VEDA-TIMES Advanced DemoS Model Description

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by

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General Introduction

This report is describing the advanced VEDA-TIMES DemoS steps based on the structure developed for the basic VEDA-TIMES DemoS described in the TIMES documentation Part IV[1]. New VEDA-TIMES users should start first with the VEDA-TIMES basic DemoS[2] and then move to this version of the model.

The detailed description of the starting structure of the DemoS is provided in TIMES documentation Part IV with a step-by-step introduction to build a TIMES model in the VEDA-Front End (VFE) model management software. It first offers an orientation to the basic features of VFE, including folder organization, data files and tables, and model management features. It then describes in detail twelve Demo models (available for download from the ETSAP website, via footnote 2) that progressively introduce VEDA-TIMES principles and modeling techniques.

TIMES documentation Part V[3] describes the VEDA Back-End (VBE) software, which is widely used for analyzing results from TIMES model runs. It provides a complete guide to using VBE, including how to get started, import model results, create and modify user sets, create and view tables, and step through model results by cascading through the Reference Energy System (RES) network.

[1] TIMES documentation Part IV: Building a TIMES model using VEDA-FE
[2] VEDA-TIMES Demo Models
[3] TIMES documentation Part V: Analysing results from TIMES models using VEDA-BE

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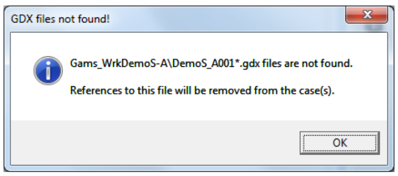
1 Introduction

This report describes the VEDA-TIMES Advanced DemoS. This model is based on the approach developed for the basic TIMES-DemoS (from DemoS_001 to DemoS_012), using a series of six steps implemented through additional scenarios and Subres workbooks, to progressively include some additional VEDA-TIMES features.

The complete VEDA-TIMES Advanced Demo is assembled in the single VEDA_Models subfolder called DemoS_Adv. In this folder are all the sub-folders and Excel workbooks needed by VEDA for setting up and using the model.

The first time the user will start using the VEDA-TIMES Advanced DemoS model it is important to load the DemoS_A001 and run it to generate a gdx filke that is needed from some of the other runs. Starting from other runs without running the DemoS_A001 will generate the following error.



1.1 Downloading and setting up the DemoS_Adv model

The advanced VEDA-TIMES DemoS_Adv is available on the ETSAP Projects web page (https://iea-etsap.org/index.php/etsap-projects) under ‘Advanced VEDA-TIMES Demo’. You will also need VEDA (FE and BE) and GAMS installed in order to follow along with this report. VEDA and GAMS Installation instructions are available at http://support.kanors-emr.org/.

The ETSAP_DemoS_Adv model zip file include three sub-folders.

1. ETSAP_DemoS_Adv: contains the complete set of VEDA-TIMES Advanced Demo input data templates comprising the model reside in the ETSAP_DemoS_Adv folder. This folder should be placed under your VEDA_Models folder (C:\VEDA\VEDA_Models, if you did not change the path during installation).
   In this folder are all the sub-folders and Excel workbooks needed by VEDA for setting up and using the model.
2. DemoS_A_VBE: contains a database with predefined sets and tables for analyzing results of the DemoS_Adv model runs (DemoS_A001 to DemoS_A005).
3. DemoS_A-Stoch_VBE: contains a database with predefined sets and tables for analyzing results of the DemoS_Adv stochastic run (DemoS_A006). [Note that a separate database is needed for the stochastic results because the State-of-the-World (SoW) index is added to each attribute.]

Folders 2 and 3 should be pasted under your VEDA-BE databases folder (C:\VEDA\Veda_BE\Databases, if you did not change the path during installation).

2 VEDA-TIMES Advanced Demo Model

This section shortly explains how to use the advanced VEDA-TIMES DemoS_Adv with references to the TIMES documentation for more details. This model, as noted above, starts from the structure of DemoS_012 described in the TIMES documentation Part IV. The structure of DemoS_012 has been slightly change to better represents the features of the DemoS_Adv, with all the changes explained in the next section.

The VEDA-TIMES DemoS_Adv consists of several modeling steps. For each step (from 1 to 6) there are multiple runs for introducing different features or for sensitivity analysis for better understanding the approach, as elaborated in Table 1.

Table 1. The Advanced Demo model (DemoS_Adv) runs

<table>
<tr><th>Step Name</th><th>Run names</th><th>Short description</th></tr>
<tr><td rowspan="7">Advanced features</td><td>DemoS_A001</td><td>Run including the new updates done to the DemoS_012 model</td></tr>
<tr><td>DemoS_A001a</td><td>Limit CO_2 across Regions</td></tr>
<tr><td>DemoS_A001b</td><td>Fixing solution for some years based on a previous run</td></tr>
<tr><td>DemoS_A001c</td><td>Subsidies on solar technologies</td></tr>
<tr><td>DemoS_A001d</td><td>Adding a build rate constraint on solar technologies</td></tr>
<tr><td>DemoS_A001e</td><td>Vintage new solar and wind technologies</td></tr>
<tr><td>DemoS_A001f</td><td>TIMES-Stepped myopic model run solution</td></tr>
<tr><td rowspan="2">Macro Stand Alone (MSA)</td><td>DemoS_A002_MSA-Calibration</td><td>Calibration of Macro Stand Alone TIMES extension: CSA routine</td></tr>
<tr><td>DemoS_A002a</td><td>Macro Stand Alone alternative run based on CSA calibration</td></tr>
<tr><td rowspan="3">Budget constraints</td><td>DemoS_A003</td><td>Bound specified on regional costs in given milestone years</td></tr>
<tr><td>DemoS_A003a</td><td>Bound specified on regional costs cumulative over a year range</td></tr>
<tr><td>DemoS_A003b</td><td>Limit the total amount of subsidies for a technology</td></tr>
<tr><td rowspan="4">Endogenous Technology Learning (ETL)</td><td>DemoS_A004</td><td>Endogenous technology learning set up</td></tr>
<tr><td>DemoS_A004a</td><td rowspan="3">Sensitivity runs with different technology learning rate for comparison with DemoS_A004 run</td></tr>
<tr><td>DemoS_A004b</td></tr>
<tr><td>DemoS_A004c</td></tr>
<tr><td rowspan="2">Storage technologies</td><td>DemoS_A005</td><td>Hydro pump storage technologies</td></tr>
<tr><td>DemoS_A005a</td><td>Electric car (storage)</td></tr>
<tr><td rowspan="3">Stochastic</td><td>DemoS_A006</td><td>Stochastic TIMES set up</td></tr>
<tr><td>DemoS_A006a</td><td>Impose a CO_2 constraint starting from 2030 for comparing results with the next runs</td></tr>
<tr><td>DemoS_A006b to DemoS_A006i</td><td>Sensitivity runs with different probabilities for comparison with DemoS_A006a run</td></tr>
</table>

2.1 Advanced features - DemoS_A001 runs

Description. The DemoS_Adv is based on an updated DemoS_A012, in particular this version includes the following structural changes:

- Increased the number of timeslice from 4 to 12 (4 seasons, day/night/peak);

- Availability factors (AF) by timeslices added in the BY_Trans and SubRes_NewTechs_Trans;
- The COM_FR attribute has been moved from BY templates (VT_ files) to the Scen_COM_FR scenario workbook;
- Updated the UC_Growth scenario including Nuclear growth constraint;
- Some minor data adjustments to the BY templates, and
- Changed the efficiency of electric cars and operating costs and AF for LPG in the SubRES_NewTechs, sheet TRA.

Objective. The objective is to introduce examples showing how to:

- Impose bounds across regions;
- fix the model solution for some years based on a previous run;
- introduce subsidies and penetration rate limits on technologies, and vintage them, and
- Run TIMES in a time-stepped (myopic) rather than clairvoyant manner.

2.1.1 Runs DemoS_A001 and DemoS_A001a

These two steps are not introducing any new features compared to the DemoS_001 to DemoS_012 but are implemented for checking the updated model and to establish the results for comparison with the next runs. The only difference between the two runs DemoS_A001 and DemoS_A001a is the scenario file Scen_UC_CO2_Regions is included in the latter.

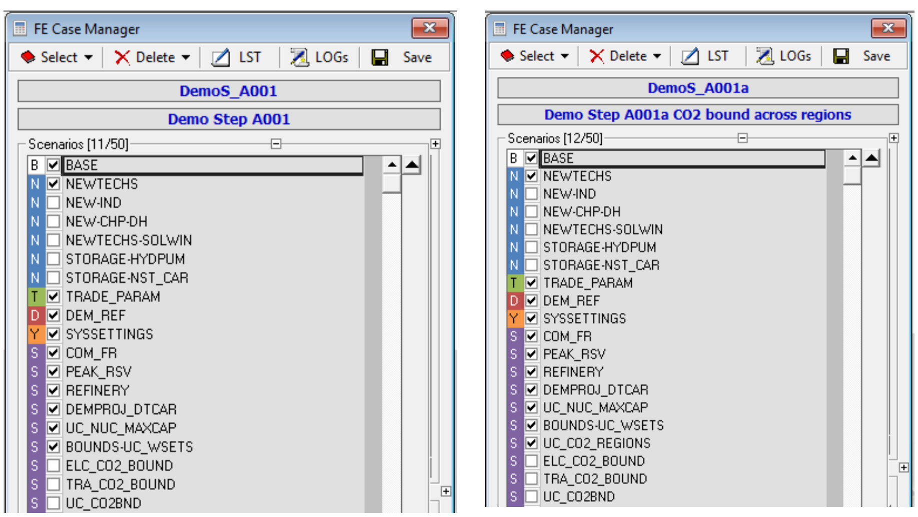


Figure 1. Case Manager view for DemoS_A001 and DemoS_A001a runs

The next figures show an example of results (final energy and emissions) for these two model runs, just for comparison.

Consumption by Sector

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

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

ProcessSet	~Scenario~	2005	2006	2010	2015	2020	2025	2030	2035	2040	2045	2050
Fuel Consumption Agriculture Sector	DemoS_A001	1,125	1,170	1,370	1,672	2,045	2,507	2,570	2,635	2,702	2,770	2,840
	DemoS_A001a	1,125	1,170	1,370	1,672	2,045	2,507	2,570	2,635	2,702	2,770	2,840
Fuel Consumption Commercial Sector	DemoS_A001	5,662	5,745	6,632	8,021	9,729	11,871	12,134	12,397	12,672	12,934	13,254
	DemoS_A001a	5,662	5,754	6,615	7,987	9,644	11,708	11,991	12,277	12,578	12,887	13,206
Fuel Consumption Industry Sector	DemoS_A001	13,159	13,169	13,209	13,258	13,308	13,358	13,408	13,459	13,509	13,560	13,611
	DemoS_A001a	13,159	13,169	13,209	13,258	13,308	13,358	13,408	13,459	13,509	13,560	13,611
Fuel Consumption Residential Sector	DemoS_A001	13,277	13,188	13,757	14,584	15,494	16,530	16,947	17,373	17,752	18,141	18,507
	DemoS_A001a	13,277	13,206	13,777	14,605	15,453	16,442	16,761	17,131	17,519	17,900	18,294
Fuel Consumption Transport Sector	DemoS_A001	13,269	13,619	14,029	15,439	17,446	26,291	26,947	27,620	28,317	29,032	29,765
	DemoS_A001a	13,269	13,619	14,029	15,439	17,446	26,291	26,947	27,620	28,317	29,032	29,765

Figure 2. Final energy consumption by sector (DemoS_A001 and DemoS_A002)

Emissions by Sector

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

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

Commodity	~Scenario~	2005	2006	2010	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture Carbon dioxide	DemoS_A001	36	38	45	56	71	89	93	97	101	106	111
	DemoS_A001a	36	38	45	56	71	89	93	97	101	106	111
Commercial Carbon dioxide	DemoS_A001	193	207	269	355	449	566	557	543	533	506	519
	DemoS_A001a	193	213	255	328	327	378	383	384	393	401	412
Electricity Plants Carbon dioxide	DemoS_A001	1,052	982	1,043	1,199	1,224	1,278	1,212	1,293	1,281	1,170	1,146
	DemoS_A001a	1,052	960	1,024	1,024	1,001	394	426	427	412	407	396
Industry Carbon dioxide	DemoS_A001	583	586	598	614	629	644	660	676	692	708	724
	DemoS_A001a	583	586	598	614	629	644	660	676	692	708	724
Residential Carbon dioxide	DemoS_A001	563	604	680	779	888	926	989	1,054	1,075	1,096	1,093
	DemoS_A001a	563	609	691	796	797	752	739	759	787	803	821
Transport Carbon dioxide	DemoS_A001	951	979	994	1,108	1,255	1,915	1,963	2,013	2,063	2,116	2,169
	DemoS_A001a	951	979	994	1,108	1,255	1,915	1,963	2,013	2,063	2,116	2,169

Figure 3. Emissions by sector (DemoS_A001 and DemoS_A002)

2.1.2 Run DemoS_A001b

This run is introducing how to fix the model solution up to some years based on a previous run. This feature is useful when for example for alternative scenarios consistency is desired for historical years between all the runs.

To fix the solution in some years a TIMES switch that can be enabled in VEDA-FE control panel needs to be activated by selecting a GAMS GDX solution file from a previous run and the years to lock down. This run uses the same combination of scenarios and Subres as in the run DemoS_A001a, the only difference is that the model solution is fixed up to 2015 based on the previous run DemoS_A001. Figure 4 shows a portion of the Control Panel brought up from the Case Manager indicating how to activate the switch for fixing solution up to 2015 based on the GDX file generated by the run DemoS_A001 (selected via the file browse button).

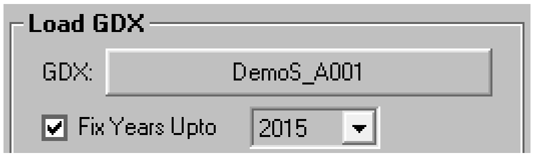


Figure 4. Control panel fixing the model solution for some years

In Figure 2 and Figure 3 results in residential and commercial sector for the two runs DemoS_A001 and DemoS_A001a are already different in 2006 but in Figure 5 DemoS_A001 and DemoS_A001b are the same up to 2015 as desired.

Consumption by Sector

Original Units: PJ Active Unit PJ Data values filter:

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

ProcessSet	~Scenario~	2005	2006	2010	2015	2020	2025	2030	2035	2040	2045	2050
Fuel Consumption Agriculture Sector	DemoS_A001	1,125	1,170	1,370	1,672	2,045	2,507	2,570	2,635	2,702	2,770	2,840
	DemoS_A001a	1,125	1,170	1,370	1,672	2,045	2,507	2,570	2,635	2,702	2,770	2,840
	DemoS_A001b	1,125	1,170	1,370	1,672	2,045	2,507	2,570	2,635	2,702	2,770	2,840
Fuel Consumption Commercial Sector	DemoS_A001	5,662	5,745	6,632	8,021	9,729	11,871	12,134	12,397	12,672	12,934	13,254
	DemoS_A001a	5,662	5,754	6,615	7,987	9,644	11,708	11,991	12,277	12,578	12,887	13,206
	DemoS_A001b	5,662	5,745	6,632	8,021	9,678	11,816	12,079	12,343	12,641	12,770	13,089
Fuel Consumption Industry Sector	DemoS_A001	13,159	13,169	13,209	13,258	13,308	13,358	13,408	13,459	13,509	13,560	13,611
	DemoS_A001a	13,159	13,169	13,209	13,258	13,308	13,358	13,408	13,459	13,509	13,560	13,611
	DemoS_A001b	13,159	13,169	13,209	13,258	13,308	13,358	13,408	13,459	13,509	13,560	13,611
Fuel Consumption Residential Sector	DemoS_A001	13,277	13,188	13,757	14,584	15,494	16,530	16,947	17,373	17,752	18,141	18,507
	DemoS_A001a	13,277	13,206	13,777	14,605	15,453	16,442	16,761	17,131	17,519	17,900	18,294
	DemoS_A001b	13,277	13,188	13,757	14,584	15,433	16,485	16,810	17,180	17,647	17,846	18,244
Fuel Consumption Transport Sector	DemoS_A001	13,269	13,619	14,029	15,439	17,446	26,291	26,947	27,620	28,317	29,032	29,765
	DemoS_A001a	13,269	13,619	14,029	15,439	17,446	26,291	26,947	27,620	28,317	29,032	29,765
	DemoS_A001b	13,269	13,619	14,029	15,439	17,446	26,340	26,996	27,620	28,317	29,032	29,765

Figure 5. Final energy consumption by sector (DemoS_A001, DemoS_A001a and DemoS_A001b)

The DemoS_A001b includes a new scenario template for imposing a maximum potential for the solar technologies from 2010 on.

- Scen_UC_RNW_MAXCAP for implementing absolute user constraints on the maximum capacity for renewable technologies (hydro, solar and wind).

~UC_Sets: R_E: AllRegions
~UC_Sets: T_E:
~UC_T:UC_RHSRT

UC_N	Pset_Set	Pset_CI	Year	LimType	UC_CAP	REG1	REG2	UC_RHSRT~0	UC_Desc
\I:						GW	GW		
AU_WIN_MaxCAP	ELE	ELCWIN	2015	UP	1	26	26	15	Max Wind Power Plants Capacity
	ELE	ELCWIN	2030	UP	1	75	125		
	ELE	ELCWIN	2050	UP	1	150	250		
AU_SOL_MaxCAP	ELE	ELCSOL	2015	UP	1	8	8	15	Max PV Power Plants Capacity
	ELE	ELCSOL	2030	UP	1	100	50		
	ELE	ELCSOL	2050	UP	1	400	150		
AU_HYD_MaxCAP	ELE	ELCHYD	2015	UP	1	33	33	15	Max Hydro Power Plants Capacity
	ELE	ELCHYD	2030	UP	1	35	35		
	ELE	ELCHYD	2050	UP	1	40	40		

Figure 6. Scen_UC_RNW_MAXCAP

Figure 7 show a comparison of the DemoS_A001b with renewable maximum capacity with the DemoS_A001 and DemoS_A001a without bound.

ELC plants capacity

Original Units: GW Active Unit GW Data values filter:

Attribute | Process | Region | Vintage

ProcessSet	Scenario	2005	2006	2010	2015	2020	2025	2030	2035	2040	2045	2050
Hydro power plants	DemoS_A001	62	62	62	62	62	81	86	83	70	74	79
	DemoS_A001a	62	62	62	62	62	62	62	45	32	32	32
	DemoS_A001b	62	62	62	62	62	65	65	48	35	55	56
Solar/PV power plants	DemoS_A001	14	13	10	5							
	DemoS_A001a	14	13	10	5							
	DemoS_A001b	14	13	10	5							
Wind Power Plants	DemoS_A001	68	65	51	34	30	33	44	66	101	111	122
	DemoS_A001a	68	65	51	59	102	514	514	489	509	500	500
	DemoS_A001b	68	65	51	34	73	158	192	247	300	350	400

Figure 7. Renewable power plants capacity in DemoS_A001b

2.1.3 Run DemoS_A001c

This step, based on DemoS_A001b run, shows how to introduce subsidies for a technology using two TIMES attributes:

- FLO_SUB, subsidy for the production/use of a commodity by process, and
- NCAP_ISUB, subsidy for new investments by process in a period.

More information on these attributes are available in the TIMES documentation Part II.

The DemoS_A001c includes a new scenario template for introducing the subsidies and imposing a maximum potential for the solar technologies from 2010 on.

- Scen_Solar_Subsidies with a ~TFM_INS table for using the two attributes for subsidies on solar technologies, and

~TFM_INS

Attribute	Year	REG1	REG2	Pset_CI	Cset_CN
\I: "Credit" for using /producing a commodity c by a process ; cost in financi		MEuro2005/PJ	MEuro2005/PJ		
FLO_SUB	2010	10	5	ELCSOL	ELC
FLO_SUB	2020	18	18	ELCSOL	ELC
FLO_SUB	2050	18	18	ELCSOL	ELC
FLO_SUB	0	5	5	ELCSOL	ELC
\I: Subsidy for investments;Cost in financial source per unit of capacity		MEuro2005/GW	MEuro2005/GW	Pset_CI	Cset_CN
NCAP_ISUB	2010	500	500	ELCSOL	
NCAP_ISUB	0	5	5	ELCSOL	

Figure 8. Scen_Solar_Subsidies

ELC Plants Production

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

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

ProcessSet	~Scenario~	2005	2006	2010	2015	2020	2025	2030	2035	2040	2045	2050
Biomass power plants	DemoS_A001b			39	22	24	39					
	DemoS_A001c			39	22	24	39					
Coal Power Plants	DemoS_A001b	3,686	3,563	3,224	3,679	2,134		739	420	71		395
	DemoS_A001c	3,686	3,563	3,224	3,679	2,134		883	292			1,041
Gas Power Plants	DemoS_A001b	1,231	882	2,184	2,817	4,957	7,225	6,128	5,782	5,649	4,693	3,488
	DemoS_A001c	1,231	882	2,184	2,817	4,950	6,561	5,241	5,070	4,913	3,628	1,164
Hydro power plants	DemoS_A001b	978	978	978	978	978	1,028	1,028	758	555	863	883
	DemoS_A001c	978	978	978	978	978	1,028	1,028	925	758	863	883
Nuclear Power Plants	DemoS_A001b	3,267	3,267	3,267	3,267	3,330	3,393	3,457	3,828	4,018	4,207	4,397
	DemoS_A001c	3,267	3,267	3,267	3,267	3,330	3,393	3,457	3,828	4,018	4,207	4,397
Oil Power Plants	DemoS_A001b				7	73	249	213	216	230	252	326
	DemoS_A001c				7	74	227	181	185	199	189	155
Solar/PV power plants	DemoS_A001b	136	127	91	45							
	DemoS_A001c	136	127	91	45		656	656	656	608	1,334	2,754
Wind Power Plants	DemoS_A001b	754	716	565	377	801	1,748	2,123	2,731	3,311	3,863	4,415
	DemoS_A001c	754	716	565	377	807	1,748	2,208	2,759	3,311	3,592	3,414

Figure 9 show a comparison the DemoS_A001b run without subsidies and the new DemoS_A001c run with subsidies. The Solar/PV power plants production in the DemoS_A001c is increasing from 2020 to 2050 due to the subsidies on the new solar technologies.

Figure 10 shows the system costs in MEuro for the two runs where the line Cost_Flox, for the DemoS_A001c, is the annual subsidies due to the use of the FLO_SUB attribute for the solar electricity.

ELC Plants Production

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

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

ProcessSet	~Scenario~	2005	2006	2010	2015	2020	2025	2030	2035	2040	2045	2050
Biomass power plants	DemoS_A001b			39	22	24	39					
	DemoS_A001c			39	22	24	39					
Coal Power Plants	DemoS_A001b	3,686	3,563	3,224	3,679	2,134		739	420	71		395
	DemoS_A001c	3,686	3,563	3,224	3,679	2,134		883	292			1,041
Gas Power Plants	DemoS_A001b	1,231	882	2,184	2,817	4,957	7,225	6,128	5,782	5,649	4,693	3,488
	DemoS_A001c	1,231	882	2,184	2,817	4,950	6,561	5,241	5,070	4,913	3,628	1,164
Hydro power plants	DemoS_A001b	978	978	978	978	978	1,028	1,028	758	555	863	883
	DemoS_A001c	978	978	978	978	978	1,028	1,028	925	758	863	883
Nuclear Power Plants	DemoS_A001b	3,267	3,267	3,267	3,267	3,330	3,393	3,457	3,828	4,018	4,207	4,397
	DemoS_A001c	3,267	3,267	3,267	3,267	3,330	3,393	3,457	3,828	4,018	4,207	4,397
Oil Power Plants	DemoS_A001b				7	73	249	213	216	230	252	326
	DemoS_A001c				7	74	227	181	185	199	189	155
Solar/PV power plants	DemoS_A001b	136	127	91	45							
	DemoS_A001c	136	127	91	45		656	656	656	608	1,334	2,754
Wind Power Plants	DemoS_A001b	754	716	565	377	801	1,748	2,123	2,731	3,311	3,863	4,415
	DemoS_A001c	754	716	565	377	807	1,748	2,208	2,759	3,311	3,592	3,414

Figure 9. Electricity production by plant type (DemoS_A001b and DemoS_A001c)

The higher investment cost in the last run is due to a different power sector portfolio compared to the previous run, in particular the model installs more in solar technologies and less gas and oil. The overall discounted total system cost is lower in the new run but comparing the annual undiscounted costs they are slightly higher, but this is compensated by higher salvage values in some periods.

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

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

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

~Scenario~	Attribute	-	2005	2006	2010	2015	2020	2025	2030	2035	2040	2045	2050
DemoS_A001b	Cost_Act [Annual activity costs]		5,549	5,330	5,599	5,807	6,072	6,657	6,875	12,772	12,852	13,765	14,211
	Cost_Flo [Annual flow costs (including import/export prices)]		268,530	235,124	245,631	285,059	321,135	413,108	419,931	439,255	452,760	456,487	461,853
	Cost_Fom [Annual fixed operating and maintenance costs]		75,616	79,271	82,566	89,726	106,064	154,239	156,618	161,871	165,559	169,908	173,881
	Cost_Inv [Annual investment costs]			88,950	400,527	830,525	927,551	1,453,340	1,483,925	1,527,415	1,561,531	1,600,747	1,642,488
	Cost_Salv [Salvage values of capacities at EOH+1]	360,760											
	Cost_ire [Annual implied costs of endogenous trade]				0	0	0	0	0	0	0	0	0
	Total	360,760	349,696	408,675	734,324	1,211,116	1,360,823	2,027,345	2,067,348	2,141,313	2,192,702	2,240,908	2,292,433
DemoS_A001c	Cost_Act [Annual activity costs]		5,549	5,330	5,599	5,807	6,074	6,486	6,723	12,880	13,027	13,378	13,397
	Cost_Flo [Annual flow costs (including import/export prices)]		268,530	235,124	245,631	285,059	321,135	406,396	412,445	435,571	448,237	449,980	446,873
	Cost_Flox [Annual flow taxes/subsidies]		0	0	0	0		-7,376	-8,196	-9,015	-9,120	-21,686	-48,188
	Cost_Fom [Annual fixed operating and maintenance costs]		75,616	79,271	82,566	89,726	106,058	155,580	159,308	164,722	168,370	175,668	185,544
	Cost_Inv [Annual investment costs]			88,950	400,527	830,525	927,563	1,467,803	1,502,681	1,540,217	1,574,304	1,628,245	1,703,162
	Cost_Salv [Salvage values of capacities at EOH+1]	387,632											
	Cost_ire [Annual implied costs of endogenous trade]				0	0	0	0	0	0	0	0	0
	Total	387,632	349,696	408,675	734,324	1,211,116	1,360,830	2,028,889	2,072,961	2,144,375	2,194,817	2,245,585	2,300,788

Figure 10. Annual system costs and subsidies (DemoS_A001b and DemoS_A001c)

2.1.4 Run DemoS_A001d

This step, based on DemoS_A001c run, includes limits on the new build rate for the solar and wind technologies, based on a maximum annual construction rate. This is accomplished by means of a user constraint is in the scenario file:

- Scen_UC_NCAP_BuildRateNCAP_ISUB, subsidy for new investments by process in a period.

Error! Reference source not found. shows the structure of the build rate user constraint for each region to bound the maximum new capacity rate per year for wind technologies (UC_ELC-Wind_BuildRate) and solar technologies (UC_ELC-Solar_BuildRate).

~UC_Sets: R_E: AllRegions										
~UC_Sets: T_E:										
		~UC_T: UC_RHSRT~UP								
UC_N	**PSET_CI**	**UC_ATTR**	**UC_NCAP**	**2006**	**2015**	**2020**	**2030**	**2050**	**0**	**UC_Desc**
UC_ELC-Wind_BuildRate	ELCWIN	NCAP,BUILDUP	1	2	10	15	20	30	5	Max wind capacity installed per year
UC_ELC-Solar_BuildRate	ELCSOL	NCAP,BUILDUP	1	1	5	7	10	20	5	Max PV solar capacity installed per year

Figure 11. Build rate user constraint

When a model attribute is to be used as a coefficient in a user constraint it is specified by means of $UC\_ATTR_{r,uc\_n,'LHS',VAR,ATTR}$ (see section 6.4 and 6.4.6 of TIMES documentation Part II for more information). The user constraint type is specified by the attribute being used (in this example BUILDUP) which will be applied as the coefficient for the variable identified (in this example NCAP), placed on the left hand side (LHS) of the user constraint (uc_n) in region (r). With this UC_ATTR modifier we have the VAR_NCAP value divided by the number of years during which the capacity build-up is assumed to take place, in order to refer to the **annual amount of new capacity** installed in a user constraint. For more ATTR/VAR options see **Error! Reference source not found.**.

Table 2. Coefficients for user constraints

Attribute	Description	Applicable UC components
COST	Multiple by primary cost attribute (summing together with other cost attributes requested)	NCAP,ACT, FLO, COMPRD, COMCON

TAX	Multiple by tax attribute (summing together with other cost attribute requested)	NCAP,FLO
SUB	Multiple by subsidy attribute (summing together with other cost attribute requested)	NCAP,FLO
DELIV	Multiple by delivery cost attribute (summing together with other cost attribute requested)	FLO
INVCOST	Multiple by investment cost annuities; implies CUMSUM	NCAP
INVTAX	Multiple by investment tax annuities; implies CUMSUM	NCAP
INVSUB	Multiple by investment subsidy annuities; implies CUMSUM	NCAP
CAPACT	Multiply by PRC_CAPACT	CAP
CAPFLO	Apply coefficients also to any capacity-related flows	FLO
CUMSUM	Sum over all periods up to current or previous period (DYN only)	All
EFF	Multiply by COM_IE (UC_COMPRD), divide by COM_IE (UC_COMCON)	COMPRD, COMCON
GROWTH	Interpret coefficients as annual change coefficients (DYN only)	All
NET	Apply to net production (UC_COMPRD) or consumption (UC_COMCON)	COMPRD, COMCON
NEWFLO	Apply coefficient to the flows of the new vintage only	ACT, FLO, IRE
ONLINE	Apply coefficient to the on-line capacity only (assumed equal to the full capacity if ACT_MINLD has not been defined)	CAP
PERIOD	Multiply by period length (all but NCAP) or CEFF_RPTI (NCAP)	All but CAP
SYNC	Synchronize LHS and RHS sides to refer to the same period	All (RHS only)
YES	Declares the constraint to be dynamic, of type (t-1, t)	All (RHS only)
BUILDUP	Applied in order to refer to the annual amount of a variable in a user constraint	

Figure 12 shows total installed and new capacity by region for DemoS_A001c and DemoS_A001d, where for example in 2020 the VAR_NCAP in REG1 in DemoS_A001d is 35 GW (a maximum of 7 GW per year but considering that in this model there are 5 years periods from 2010, the maximum new capacity in the period 2020 is 35 GW).

ELC plants capacity and new capacity for solar techs

Original Units: GW Active Unit GW Data values filter:

Vintage

ProcessSet	Region	Attribute	~Scenario~	Process	2005	2006	2010	2015	2020	2025	2030	2035	2040	2045	2050
Solar/PV power plants	REG1	VAR_Cap	DemoS_A001c	ELCRESOL00	7	7	5	2							
				ELCRNSOL01					39	69	100	175	229	250	189
			DemoS_A001d	ELCRESOL00	7	7	5	2							
				ELCRNSOL01					35	69	100	128	168	225	189
		VAR_Ncap	DemoS_A001c	ELCRNSOL01					39	31	31	114	85	52	52
			DemoS_A001d	ELCRNSOL01					35	34	31	63	75	88	27
	REG2	VAR_Cap	DemoS_A001c	ELCRESOL00	7	7	5	2							
				ELCRNSOL01					22	36	50	75	100	125	150
			DemoS_A001d	ELCRESOL00	7	7	5	2							
				ELCRNSOL01					22	36	50	75	100	125	150
		VAR_Ncap	DemoS_A001c	ELCRNSOL01					22	14	14	47	39	39	72
			DemoS_A001d	ELCRNSOL01					22	14	14	47	39	39	72

Figure 12. Capacity and new capacity for solar technologies (DemoS_A001c and DemoS_A001d)

2.1.5 Runs DemoS_A001e

DemoS_A001e adds to the model a new Subres with vintage solar and wind new technologies to capture the changing costs and availability factors associated with the improving technologies over time. The approach for including vintage technologies has been explained in TIMES documentation part IV for the DemoS_006. The new Subres included in the model run is:

- SubRES_NewTechs-SolWin.

This step is needed only for results comparison with the next step.

2.1.6 Runs DemoS_A001f

This run introduces the time-stepped solution, enabled through a TIMES switch available in the Control Panel of VEDA-FE Case Manager, as shown in Figure 13. More information on how to use TIMES with limited foresight (time-stepped) is available on the TIMES documentation Part I from page 103.

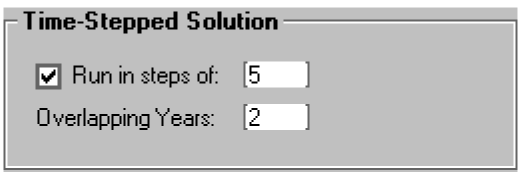


Figure 13. TIME-Stepped activation in VFE Case Manager

This run is a combination of DemoS_A001e with the time-stepped solution, with steps of 5 years length and an amount of overlapping years between successive steps of 2 years (the amount of overlapping years between successive steps is by default half of the active step length, but it can be controlled by the user). The model is already fix up to 2015 of the DemoS_A001 so in this case the stepped solution will start from 2015.

ELC plants capacity

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

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

ProcessSet	~Scenario~	2005	2006	2010	2015	2020	2025	2030	2035	2040	2045	2050
Biomass power plants	DemoS_A001e	10	10	8	6	4	2					
	DemoS_A001f	10	10	8	6	4	2					
Coal Power Plants	DemoS_A001e	137	133	120	137	114	91	69	46	46	46	40
	DemoS_A001f	137	133	120	137	114	91	69	46	46	46	40
Gas Power Plants	DemoS_A001e	104	98	81	106	168	247	247	247	243	193	105
	DemoS_A001f	104	98	81	106	212	293	293	293	289	239	107
Hydro power plants	DemoS_A001e	62	62	62	62	62	65	65	48	35	35	35
	DemoS_A001f	62	62	62	62	62	65	65	48	35	35	35
Nuclear Power Plants	DemoS_A001e	115	115	115	115	117	119	121	128	128	128	128
	DemoS_A001f	115	115	115	115	117	119	121	128	128	128	128
Oil Power Plants	DemoS_A001e	11	11	22	75	174	280	279	288	288	288	325
	DemoS_A001f	11	11	22	75	157	225	234	232	232	232	326
Solar/PV power plants	DemoS_A001e	14	13	10	5	29	72	150	230	288	350	413
	DemoS_A001f	14	13	10	5	57	105	150	203	268	350	413
Wind Power Plants	DemoS_A001e	68	65	51	34	102	151	151	151	252	350	400
	DemoS_A001f	68	65	51	34	21	146	146	197	300	350	400

Figure 14. Power plant capacity (DemoS_A001e and DemoS_A001f)

Figure 14 compares results on DemoS_A001e and DemoS_A001f for which the only difference is the time-stepped nature of the second run. Enabling this switch on the long term horizon we get two similar solutions for the installed power plants capacity but in the medium period there are some different behaviours between the two runs. For example the investment in wind is anticipated in DemoS_A001e (2020) and delayed in DemoS_A001f (2025).

2.2 Macro Stand Alone (MSA) - DemoS_A002 runs

Description. This step of the advanced demos set up the Macro Stand Alone TIMES extension in the VEDA templates. All the needed changes are implemented in additional scenario files without changing the base structure of the model. The MSA formulation support multiple regions.

Objective. The objective of the following run steps is to show how to implement and use the Macro Stand Alone TIMES extension in the VEDA templates.

Note that a Non-Linear Solver is employed to solve the Macro module of TIMES.

More information about MACRO is available on TIMES documentation part I, from page 121 chapter 12 (General equilibrium extensions) and a detailed documentation of the MSA mathematical approach and implementation is available on the ETSAP web site on TIMES Extensions documentation – Macro MSA https://iea-etsap.org/docs/TIMES-Macro-MSA.pdf.

2.2.1 Stand-alone calibration (CSA) – run DemoS_A002_MSA-Calibration

The TIMES Macro Stand Alone (MSA) is a coupled model linking TIMES with a simplified single sector producer-consumer macroeconomic model, which has the benefit of endogenizing the level of the energy service demands that drive the model.

To use TIMES-MSA requires that demand decoupling factors (DDFs) and labour growth rates are first calibrated with the Baseline scenario and corresponding GDP growth projections. The Baseline calibration is based on a decomposed formulation described in the TIMES Extensions documentation – Macro MSA paragraph 2.4 at page 11.

The calibration routine (and so the MSA model) requires the definition of some Macro input parameters. The MSA module already includes some default values for the basic macro parameters (see section 3.2 of the Macro-MSA documentation for the full list of input and output parameters, including the default values), but the user must provide the first period GDP and the projected percent annual GDP growth rate. This example is using a new scenario called Scen_MSA_Parameters for including the MACRO input parameters (Figure 15):

- TM_GDP0(r): GDP in base year (currency units);
- TM_GR(r,y): GDP growth projection (per cent/a), and
- TM_DMTOL: to change the default value for the lower bound factor for the demand variables parameter (so demand may only be reduced 10% here).

The calibration procedure can be activated by using the CSA switch available in the control panel of the VFE Case Manager (Figure 16). In this example the calibration uses the DemoS_A001 run.The calibration produces a file containing the calibrated parameters (named MSADDF.DD), which as discussed in the next section is then included in the subsequent policy scenarios to be evaluated.

Macro Stand Alone (MSA)			
~TFM_INS			
Attribute	Year	REG1	REG2
TM_GDP0		4000	6000
TM_GR	2005	1.2	1.01
TM_GR	2010	1.2	1.05
TM_GR	2020	1.1	1.10
TM_GR	2030	1.0	1.10
TM_GR	2040	1.0	1.12
TM_GR	2050	0.8	1.15
TM_DMTOL		0.1	

Figure 15. Macro input parameters

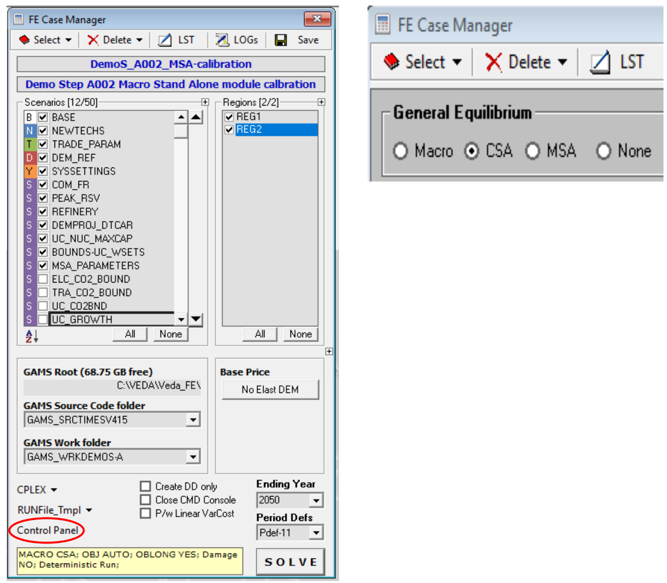


Figure 16. CSA switch and calibration routine run

Since the CSA routine is calibrating the MSA module to the baseline scenario we should get the same results as in the baseline scenario (for this example run DemoS_A001). The policy/alternative scenarios will generate new results, which could be compared with similar scenarios without the MSA module activated to see the impact on the model results of endogenizing the demands (adding an additional degree of freedom to the model , thereby usually lower the overall cost seen in the policy run).

Objective Function Value

Original Units: M Euro Active Unit M Euro

Attribute / ~Scenario~ \ Region	REG1	REG2	Total
DemoS_A001	10,896,153	14,003,887	24,900,041
DemoS_A002_MSA-calibration	10,896,153	14,003,887	24,900,041

Figure 17. Objective function - calibration (DemoS_A001 and DemoS_MSA)

2.2.2 MACRO Stand-alone (MSA) policy run - Run DemoS_A002a

The CSA calibration procedure a file MSADDF.DD which contains the calibrated parameters for MSA. This file is automatically included in subsequent TIMES-MSA policy runs by using the MSA switch available in the control panel of the VFE Case Manager.

At this point is possible to set up an alternative policy scenario (based on the DemoS_A001a run) in the VFE Case Manager (Figure 18) by selecting MSA, unchecking the Scen_MSA_Parameters (this information is included in the MSADDF.DD by the CSA routine), and including one or more alternative scenarios, for example in this run the ScenUC_CO2_Regions is included, and then solved as a MSA model.

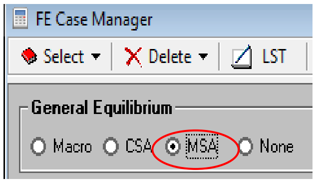


Figure 18. MSA switch in control panel and alternative scenario run

The following figures show an example of results comparing DemoS_A001a and Demos_A002 runs.

Objective Function Value

Original Units: M Euro   Active Unit: M Euro

Attribute

~Scenario~	REG1	REG2	Total
DemoS_A001a	10,964,985	14,081,552	25,046,537
DemoS_A002	10,736,414	13,905,001	24,641,414

Figure 19. Objective function (DemoS_A001a and DemoS_A002)

Consumption by Sector

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

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

ProcessSet	~Scenario~	2005	2006	2010	2015	2020	2025	2030	2035	2040	2045	2050
Fuel Consumption Agriculture Sector	DemoS_A001a	1,125	1,170	1,370	1,672	2,045	2,507	2,570	2,635	2,702	2,770	2,840
	DemoS_A002	1,125	1,170	1,366	1,645	1,951	2,351	2,423	2,522	2,552	2,615	2,687
Fuel Consumption Commercial Sector	DemoS_A001a	5,662	5,754	6,615	7,987	9,644	11,708	11,991	12,277	12,578	12,887	13,206
	DemoS_A002	5,662	5,783	6,630	7,981	9,286	11,123	11,429	11,776	11,973	12,286	12,620
Fuel Consumption Industry Sector	DemoS_A001a	13,159	13,169	13,209	13,258	13,308	13,358	13,408	13,459	13,509	13,560	13,611
	DemoS_A002	13,159	13,166	13,176	13,144	12,678	12,502	12,601	12,820	12,732	12,774	12,819
Fuel Consumption Residential Sector	DemoS_A001a	13,277	13,206	13,777	14,605	15,453	16,442	16,761	17,131	17,519	17,900	18,294
	DemoS_A002	13,277	13,175	13,752	14,490	14,773	15,464	15,848	16,359	16,558	16,973	17,373
Fuel Consumption Transport Sector	DemoS_A001a	13,269	13,619	14,029	15,439	17,446	26,291	26,947	27,620	28,317	29,032	29,765
	DemoS_A002	13,269	13,618	14,023	15,412	17,285	25,915	26,588	27,321	27,959	28,682	29,416

Figure 20. Final energy consumption by sector (DemoS_A001a and DemoS_A002)

Emissions by Sector

Original Units: Kt Active Unit Kt Data values filter:

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

Commodity	~Scenario~	2005	2006	2010	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture Carbon dioxide	DemoS_A001a	36,156	37,786	45,105	56,370	70,577	88,524	92,611	96,849	101,241	105,794	110,512
	DemoS_A002	36,156	37,784	44,981	55,511	67,348	82,996	87,323	92,683	95,589	99,892	104,574
Commercial Carbon dioxide	DemoS_A001a	192,913	212,987	254,892	327,785	326,642	377,501	382,811	384,228	392,504	401,179	412,243
	DemoS_A002	192,913	231,544	273,387	354,137	375,622	385,848	382,154	373,789	393,597	396,183	406,358
Electricity Plants Carbon dioxide	DemoS_A001a	1,051,874	959,687	1,024,244	1,023,985	1,000,931	393,973	426,113	426,954	412,025	406,929	396,219
	DemoS_A002	1,051,874	981,031	1,019,733	1,035,928	1,013,497	503,832	536,944	525,698	526,546	525,860	515,057
Industry Carbon dioxide	DemoS_A001a	583,079	586,108	598,270	613,567	628,971	644,484	660,105	675,835	691,675	707,626	723,688
	DemoS_A002	583,079	585,967	596,792	608,257	599,168	603,206	620,374	643,761	651,909	666,565	681,548
Residential Carbon dioxide	DemoS_A001a	562,785	608,965	690,502	795,540	796,655	751,794	738,608	759,135	787,056	803,193	820,959
	DemoS_A002	562,785	574,833	673,656	772,873	778,460	706,374	698,205	727,897	741,419	759,952	780,021
Transport Carbon dioxide	DemoS_A001a	950,665	978,562	994,402	1,107,534	1,254,861	1,914,684	1,963,032	2,012,601	2,063,422	2,115,526	2,168,946
	DemoS_A002	950,665	978,529	994,088	1,106,336	1,244,542	1,888,703	1,938,280	1,991,775	2,038,865	2,091,794	2,145,010

Figure 21. CO2 emissions by sector (DemoS_A001a and DemoS_A002)

The MSA output reporting includes some Macro-specific result attributes, in addition to most of the standard results parameters (only some results related to the standard TIMEs objective function are omitted, for more information see the MSA and MACRO documentation). The Macro-specific result attributes, shown in Figure 22, provided by region for each period, are:

- GDP-REF - Baseline GDP projection;
- GDP-ACT - Actualized GDP;
- PRD-Y - Annual Macro production;
- CON-C - Annual Macro consumption;
- INV-I - Annual Macro investments;
- ESCOST - Annual energy system costs , and
- GDPLOS - Percent GDP loss in each period.

Macro_Results

Original Units: Active Unit Data values filter:

Attribute

~Scenario~	Region	Commodity	2005	2006	2010	2015	2020	2025	2030	2035	2040	2045	2050
DemoS_A002	REG1	TM_CON-C	3,393	3,593	3,556	3,795	4,022	4,349	4,544	4,855	5,502	6,054	5,826
		TM_ESCOST	377	392	458	556	659	803	825	863	880	899	922
		TM_GDP-ACT	4,000	4,048	4,245	4,500	4,757	5,012	5,279	5,551	5,828	6,110	6,383
		TM_GDP-REF	4,000	4,048	4,246	4,507	4,772	5,040	5,310	5,581	5,859	6,142	6,416
		TM_GDPLOS		0	0	0	0	1	1	1	1	1	1
		TM_INV-I	607	475	676	797	734	749	669	735	309	64	551
		TM_PRD-Y	4,377	4,440	4,703	5,057	5,416	5,815	6,103	6,414	6,709	7,010	7,305
	REG2	TM_CON-C	5,123	5,304	5,164	5,485	5,820	6,403	6,710	7,182	8,204	9,108	8,865
		TM_ESCOST	544	565	657	795	950	1,147	1,177	1,227	1,253	1,285	1,317
		TM_GDP-ACT	6,000	6,060	6,310	6,647	7,009	7,388	7,802	8,241	8,709	9,212	9,747
		TM_GDP-REF	6,000	6,061	6,311	6,650	7,015	7,409	7,826	8,266	8,735	9,235	9,771
		TM_GDPLOS		0	0	0	0	0	0	0	0	0	0
		TM_INV-I	877	736	1,158	1,071	1,190	899	1,158	1,020	524	96	889
		TM_PRD-Y	6,544	6,625	6,966	7,442	7,958	8,535	8,979	9,468	9,962	10,497	11,064

Figure 22. MACRO outputs

2.3 Budget constraints - DemoS_A003 runs

Description. This step is used to specify various bounds on costs in the TIMES model. In TIMES, the total objective function is calculated from detailed annual payments related to investments, fixed O&M costs and variable costs (including fuel), along with taxes and subsidies on energy carriers and investments.

There two attributes available, described in the next two sections, that are used to set a regional bound by period on costs (REG_BNDCST) and a regional cumulative bound on costs (REG_CUMCST).

Objective. The objective of the following run steps is to show how to use the TIMES attributes in the VEDA templates for specifying bounds on various types of cost components, by region and currency.

More information on the attributes used in the next paragraphs can be found on the TIMES documentation Part II.

2.3.1 Bound specified on regional costs in given milestone years - DemoS_A003

In this step, a bound on regional costs by type of cost aggregation for the investment costs (annuities) has been implemented in a new scenario.

- Scenario template: Scen_Cost_Reg_Bounds
- TIMES attribute: REG_BNDCST(r,y,item,cur,bd) - is a regional bound on costs of type "item" in year "y", specified in currency "cur", with bound type (FX, LO, UP) "bd".
  The cost component "types" that can be bounded are listed in Table 3.

Table 3. List of cost aggregation types available for user-defined constraints

Cost type	Description
INV	Investment costs (annuities)
INVTAX	Investment taxes (annuities)
INVSUB	Investment subsidies (annuities)
INVTAXSUB	Investment taxes and subsidies (annuities)
INVALL	All investment costs, taxes and subsidies (annuities)
FOM	Fixed O&M costs
FOMTAX	Fixed operating taxes
FOMSUB	Fixed operating subsidies
FOMTAXSUB	Fixed operation taxes and subsidies
FOMALL	All fixed operation costs, taxes and subsidies
COMTAX	Commodity taxes
COMSUB	Commodity subsidies
COMTAXSUB	Commodity taxes and subsidies
FLOTAX	Flow Taxes
FLOSUB	Flow Subsidies
FLOTAXSUB	Flow taxes and subsidies
FIX	Total fixed costs (investment+fixed O&M costs)
FIXTAX	Total fixed taxes

FIXSUB	Total fixed subsidies
FIXTAXSUB	Total fixed taxes and subsidies
FIXALL	All fixed costs, taxes and subsidies
ALLTAX	All taxes
ALLSUB	All subsidies
ALLTAXSUB	All taxes and subsidies

All the cost components related to investments are expressed in terms of annualized capital costs, i.e. as annuities paid in the year(s) in question. Note also that in all combined cost aggregations subsidies are treated as negative costs, but when bounded alone they are treated as positive. More information on this constraint can be found on TIMES documentation Part II, page 194.

Figure 23 shows the transformation insert table in the template Scen_Cost_Reg_Bounds used to specify inputs to REG_BNDCST attribute, applied only to REG1, by periods (column Year) with the INV cost component (column Other_Indexes) with bound type upper (UP).

~TFM_INS

LimType	Attribute	Year	Other_Indexes	REG1	REG2
UP	REG_BNDCST	2006	INV	41645	
UP	REG_BNDCST	2010	INV	191027	
UP	REG_BNDCST	2015	INV	394786	
UP	REG_BNDCST	2020	INV	426463	
UP	REG_BNDCST	2025	INV	590044	
UP	REG_BNDCST	2030	INV	607647	
UP	REG_BNDCST	2035	INV	635285	
UP	REG_BNDCST	2040	INV	624129	
UP	REG_BNDCST	2045	INV	641887	
UP	REG_BNDCST	2050	INV	658095	

Figure 23. Transformation insert table for investment cost limits

The cost components for this example has been estimated based upon the results of DemoS_A001e, so the results of DemoS_A003 run are compared with it. In Figure 24 a quick comparison of the investment levels shows lower values for DemoS_A003, with all the investments equal or lower than the bound specified in the scenario.

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

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

Process *Vintage* *UserConstraint* *Commodity*

~Scenario~	-Region-	-Attribute-	2006	2010	2015	2020	2025	2030	2035	2040	2045	2050
DemoS_A001e	REG1	Cost_Inv [Annual investment costs]	41,645	191,117	395,762	433,056	597,556	617,574	650,319	659,423	677,711	693,481
DemoS_A003	REG1	Cost_Inv [Annual investment costs]	41,645	191,117	395,762	424,395	584,254	605,223	624,747	626,452	643,826	658,806

Figure 24. Annual investment expenditures (DemoS_A001e and DemoS_A003)

The comparison of the investment levels by sector in Figure 25 for DemoS_A001e and DemoS_A003 show that the main investment shifts take place in commercial and electricity sectors.

InvestmentCosts by sector

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

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

ProcessSet	~Scenario~	2006	2010	2015	2020	2025	2030	2035	2040	2045	2050
SECCOM	DemoS_A001e	3,096	6,588	10,282	13,967	20,440	19,318	19,015	16,619	17,932	18,332
	DemoS_A003	3,096	6,588	10,282	13,849	26,963	23,653	23,637	24,032	17,486	17,938
SECELC	DemoS_A001e		874	7,621	31,335	57,889	72,612	106,157	114,915	120,996	122,195
	DemoS_A003		874	7,621	26,673	55,985	70,708	99,544	93,749	98,348	99,670
SECRES	DemoS_A001e	8,478	14,556	21,147	27,542	38,715	34,737	35,475	30,789	32,842	32,791
	DemoS_A003	8,478	14,556	21,147	27,518	38,489	34,488	35,226	34,990	30,584	32,078
SECTRA	DemoS_A001e	77,377	378,509	791,475	864,498	1,362,165	1,395,671	1,385,813	1,420,476	1,456,344	1,493,119
	DemoS_A003	77,377	378,509	791,475	864,439	1,334,782	1,368,288	1,385,813	1,420,476	1,456,344	1,493,119

Figure 25. Annual investments by sector (DemoS_A001e and A003)

2.3.2 Bound specified on cumulative regional costs over a year range - DemoS_A003a

In this step, a bound on cumulative regional costs by type of the aggregated investment costs (annuities) is implemented in a new scenario.

- Scenario template: Scen_Cost_Reg_Cum
- TIMES attribute: **REG_CUMCST**(r,y1,y2,item,cur,bd) - is a regional cumulative bound on costs of type "item" during the period from year1 "y1" to year2 "y2" (inclusive), specified in currency "cur", with bound type (FX, LO, UP) "bd". The type "item" of cost components correspond to those in Table 3.

Figure 26 shows the transformation insert table in the template Scen_Cost_Reg_Cum used to specify the REG_CUMCST attribute, applied only to REG1, on cumulative costs over years 2023-2032 (column Year) for the INV cost component (column Other_Indexes) with bound type upper (UP).

~TFM_INS

LimType	Attribute	Year	Other_Indexes	REG1	REG2
UP	REG_CUMCST	2023-2032	INV	5988458	

Figure 26. Transformation insert table for cumulative cost limit

The cost component of this example has been estimated from results of DemoS_A001e so results of DemoS_A003a are compared with it and DemoS_A003. In Figure 27 are the annuities for REG1 (the one for which the constraint has been implemented) and a quick comparison shows lower investments in DemoS_A003, indicating that the cumulative limits level the model to decide when to limit investment. This bound on investment is changing model behavior as can be seen in **Error! Reference source not found.**,where the final energy consumption by sector changes, though the DemoS_A003a run is closer to the unconstrained DemoS_001a.

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

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

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

-Region-	-Attribute-	~Scenario~	2006	2010	2015	2020	2025	2030	2035	2040	2045	2050
REG1	Cost_Inv [Annual investment costs]	DemoS_A001e	41,645	191,117	395,762	433,056	597,556	617,574	650,319	659,423	677,711	693,481
		DemoS_A003	41,645	191,117	395,762	424,395	584,254	605,223	624,747	626,452	643,826	658,806
		DemoS_A003a	41,645	191,117	395,762	431,700	585,913	607,032	640,522	656,426	676,999	693,703

Figure 27. Annual investment expenditures (DemoS_A001e, A003 and A003a)

InvestmentCosts by sector

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

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

ProcessSet	~Scenario~	2006	2010	2015	2020	2025	2030	2035	2040	2045	2050
SECCOM	DemoS_A001e	3,096	6,588	10,282	13,967	20,440	19,318	19,015	16,619	17,932	18,332
	DemoS_A003	3,096	6,588	10,282	13,849	26,963	23,653	23,637	24,032	17,486	17,938
	DemoS_A003a	3,096	6,588	10,282	13,967	21,493	20,371	20,354	20,750	18,602	19,043
SECELC	DemoS_A001e		874	7,621	31,335	57,889	72,612	106,157	114,915	120,996	122,195
	DemoS_A003		874	7,621	26,673	55,985	70,708	99,544	93,749	98,348	99,670
	DemoS_A003a		874	7,621	30,556	57,343	72,066	108,620	112,350	120,992	122,525
SECRES	DemoS_A001e	8,478	14,556	21,147	27,542	38,715	34,737	35,475	30,789	32,842	32,791
	DemoS_A003	8,478	14,556	21,147	27,518	38,489	34,488	35,226	34,990	30,584	32,078
	DemoS_A003a	8,478	14,556	21,147	27,542	31,558	28,682	29,420	30,700	32,342	32,174
SECTRA	DemoS_A001e	77,377	378,509	791,475	864,498	1,362,165	1,395,671	1,385,813	1,420,476	1,456,344	1,493,119
	DemoS_A003	77,377	378,509	791,475	864,439	1,334,782	1,368,288	1,385,813	1,420,476	1,456,344	1,493,119
	DemoS_A003a	77,377	378,509	791,475	864,498	1,366,885	1,400,391	1,385,813	1,420,476	1,456,344	1,493,119

Figure 28. Annual investments by sector (DemoS_A001e, A003 and A003a)

2.3.3 User constraint on total amount of subsidies for a technology - DemoS_A003b

In this step, a user constraint on total amount of subsidies on solar technologies by region and period is implemented in a new scenario

- Scen_Cost_UC-Subs_Reg.

This type of user constraints has been explained in 2.1.4.

This user constraint is used to set up a maximum amount (5%) of subsidies for solar technologies in each period, based upon the total new investments for all power plants in that period. As always the filter columns are used to identify processes involved in this constraints and the UC_ATTR is applied on both LHS and RHS (column side). On the LHS the variable is FLO and the attribute is SUB, while on the RHS the variable is NCAP and attribute INVCOST. The SYNC attribute in column UC_ATTR~RHS is used in dynamic constraints to synchronize the RHS milestone year to be the same as the LHS year. SYNC is applicable only on UC components on RHS. Figure 29 shows the user constraint for the solar subsidies budget as found in the Scen_Cost_UC-Subs_Reg.

~UC_Sets: R_E: AllRegions
~UC_Sets: T_E:

UC_N	Side	UC_ATTR	UC_ATTR~RHS	PSET_SET	PSET_PN	PSET_CI	Cset_CN	~UC_T LimType	UC_NCAP	UC_FLO	UC_RHSRT	UC_RHSRT~0	UC_Desc
UCE_FloSubLim	LHS	FLO,SUB			-ELCRESOL(	ELCSOL	ELC			-1	0	3	Total amount of subsidies on solar technologies
	RHS		NCAP,INVCOST	ELE	-ELC*00				0.05				
	RHS		NCAP,SYNC										

Figure 29. User constraint for total subsidy for a technology

For the DemoS_A003b run Figure 30 shows the total amount of subsidies (Cost_Flox) for solar technologies by period and investments in new capacity by plant type and period, where Figure 31 calculates the percentage of subsidies as ratio of Cost_Flox on Cons_Inv (for all plants). The maximum percentage by period as set up in the user constraint is 5%.

Investments and subsidies for power sector

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

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

~Scenario~	Attribute	ProcessSet	2020	2025	2030	2035	2040	2045	2050
DemoS_A003b	Cost_Flox	Solar/PV power plants	-1,301	-1,301	-2,356	-3,601	-4,018	-4,062	-3,972
	Cost_Inv	Coal Power Plants	4,176	4,176	4,176	4,176	4,176	4,176	3,654
		Gas Power Plants	7,299	12,536	12,536	12,536	12,361	10,026	5,237
		Hydro power plants		498	626	2,161	2,161	3,561	3,561
		Nuclear Power Plants	398	796	1,195	24,106	25,301	26,495	27,690
		Oil Power Plants	2,285	3,801	3,972	4,271	4,271	4,302	5,662
		Solar/PV power plants	2,164	2,164	3,332	3,496	3,784	3,479	2,729
		Wind Power Plants	9,704	17,294	21,276	21,276	28,305	29,196	30,913

Figure 30. Flow subsidies for solar and investments for all plants (DemoS_A003b)

Scenario	Attribute	ProcessSetDesc\Period	2020	2025	2030	2035	2040	2045	2050
DemoS_A003b	Cost_Flox	Solar/PV power plants	-1301	-1301	-2356	-3601	-4018	-4062	-3972
DemoS_A003b	Cost_INV	Total	26026	41265	47112	72021	80359	81236	79444
	%	Solar/PV power plants/Total	5%	3%	5%	5%	5%	5%	5%

Figure 31. Percentage calculation for solar subsidies

2.4 Endogenous Technology Learning (ETL) - DemoS_A004 runs

Description. This step shows how to employ the Endogenous Technological Learning (ETL) feature for a solar technology.

Objective. The objective of the following run steps is to show how use the TIMES ETL extension by introducing the needed attributes in VEDA templates and setting the necessary Case Manager switches.

More information on the ETL extension and mathematical implementation on TIMES documentation part II, chapter 11.

2.4.1 Endogenous technology learning (ETL) set up - DemoS_A004

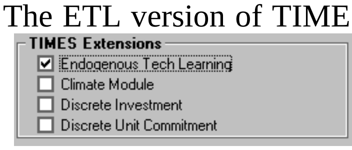
The ETL formulation describes how the unit investment cost changes over time as a function of cumulative investment in a technology. Since the cost of the a technology is determined during the optimization it is considered endogenous.

Mixed Integer Programming (MIP) is employed in order to model ETL in TIMES. MIP problems are much more difficult to solve than standard LP problems, and so the ETL feature should be applied only where it is deemed necessary to model a limited number of technologies as candidates for endogenous learning. This caution is especially required for larger TIMES models.

The ETL parameters are shown and briefly described in Table 4.

Table 4. ETL parameters

Parameter	Unit	Description
CCAP0	Units of capacity	The initial cumulative capacity (starting point on the learning curve) for a (non-resource) technology that is modeled as one for which endogenous technology learning (ETL) applies. Learning only begins once this level of installed capacity is realized.
CCAPM	Units of capacity	The maximum cumulative capacity (ending point on the learning curve) for a (non-resource) technology that is modeled as one for which endogenous technology learning (ETL) applies.
SC0	Base year monetary units per unit of capacity	The investment cost corresponding to the starting point on the learning curve for a technology that is modeled as one for which endogenous technology learning (ETL) applies.
SEG	Number of steps	The number of segments to be used in approximating the learning curve for a technology that is modeled as one for which endogenous technology learning (ETL) applies.
PRAT	Fraction	The "progress ratio" for a technology that is modeled as one for which endogenous technology learning (ETL) applies. The progress ratio, which is referred to as the learning rate, is defined as the ratio of the change in unit investment cost each time cumulative investment in an ETL **technology doubles**. That is, if the initial unit investment cost is SC0 and the progress ratio is PRAT, then after cumulative investment is doubled the unit investment cost will be PRAT * SC0.

The ETL version of TIMES is enabled through a switch available in the VFE Control Panel 

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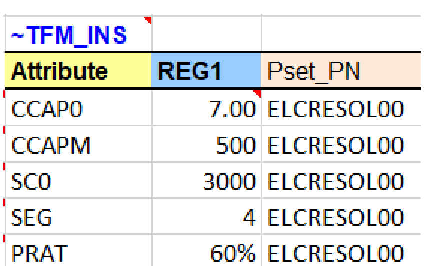
The ETL is implemented in a new scenario.

- Scen_ETL_Solar_Prat-40

The Scen_ETL_Solar_Prat-40, shown in Figure 32, uses a transformation insert table to specify the input values needed for ETL. In this example the CCAP0 value is based on the existing capacity for the ELCRESOL00 specified in the model.



~TFM_INS		
Attribute	REG1	Pset_PN
CCAP0	7.00	ELCRESOL00
CCAPM	500	ELCRESOL00
SC0	3000	ELCRESOL00
SEG	4	ELCRESOL00
PRAT	60%	ELCRESOL00

Figure 32. ETL parameters for solar power plant

The table shown in Figure 33 is not strictly related to the implementation of ETL but to the actual RES of the advanced DemoS in which we have existing and new solar technology. Since the ETL is set to operate on the capacity of the existing solar technologies no new technologies should be includes. The easiest way to accomplish this is to change the START year for ELCRNSOL01 to 2100, so this technology will not be available during the time horizon of this analysis. The NCAP_BND interpolation rule number 2 (included by default in VEDA) on the ELCRESOL00 is changed to 0, so that additional capacity can be added to this existing technology base (which is usually prevented by convention in VEDA).

~TFM_INS			
Attribute	**Year**	**REG1**	Pset_PN
START		2100	ELCRNSOL01
NCAP_BND	0	0	ELCRESOL00

Figure 33. Additional information to ready solar power plant for ETL

2.4.2 Endogenous technology learning sensitivity runs - DemoS_A004a to DemoS_A004c

The following scenarios are used to compare results for different technology learning rates (ratio of the change in unit investment cost each time cumulative investment in an ETL technology doubles) for ELCRESOL00:

- Scen_ETL_Solar_Prat-40 used for run DemoS_A004, learning at 40%;
- Scen_ETL_Solar_Prat-35 used for run DemoS_A004a, learning at 35%;
- Scen_ETL_Solar_Prat-30 used for run DemoS_A004b, learning at 30%, and
- Scen_ETL_Solar_Prat-25 used for run DemoS_A004c, learning at 25%.

Figure 34 shows the different investment profiles for solar plants based on the value of the learning rate. As can be seen, depending upon the learning rate the model accelerates investment in new capacity to promote the corresponding cost reduction of the solar technology.

ETL-Results_SolarPlants

Original Units: GW Active Unit GW Data values

Attribute Process Region

~Scenario~	Period 2015	2020	2025	2030	2035	2040
DemoS_A004	160	62	253	17		
DemoS_A004a		188	224		80	
DemoS_A004b			326			167

Figure 34. Install new capacity of solar power plants (DemoS_A004 runs)

2.5 Storage technologies - DemoS_A005 runs

Description. This step show how to use storage technologies in a TIMES model.

Objective. The objective of the following run steps is to show how implement a storage technology in the VEDA templates and check results in VEDA-BE.

Storage processes are used to store a commodity either between periods or between timeslices. The possible type of storage processes are the following:

- General timeslice storage (TSS) - TSS processes are used to set storages between different timeslices of a period (can be set either at Seasonal/Weekly/DayNite level) or both timeslices and periods;
- Inter-period storage (IPS) - IPS processes are used to model commodity storages between different model periods (operates at ANNUAL level), and
- Night-storage device (NST)[4] - NST processes works similarly to TSS with the difference that the charging timeslice is set exogenously by the user, where more than one timeslice can be specified as charging timeslices, the non-specified timeslices are assumed to be discharging timeslices.

Note that for storage processes, the capacity describes the volume of the storage and the activity the storage content, such that:

- Activity = amount of the commodity being stored that can be kept in storage process, and
- Capacity = maximum commodity amount that can be kept in storage.

Storage processes can be modelled setting the capacity either to represent:

- the amount of storable energy, or
- the maximum output or input flow (e.g. output turbine capacity).

The activity of a storage process is however interpreted as the amount of the commodity being stored in the storage process, while the capacity of a storage process can describe the maximum commodity amount that can be kept in storage (Figure 35) or the maximum input or output flow. To control this the attribute NCAP_AFC is used such that:

- NCAP_AFC(o) = 1 for the output commodity, this means that the output flow is the basis for capacity;
- NCAP_AFC(i) = 1 for the input, the input flow is the basis for capacity, or
- the basis is the amount stored.

[4] An example of how to implement in VFE an electrical night storage car is available on VEDAsupport web site http://support.kanors-emr.org/ in the section VEDA-FE/Model library/Night Storage devices.

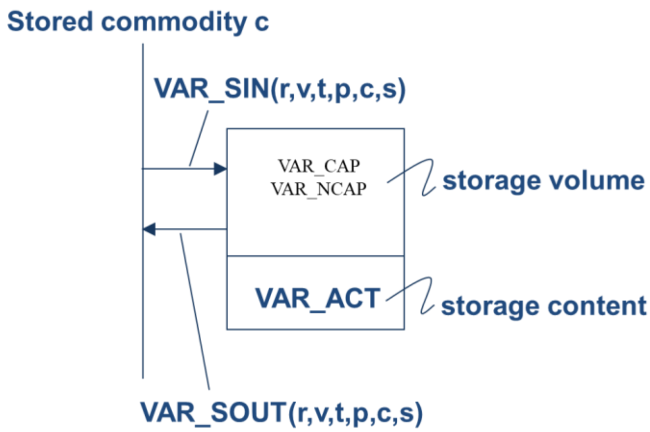


Figure 35. Capacity and activity in a storage process

The storage attributes includes:

- STG_EFF: storage efficiency in charging/discharging operation;
- STG_CHRG: annual exogenous charging of a storage technology in a timeslice s (the initial stock can be specified by using this attribute);
- STG_LOSS: annual energy loss per unit of average energy stored;
- STGIN_BND/STGOUT_BND: Bound on the input/output flow in a timeslice s;
- Auxiliary input or output commodities, as long as they are distinct from the main storage commodity;
- Costs for charging/discharging a storage processes, by:
  - FLO_COST, which is applied to input flows (charge) and
  - FLO_DELIV, which is applied to output flows (discharge), and
- PRC_NSTTS: only used for NST storage processes to set the charging timeslices, where all timeslices not included are assumed to be discharging timeslices.

More information on storage processes and equations on TIMES documentation Part I section 2.4.2.2 and Part II paragraph 4.3.

Storage processes in VEDA-FE can be declared as usual in a ~FI_PROCESS table following these steps.

- Specifying the sets in the column ‘Sets’ according to the following list:
  - STG: for general timeslice storage;
  - STS: for simultaneous DayNite/Weekly/Seasonal operation;
  - STK: for simultaneous DayNite/Weekly/Seasonal and inter-period operation;
  - IPS: for inter-period storage, or
  - NST: for night storage device (see section 2.5.2).
- Defining the operational level in the column ‘Tslvl’ according to the available options for the chosen storage process.

- Defining the primary commodity group in the column ‘PrimaryCG’ when the input and output commodity have different names.

2.5.1 Hydro pump storage technologies - DemoS_A005

In this example two hydro pump storage technologies (STG and STS) are implemented in a SubRes.

- SubRes_Storage-HydPum.

		~FI_T							
TechName	Comm-IN	Comm-OUT	START	LIFE	STG_EFF	NCAP_AFC	INVCOST~2015	FIXOM~2015	CAP2ACT
*Technology Name	Input Commodity	Output Commodity		Years	%		€/kW	€/kW	
ELCSTGELC01	ELC	ELC	2010	80	90%	0.33	1500	3.0	31.54
ELCSTSELC01	ELC	ELC	2010	80	90%	0.33	1500	3.0	31.54

~FI_Process							
Sets	TechName	TechDesc	Tact	Tcap	Tslvl	PrimaryCG	Vintage
*Process Set Membership	Technology Name	Technology Description	Activity Unit	Capacity Unit	TimeSlice Level of oprn	Primary CommGrp	Vintage Tracking
ELE,STG	ELCSTGELC01	Pumped Hydro ELC Storage: DayNite	PJ	GW	DAYNITE		
ELE,STS	ELCSTSELC01	Pumped Hydro ELC Storage: DayNite/Seasonal	PJ	GW	DAYNITE		

Figure 36. Hydro pump storage in a SubRes file

The two storage technologies are represented with the same information, including the NCAP_AFC for the output commodity, this means that the output flow is the basis for capacity, like in any standard power plant. The technology ELCSTGELC01 operates at the daynite level in the same seasonal TS, while the ELCSTSELC01 can operate at the daynite/seasonal level simultaneously.

In this example input and output of the process are in ‘PJ’ while the capacity is in ‘GW’ due to the use of NCAP_AFC (that also reflect and CAP2ACT attributes). For example, a capacity of 1 GW is assumed to represent a storage capacity of 24 GWh for a DAYNITE storage, and if the real daily storage capacity is, say 8 GWh / GW, the maximum availability factor should be 0.333 as in this example.

Figure 37 show some results for REG2 of the DemoS_A005 with the new SubRes_Storage-HydPum. In this run both types of storage technologies are used.

Storage-HydroPump

Original Units: Active Unit Data values filter:

Commodity *Vintage* *TimeSlice* ~Scenario~ ProcessSet

Region	Process	Attribute	2015	2020	2025	2030	2035	2040	2045	2050
REG2	ELCSTGELC01	VAR_Cap		3.7	20.6	21.9	21.9	21.9	21.9	21.9
		VAR_FIn		42.6	237.7	252.8	252.8	252.8	252.8	252.8
		VAR_FOut		38.4	214.0	227.5	227.5	227.5	227.5	227.5
	ELCSTSELC01	VAR_Cap	3.3	15.4	15.4	15.4	17.0	17.1	19.7	22.1
		VAR_FIn	37.8	177.6	177.6	177.6	196.1	197.5	227.8	255.2
		VAR_FOut	34.0	159.8	159.8	159.8	176.5	177.7	205.1	229.7

Figure 37. Hydro pump storage capacity and flows (DemoS_A005)

Figure 38 shows the different way the STG and STS technologies operate by timeslice in a single period. For the STG process the charging/discharging operation occurs in each season, charging 45 PJ (VAR_FIN) in the timeslice SN and discharging 40.5 PJ (VAR_FOUT) in SP, due to a storage efficiency (STG_EFF) of 90%, then charging again in WD and WN to discharge in WP. The STS process can charge and discharge simulctaneously at daynite/seasonal level so in SD and SN is charging a total of 66.1 PJ and discharging 57.8 PJ, and in SP with a residual stored commodity (1.7 PJ) then discharged in the timeslice FP.

Storage-HydroPump

Original Units: Active Unit Data values filter:

Commodity *Vintage* ~Scenario~ ProcessSet

-Period- TimeSlice

2050

-Region-	Process	-Attribute-	FP	SD	SN	SP	WD	WN	WP
REG2	ELCSTGELC01	VAR_FIn			45.0		86.3	121.4	
		VAR_FOut				40.5			187.0
	ELCSTSELC01	VAR_FIn		0.9	65.2		189.1		
		VAR_FOut	1.7			57.8			170.2

Figure 38. Hydro pump storage activity by timeslice in 2050 (DemoS_A005)

2.5.2 Storage electric car - DemoS_A005a

In this example astorage (STG) electric car is implemented in the model using the following SubRes.

- SubRes_Storage-STG_Car.

In this Subres the electric storage car is consuming TRABAT. The battery (Battery-TRA_STG) is modelled separately from the car itself and it is a STG general timeslice storage process. Figure 39 show how the battery storage technology is described in the VFE template, while in Figure 40 it is described the electricity car using in input the TRABAT produced from the battery storage technology.

Battery storage

~FI_T

TechName	Comm-IN	Comm-OUT	START	STG_EFF	INVCOST	FIXOM	LIFE	PRC_CAPACT
*Technology Name	Input Commodity	Output Commodity		Efficiency	Investment Cost	Fixed O&M Cost	Remaining Lifetime	
*Units				MVkm/PJ	M€/PJ	M€/Pja	Years	
Battery-TRA_STG	TRAELC	TRABAT	2010	0.95			10	0.0036

~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
STG		Battery-TRA_STG	Car electric battery	PJ	GWh	DAYNITE	NRG	

~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		TRABAT	Battery output for EV	PJ		DAYNITE		

Figure 39. Battery storage for electric car

Electric car

~FI_T

TechName	Comm-IN	Comm-OUT	START	EFF	AF	ACTFLO	INVCOST	INVCOST~2020	INVCOST~2030	INVCOST~2050	FIXOM	LIFE	PRC_CAPACT
*Technology Name	Input Commodity	Output Commodity		Efficiency	Availability Factor	Activity to Flo	Investment Cost	Investment Cost 2020	Investment Cost 2030	Investment Cost 2050	Fixed O&M Cost	Remaining Lifetime	
*Units						Passenger/Car	M€/000_Units	M€/000_Units	M€/000_Units	M€/000_Units	M€/000_Units/a	Years	
TCARSTGNELC	TRABAT	DTCAR	2010	1.25	12	1.25	25.0	20.0	17.5	15.0	0.25	10	0.001

~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		TCARSTGNELC	Demand Technologies Transport Sector - Cars - Electricity technology	BPkm	000_Units	DAYNITE		

Figure 40. Electric car using the battery storage output

The DemoS_A005a run also includes a scenario file called Scen_STG-Cars for changing the start of the electric cars in the NewTechs subres to 2100 and adding a maximum bound on the TRACO2 commodity. This is not related to the storage technology but to make some more interesting results for this specific example. As shown in Figure 41, for example for the year 2045 in region REG1, some of the fleet is charging and some is discharging at daynite level.

Storage electric battery

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

Process | *Vintage* | Scenario

Region	Period	Attribute	Commodity	FD	FN	FP	RD	RN	RP	SD	SN	SP	WD	WN	WP
REG1	2045	VAR_FIn	TRAELC	167	198		159	188		214	253		233	276	
		VAR_FOut	TRABAT	159	174	14	151	165	14	203	222	18	221	242	20
	2050	VAR_FIn	TRAELC	339	401		434	269		434	513		520	511	
		VAR_FOut	TRABAT	323	352	29	306	334	28	412	450	37	449	490	41
REG2	2045	VAR_FIn	TRAELC	335	396		318	376			935		467	552	
		VAR_FOut	TRABAT	318	347	29	302	330	27	407	444	37	443	484	40
	2050	VAR_FIn	TRAELC	550	600	50	522	617		703	831		766	905	
		VAR_FOut	TRABAT	522	570	47	496	541	45	668	729	61	727	793	66

Figure 41. Storage battery for electric car charging/discharging (DemoS_A005a)

2.6 Stochastic - DemoS_A006 runs

Description. This step shows how to use the TIMES stochastic extension, comparing several cases.

Objective. The objective of the following run steps is to show how use the TIMES stochastic extension, by specifying the needed attributes in VEDA templates, conducting the run, and setting up VEDA-BE for stochastic runs.

Stochastic Programming is a method for making optimal decisions under uncertainty. The uncertainty consists of risks regarding the values of some key technology characterization (e.g., future investment cost or performance) or policy (e.g., level of CO_2 mitigation achieved) assumptions. Each uncertain parameter is considered to be a unknown variable, with a probabilities associated with states-of-the-world (SoW).

Uncertainty on a given parameter is said to be know, either fully or partially, at the time of resolution, i.e. the time at which the actual value of the parameter is revealed. Different parameters may have different times of resolution, resulting in multi-stage stochastics. Both the resolution times and the probability distributions of the parameters may be represented on an event tree, depicting a possible energy/environmental situation to arise in the future, for example as shown in Figure 42.

In the stochastic extension the uncertain attributes are similar to the corresponding standard TIMES attributes, but they can be defined over a discrete set of SOWs, which are then all consider simultaneously during a single optimization. In stochastic programming the SOWs correspond to the branches of the event tree. In Figure 42, two parameters are uncertain: mitigation level, and demand growth rate. The first may have only two values (High and Low), and becomes known in 2005. The second also has two values (High and Low) and becomes known in 2010. The probabilities of the outcomes are shown along the branches. This example is said to have three stages (the hedging phase will 2005 and two resolution times branch), resulting in four sets of model results, one for each of the possible futures.

The key observation is that prior to resolution time, the decision maker (and hence the model) does not know the eventual values of the random parameters, but still has to take decisions. On the contrary, after resolution, the decision maker knows with certainty the outcome of some event(s) and his decisions will be different depending of which outcome has occurred. Thus the hedging phase weighs to possible future events (according to their probabilities) to inform the decision-maker of that choice are robust consider the uncertain future. The choice made during that phase will very likely be different than those made when the model takes each of the uncertain future paths as a given, and thus the benefits of using stochastics!

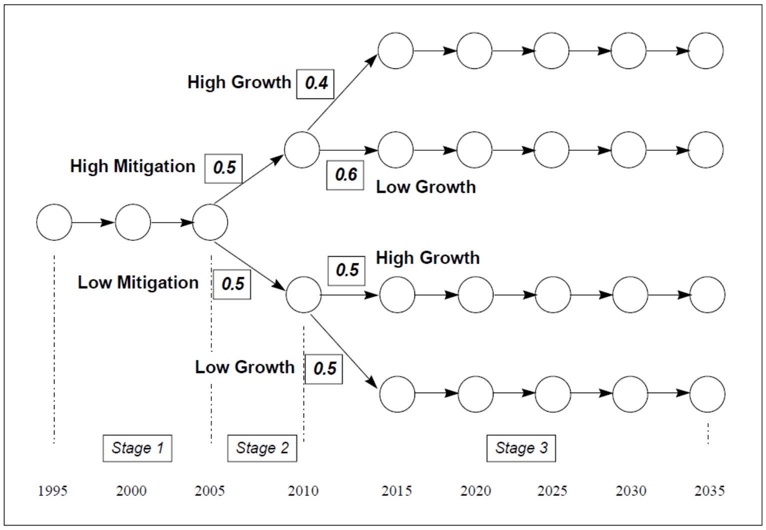


Figure 42. Event tree for a three-stage stochastic TIMES example

In TIMES the control parameters for stochastic have a prefix 'SW_'. Table 5 shows the list stochastic control parameters, while in Table 6 Uncertain input parameters for stochastic TIMES the list of input parameters that can take on an uncertain state are listed.

Table 5. Stochastic parameters

Parameter	Description
SW_START (j)	The year corresponding to the resolution of uncertainty at each stage, and thus the last year of the hedging phase and the point from which the event tree fans out for each of the SOW. It is used to indicate when each of the stochastic stages begins.
SW_SUBS (j,w)	The number of sub-states (branches) of the world for each SOW at stage j.
SW_SPROB (j,w)	The conditional probability of each sub-state at stage j. These conditional probabilities can be overridden by SW_PROB
SW_PROB (w)	The total probability of each SOW at the stage. If specified, overrides the stage-specific conditional probabilities.
SW_LAMBDA	Risk aversion coefficient. If not specified, the objective function represents the expected total discounted system costs without risk aversion.

Table 6 Uncertain input parameters for stochastic TIMES

Parameter	Description
S_CAP_BND	Bound on total installed capacity (Absolute)
S_CM_CONST	Uncertain Climate Sensitivity - Stochastic
S_CM_MAXC	Maximum level of Climate variable (upper bound) - Stochastic
S_CM_MAXCO2C	Bound on maximum CO2 concentration (Absolute)
S_COM_CUMNET	Cumulative bound on commodity net production (Absolute)
S_COM_CUMPRD	Cumulative bound on commodity production (Absolute)
S_COM_FR	Non-default fraction of demand for season, time of day (Stoc)
S_COM_PROJ	Demand projection (Relative)
S_DAM_COST	Stochastic: Marginal damage cost of emission c at reference emission level
S_FLO_CUM	Bound on cumulative process FLO/ACT (uncertain)
S_FLO_FUNC	Multiplier for process transformation coefficient
S_NCAP_AFS	Seasonal availability/utilization factor (Stochastic)
S_NCAP_COST	Multiplier for process investment cost
S_UC_RHSxxx	Stochastic: UC-RHS constant of user constraints

More information on the stochastic extension and mathematical implementation on TIMES documentation Part I, Chapter 8.

2.6.1 Stochastic TIMES extension set up - DemoS_A006 and DemoS_A006a

This step shows how to set up a stochastic run with VEDA and how to set up the VEDA-BE database for results analysis. In this step a stochastic run and standard (DemoS_A006a) run are compared. The new scenario files included in the model are:

- Scen_UC_CO2_Regs_VS_Stoch - is used to set up an over region user constraint starting in 2030 on TOTCO2 to compare results with and without stochastic extension.
- Scen_UC_CO2_Regs_Stoch-90_SW1 (Figure 43) - is used to implement the structure and data needed by stochastic extension.

The scenario files include both an insert and UC table, the first specifies the stochastic parameters 'SW', while the second gives the S_UC_RHSTS input parameter with the uncertainty values. In the insert table the STAGE and SOW (state-of-the-world) columns identify number of stages (2) and start of the 2nd stage (2030) along with the SOW1 stage having a 90% probability and SOW2 10% probability (as depicted in Figure 44).

~TFM_INS

Attribute	STAGE	SOW	AllRegions
\I:	Stage	State of World	
SW_START	2		2030
SW_SUBS	1	1	2
SW_PROB		1	0.9
SW_PROB		2	0.1

~UC_Sets: R_S: AllRegions
~UC_Sets: T_E:

~UC_T

UC_N	Cset_CN	STAGE	SOW	Year	LimType	UC_COMNET	S_UC_RHSTS	S_UC_RHSTS~0	UC_Desc
AU_CO2BND_AllReg_Stoc	TOTCO2	2	1	2030	UP	1	3765944	5	CO2 upper bound on the toal emissions of All Regions - Stochastic
	TOTCO2	2	1	2050	UP	1	2764994		

Figure 43. Specification of 2-stage stochastic problem limiting CO2 emissions (Scen_UC_CO2_Regs_Stoch-90_SW1)

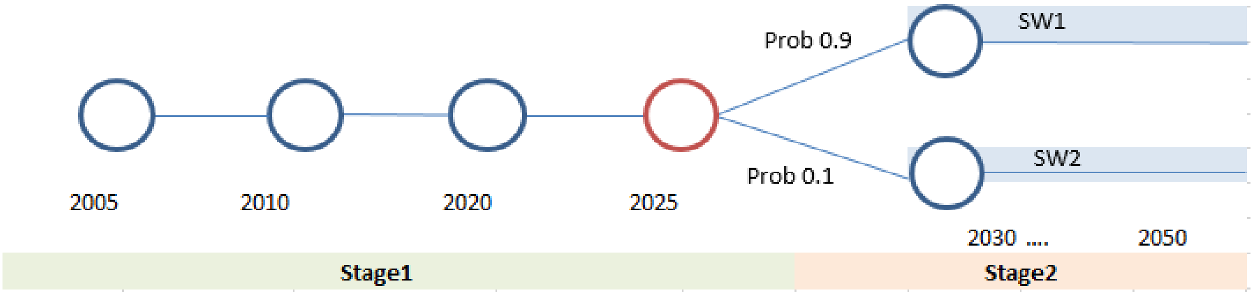


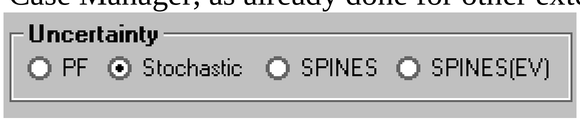
Figure 44. Event tree for 2-stage stochastic problem

The user constraint AU_CO2BND_AllReg_Stoc indicates the uncertain input from 2030, with 90% probabilities that this target will be applied and 10% probabilities that no target will be applied (since no limit values provided for SOW1).

The only difference with the equivalent user constraint built for the standard LP problem are the columns:

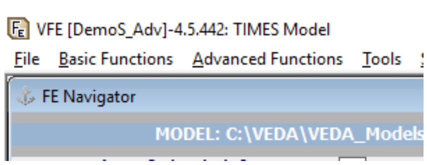
- STAGE, to indicate at which stage there is the uncertainty, so in this example stage 2;
- SOW, to provide the probability for each SOW; so in this example for SW1 there is a 90% probability, and
- S_UC_RHSTS, stochastic form to input the absolute value of the constraint.

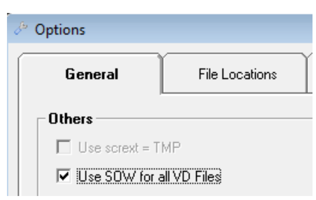
The implementation of a stochastic run also require a TIMES switch that can be enable from VEDA-FE Case Manager, as already done for other extensions.



For the stochastic run results it is required to build a new VEDA-BE database (see TIMES documentation Part V) based on the structure of a stochastic run, to include the new dimension SOW, not available in the standard database.

This VEDA-FE switch, found on the Tools/Options form, is needed for importing results into a VEDA-BE stochastic database.

- 



2.6.2 Stochastic TIMES extension sensitivity runs - DemoS_A006b to DemoS_A006i

This step focuses on sensitivity runs that decrease the probability of SW1 from 90% to 10% in steps of 10% for each scenario. The new scenarios and Scen_UC_CO2_Regs_Stoch-%%_SW1, with %% ranging from 80 down to 10.

The run DemoS_A006a is the standard run without stochastic extensions, for all the other runs there are results for two SOWs, representing the two branches with and without applying the user constraints based on the probabilities defined in each scenario.

Objective Function Value

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

Attribute | Commodity | *UserConstraint* | *Region*

~Scenario~ \ Sow	1	2
Demo Step A006 over regs CO2 bound stoch 90%SW1	25,281,312	24,885,480
Demo Step A006a over regs CO2 bound PF VS stochastic	25,281,082	
Demo Step A006b over regs CO2 bound stoch 80%SW1	25,281,664	24,883,280
Demo Step A006c over regs CO2 bound stoch 70%SW1	25,282,010	24,882,236
Demo Step A006d over regs CO2 bound stoch 60%SW1	25,282,138	24,882,011
Demo Step A006e over regs CO2 bound stoch 50%SW1	25,287,944	24,875,753
Demo Step A006f over regs CO2 bound stoch 40%SW1	25,289,637	24,874,274
Demo Step A006g over regs CO2 bound stoch 30%SW1	25,290,251	24,873,872
Demo Step A006h over regs CO2 bound stoch 20%SW1	25,292,179	24,873,203
Demo Step A006i over regs CO2 bound stoch 10%SW1	25,297,884	24,872,244

Figure 45. Objective function from stochastic runs (DemoS_A006 to DemoS_A006i)

As said above, the key observation is that prior to the resolution of uncertainty (in 2030 here), the decision maker (and hence the model) does not know the eventual values of the random parameters, but still has to take decisions. So the main focus in stochastic outputs is the system behaviour prior to that time. On the contrary, after resolution, the decision maker knows with certainty the outcome of some event(s) and his decisions will be different depending of which outcome has occurred. In Figure 46 there is an example of results for wind power plants production in the periods 2020 and 2030 across the different scenarios, where we see that less wind is deployed as the likelihood of having a emission limit imposed is reduced.

ELC Plants Production

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

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

-Period- / Sow		2005		2010		2020		2025		2030		2035		2040		2045		2050	
-ProcessSet-	~Scenario~	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Wind Power Plants	DemoS_A006	209	209	157	157	104	104	203	203	613	267	807	376	1,030	619	1,303	1,303	1,577	1,577
	DemoS_A006a	209		157		120		220		613		806		1,029		1,303		1,577	
	DemoS_A006b	209	209	157	157	100	100	198	198	613	261	807	375	1,030	618	1,303	1,303	1,577	1,577
	DemoS_A006c	209	209	157	157	100	100	196	196	613	259	807	373	1,030	616	1,303	1,303	1,577	1,577
	DemoS_A006d	209	209	157	157	100	100	209	209	613	272	806	386	1,028	629	1,303	1,303	1,577	1,577
	DemoS_A006e	209	209	157	157	100	100	191	191	613	253	808	370	1,031	612	1,303	1,303	1,577	1,577
	DemoS_A006f	209	209	157	157	100	100	191	191	613	247	808	367	1,031	609	1,303	1,301	1,577	1,577
	DemoS_A006g	209	209	157	157	100	100	191	191	613	240	808	367	1,031	609	1,303	1,301	1,577	1,577
	DemoS_A006h	209	209	157	157	100	100	190	190	613	238	808	367	1,031	609	1,303	1,302	1,577	1,577
	DemoS_A006i	209	209	157	157	100	100	190	190	613	238	808	367	1,031	609	1,303	1,302	1,577	1,577

Figure 46. Wind generation for various stochastic runs (DemoS_A006 to DemoS_A006i)