	ELC			52	52
ELCREBIO00	ELCBIO	ELC			8	
ELCREHYD00	ELCHYD	ELC	15	16		
ELCREWIN00	ELCWIN	ELC			24	
ELCRESOL00	ELCSOL	ELC			7	

Figure 142. Declare past investments that took place before 2005

3.9.1.2 BY_Trans

The BY_Trans file works like a scenario file, except that the rule-based filters and the update/insert changes apply only to those process and commodities already existing in the B-Y templates. In this example (Figure 143), the file is used to insert new information: the availability factor (AF) by time slice (SD, SN, etc.) for existing wind and solar plants (ELCREWIN00 and ELCRESOL00).

~TFM_INS									
TimeSlice	LimType	Attribute	Year	AllRegions	REG1	REG2	Pset_Set	Pset_PN	Pset_PD
SD		AF	2010		0.38	0.35		ELCREWIN00	
SN		AF	2010		0.25	0.30		ELCREWIN00	
WD		AF	2010		0.40	0.45		ELCREWIN00	
WN		AF	2010		0.35	0.25		ELCREWIN00	
SD		AF	2010		0.30	0.35		ELCRESOL00	
SN		AF	2010		0.20	0.15		ELCRESOL00	
WD		AF	2010		0.30	0.25		ELCRESOL00	
WN		AF	2010		0.20	0.15		ELCRESOL00	

Figure 143. Using the transformation file to insert new attributes for existing processes

The transformation file is also used to insert a new interpolation rule (2 = interpolation, but extrapolation with EPS (epsilon, or effectively zero), which inserts EPS in every year if no bound value is declared in any year) to avoid the installation of new capacity (NCAP_BND) after the base year for the existing hydro power plants (ELCREHYD00). VEDA-FE creates this entry by default for all technologies for which STOCK is declared. Since we have switched to using PASTI we need to declare it manually (Figure 144).

~TFM_INS								
TimeSlice	LimType	Attribute	Year	AllRegion	REG1	REG2	Pset_Set	Pset_PN
		NCAP_BND	0	2				ELCREHYD00

Figure 144. Using the transformation file to insert a new interpolation rule

3.9.2 SubRES_NewTechs_Trans

Similarly to the BY_Trans file, a transformation file exists for each of the SubRES created. They are used to update/insert information for new processes and commodities declared in the corresponding SubRES and to declare the availability or non-availability of each process in each region. In this example, the transformation file of the SubRES_NewTechs is used to insert the availability factor for new wind and solar plants (ELCRNWIN01 and ELCRNSOL01) exactly as for the existing ones.

To assign the availability of processes to regions, a new ~TFM_AVA table is created (Figure 145). The first line says that all processes (Pset_PN=*) are available in all regions. The second line modifies this to say that the new hydro power plant is not available in REG1 (1=available; 0=non-available).

~TFM_AVA			
Pset_PN	AllRegions	REG1	REG2
*	1		
ELCRNHYD01		0	

Figure 145. Using the SubRES transformation file to declare process availability

3.9.3 SubRES_New-IND

In the new SubRES_New-IND file, a simplified iron & steel sector is added to the model (Figure 146). This file includes two sheets (IND and PRI); sheet names need to start with the name of one of the model sectors.

Production of Finished Steel		~FI_T					
TechName	Comm-IN	Comm-OUT	Input	Output	Stock	FIXOM	VAROM
*					Mt-y	€/ton-a	
IDMIIS	IISRST		1.00		100	1	0.1
	INDOIL		0.03				
	INDGAS		1.15				
	INDELC		0.60				
		DIIS		1.00			

Production of Raw Steel		~FI_T					
TechName	Comm-IN	Comm-OUT	Input	Output	Stock	FIXOM	VAROM
*					Mt-y	€/ton-a	
ITIISBOF	IISIRO		1.00		100	1	0.1
	INDGAS		0.20				
	INDELC		0.20				
	INDOXY		0.09				
		IISRST		1.00			

Figure 146. Examples of processes in the iron & steel sector

For policy analysis, it is useful to develop the most energy-intensive industrial sectors, such as iron & steel, in more detail, using a process-oriented approach rather than using generic processes capturing the energy mix. Here the demand is expressed in millions tons (Mt) of finished steel production, and a series of processes are modelled to represent the main steps of the transformation chain, from raw material extraction to the production of finished products (with capacity and activity units in Mt). The last process (IDMIIS) is described like a demand process, while the others are described as (upstream) processes in the chain. This means that they consume energy commodities and/or materials to produce new materials useful for the iron &

steel chain production. The last process, which is a demand technology, finally consumes energy commodities and materials produced in the chain to satisfy the iron and steel demand (DIIS).

These processes use a mix of energy inputs and material inputs. These materials are declared as MAT commodities and tracked in Mt (Figure 147).

~FI_Comm							
Csets	CommName	CommDesc	Unit	LimType	CTSLvl	PeakTS	Ctype
*Commodity Set Membership	Commodity Name	Commodity Description	Unit	Balance Equ Type Override	Timeslice Tracking Level	Peak Monitoring	Electricity Indicator
MAT	IISSIN	Industrial Sinter	Mt				
	IISIRO	Industrial Iron	Mt				
	IISRST	Industrial Steel	Mt				
DEM	DIIS	Demand Iron&Steel	Mt				

Figure 147. Energy and material input commodities for the iron & steel sector

3.9.4 SubRES_New-CHP-DH

This file includes two sheets (ELC_CHP and RCA), recalling that SubRES sheet names need to start with the name of one of the model sectors. The first sheet is used to add the combined heat and power (CHP) sector to the model (Figure 148). Cogeneration power plants, or combined heat and power plants (CHP), are plants that consume one or more commodities and produce two commodities, electricity (ELC) and heat (HET). The new CHP processes are characterized with additional attributes compared with conventional power plants.

- The new processes do not have an existing installed capacity, but they are available in the database to be invested in. They are characterized with an efficiency (EFF), an annual availability factor (AFA), fixed and variable O&M costs (FIXOM, VAROM), a life time (LIFE), a capacity to activity factor (CAP2ACT in PJ/GW), and an investment cost (INVCOST), as well as the year in which they become available (START). Maximum input shares (Share-I~UP) are also specified for the dual input process ELCBNGAB01 consuming a maximum of 60% of biomass.
- Two new attributes are introduced: the ratio of electricity lost to heat gained (CEH) as well as the ratio of heat produced to electricity produced (CHPR).

Two main types of cogeneration power plants can be distinguished according to the flexibility of the outputs: a back pressure process (ELCBNGAB01) and a condensing process (ELCCNGAS01).

- Back pressure turbines are systems in which the ratio of the production of electricity and heat is fixed, so that the electricity generation is directly proportional to the steam produced. In a real system, a back pressure turbine is defined using the electrical efficiency, the thermal efficiency, and the load utilization. The **CHPR** attribute is then fixed (FX), so the production of electricity and heat is in a fixed proportion, but one could also use a (LO) CHPR for defining the back-pressure point, if so desired (to allow by-passing the turbine to produce more heat). CEH can be either 0 (or missing) or 1:
    - If it is 0 (or missing) as in this example, the activity represents the electricity generation and the capacity represents the electrical capacity;

- If it is 1, the activity represents the total energy output and the capacity represents the total capacity (electricity + heat).

- The condensing pass-out or extraction turbines do not have to produce heat, permitting electricity only to be generated, and permitting the amount of heat generated to be directly adjusted to the heat demand, while the electricity generation is reciprocally proportional to heat generation (electricity losses because of heat extraction). They are thus described differently:
  - 1. Coefficient of electricity to heat, via attribute **CEH** such that: a) <= 1: electricity loss per unit of heat gained (moving from condensing to backpressure mode), indicating that activity is measured in terms of electricity, or b) >= 1: heat loss per unit of electricity gained (moving from backpressure to condensing mode), indicating that activity is measured in terms of total output (electricity plus heat).
  - 2. Efficiencies, according to 1: a) are specified for the condensing point, or b) are specified for backpressure point.
  - 3. Costs, according to 1: a) are specified based according to condensing mode, or b) are specified based on total electricity and heat output at backpressure point.
  - 4. Ratio of heat produced to electricity produced (**CHPR**): Ratio of heat to power at backpressure point; at least a maximum value is required, but in addition also a minimum value may be specified.
- See Section 4.1 of Part II of the TIMES documentation for more on CHP processes and their attributes.

The CHP processes are declared as CHP processes in the process declaration table with a time slice level of activity (DAYNITE). The heat (HET) is also declared as a new energy commodity in the commodity declaration table.

		~FI_T													
TechName	**Comm-IN**	**Comm-OUT**	**START**	**EFF**	**AFA**	**Share-I~UP**	**CEH**	**CHPR ~FX**	**CHPR ~UP**	**INVCOST**	**FIXOM**	**VAROM**	**LIFE**	**CAP2ACT**	**Peak**
*Technology Name	Input Commodity	Output Commodity		Efficiency	Utilisation Factor	Input share				Invesctment Cost	Fixed O&M Cost	Variable O&M Cost	Lifetime	Capacity to Activity Factor	% contribution to PEAK
*Units										M€/GW	M€/PJa	M€/PJ	Years	(Act Unit/Cap Unit)	
ELCCNGAS01	ELCGAS	ELC	2015	0.40	0.85		0.20		1.20	950	30.00	0.35	30	31.536	1.00
		HET													
ELCBNGAB01	ELCGAS	ELC	2015	0.40	0.85			1.20		1100	40.00	0.40	30	31.536	1.00
	ELCBIO	HET				0.60									

Figure 148. Examples of combined heat and power processes

The RCA sheet is used to add a district heating option to the model (Figure 149): a process is created as the district heating option (RSHNHET1) and a sector fuel process (FTE-RSDHET) is created to produce sector heat (RSDHET) from primary heat (HET).

- They are characterized with an efficiency (EFF), an annual availability factor (AFA), fixed O&M costs (FIXOM), a life time (LIFE), a capacity to activity factor (CAP2ACT in PJ/GW), and an investment cost (INVCOST), as well as the year in which they become available (START).

		~FI_T							
TechName	**Comm-IN**	**Comm-OUT**	**START**	**EFF**	**AFA**	**CAP2ACT**	**INVCOST**	**FIXOM**	**LIFE**
*Technology Name	Input Commodity	Output Commodity		Efficiency	Utilisation Factor		Invesctment Cost	Fixed O&M Cost	Lifetime
*Units						Capacity Unit/PJ	M€/Capacity Unit	M€/Capacity unit	Years
RSHNHET1	RSDHET	DRSH	2015	0.96	0.30	31.536	250	5	20
FTE-RSDHET	HET	RSDHET	2015	0.95	1.00	1	1000	10	20

Figure 149. Demand for heat and district heating options

3.9.5 Scenario files

3.9.5.1 Scen_IND_NewRES

A transformation table is used to update the base year industrial demand (DIDM1): the base year valued defined in the B-Y Templates are multiplied by 0.9 (Figure 150). This essentially reduces the DIDM1 demand that was used to model all industrial sector energy consumption by an amount roughly corresponding to that consumed by the new iron and steel sector. (Although note that we are not trying to replicate calibration to the energy balance precisely in this simple example.)

Another transformation table is used to define the demand value for the new iron and steel demand (DIIS), activating this sector when the SubRES is included in a model run, and to specify the retirement profile for the iron and steel processes (STOCK in 2050). (In this case the STOCK has been introduced in a SubRES template so VEDA-FE will not create any interpolation rule to prohibit new investments.)

~TFM_UPD																	
TimeSlice	**LimType**	**Attribute**	**Year**	**Attrib_Cond**	**Val_Cond**	**AllRegions**	**REG1**	**REG2**	Pset_Set	Pset_PN	Pset_PD	Pset_CI	Pset_CO	Cset_Set	Cset_CN	Cset_CD
		Demand	2005				*0.9	*0.9							DIDM1	
~TFM_INS																
TimeSlice	**LimType**	**Attribute**	**Year**	**Attrib_Cond**	**Val_Cond**	**AllRegions**	**REG1**	**REG2**	Pset_Set	Pset_PN	Pset_PD	Pset_CI	Pset_CO	Cset_Set	Cset_CN	Cset_CD
		Demand	2005				10	12							DIIS	
		STOCK	2050				100	100		*IIS*						

Figure 150. Update existing information and insert new information in the industrial sector

3.9.5.2 Scen_UC_DH_MinProd

A user constraint is built to specify the minimum district heating penetration requirement in specific years (2020 and 2050) with an interpolation/extrapolation rules between those years (rule 15=interpolation migrated at start, forward extrapolation) (Figure 151). The constraint says that the production of **DRSH** by processes that consume **RSDHET** (Pset_CI) must be the minimum (LimType=**LO**) percentage specified in each region/year combination of *all* production (table level declaration **UC_COMPRD**) of DRSH.

~UC_Sets: R_E: AllRegions														
~UC_Sets: T_E:														
								~UC_T: UC_COMPRD						
UC_N	**Pset_Set**	**Pset_PN**	**Pset_CI**	**Pset_CO**	**Cset_CN**	**Attribute**	**Year**	**LimType**	**UC_FLO**	REG1	REG2	UC_RHSRTS	UC_RHSRTS~0	**UC_Desc**
UC_DH_LOW	DMD		RSDHET		DRSH		2020	LO	1	-5%	-10%	0	15	Minimum district heating penetration
	DMD		RSDHET		DRSH		2050	LO	1	-10%				

Figure 151. Minimum district heating penetration using a user constraint

3.9.6 Results

The model variant DemoS_009d is solved with the new iron & steel sector. Figure 152 shows the demand production (DIIS in Mt) from the finished steel production process (IDMIIS), consuming industrial steel (IISRST in Mt) and a mix of energy in PJ.

The model variant DemoS_009e is solved with the new district heating option. Figure 153 shows the contribution of district heat in meeting the demand for residential space heating in both regions together.

Indusrial Iron&Steel Demand Technology

Original Units: **Active Unit**

Region | *Vintage* | TimeSlice

~-Scenario-~	Attribute	Process	Commodity	2005	2006	2010	2015	2020	2025	2030	2035	2040	2045	2050
DemoS_009d	VAR_FIn	IDMIIS	IISRST	22	22	22	22	22	22	22	22	22	22	22
			INDELC	13	13	13	13	13	13	13	13	13	13	13
			INDGAS	25	25	25	25	25	25	25	25	25	25	25
			INDOIL	1	1	1	1	1	1	1	1	1	1	1
	VAR_FOut	IDMIIS	DIIS	22	22	22	22	22	22	22	22	22	22	22
			INDCO2	1,470	1,470	1,470	1,470	1,470	1,470	1,470	1,470	1,470	1,470	1,470

Figure 152. Results – Finished steel production in DemoS_009

Consumption by Sector and fuel

Original Units: PJ **Active Unit** PJ **Data values filter:**

Attribute | *Process* | *Vintage* | *TimeSlice* | *Region* | *CommoditySet* | -ProcessSet-

~-Scenario-~	Commodity	2005	2006	2010	2015	2020	2025	2030	2035	2040	2045	2050
DemoS_009	Residential Biomass	1,470	2,214	1,912	1,533	1,094	856	856	856	1,094	1,094	1,094
	Residential Natural Gas	5,663	4,498	3,626	2,537	1,517	1,412	1,491	1,346	1,861	2,334	2,373
	Residential Oil	2,760										
	Residential Solar energy	3,024	2,706	2,635	2,597	2,559	2,559	2,559	2,559	2,559	2,559	2,559
	Residential Solid Fuels	360	3,611	4,789	6,261	7,726	8,074	7,991	8,145	7,362	6,863	6,821
	Total	13,277	13,029	12,962	12,928	12,896	12,901	12,897	12,905	12,876	12,849	12,847
DemoS_009c	Residential Biomass	1,470	2,411	2,388	1,935	1,452	1,844	2,099	1,704	1,759	1,832	1,832
	Residential Natural Gas	5,663	4,885	5,177	4,792	4,288	4,512	3,334	3,214	3,214	3,214	4,076
	Residential Oil	2,760										
	Residential Solar energy	3,024	2,706	2,635	2,597	2,559	2,559	2,559	2,559	2,559	2,559	2,559
	Residential Solid Fuels	360	3,007	2,671	3,476	4,439	3,810	4,800	5,322	5,266	5,193	4,283
	Total	13,277	13,009	12,871	12,800	12,738	12,725	12,792	12,799	12,799	12,799	12,750
DemoS_009e	Residential Biomass	1,470	2,321	2,066	1,802	1,178	1,315	1,483	1,373	1,483	1,483	1,483
	Residential Natural Gas	5,663	4,553	4,778	4,431	3,519	3,866	2,923	2,329	2,329	2,329	3,043
	Residential Oil	2,760										
	Residential Solar energy	3,024	2,706	2,635	2,597	2,559	2,559	2,559	2,559	2,559	2,559	2,559
	Residential Solid Fuels	360	3,444	3,416	3,991	4,900	4,364	5,159	5,864	5,721	5,688	4,901
	Residential heat from district heating network					574	604	634	664	693	723	753
	Total	13,277	13,024	12,896	12,821	12,730	12,707	12,758	12,789	12,786	12,784	12,740

Figure 153. Results – Fuel used for residential space heating in DemoS_009

Objective-Function = 19,183,729 M euros (see the _SysCost table in VEDA-BE) with 9,084,193 M euros for REG1 and 10,099,536 M euros for REG2. These costs are similar to those computed with the previous step model DemoS_008. The total cost is 3% higher with the emission limits, growth rates, elastic demands, and the new iron and steel sector (19,721,879 M euros) and 5% with the new district heating option (20,187,883 M euros) and the new investment required to satisfy the minimum constraint on district heating penetration.

3.10 DemoS_010 - Demand projections and elastic demand

Description. At the tenth step, the model structure and database remain the same but energy service demands are projected using an internal VEDA-FE routine.

Objective. The objective is to show how to prepare the files required to automatically project end-use demands for energy services using demand drivers along with sensitivity and calibration series.

Attributes introduced:	Files updated
N.A.	Scen_ElasticDem Files created Dem_Alloc+Series ScenDem_DEM_Ref

Files. The tenth step model is built:

1. by creating one file that allocates a demand driver to each end-use demand (Dem_Alloc+Series) and defines sensitivity and calibration series, and one file (ScenDem_DEM_Ref) that defines demand drivers;
2. by modifying the elastic demand scenarios to cover all end-use demands for energy services (Figure 154).

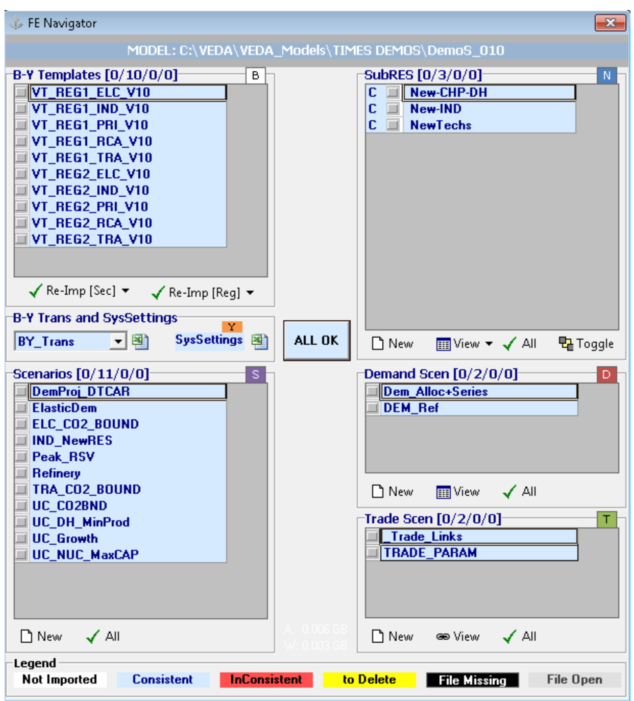


Figure 154. The files included in DemoS_010

3.10.1 Demand files

3.10.1.1 <u>ScenDem_DEM_Ref</u>

The ~DRVR_Table table is used to declare a coherent set of driver growth rates (or indexes, with 2005=1) to drive all end-use demands in all regions (Figure 155). These drivers can be more general, such as macroeconomic indicators, as in this example (Gross Domestic Product (GDP), population (POP), industrial output demand (INDD)), or more specific, like vehicle-kilometres for energy service demands in the transportation sector, for instance. It is possible to build multiple files called ScenDem_<file name> with different drivers to generate, for example, a reference case along with low and high growth cases.

	~DRVR_Scenario: : DEM_Ref											
	~DRVR_Table											
Region	Driver	\~2005	\~2006	\~2007	\~2008	\~2009	\~2010	\~2011	(...)	\~2048	\~2049	\~2050
REG1	GDP	1.00	1.03	1.06	1.09	1.13	1.16	1.19	(...)	2.03	2.04	2.05
REG1	POP	1.00	1.01	1.02	1.03	1.04	1.05	1.06	(...)	1.37	1.38	1.38
REG1	GDPP	1.00	1.02	1.04	1.06	1.08	1.10	1.12	(...)	1.66	1.67	1.68
REG1	INDD	1.00	1.00	1.00	1.00	1.00	1.00	1.00	(...)	1.02	1.02	1.02
REG2	GDP	1.00	1.05	1.10	1.16	1.22	1.28	1.34	(...)	2.98	2.99	3.01
REG2	POP	1.00	1.02	1.04	1.06	1.08	1.10	1.13	(...)	1.67	1.67	1.68
REG2	INDD	1.00	1.00	1.00	1.00	1.00	1.01	1.01	(...)	1.04	1.04	1.05

Figure 155. Demand drivers for end-use demand projections

3.10.1.2 Dem_Alloc+Series

The ~Series table is used to define sensitivity and calibration series (Figure 156). The sensitivity series represents the sensitivity of each end-use demand to one unit change in its driver. The calibration series can optionally be used to provide additional control over the resulting demand levels.

The growth rates of the various drivers are applied to the 2005 base year demands using the following formula:

$$D_t = D_{t-1} * \left(Calibration + \left(\frac{Driver_t}{Driver_{t-1}} - 1 \right) * Sensitivity \right)$$

The ~DRVR_Allocation table is used to allocate a particular driver to each end-use demand in each region (Figure 157). Only one such allocation file, always named Dem_Alloc+Series, may be built. That is, it is envisioned that in different scenarios, the projection of the driver for each demand may change (higher or lower population growth, for example), but the association of each demand with a particular driver will not change. (For example, DRSH is always driven by population growth with the same sensitivity.) Only one driver series may be associated with each demand. However, one may easily create a composite series if combining two drivers is desired. In this example, the demand DAOT will be projected using the driver GDP, adjusted with calibration and sensitivity series (Constant; =1 over the whole model horizon).

~Series												
Series	\~2005	\~2006	\~2007	\~2008	\~2009	\~2010	\~2011	\~2012	\~2013	\~2014	\~2015	(...)
Constant	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	(...)
Ser_0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	(...)

Figure 156. Sensitivity and calibration series for end-use demand projections

~DRVR_Allocation				
Region	**Demand**	**Driver**	**Calibration**	**Sensitivity**
REG1	DAOT	GDP	Constant	Constant
REG1	DCAP	GDP	Constant	Constant
REG1	DCOT	GDPP	Constant	Constant
REG1	DCSH	GDP	Constant	Constant
REG1	DIDM1	INDD	Constant	Constant
REG1	DRAP	POP	Constant	Constant
REG1	DROT	NewDriver	Constant	Constant
REG1	DRSH	POP	Constant	Constant
REG1	DTCAR	GDP	Constant	Constant
REG1	DTPUB	POP	Constant	Constant
REG2	DAOT	GDP	Constant	Constant
REG2	DCAP	GDP	Constant	Constant
REG2	DCOT	GDPP	Constant	Constant
REG2	DCSH	GDP	Constant	Constant
REG2	DIDM1	INDD	Constant	Constant
REG2	DRAP	POP	Constant	Constant
REG2	DROT	NewDriver	Constant	Constant
REG2	DRSH	POP	Constant	Constant
REG2	DTCAR	GDP	Constant	Constant
REG2	DTPUB	POP	Constant	Constant

Figure 157. Allocation of demand drivers and series for end-use demand projections

All the demands projected with the internal VEDA-FE module can also be managed from the menu: **Advanced Functions/Demand Master**. Changes made within the Demand Master will be reflected in the templates. For more information on the Demand Master function, see http://support.kanors-emr.org/.

3.10.2 Results

The resulting demand projections in the reference case (DemoS_010) using the driver and series allocation presented above are shown (Figure 158), as well as the demand reactions when including all additional constraints (limits on emissions, growth rates of cars, minimum penetration of district heating, etc.).

Demands

Original Units: **Active Unit** **Data values filter:**

Attribute | *Process* | *Vintage* | TimeSlice | CommoditySet | *Region*

Commodity	~-Scenario-~	2005	2006	2010	2015	2020	2025	2030	2035	2040	2045	2050
DAOT	DemoS_010	1,125	1,170	1,370	1,672	2,045	2,507	2,570	2,635	2,702	2,770	2,840
	DemoS_010e	1,125	1,170	1,329	1,599	2,014	2,349	2,393	2,487	2,544	2,624	2,669
DCAP	DemoS_010	2,297	2,389	2,798	3,415	4,178	5,123	5,252	5,384	5,520	5,660	5,803
	DemoS_010e	2,297	2,389	2,714	3,266	4,093	4,815	4,937	5,103	5,272	5,363	5,455
DCOT	DemoS_010	733	741	779	829	885	947	964	981	999	1,017	1,035
	DemoS_010e	733	735	749	789	867	888	903	929	934	959	968
DCSH	DemoS_010	2,280	2,376	2,805	3,457	4,270	5,285	5,418	5,555	5,695	5,839	5,986
	DemoS_010e	2,280	2,376	2,686	3,280	4,185	4,833	4,983	5,210	5,197	5,379	5,572
DIDM1	DemoS_010	13,159	13,169	13,209	13,258	13,308	13,358	13,408	13,459	13,509	13,560	13,611
	DemoS_010e	11,843	13,169	12,812	12,661	13,009	12,456	12,403	12,739	12,597	12,848	12,794
DIIS	DemoS_010e	22	22	22	22	22	22	22	22	22	22	22
DRAP	DemoS_010	2,610	2,650	2,813	3,033	3,272	3,532	3,621	3,713	3,806	3,903	4,001
	DemoS_010e	2,610	2,650	2,728	2,899	3,226	3,320	3,404	3,542	3,635	3,698	3,761
DROT	DemoS_010	2,250	2,250	2,250	2,250	2,250	2,250	2,250	2,250	2,250	2,250	2,250
	DemoS_010e	2,250	2,233	2,182	2,165	2,216	2,148	2,148	2,165	2,148	2,161	2,148
DRSH	DemoS_010	7,230	7,341	7,800	8,420	9,095	9,830	10,078	10,333	10,594	10,861	11,135
	DemoS_010e	7,230	7,341	7,458	7,940	7,731	8,355	8,566	8,493	8,210	8,010	7,797
DTCAR	DemoS_010	6,168	6,356	7,018	7,947	9,004	13,738	14,085	14,440	14,805	15,179	15,562
	DemoS_010e	6,168	6,356	7,018	7,827	8,869	13,532	13,787	14,170	14,472	14,780	15,095
DTPUB	DemoS_010	3,479	3,531	3,748	4,040	4,358	4,704	4,823	4,945	5,069	5,197	5,329
	DemoS_010e	3,479	3,531	3,692	3,951	4,328	4,563	4,606	4,759	4,904	4,999	5,169

Figure 158. Results – Demand projections in DemoS_010

Objective-Function = 24,831,217 M euros (see the _SysCost table in VEDA-BE) with 10,869,234 M euros for REG1 and 13,961,983 M euros for REG2. The total cost is 7% higher with all model variants (26,475,198 M euros).

3.11 DemoS_011 - Linking input templates and VEDA-BE sets

Description. At the eleventh step, the model structure and database still remain the same but process and commodity sets defined in VEDA-BE are linked with the VEDA-FE model.

Objective. The objective is to show how to link VEDA-BE sets with VEDA-FE models. It is possible to create sets of commodities and processes in VEDA-BE using filters and rules. These sets are generally used to build tables to view results in VEDA-BE, but it is also possible to link the VEDA-BE database with a VEDA-FE model to use these sets in VEDA templates. We also provide an example in which VEDA-BE sets are used in the VEDA-FE database: a user constraint on the minimum penetration of renewable power plants is built using a user defined set of renewable processes. (See Part V of the TIMES documentation for more on creating VEDA-BE sets and using them to view results within VEDA-BE.)

Attributes introduced:	Files created
N.A.	Scen_BOUNDS-UC_WSETS

Files. The eleventh step model is built:

1. by creating one scenario file that explains VEDA Sets specification and includes a user constraint using a VEDA-BE table.

3.11.1 Scen_Bounds-UC-wSets

The new scenario file contains two sheets: one that explains how to access VEDA-BE sets within VEDA-FE, and one that includes a user constraint using a VEDA-BE table (UC_Set). The steps to link the VEDA-BE database with a VEDA-FE database are:

- Click on **Veda_SnT.MDB** in the main menu bar of VEDA-FE.
- In the Options window, File Locations tab, click **Veda-BE Database** button (Figure 159), and locate the path where the VEDA-BE database is stored (e.g. C:\VEDA\Veda_BE\Databases\DemoS_VBE), and click **OK**.
    - The selected Veda_SnT.MDB path will now appear in the main menu bar of VEDA-FE (e.g. C:\VEDA\Veda_BE\Databases\DemoS_VBE\Veda_SnT.MDB).
- VEDA-BE sets will now appear in the VEDA-FE browser (See Section 2.4.1). The sets of commodities and processes can be viewed in the dropdown menus below the main Process and Commodity boxes. Selecting one of the sets will change the Process or Commodity list to show only the processes or the commodities included in this set: the PP_RENEW set that includes all renewable power plants in this example (Figure 160). Any of these sets can now be used directly in VEDA-FE files to insert or update information for a group of processes or commodities.

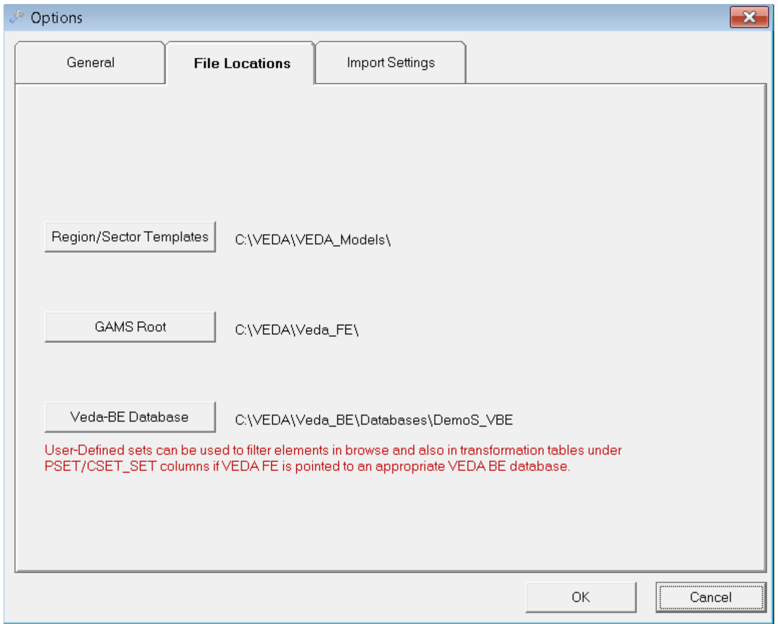


Figure 159. Create the link to VEDA-BE databases in VEDA-FE

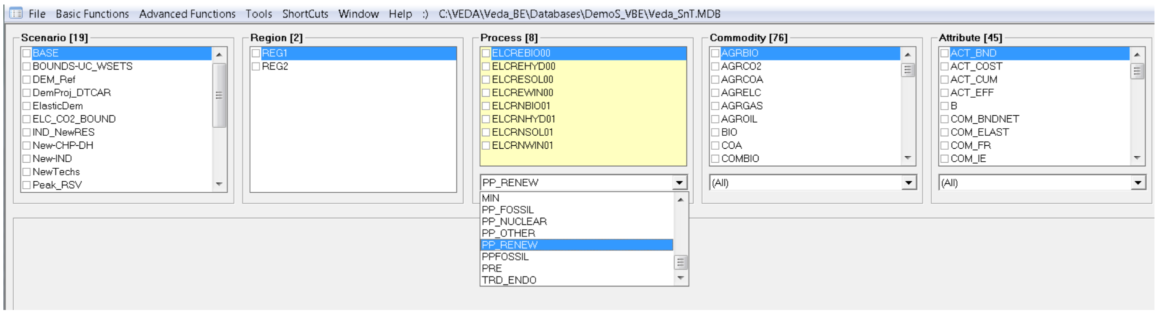


Figure 160. VEDA-BE sets in the VEDA-FE browser

As an example, a user constraint is built using the process set PP_RENEW (column PSet_SET) that includes all renewable power plants: it specifies a minimum renewable penetration share of 10% in 2020 and 15%-20% in 2050, depending on the region, along with an interpolation/extrapolation rule (Figure 161).

~UC_Sets: R_E: AllRegions
~UC_Sets: T_E:

								~UC_T: UC_COMPRD					
UC_N	Pset_Set	Pset_PN	Pset_CI	Pset_CO	Cset_CN	Attribute	Year	LimType	UC_FLO	REG1	REG2	UC_RHSRTS	UC_RHSRTS~0	UC_Desc
UC_RNW-PP_LOW	PP_RENEW				ELC		2020	LO	1	-10%	-10%	0	15	Minimum renewable power plants penetration
	PP_RENEW				ELC		2050	LO	1	-20%	-15%			

Figure 161. User constraint on renewable power using a VEDA-BE set

3.11.2 Results

Figure 162 shows the impact of the new user constraint on the renewable share of total power generation. While the share of renewables is going to 0 without the user constraint in the previous reference case (DemoS_010), it reaches 18% across both regions in 2050 in the new reference case (DemoS_011), and 20% when including all additional constraints (limits on emissions, growth rates of cars, minimum penetration of district heating, etc.).

Electric Generation by Fuel Group

Original Units: PJ   Active Unit: PJ   Data values filter:

Attribute | Commodity | *Process* | *Vintage* | *TimeSlice* | CommoditySet | *Region*

~Scenario~	ProcessSet	2005	2006	2010	2015	2020	2025	2030	2035	2040	2045	2050
DemoS_010	Fossil Power Plants	4,966	4,492	5,700	6,988	8,230	9,652	9,918	9,808	9,666	9,528	9,395
	Nuclear Power Plants	3,267	3,267	3,267	3,267	3,330	3,393	3,457	3,828	4,018	4,207	4,397
	Renewable Power Plants	1,818	1,774	1,368	936	688	505	217				
	Total	10,051	9,533	10,335	11,191	12,248	13,550	13,591	13,636	13,684	13,735	13,792
DemoS_010e	Fossil Power Plants	4,549	4,517	5,286	5,918	7,344	7,570	7,530	7,597	7,447	6,861	6,538
	Nuclear Power Plants	3,267	3,267	3,267	3,267	3,330	3,393	3,457	3,828	4,018	4,207	4,397
	Renewable Power Plants	1,818	1,774	1,472	1,108	811	1,097	1,024	807	807	1,226	1,304
	Total	9,633	9,558	10,024	10,294	11,485	12,060	12,011	12,232	12,271	12,294	12,239
DemoS_011	Fossil Power Plants	4,966	4,492	5,700	6,988	7,576	8,506	8,300	7,780	7,558	7,129	6,812
	Nuclear Power Plants	3,267	3,267	3,267	3,267	3,330	3,393	3,457	3,828	3,920	4,207	4,397
	Renewable Power Plants	1,818	1,774	1,368	936	1,342	1,651	1,834	2,034	2,206	2,407	2,582
	Total	10,051	9,533	10,335	11,191	12,248	13,550	13,591	13,642	13,684	13,743	13,792
DemoS_011e	Fossil Power Plants	4,549	4,517	5,222	5,711	6,928	7,117	6,974	6,608	6,394	5,783	5,643
	Nuclear Power Plants	3,267	3,267	3,267	3,267	3,330	3,393	3,457	3,828	4,018	4,207	4,397
	Renewable Power Plants	1,818	1,774	1,580	1,375	1,331	1,734	1,838	1,972	2,193	2,269	2,527
	Total	9,633	9,558	10,069	10,354	11,589	12,244	12,269	12,408	12,605	12,259	12,567

Figure 162. Results – Demand projections in DemoS_011

Objective-Function = 24,867,969 M euros (see the _SysCost table in VEDA-BE) with 10,886,683 M euros for REG1 and 13,981,286 M euros for REG2. The total cost is 6% higher with all model variants (26,483,468 M euros).

3.12 DemoS_012 – More modelling techniques

Description. At the twelfth step, taxes and subsidies are added to the model database and a new modelling technique is introduced, namely the lumpy investment concept.

Objective. The objective is to show how to add taxes and subsidies for processes or commodities, such as a tax on diesel and total CO2 for all sectors and regions, as well as a subsidy on solar power plants in this example. Another objective is to show how to use the lumpy investment feature of TIMES through discrete capacity for the new nuclear power plants.

Attributes introduced:	Files updated
N.A.	VT_REG1_PRI_v12 VT_REG2_PRI_v12 SubRES_NewTechs Files created Scen_TRADSL_Tax Scen_CO2_Tax Scen_Solar_Subsidies Scen_UC_CO2_Regions Scen_NUC_DiscInv

Files. The twelfth step model is built:

1. by updating two B-Y Templates (VT_REG1_PRI_v12, VT_REG2_PRI_v12) to create an aggregated CO2 emission commodity;
2. by updating the SubRES_NewTechs file to specify discrete investment options;
3. by creating scenario files for introducing taxes, subsidies, and an emission constraint for all sectors and regions, as well as for discrete investments for nuclear power plants.

3.12.1 B-Y Template VT_REG*_Pri_V12

The only B-Y Templates that are modified are the primary energy ones (VT_REG1_PRI_V12 and VT_REG2_PRI_V12).

3.12.1.1 TOTCO2

A sheet is added with a **~COMAGG** table is that is used to define an aggregated commodity (TOTCO2), including all sectoral CO2 emissions using multipliers of 1. This is equivalent to making TOTCO2 the sum of all sectoral CO2 emissions (Figure 163). It is possible to add more aggregated commodities and change multipliers. For instance, when there are different types of GHG emissions (CH4, N2O, etc.), an aggregated commodity can be created in CO2-equivalent to account for their respective global warming potential (CH4=36; N2O=298).

~COMAGG

CommName	AGRCO2	COMCO2	RSDCO2	ELCCO2	TRACO2	INDCO2
TOTCO2	1	1	1	1	1	1

~FI_Comm

Csets	Region	CommNar	CommDes	Unit	LimType	CTSLvl	PeakTS	Ctype
*Commodity Set Membership	Region Name	Commodity Name	Commodity Description	Unit	Sense of the Balance EQN.	Timeslice Level	Peak Monitoring	Electricity Indicator
ENV		TOTCO2	Total CO2	kt				

Figure 163. Aggregation of emission commodities

3.12.2 SubRES_NewTechs (ELC sheet)

The first step necessary to enable lumpy investments is to specify discrete investment options in the default process table, for new nuclear power plants in this example (ELCNNUC01), by changing the process set from ELC to ELC, DSCINV (Figure 164).

~FI_Process

Sets	Region	TechName	TechDesc	Tact	Tcap	Tslvl	PrimaryCG	Vintage
*Process Set Membership	Region Name	Technology Name	Technology Description	Activity Unit	Capacity Unit	TimeSlice level of Process Activity	Primary Commodity Group	Vintage Tracking
*								
ELE		ELCTNCOA01	Power Plants New 1 - Solid Fuels	PJ	GW	SEASON		
		ELCTNOIL01	Power Plants New 1 - Oil	PJ	GW			
		ELCTNGAS01	Power Plants New 1 - Natural Gas	PJ	GW			Yes
		ELCRNBIO01	Power Plants New 1 - Biomass	PJ	GW			
		ELCRNHYD01	Power Plants New 1 - Hydro power	PJ	GW			
		ELCRNWIN01	Power Plants New 1 - Wind energy	PJ	GW			
		ELCRNSOL01	Power Plants New 1 - Solar energy	PJ	GW			
ELE,DSCINV		ELCNNUC01	Power Plants New 1 - Nuclear	PJ	GW	ANNUAL		

Figure 164. Discrete investment option for nuclear power plants

3.12.3 Scenario files

3.12.3.1 Scen_NUC_DiscInv – lumpy investments

The second step necessary to enable lumpy investments is to specify allowable discrete capacity investments (NCAP_DISC) in specific years for new nuclear power plants (ELCNNUC01). In this example (Figure 165) the capacity installed for this process can be a module of 1 GW in 2015, while in 2033 the model can install 2 GW or 3 or 4 or 5 GW.

~TFM_INS						
TimeSlice	LimType	Attribute	Year	Other_Indexes	AllRegions	Pset_PN
		NCAP_DISC	2015	1	1	ELCNNNUC01
		NCAP_DISC	2033	2	2	ELCNNNUC01
		NCAP_DISC	2033	3	3	ELCNNNUC01
		NCAP_DISC	2033	4	4	ELCNNNUC01
		NCAP_DISC	2033	5	5	ELCNNNUC01
		NCAP_DISC	0	1	5	ELCNNNUC01
		NCAP_DISC	0	2	5	ELCNNNUC01
		NCAP_DISC	0	3	5	ELCNNNUC01
		NCAP_DISC	0	4	5	ELCNNNUC01
		NCAP_DISC	0	5	5	ELCNNNUC01

Figure 165. Discrete capacity at specific years for nuclear power plants

In summary, the TIMES lumpy investment variant can be enabled following four steps:

1. Specify the SET DSCINV for the process for which lumpy investment is to be enabled (here new power plants (ELCNNUC01) in the ELC sheet of the SubRES_NewTechs file).
2. Build a scenario file with the discrete capacity modules to be allowed: capacities for the new power plants (ELCNNUC01) in the NUC_DSCINV sheet of the Scen_NUC_DiscInv scenario.
3. Before solving the model, it is necessary to enable the variant discrete investment in VEDA-FE. From the FE Case Manager, select the **Control Panel** button, check the box for Discrete Investment at the top right in the TIMES Extensions section (Figure 166), and click the **OK** button. Back in the FE Case Manager, the inscription DSC YES in the yellow section at the bottom of the window shows that the option is enabled.
4. In the Control Panel, set OPTCR (optimization criterion, or tolerance) to 0, in order to get a truly optimal solution. For example, if you leave OPTCR at its default value 0.1, in most models this will leave room for very different MIP solutions that would satisfy the optimality tolerance, and thus you could see lots of flip-flopping between model runs (even when using exactly the same scenario data).

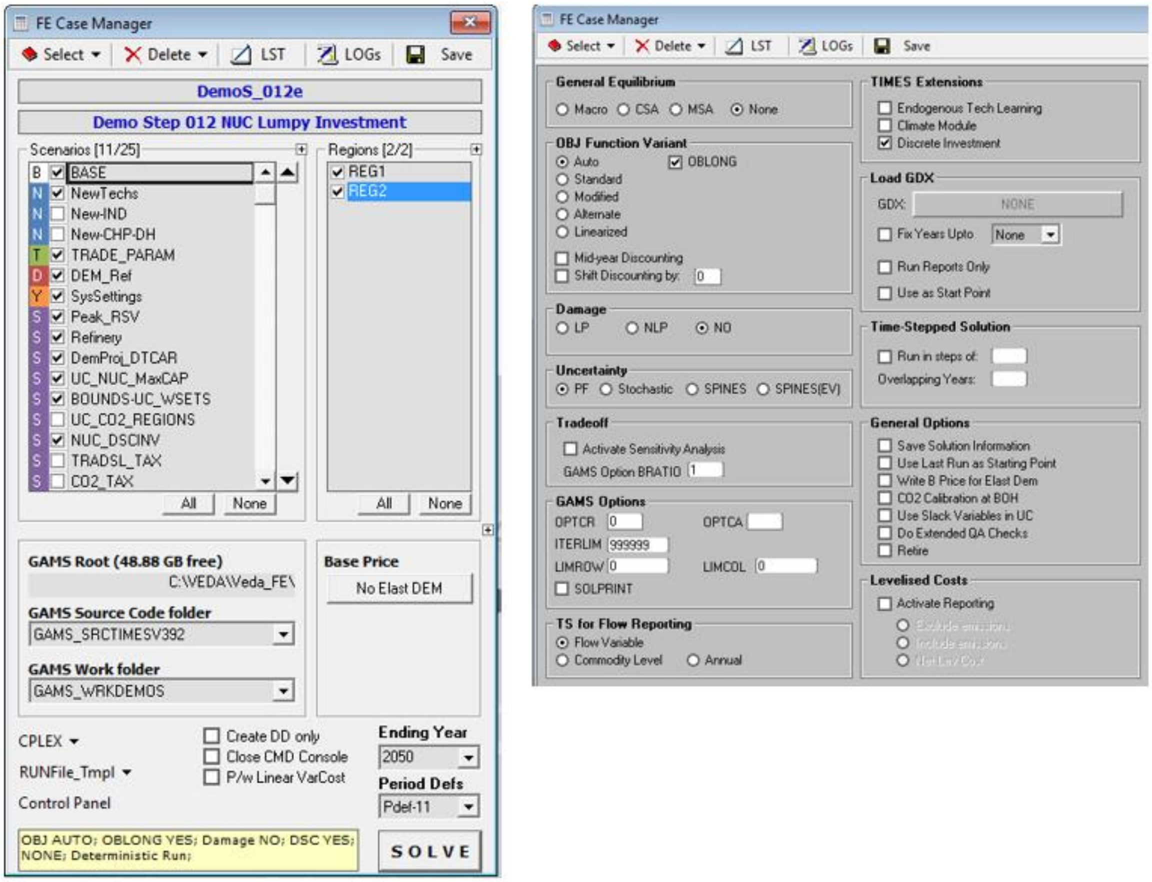


Figure 166. Enable the variant discrete investment in VEDA-FE

3.12.3.2 <u>Scen_TRADSL_Tax</u>

This file is used to introduce a flow tax (FLO_TAX) on processes and commodities (input/output) (Figure 167). This is a new attribute that allows imposing an incremental cost of using/producing a commodity by a process (cost in Currency per unit of commodity produced or consumed). Here it is used to impose a flow tax on all the transportation processes (T*) consuming the diesel commodity (TRADSL) at specific years in each region.

~TFM_INS							
TimeSlice	**LimType**	**Attribute**	**Year**	**REG1**	**REG2**	**Pset_PN**	**Cset_CN**
		FLO_TAX	2015	10	10	T*	TRADSL
		FLO_TAX	2050	30	20	T*	TRADSL
		FLO_TAX	0	5	5	T*	TRADSL

Figure 167. Flow tax on commodities

3.12.3.3 <u>Scen_CO2_Tax</u>

This file is used to introduce a tax on a net quantity of commodity (COM_TAXNET). Here we impose a tax on the new emission aggregated commodity (TOTCO2) created in B-Y Templates (VT_REG*_PRI_V12) at specific years (Figure 168).

~TFM_INS						
TimeSlice	LimType	Attribute	Year	REG1	REG2	Cset_CN
		COM_TAXNET	2015	20	15	TOTCO2
		COM_TAXNET	2050	50	50	TOTCO2
		COM_TAXNET	0	5	5	TOTCO2

Figure 168. Tax on net quantity of commodities

3.12.3.4 Scen_Solar_Subsidies

This file is used to introduce a flow subsidy (FLO_SUB) on commodities (Figure 169). This is a new attribute that allows creating a credit for using/producing a commodity by a process (cost in Currency per unit of commodity produced or consumed). Here a flow subsidy on the electricity (ELC) commodity produced by all processes consuming the solar energy commodity (ELCSOL) is created with various values at specific years in each region.

~TFM_INS							
TimeSlice	LimType	Attribute	Year	REG1	REG2	Pset_CI	Cset_CN
		FLO_SUB	2010	15	10	ELCSOL	ELC
		FLO_SUB	2050	25	25	ELCSOL	ELC
		FLO_SUB	0	5	5	ELCSOL	ELC

Figure 169. Flow subsidy on commodities

3.12.3.5 Scen_UC_CO2_Regions

This file introduces a new user constraint that imposes limits on all CO2 emissions, summed over all regions and sector emissions. These upper bounds (or limits) are calculated as a percentage reduction target from the total CO2 emissions (TOTCO2 in kt) in a reference scenario for 2020 (10%) and 2050 (15%). It is necessary to run the step model without any limit on emissions first to get the reference emission trajectory (run DemoS_012) and to calculate the bounds as reduction from the reference emissions.

Comparing this scenario with Scen_UC_BND, the differences are the ~UC_Sets (using R_S: AllRegions rather than R_E: AllRegions) and the declaration (UC_RHSTS rather than UC_RHSRTS).

~UC_Sets: R_S: AllRegions							
			~UC_T				
UC_N	Cset_CN	Year	LimType	UC_COMNET	UC_RHSTS	UC_RHSTS~0	UC_Desc
AU_CO2BND_AllRegions	TOTCO2	2020	UP	1	4078637	5	CO2 upper bound on the toal emissions of All Regions
	TOTCO2	2050	UP	1	4632568		

Figure 170. User constraint on the aggregation of emission commodities

3.12.4 Results

This model is mainly run to show the impacts of the different taxes and subsidies, as well as the effects of the lumpy investment feature of TIMES through the discrete capacity requirement for the new nuclear power plants. Regarding fuel consumption in transportation (Figure 171):

- The tax on diesel consumption in the transportation sector (DemoS_012a) leads to a rapid decrease in refined products, reaching zero by 2025, to the benefit of renewable energies, which meet most of the demand by 2050.
- The tax on total CO2 emissions (DemoS_012b) leads to an even more drastic decrease of refined products, reaching zero by 2010, to the benefit of renewable energies.
- The limit on total CO2 emissions (DemoS_012d) does not have an impact on the transportation fuel mix but affects other parts of the whole energy system. The tax puts much higher pressure on the energy system than the limit.

Regarding the electricity generation capacity (Figure 172):

- The tax on total CO2 emissions (DemoS_012b) has important impacts on the electricity sector as well, where most of the thermal generation capacity is replaced with wind power.
- The subsidy on solar power (DemoS_012c) leads to a more diversified mix, as part of the wind power is replaced with solar power.
- The declaration of discrete capacity for nuclear power plants (DemoS_012e) limits the nuclear growth, with only 1 GW of new capacity addition in 2020, 2025, 2030 and 10 GW in 2035 compared with 121 GW in the reference case (Figure 173).

Consumption by Sector and fuel

Original Units: PJ Active Unit PJ Data values filter:

Attribute | *Vintage* | *TimeSlice* | *Commodity* | *Region* | *Process*

~-Scenario-~	-ProcessSet-	CommoditySet	2005	2006	2010	2015	2020	2025	2030	2035	2040	2045	2050
DemoS_012	Fuel Consumption Transport Sector	Electricity	269	260	590	638	689	745	765	785	805	825	846
		Natural Gas	21	19	11								
		Petroleum & Products	12,816	13,190	13,329	14,767	16,731	25,529	26,174	26,835	27,512	28,207	28,919
		Renewables	163	150	98	34	25	17	8				
		Total	13,269	13,619	14,029	15,439	17,446	26,291	26,947	27,620	28,317	29,032	29,765
DemoS_012a	Fuel Consumption Transport Sector	Electricity	269	260	590	638	689	745	765	785	805	825	846
		Natural Gas	21	19	11								
		Petroleum & Products	12,816	13,190	13,329	8,331	1,575						
		Renewables	163	150	98	6,749	15,679	26,184	26,837	27,506	28,200	28,912	29,642
		Total	13,269	13,619	14,029	15,718	17,943	26,929	27,601	28,290	29,005	29,737	30,488
DemoS_012b	Fuel Consumption Transport Sector	Electricity	269	260	590	638	689	745	765	785	805	825	846
		Natural Gas	21	19									
		Petroleum & Products	12,816	13,190									
		Renewables	163	150	13,412	15,170	17,175	26,184	26,837	27,506	28,200	28,912	29,642
		Total	13,269	13,619	14,003	15,808	17,864	26,929	27,601	28,290	29,005	29,737	30,488
DemoS_012d	Fuel Consumption Transport Sector	Electricity	269	260	590	638	689	745	765	785	805	825	846
		Natural Gas	21	19	11								
		Petroleum & Products	12,816	13,190	13,329	14,767	16,731	25,529	26,174	26,835	27,512	28,207	28,919
		Renewables	163	150	98	34	25	17	8				
		Total	13,269	13,619	14,029	15,439	17,446	26,291	26,947	27,620	28,317	29,032	29,765

Figure 171. Results – Fuel consumption for transportation in DemoS_012

ELC plants capacity and new capacity

Original Units: GW **Active Unit** GW **Data values filter:**

Attribute | *Process* | *Vintage* | *Region*

~-Scenario-~	ProcessSet	2005	2006	2010	2015	2020	2025	2030	2035	2040	2045	2050
DemoS_012	Coal Power Plants	137	133	127	146	123	103	91	71	71	71	66
	Gas Power Plants	104	98	86	115	160	215	219	219	211	196	188
	Hydro power plants	62	62	45	32	32	32	14				
	Nuclear Power Plants	115	115	115	115	117	119	121	128	131	140	147
	Oil Power Plants	11	11	10	8	16	19	21	25	26	26	28
	Solar/PV power plants	14	13	10	5							
	Wind Power Plants	68	65	51	34	75	103	147	184	200	218	234
	Total	512	498	443	454	522	590	612	628	639	652	663
DemoS_012b	Coal Power Plants	137	133	115	92	69	46	23				
	Gas Power Plants	104	98	78	52	26						
	Hydro power plants	62	62	45	32	32	32	14				
	Nuclear Power Plants	115	115	115	115	117	119	121	128	134	140	147
	Oil Power Plants	11	11	10	8	6	36	61	84	87	90	93
	Solar/PV power plants	14	13	10	5							
	Wind Power Plants	68	65	599	732	861	1,012	1,072	1,099	1,123	1,148	1,173
	Total	512	498	971	1,035	1,111	1,245	1,291	1,311	1,344	1,378	1,413
DemoS_012c	Coal Power Plants	137	133	127	146	123	101	89	70	70	70	66
	Gas Power Plants	104	98	86	115	160	216	220	220	212	199	188
	Hydro power plants	62	62	45	32	32	32	14				
	Nuclear Power Plants	115	115	115	115	117	119	121	128	131	140	147
	Oil Power Plants	11	11	10	8	16	19	21	25	28	28	34
	Solar/PV power plants	14	13	10	5					48	85	125
	Wind Power Plants	68	65	51	34	75	103	147	184	161	148	131
	Total	512	498	443	454	522	590	612	628	649	670	691
DemoS_012e	Coal Power Plants	137	133	127	146	123	102	90	124	124	124	113
	Gas Power Plants	104	98	86	115	161	218	224	295	287	275	268
	Hydro power plants	62	62	45	32	32	32	14				
	Nuclear Power Plants	115	115	115	115	116	117	118	13	18	23	33
	Oil Power Plants	11	11	10	8	16	19	21	20	20	20	23
	Solar/PV power plants	14	13	10	5							
	Wind Power Plants	68	65	51	34	75	103	147	184	200	218	234
	Total	512	498	443	454	523	590	613	635	648	660	671

Figure 172. Results – Electricity generation capacity in DemoS_012

ELC plants new installed capacity in each period

Original Units: GW **Active Unit** GW **Data values filter:**

Attribute | *Process* | *Region*

~Scenario~	ProcessSet	2010	2015	2020	2025	2030	2035	2040	2045	2050
DemoS_012	Coal Power Plants	12	42		3	11	4			7
	Gas Power Plants	8	55	71	81	4			40	63
	Nuclear Power Plants			2	2	2	121	3	10	6
	Oil Power Plants			10	4	4	6	1		2
	Wind Power Plants			57	45	44	38	73	64	59
DemoS_012e	Coal Power Plants	12	42		2	11	57			1
	Gas Power Plants	8	55	72	83	6	71		44	65
	Nuclear Power Plants			1	1	1	10	5	5	10
	Oil Power Plants			10	4	4	1			4
	Wind Power Plants			57	45	44	37	73	64	59

Figure 173. Results – New capacity investments for electricity generation in DemoS_012