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VLEEM 2

EC/DG Research
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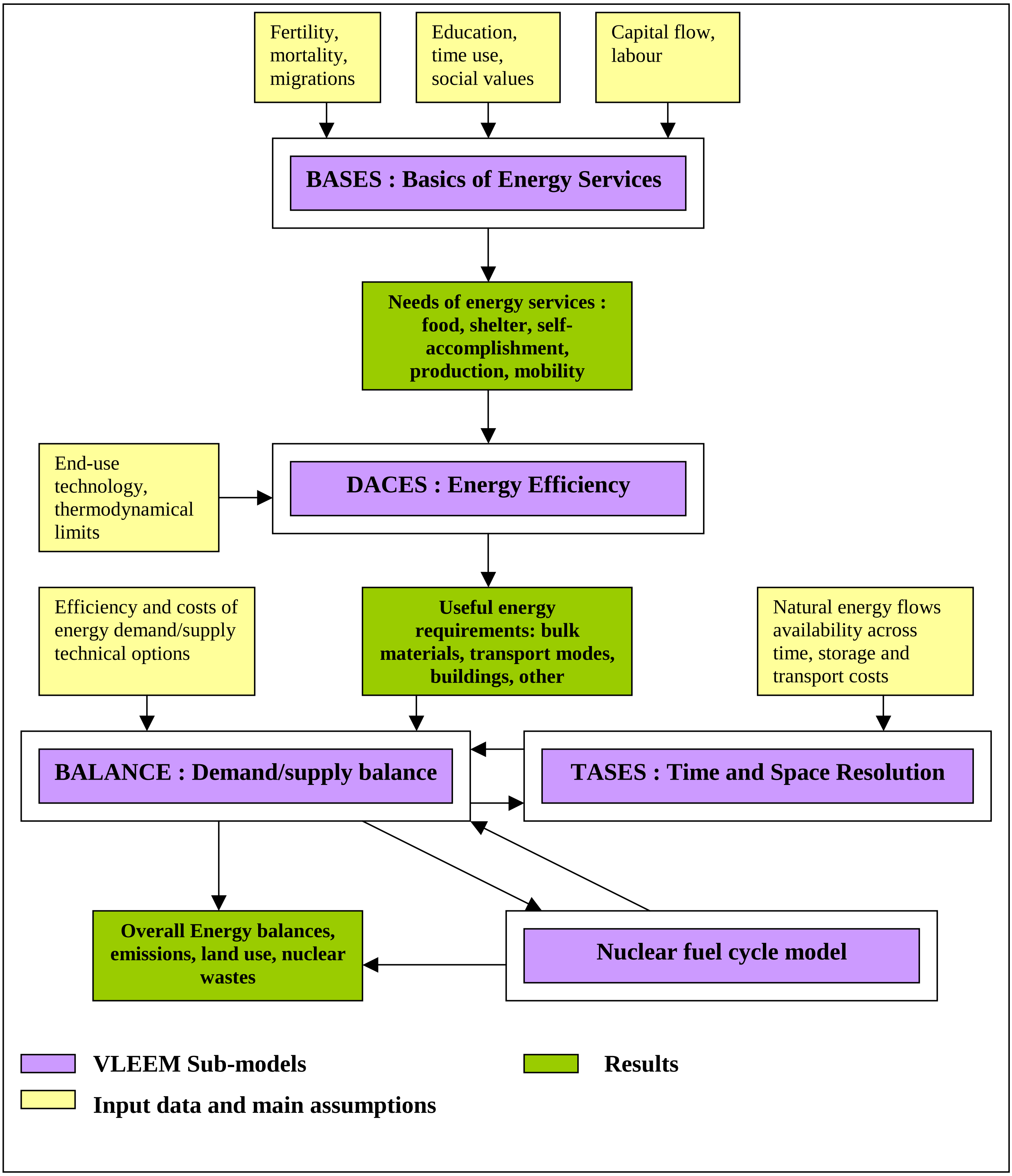
FINAL REPORT

ANNEX 4:
Summary description of the sub-models of VLEEM

Annex 4 : Summary description of the sub-models of VLEEM

VLEEM – Very Long Term Energy Environment Modelling – has been conceived as a model skeleton, made of several pieces which communicate, each piece being adapted to investigate a specific issue in a robust way for such a long range as 100 years.

The overall structure is as follows:



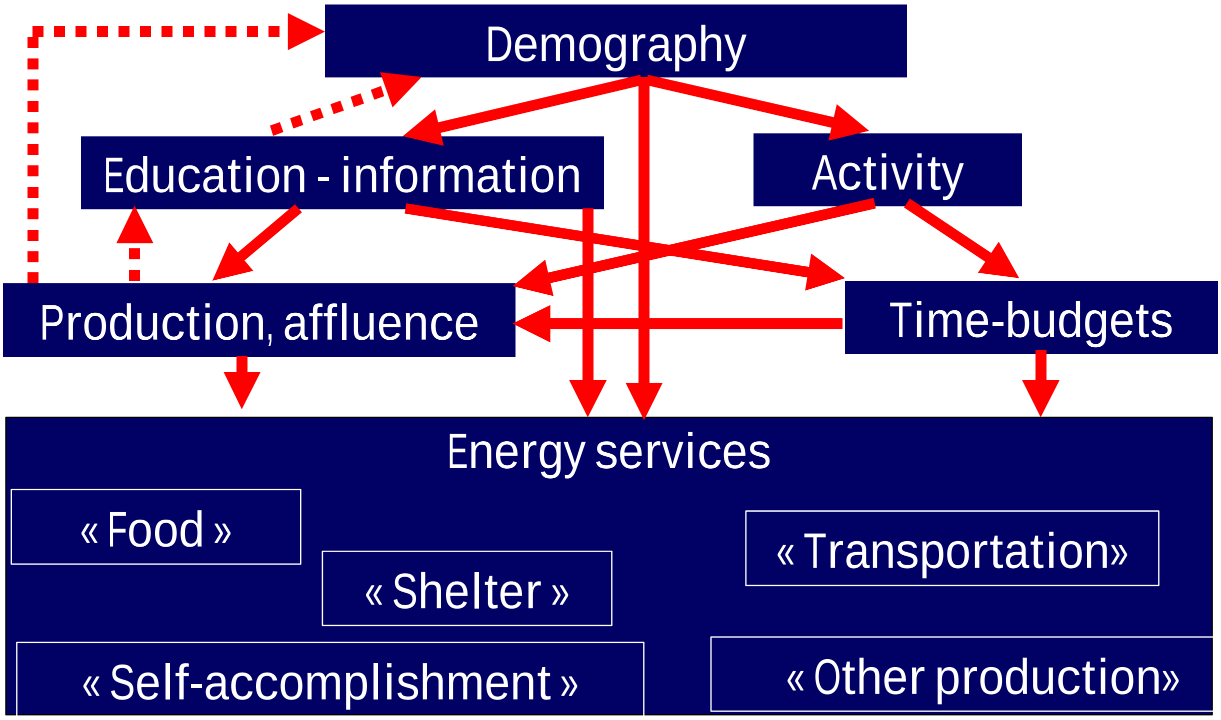
Appendix 1.A: The BASES Model

1. Introduction

The BASES Model is used to project the needs of energy services up to 2100. The model is in principle a rather simple simulation model which can provide pictures of the world every 25 years. The ergonomy is simple, based on interrelated excel sheets.

An overview of the model architecture is described in figure 1.

Figure 1: The structure of the BASES sub-model



2. Functionalities

The detailed functionalities of BASES are described in the final report of VLEEM1, annex 1, in www.VLEEM.org

3. Model equations

The model equations are written as Excel codes, for all active cells.
There are 10 Excel files of the model, corresponding to the 10 world regions, all being connected to a World aggregate Excel file.

Each Excel File is organised as follows:

VLEEM - BASES sub-model

1) Demography: population by age class, household type; households by type, age of head

- sheet "urban", "rural" : assumptions on fertility, life expectancy, maximum rural population
- sheet "migrants sub-urban" : assumptions on immigration from outside the region
- sheet "demo" : aggregation of results of urban, rural and migrants sub-urban

2) Information: calculation of the overall information level index

- sheet "information": assumptions on school-education enrolment, information content of education levels

3) Activity: calculation of the maximum (paid) activity level of the population

- sheet "activity": assumptions on retirement age and maximum activity rates per adult before retirement

4) Time budgets: calculation of the average daily hours allocated to basic functions per person

- sheet "time budgets": assumptions on % of yearly household time budget allocated to food, shelter; assumptions on conventional labour hours per year

5) Food: calculation of energy services for food function and related useful energy

- sheet "food-urb", "food-suburb" : assumptions on elasticities for the need for energy services and for useful energy per energy service
- sheet "food-rur" : assumptions on elasticities for the need for energy services and for useful energy per energy service; on agriculture production and organisation

6) Self-accomplishment: calculation of energy services for the function and related useful energy

- sheet "SA-urb", "SA-rur" , "SA-suburb" : assumptions on elasticities for the need for energy services and for useful energy per energy service

7) Shelter: calculation of energy services for shelter function and related useful energy

- sheet "shelter-urb": assumptions on elasticities for the need for energy services and for useful energy per energy service; on dwelling production, equipment and maintenance
- sheet "shelter-rur" , "shelter-suburb" : assumptions on elasticities for the need for energy services and for useful energy per energy service

8) Transport: calculation of energy services for transportation and related useful energy

- sheet "transport": assumptions on elasticities for the need for transport services and energy services, for speed and for useful energy per transport/energy service; on transport infrastructure production and maintenance

9) Production and macro-economics: calculation of macro-economic agregates, and of energy services for transportation and related useful energy

- sheet "production" : assumptions on elasticities for useful energy and organic products for the overall production

10) Matrices: useful energy related to energy services per exergy level, density and unit power

- sheet "matrices" : compilation of energy results presented as matrices of useful energy

The BASES sub-model has been partly written in C++, but this software development has rapidly appeared not compatible with the necessary flexibility of the calculation tool for the purposes of the project (see above architecture).

4. Data input and processing

There are basically three format for data input and processing in the excel files.

The first main format below is used for data input and processing necessary to draw trajectories across time, in particular in relation to demographic dimensions.

Figure 3: Example of Excel format to input and process data related to time.

Enrolment in tertiary education

	T	T+25	T+50	T+75	T+100
Born >T+75					**70%**
Born >T+50				**70%**	**70%**
Born >T+25			**70%**	**70%**	**70%**
Born >T	0	**60%**	**60%**	**60%**	**60%**
Born <T	50%	**50%**	**50%**	**50%**	**50%**
Born <T-25	25%	**25%**	**25%**	**25%**	**25%**
Born <T-50	10%	**10%**	**10%**	**10%**	**10%**
Born <T-75	5%	**5%**	**5%**	**5%**	**5%**

The second main format is used for base year data input and processing, relating needs of energy services to final energy demand.

Figure 3: Example of Excel format to input and process data relating needs of energy services to final energy demand at base year.

	Overall energy services base year			
	Food conservation	**Food preparation**	**Cooking**	**Water, washing**
Units for energy services	Mm3	Mtons	Mtons	Mm3
Quantities base year	**43**	**158**	**158**	**404**
Useful energy (PJ)	**388**	**4**	**484**	**101**

	Energy services per '000 hours, base year			
	Food conservation	**Food preparation**	**Cooking**	**Water, washing**
Units for energy services	m3	tonnes	tonnes	m3 eau
Million hours/day	**1315**	**1315**	**1315**	**1315**
Energy services (ES) /1000h	**32,86**	**119,9**	**119,9**	**307**
Useful energy (MJ/ES)	**8,99**	**0,03**	**3,07**	**0,25**
Useful energy (PJ)	**659,87**	**15,26**	**415,13**	**141,42**

The third main format is used for detailed calculations of needs of energy services for the end-point

Figure 3: Example of Excel format to calculate needs of energy services at end-point for one particular cohort

Cohort:	migrants	M3	age 25-49	
	Energy services, food and alimentation, 2100			
	Food conservation	Food preparation	Cooking	Water, washing
Units for energy services	m3	tons	tons	m3
Million hours/day	52,4	52,4	52,4	52,4
Energy services (ES) /1000h	79,0	147,8	134,0	559,6
Useful energy (MJ/ES)	9	0	3	0
Useful energy (PJ)	37,18	0,79	21,53	7,34

The other parameters are necessary to steer the process in the overall development of the model.

5. Results

For each world region, each socio-cultural function and each environment (urban, rural, sub-urban), BASES produces matrices of the following structure, for the base year and for the end-point. This applies also to any aggregation stages across environments and functions.

Figure 3: Example of Excel matrix format for the restitution of energy services at base year and end-point (Europe)

Overall needs for energy services (PJ useful energy at base year efficiency)

Base year

Density	Power	Exergy				
		low	medium	high, stationary	high, mobile	Total
Low	low	1559	161	475	999	3194
	medium	0	0	184	2370	2554
	high	0	828	600	0	1428
High	low	4676	484	1426	999	7584
	medium	0	0	0	54	54
	high	0	8098	5458	135	13691
Total		6235	9571	8143	4556	28505

2100

Density	Power	Exergy				
		low	medium	high, stationary	high, mobile	Total
Low	low	891	41	1249	1232	3413
	medium	0	0	324	3974	4299
	high	0	1201	1165	0	2366
High	low	5703	437	8233	1232	15606
	medium	0	0	0	49	49
	high	0	3075	7259	729	11063
Total		6594	4754	18232	7216	36796

Other tables display results on a comparative basis across all world regions. Examples of such tables are displayed below.

Figure 3: Example of Excel matrix format for the restitution of cross-region results across time

A2 - Active population

	T	T+25	T+50	T+75	T+100
Former USSR	91,0	68,0	64,2	56,4	57,0
Sub Saharian Africa	279,8	417,7	637,3	722,8	712,7
North Africa and Middle East	110,7	170,2	229,9	250,2	232,8
Latin America	208,0	313,7	307,7	276,7	224,1
Europe	242,2	245,8	209,8	182,1	192,0
North America	117,1	152,3	171,4	176,3	178,0
Asia OECD Pacific	88,9	80,6	69,1	64,4	60,2
Other Asia	280,1	369,4	394,4	365,0	322,3
South Asia	289,5	537,1	706,9	751,4	681,5
China	670,4	676,6	547,7	445,9	388,1
World	2377,7	3031,3	3338,3	3291,2	3048,8

Overall actual individual affluence
$US95/hab

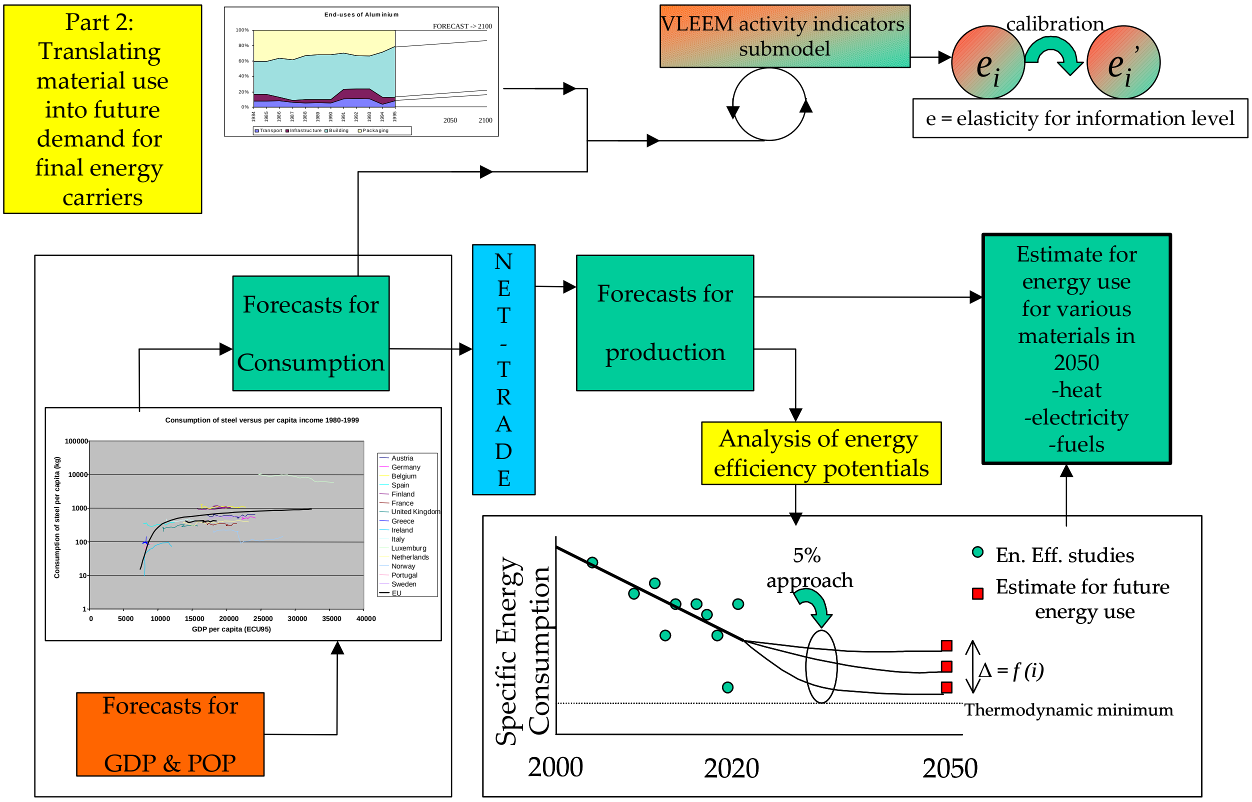
	T	T+25	T+50	T+75	T+100
Former USSR	1568	4259	12239	22130	34486
Sub Saharian Africa	676	3516	6910	12116	21135
North Africa and Middle East	2489	7209	12241	18423	22222
Latin America	3768	7981	11708	17693	30579
Europe	19013	26843	31741	38194	50274
North America	31372	42419	52185	61636	67548
Asia OECD Pacific	33603	40303	42550	51602	61258
Other Asia	3047	13952	22711	32991	41608
South Asia	478	2433	5900	12790	26128
China	833	4290	11301	24819	46692
World	5750	9899	14725	22413	34139

Appendix 1.B: DACES – energy efficiency

1. Introduction

DACES-energy efficiency is used to convert the needs of energy services (from BASES) in useful energy requirement to be supplied by the energy system.
An overview of the model architecture is described in figure 1.

Figure 1: The structure of the DACES sub-model : example of the bulk materials



Appendix 1.C: The BALANCE Model

1. Introduction

The BALANCE Model is used to formalise the scenario or case building. The model is in principle a rather simple optimisation model. Various options are included to steer the dynamic behaviour. Central task of the model is to keep track of all energy resources, emissions, capacities and so forth. A simple front- and back-end was developed.

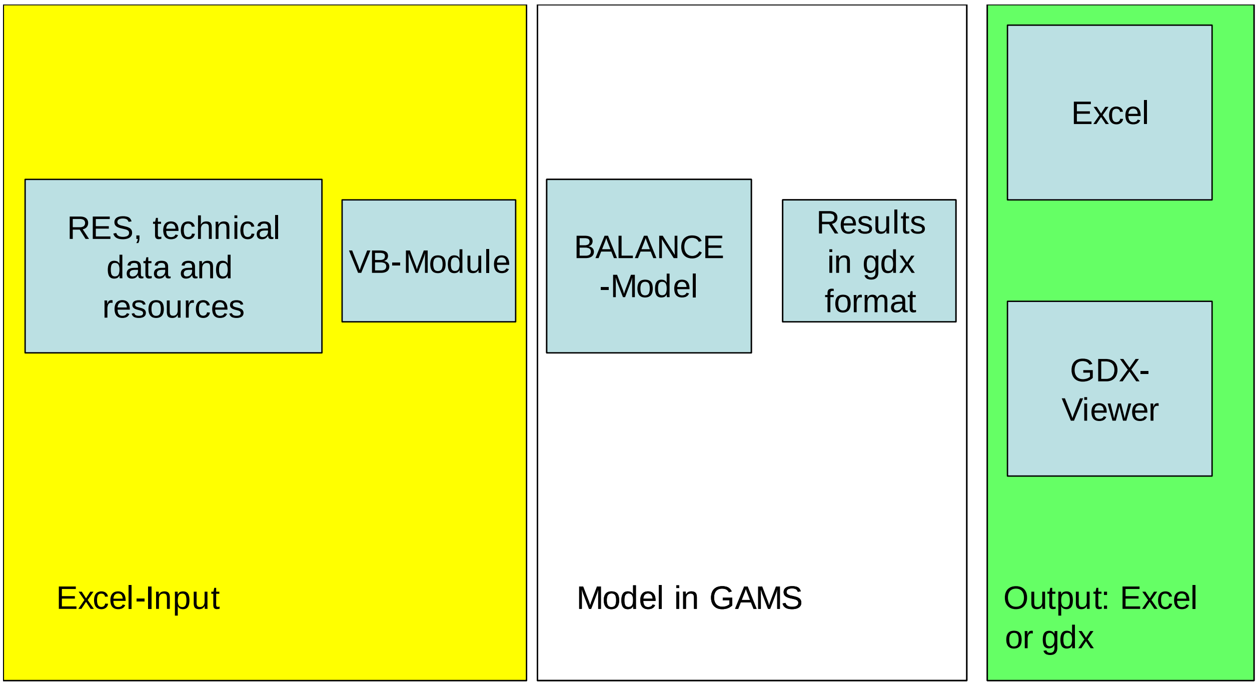


Figure 1: The structure of the BALANCE environment

An overview of the model architecture is described in figure 1.

2. Process Types

Three different process types are distinguished. A typical example for each type is sketched in figure 2. Beside the in- and output of energy carriers the processes do also produce CO2-emissions.

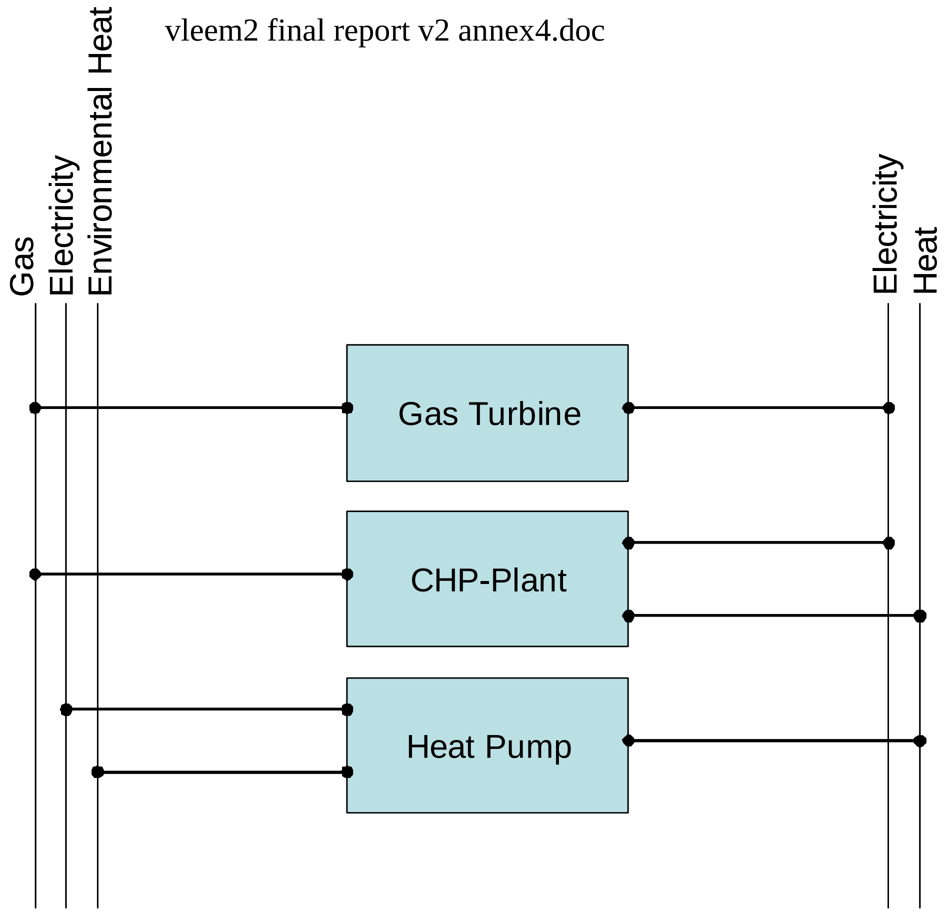


Figure 2: Different process types in BALANCE.

But it is also possible to construct with these simple elements more complex structures like a refinery (see figure 3). The relation between the amount of different products in the refinery can be fixed.

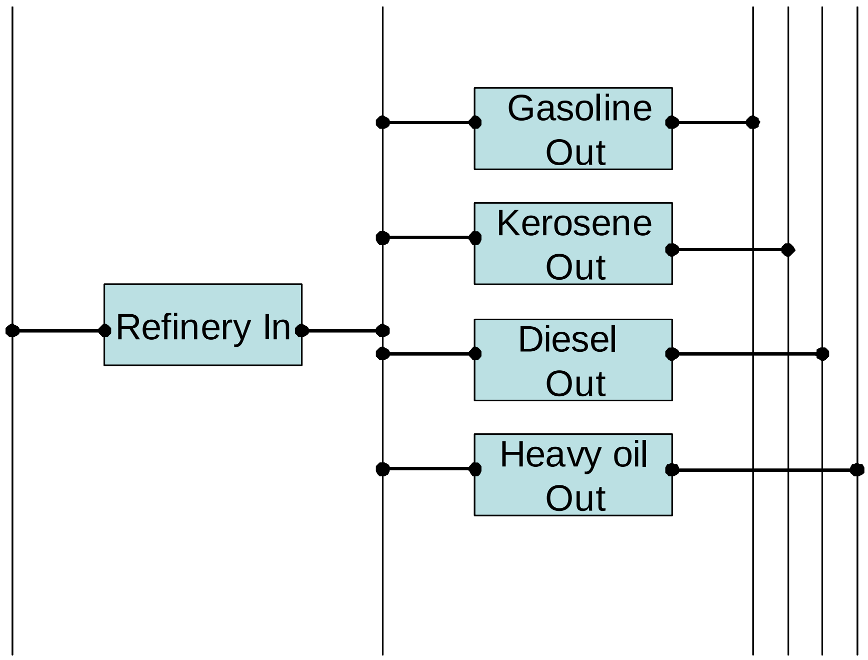


Figure 3: BALANCE model of a refinery.

3. Model equations

The model equations can be derived from the GAMS code in Appendix B. Here just a simple sketch of the most important equations should be described:

Objective function: the sum of all costs of all time periods

Commodity Balance: for each commodity a balance is made, the flow of inputs has to balance the flow of outputs, in the final demand balance the final demand is treated as an output

Process equations: the capacity multiplied with the time step and the availability has to be bigger than the processed energy, input and output energy are related by the efficiency

4. Process description

Each process is identified by the process name and the name of the input and output commodities. Each process is described by the efficiency, the availability, investment, fixed and variable cost, by the CO2 emissions, by the already installed capacities.

				1960	1970	1980	1990	2000	2010	2020	2030	2040	2050	2060
ts-ppcN	cos-tcoal	cos-elec	eff	0.380	0.400	0.420	0.440	0.450	0.455	0.460	0.465	0.470	0.475	0.480
ts-ppcN	cos-tcoal	cos-elec	ava	0.900	0.900	0.900	0.900	0.900	0.900	0.900	0.900	0.900	0.900	0.900
ts-ppcN	cos-tcoal	cos-elec	lft	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
ts-ppcN	cos-tcoal	cos-elec	ic	0.014	0.015	0.016	0.017	0.017	0.016	0.017	0.017	0.017	0.017	0.017
ts-ppcN	cos-tcoal	cos-elec	vc	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ts-ppcN	cos-tcoal	cos-elec	fc	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ts-ppcN	cos-tcoal	cos-elec	co2r	91.6666667	91.6666667	91.6666667	91.6666667	91.6666667	91.6666667	91.6666667	91.6666667	91.6666667	91.6666667	91.6666667
ts-ppcN	cos-tcoal	cos-elec	co2s	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ts-ppcN	cos-tcoal	cos-elec	past-inv	2072.368	1968.750	1875.000	1789.773	1750.000	0.000	0.000	0.000	0.000	0.000	0.000
ts-ppcN	cos-tcoal	cos-elec	frin-up	1	1	1	1	1	1	1	1	1	1	1
ts-ppcN	cos-tcoal	cos-elec	frin-lo	eps	eps	eps	eps	eps	eps	eps	eps	eps	eps	eps
ts-ppcN	cos-tcoal	cos-elec	frout-up	1	1	1	1	1	0.32	1	1	1	1	1
ts-ppcN	cos-tcoal	cos-elec	frout-lo	eps	eps	eps	eps	eps	0.32	eps	eps	eps	eps	eps
ts-ppcN	cos-tcoal	cos-elec	cap-lo	eps	eps	eps	eps	eps	eps	eps	eps	eps	eps	eps
ts-ppcN	cos-tcoal	cos-elec	cap-up	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
ts-ppcN	cos-tcoal	cos-elec	act-lo	eps	eps	eps	eps	eps	eps	eps	eps	eps	eps	eps
ts-ppcN	cos-tcoal	cos-elec	act-up	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
ts-ppcN	cos-tcoal	cos-elec	diff-min	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000
ts-ppcN	cos-tcoal	cos-elec	diff	3	3	3	3	3	3	3	3	3	3	3

Figure 3: Excel input mask to input the processes parameters.

The other parameters are necessary to steer the process in the overall development of the model.

5. Multi regions and trade

The BALANCE model is able to implement and couple of various world regions. The trade is described for a defined commodity. Different transport technologies can be implemented.

wrr	tt	ec		1960	1970	1980	1990	2000	2010	2020	2030	2040	2050	2060
FSU	ota	cos-toil	eff	1	1	1	1	1	1	1	1	1	1	1
FSU	ota	cos-toil	ava	1	1	1	1	1	1	1	1	1	1	1
FSU	ota	cos-toil	lft	3	3	3	3	3	3	3	3	3	3	3
FSU	ota	cos-toil	ic	30	30	30	30	30	30	30	30	30	30	30
FSU	ota	cos-toil	vc	30	30	30	30	30	30	30	30	30	30	30
FSU	ota	cos-toil	fc	30	30	30	30	30	30	30	30	30	30	30
FSU	ota	cos-toil	co2r	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
FSU	ota	cos-toil	co2s	30	30	30	30	30	30	30	30	30	30	30
FSU	ota	cos-toil	cap-lo	200	200	200	200	200	0	0	0	0	0	0
FSU	ota	cos-toil	cap-up	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
FSU	ota	cos-toil	act-lo	200	200	200	200	200	0	0	0	0	0	0
FSU	ota	cos-toil	act-up	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
FSU	ota	cos-toil	diff	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2

Figure 3: Excel input mask to input the transport process parameters.

6. Resources

Two types of resources are distinguished: stock and flow type resources. For the stock type resources an upper limit of the maximal integral use of the resource over all model years is set. Flow type resources describe the amount of flow which is available of a resource, especially energy flows in nature.

7. Mining processes

Special processes are assigned to the mining processes. The mining processes act on resources and define the fraction of the resource that can be made available at a special model year.

8. Needs

The needs describe the demand of a special energy service or product which is produced by the final transformation process.

	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
coes-hspace	25.12	28.79	32.86	34.75	35.61	36.43	37.10	37.63	38.63	40.20	41.75
coes-hhwater	2135.48	2363.97	2592.45	2704.40	2699.80	2695.20	2583.69	2472.17	2390.18	2337.71	2285.24
coes-hcook	1290	1339.6229	1372.15707	1370.46984	1347.43068	1324.46203	1282.04871	1238.56612	1203.2174	1176.80448	1150.39156
coes-happl	2096	2320.26292	2544.52584	2654.40147	2649.8898	2645.37813	2535.92433	2426.47053	2345.9941	2294.49506	2242.99602

Figure 3: Excel input mask to input the needs.

The units of the needs can be selected by the user.

Appendix 1.D The TACESl

1. Introduction

The TASES has been already described in the final report of VLEEM1, annex 9 (available on www.VLEEM.org)

2. Data structure

The complete simulation program is separated in different modules, which are more or less independent. Out of these modules, the class “graph" stands for data-management.

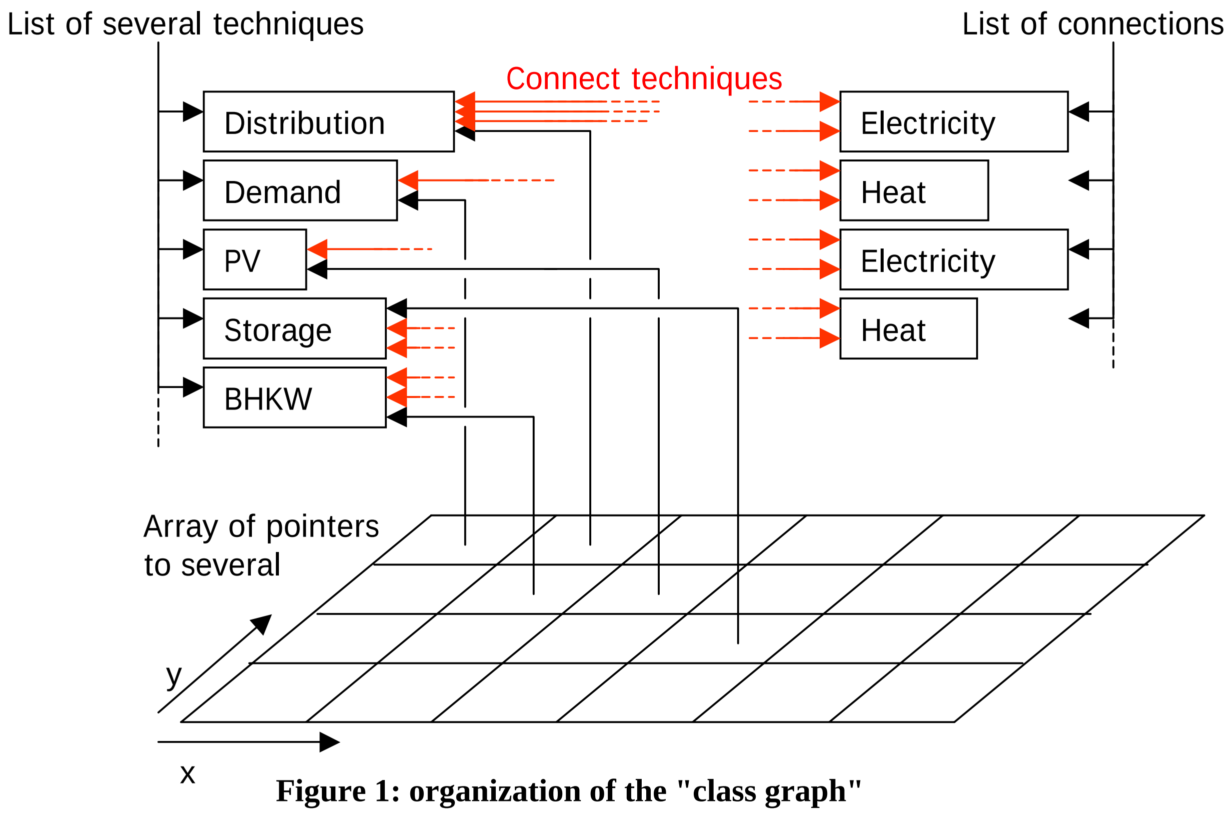


Figure 1: organization of the "class graph"

A fundamental array of pointers offers fast access regarding the spatial resolution in the given scenario. Each item in this array contains a pointer to a special member within the dataset. These connections realise descriptions of special supply techniques, demand, storage etc... and anything else involved in the scenario.
All different datasets are collected in a class "node". This class contains all data relevant to describe special proceedings such as "time dependence" (provided through an array).
Another similar class is called "link". This class contains variables to describe connections between two members of the class "node", for instance wires, pipes etc…

Members of "node" as well as members of "link" are collected in a list, in order to allow fast sequential access.

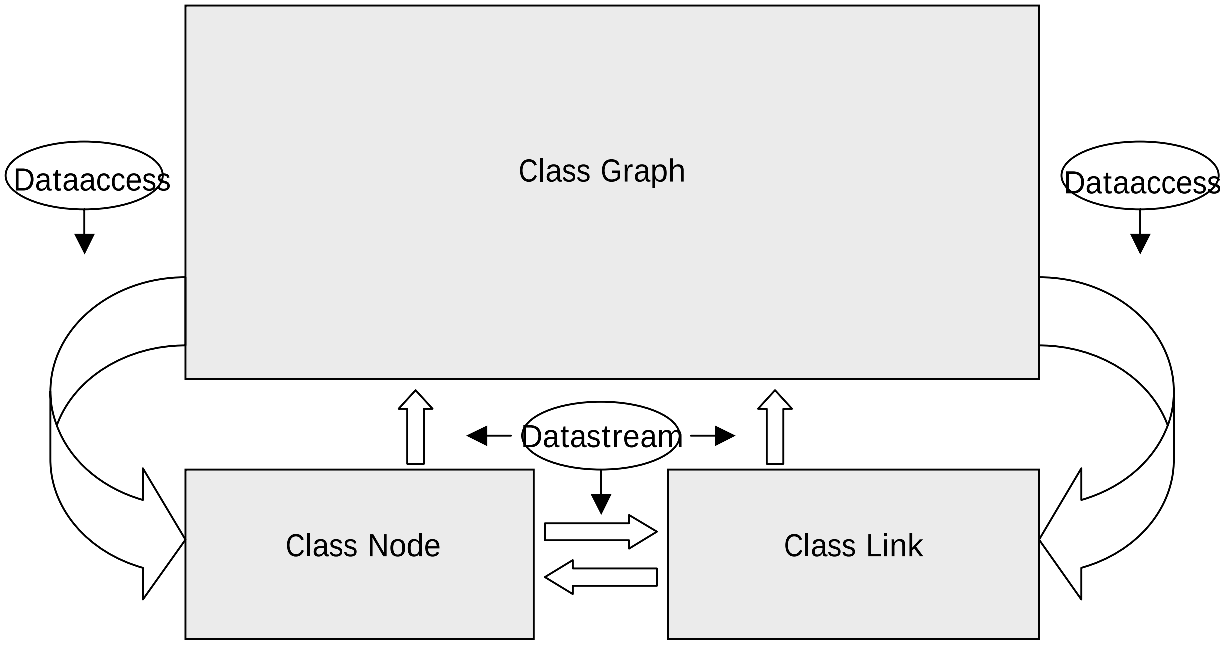


Figure 2: interaction of the classes

The three classes providing the complete data structure are implemented by means of independent modules. These classes are connected by defined interfaces.

There are several external ASCII-files providing parameters to feed the data structure with data regarding special supply, demand, storage or link techniques. All these external ASCII files are represented in a file called "typesdata" and guarantee time dependent descriptions of the mentioned functions. These files work according to the path declaration in the "typesdata"-file.
Additionally, the spatial resolution of the scenario to be simulated and ist assembling according to before mentioned functions are represented in a "scenario" - file.

Prototype (is

parameters (hardwired

availability

value or

value for each

```
.
.
*
PLANT
V_NETZ
SEFF    CONSTANT      1.00                  0.0
OCO2    CONSTANT      0.5                   0.0
OSO2    CONSTANT      0.00                  0.0
ONOX    CONSTANT      0.00                  0.0
PPP     CONSTANT      0.00                  0.0
PPE     CONSTANT      0.15                  0.0
*
PLANT
GASPIPE
GEFF    CONSTANT      1.00                  0.0
OCO2    CONSTANT      0.0                   0.0
*
PLANT
ALMERIA
SEFF    FILECONST     data/Almeria.txt      0.15
PPP     CONSTCONST    0.14                  0.15
PPE     CONSTANT      0.00                  0.0
*
.
.
```

```
0
0
0
0
0
0
0
0
0
0.019
0.1245
0.181
0.123
0.143
0.12
0.1255
0.1025
0.069
0.03
0
0
0
0
.
.
```

Figure 3: part of „Typesdata“-file (left) and part of external file

action (is

parameters (hardwired

value

```
.
.
*
CREATE
NODE    SUPPLY
TYPE    ALMERIA
NAME    S00227
SET_X   2
SET_Y   27
INST    1840030
QUAL    10
VARI    1
*

CREATE
NODE    TRANSFER
TYPE    S_NETLOK
NAME    SP09110910
FROM_X  9
FROM_Y  11
TO_X    9
TO_Y    10
INST    100000
VARI    1
*
.
.
```

Figure 4: part of „scenario“-file

Figure three and figure four show the syntax of the external files. These figures include all data necessary for the scenario and for the simulation.

It has to be noted, that the class “graph” does not only manage containing data, but does also offer search and select routines, e.g. search functions. This function provides basic features for higher classes.

3. Simulation

As soon as the data structure is feeded with all necessary information, the simulations module starts to create balanced energy estimations for each time step. The simulation module therefore uses a kind of hardwired heuristics.

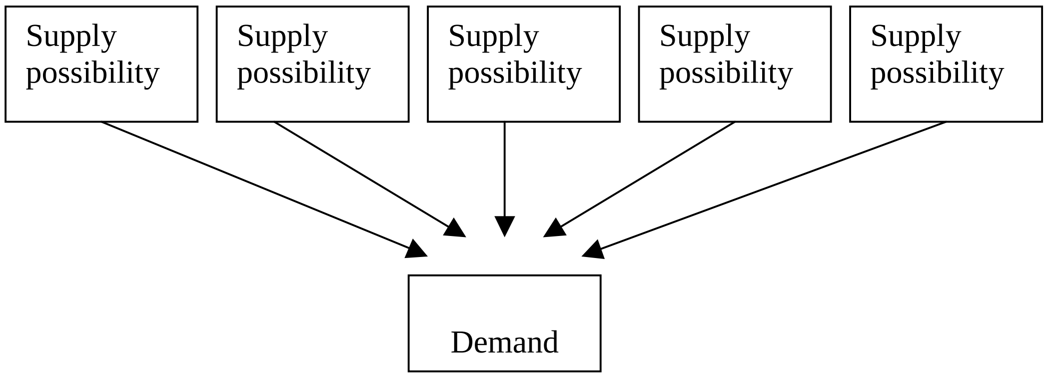
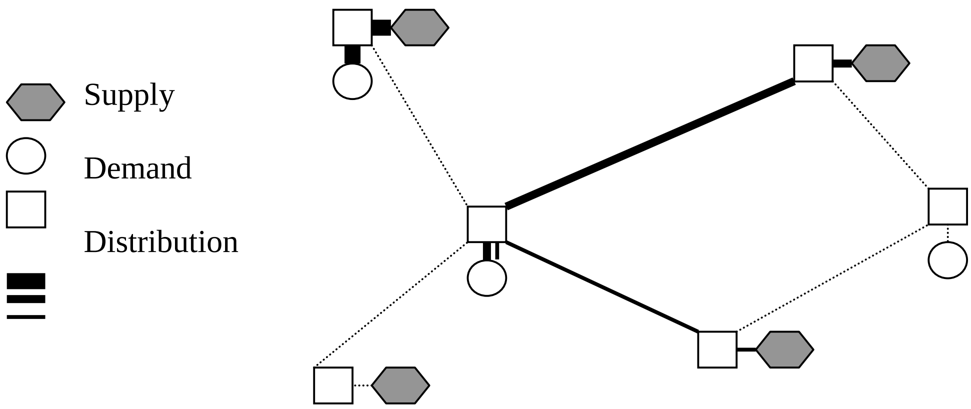


Figure 5: a given demand is satisfied following a quality sorted list of possibilities

As a result of the simulation, each supply technique participates in a balanced energy system. In order to satisfy a certain demand, a pretended quality factor is set in the scenario-file, as shown in figure five. The whole possible energy flows are collected in an extra list, classified by the quality factor and the efficiency of the connecting links.
Now the simulation starts. That means, for each time step all available demands have to be covered using the classified energy flows in the previously generated list.



In a second step the storages which operated in the first step as supply techniques are operating as demands. However, one important difference is, that only energy flows fulfilling a certain hardwired quality level are accepted now.
The mentioned heuristic works as follows: Each storage has two quality levels - one for loading and one for unloading. This arrangement makes it possible to use different storages for loading and unloading.
The data strucuture manages the handling of three different types of energy flow and their conversions (gas, current and heat). Additionally, the heuristic manages CHP as well. If a supply on one end of the energy flow offers CHP, participation in demand is always driven by heat demand. That means, electric current can only be offered if a corresponding amount of heat is inquired.

As a result of the simulation, the load values are available for every link and node. These values are shown in figure seven.

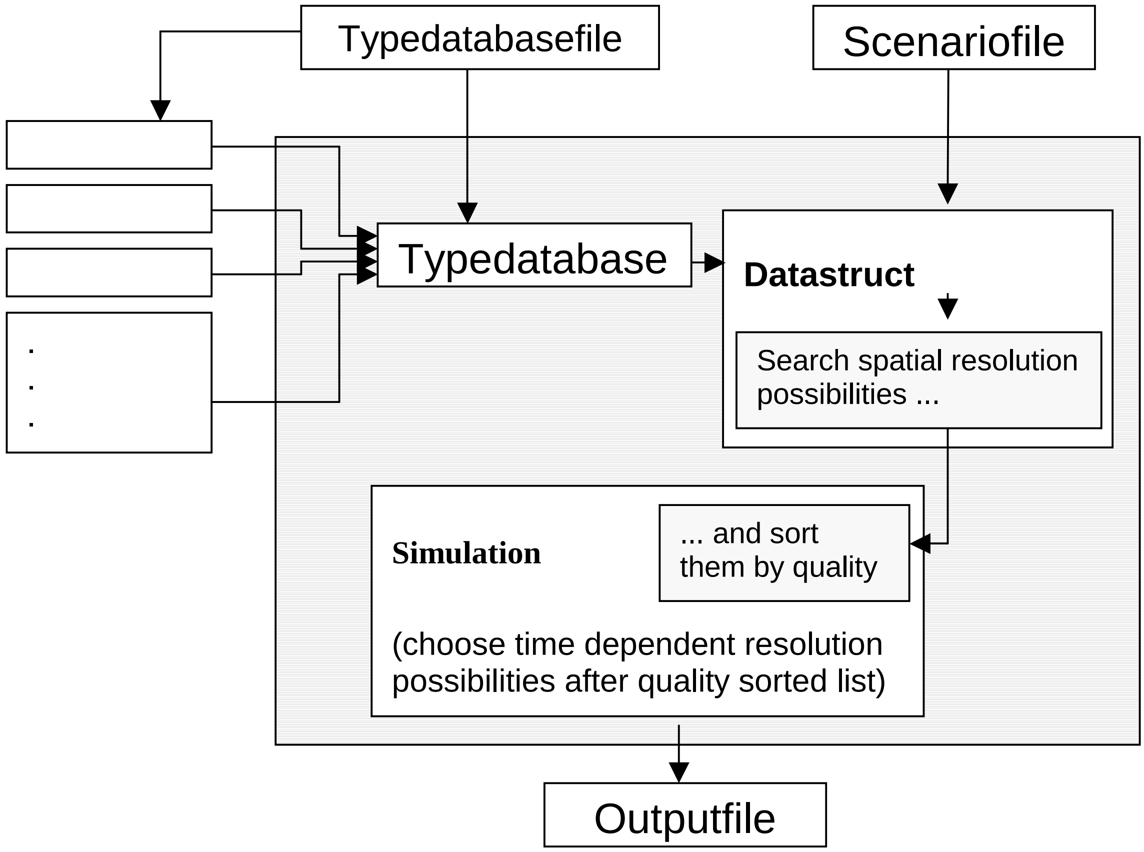
```
.

PPE.SP.534     0.00
PPE.SP.535     0.00
PPE.SP.536     0.00
PPE.SP.537     0.00
PPE.SP.538     0.00
PPE.SP.539     6675216.50
PPE.SP.540     9209305.00
PPE.SP.541     14669478.00
PPE.SP.542     15255640.00
PPE.SP.543     15255640.00
PPE.SP.544     2336986.75
PPE.SP.545     0.00
PPE.SP.546     0.00
.
.
```

Figure 7: part of the „output“-file with the result of the simulation

4. Structure of the program

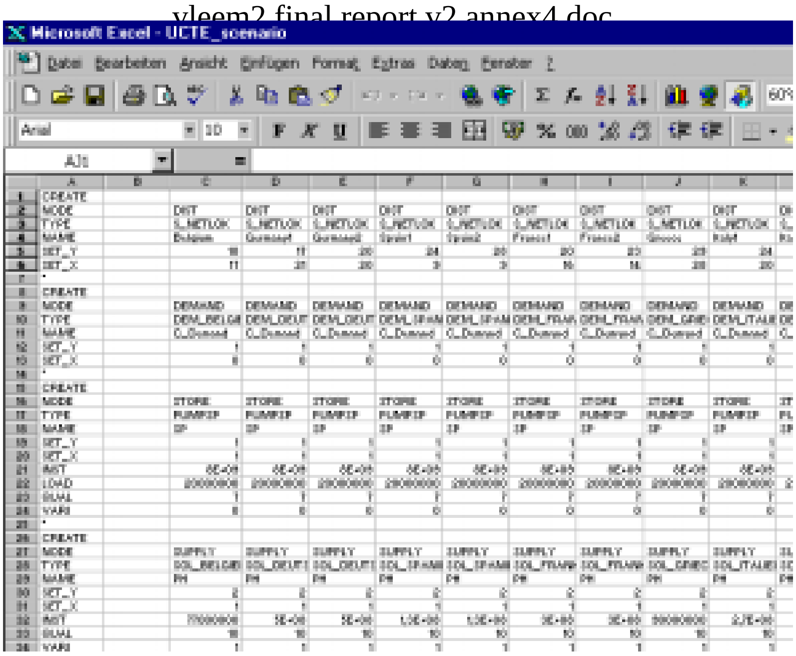
Figure eight shows the program's organisation. This is a very simplified flowchart of the input and output streams of the program.



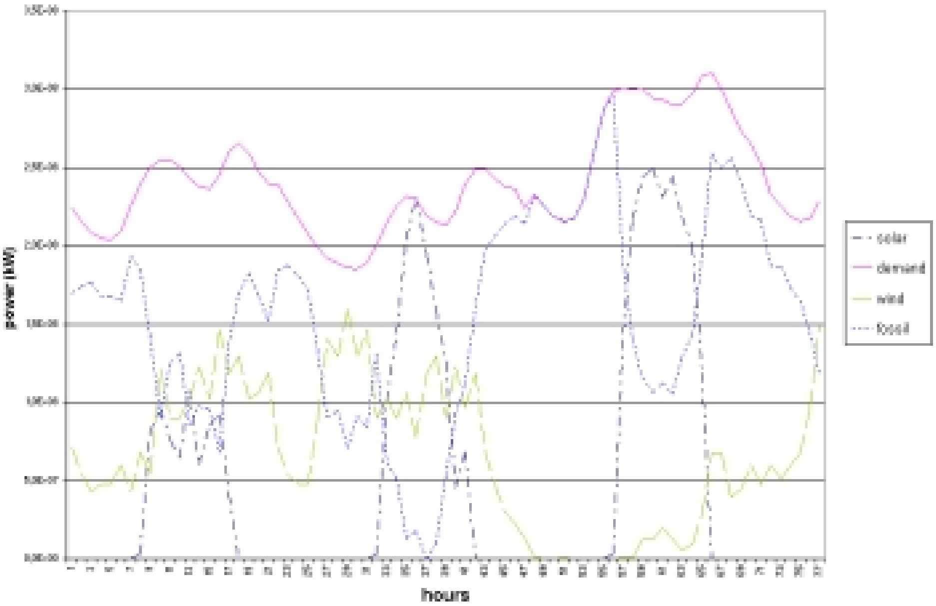
The main goal of the implementation of separated classes lies in aspired usage of the basic classes in different projects as well as in enlarged projects. Further steps might include optimisation of given scenarios with evolutionary algorithms. The class "datastructure" and the class "typedatabase" are both classes with only one duty - to handle all necessary data and to offer flexible interfaces for higher classes. The class "simulation" completes the main work. Consequently, most of the time for one run is necessary for this class scaling with
n (timesteps) • *k* (possible energy flows).

5. Handling

Due to the huge amount of input and output datasets, a well organised management of the mentioned data-sets is required. Therefore, all datasets are prepared in EXCEL. The scenario will be formulated tabularly in an EXCEL spreadsheet (figure nine). Additionally, a macro creates the already mentioned scenario-file.



For the output file the same procedure is used in the opposite direction. A visual basic macro selects the needed data rows from the output file and creates tabulated sorted files which are readable in EXCEL. These files contain the hourly scattered (depending on the scattering of the input data rows) load curves for every node and every link as it is exemplary shown in figure ten.



Finally it must be mentioned, that the restrictions for the scenario to be calculated are only given by the used computer system. Scenarios with about 100 different nodes (supplies, demands, storages etc.) and the corresponding links are no problem to be simulated on a normal PC if the time resolution is not higher than 8760 time steps (one year – hourly scattered).

All in all, TASES is a very powerful tool, to image virtual energy scenarios, especially then the option of outspread restrictions on more powerful machines is considered.

Appendix 1.E : NUCLEAR CYCLE MODELLING IN VLEEM

1. Introduction

In order to facilitate the computation of nuclear mass flows, storage contents and waste amounts of nuclear expansion strategies in VLEEM 2 a PC-based Nuclear Mass Balance Model (NMBM) has been developed and tested. The code of NMBM has been written in Microsoft Visual C++ 6.0, but the NMBM runs are executed via exe-files (and some Excel-files) which do not need the implementation of C++ at the user´s PC. The user would need C++ only if he/she would like to read the source codes or to change them.

The model consists logically of 3 parts:
The capacity programme
The mass balance programme
A programme to perform computations with deliberately small time steps based on the results of (more or less) coarse time steps of a size of (normally) some years, e.g., 5 or 10 years within a time horizon of some decades, say a 100 years.
This 3rd module is mainly of interest,
if the model is part of a comprehensive (superior) energy model with nuclear contributions, and
if this energy model simulates the operation of a plant park in small time steps (months, weeks, days or less).
The NMBM comprises therefore 3 time loops:
In the first loop the “coarse” time sequence of individual reactor capacities are calculated via the assumptions of individual capacity additions.
In the second loop the corresponding mass balances are calculated, considering operating capacities, capacity additions and retirements.
In the third loop the mass balances are calculated with deliberately small (constant) time steps and deliberately chosen load factors for each reactor type and time step (independent from the load factors in the “coarse” calculation where these factors are only reactor-dependent, not variable with time), but based on the dynamic reactor pool as defined for the “coarse” time steps (first and second loops).

The following information material on the NMBM has been prepared which briefly is presented below:

2 The Nuclear Mass Balance Model (NMBM.doc)

Describes the structure of the model, the generic input parameters, the definitions of nuclear capacities, of reactor types and their characteristics, the calculation of individual capacities, and the computation of nuclear mass flows based on a fuel cycle divided into five steps:
Fresh heavy metals: Natural Uranium – U_{nat}, and Thorium – Th
Fuel element-fabrication - fresh and recycled ones (“re-fabrication”)
Reactor operation
Interim storage for spent fuel elements, then possibly reprocessing and re-fabrication
Final repository

The numerical description for each time step goes via 8 “pots” and the final disposal:
Fresh fuel requirements (per time step and cumulated):

U_{nat}
Th
Interim storages:
Fission products (FP)
Depleted U
Irradiated U
Minor actinides (MA)
Fresh (once recycled) Pu
Multiple recycled Pu
Final disposal:
Irradiated (spent) Th and U destined for repository
Waste: Pu and MA (entire discharges or only their re-fabrication losses), FP, U, Th
For the interim storages initial values ("RESIDs") must be set.
In the case of recycling strategies the required re-fabrication capacities are computed too.

NMBM.doc is included as attachment in the forthcoming VLEEM 2 Monograph on Nuclear Fission (at the latest finished in November).

3 Operational Users´ Guide (User-Guide.doc)

Explains how to use the NMBM, lists the requirements for the execution of the NMBM and describes how to start the execution of the model. Four input Excel-files are needed:
EXCEL-file "vleem2-input" of the basic scenario input data
EXCEL-file "Matrix.xls" with the specific mass flow data for the reactors
EXCEL-file "Storage.xls" with initial values for 7 storages and 3 loss factors for re-processing
EXCEL-file "capf.xls" with capacity factors for computations with "small" time steps
Additionally required are the executable programmes
"vleem2_mass.exe" (for the nuclear mass flow computations with the "coarse" time step), and "vleem2_use.exe" (for the nuclear mass flow computations with the "small" time step, but based on the nuclear reactor structure of the coarse time steps).
These two programmes are the "source code" of the nuclear mass balance model NMBM.

An exe-file "create_charts.exe" is automatically called from *vleem2_mass.exe* and creates Excel-diagrams from the result tables so that the user gets graphical pictures (3 diagrams of capacities and 4 diagrams of nuclear mass flows) of the results with the "coarse" time steps:

Reactor capacities:
Capacities divided according to three reactor classes:
Existing reactors, new reactors for electricity and process heat.
Capacities of all reactor types
Capacity additions (new capacities) of all reactor types
Nuclear masses and mass flows:
Temporal storage contents of discharged Thorium, fission products, minor actinides, fresh and multiple recycled Plutonium
Consumption of natural Uranium
Consumption of fresh Thorium
Refabrication requirements

The Users´Guide identifies also an important consistency check:

The rationale of the main direction in long-term reactor development is the destruction of stockpiles of
Plutonium (Pu),
minor actinides (MA),
some long-lived fission products (FP).
As mentioned above the Pu-stockpile is divided into two segments:
Fresh (once recycled) Pu (Pu-f) and multiple recycled Pu (Pu-rec).
<u>The main consistency checks are twofold:</u>
The Pu-stockpiles must not be negative.
The total Pu-stockpile (Pu-rec) must not be smaller than the Pu-f stockpile.

Input data prepared for demonstrative purposes, although being more or less realistic for a “High Nuclear Case” for western Europe produce “reasonable” results with regard to the two consistency checks quoted above, as shown below in Figure 1. Figure 2 shows the corresponding capacity distributions. The lack of breeder reactors leads in this demonstration case also to a high consumption of natural U, as Figure 3 demonstrates. Time horizon is 2000-2100, with the “coarse” time steps of 10 years, i.e. 10 periods.

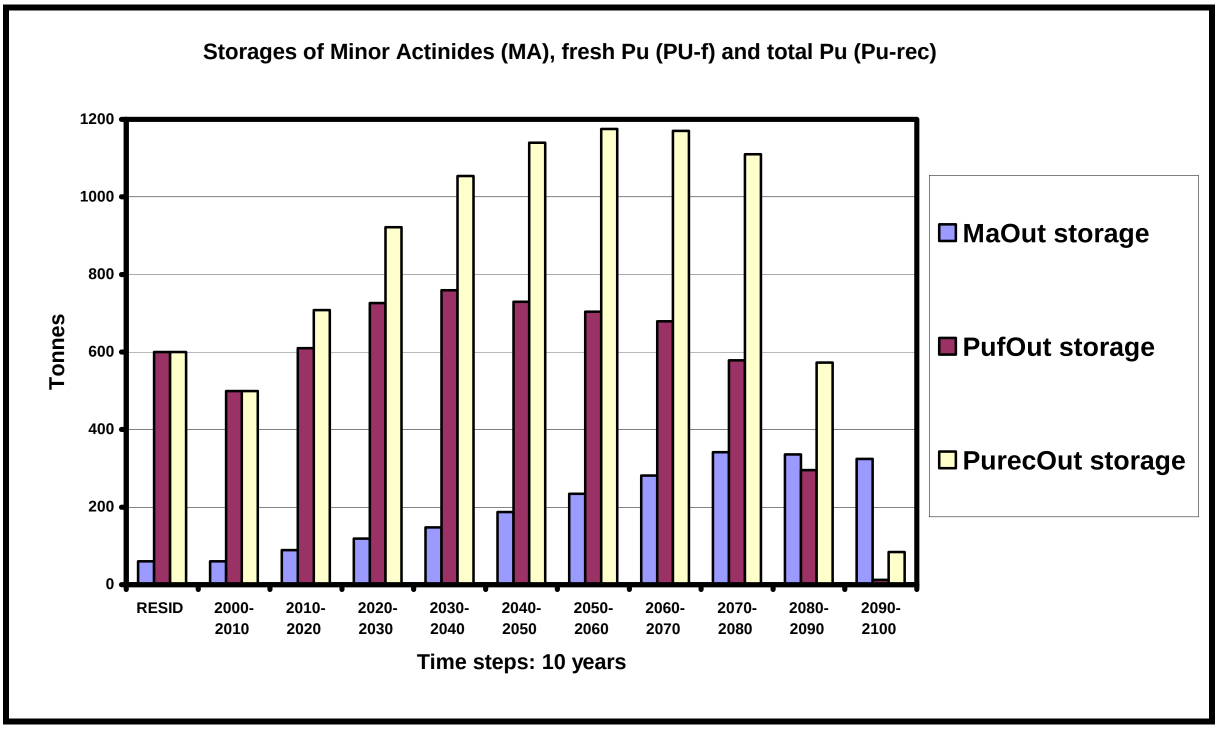


Figure 1: Dynamics of the storages for minor actinides – MA (blue), fresh (and once recycled) Pu – Puf (red), and total Pu – Purec (yellow).

User-Guide.doc contains NMBM.doc as attachment.

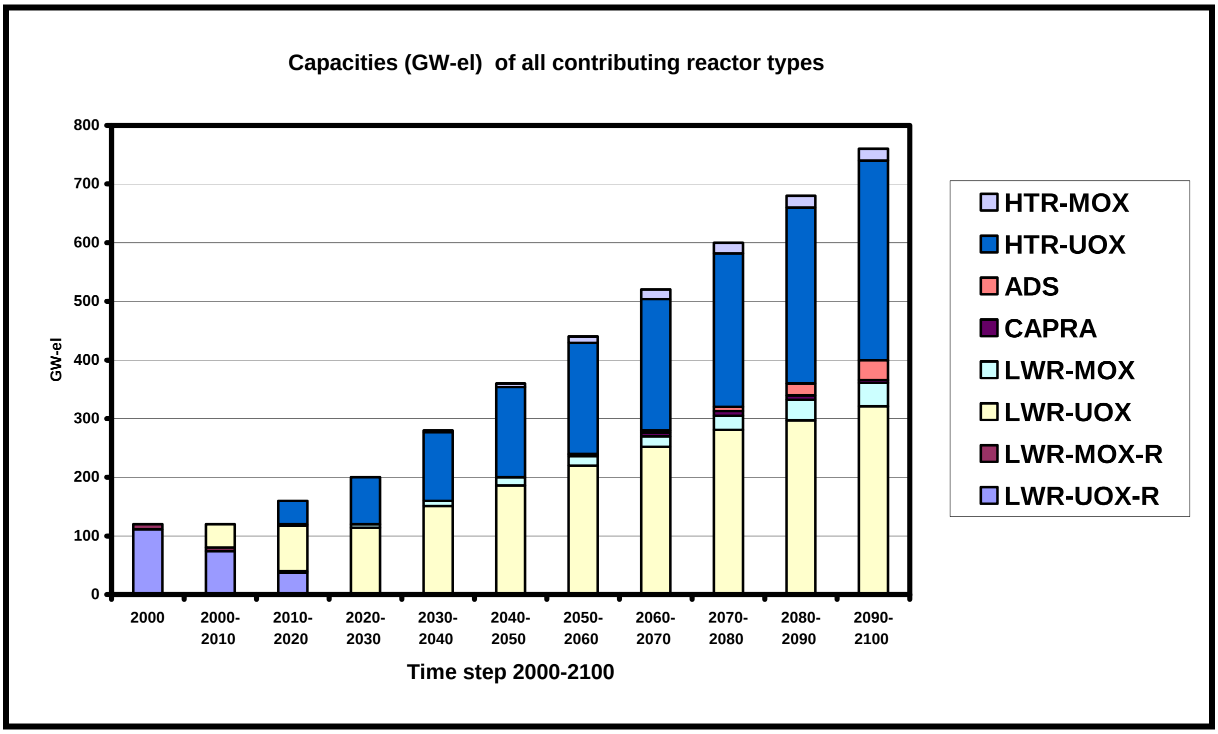


Figure 2: Dynamics of the capacities (GW-el) of 9 contributing reactor types. Observe that the two types marked by "-R" can only die out (as "RESIDs", i.e. the initially already existing reactors), but not be added again.

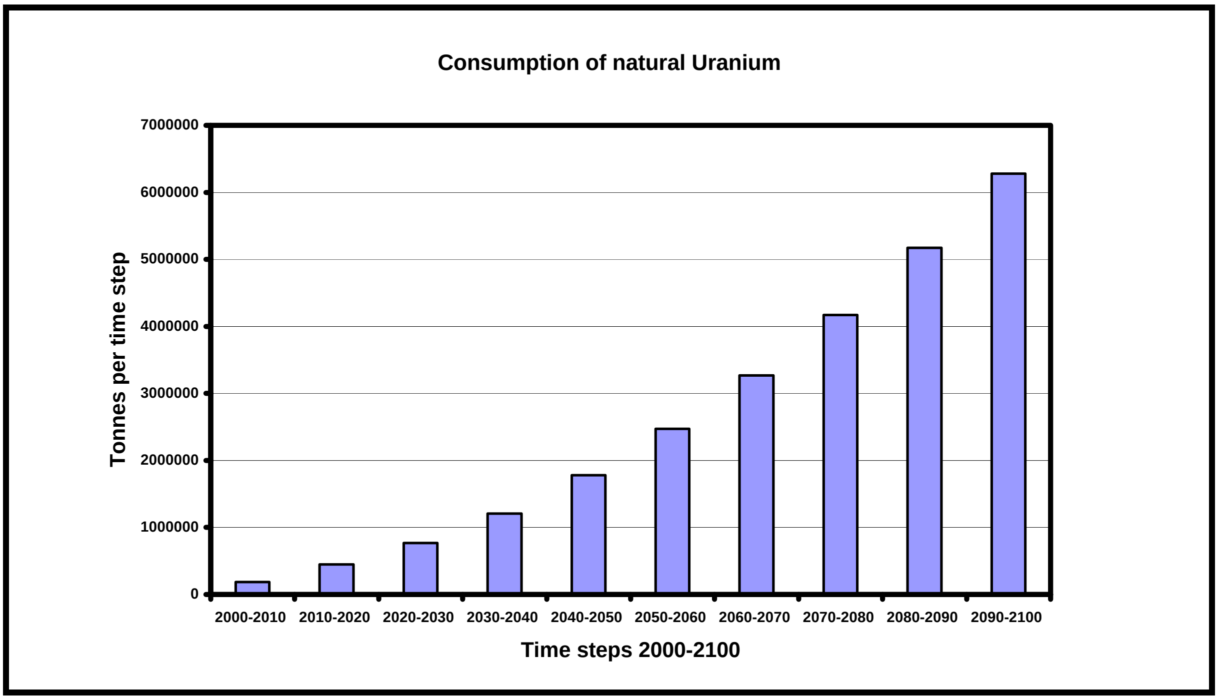


Figure 3: Dynamics of the natural-U consumption of the demonstration strategy.

This case apparently leads to a very high U-consumption, nearly twice that much as there are known mineral U-reserves with production costs below 130 US$/kg U (~ 4 million tonnes).

4 Documentation of the Nuclear Mass Balance Model (Documentation.doc)

After a brief introduction into its main structure the Documentation describes the two main algorithms (Vleem2_mass.exe and Vleem2_use.exe) and their sub-modules (“components”). These connections of the sub-modules within their main algorithms are also demonstrated graphically in two diagrams. Additionally the Documentation informs about the application of two further auxiliary exe-modules which are executed automatically during the run of the NMBM, but can be used also as stand-alone-programmes:
xls-to_txt.exe and create_charts.exe.
Behind this description the entire C++-source code is enclosed.

User-Guide.doc is attached to Documentation.doc, because it is facilitates for the purpose of better understanding to have a look into the User-Guide during reading the first part of the Documentation.