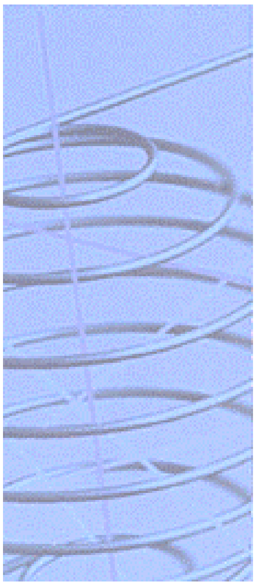
The Belgian Markal Database

CES-KULeuven - VITO



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Global change and sustainable development

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The Belgian Markal Database

CES KULeuven

VITO

DWTC/SSTC

ONDERZOEKOVEREENKOMSTEN NRs. CG/DD/221 en CG/DD/222

April 2001

1. GENERAL CHARACTERISTICS/TERMINOLOGY OF MARKAL

Markal is a long term multi-period energy technology optimisation model, that represents all energy demand and supply activities and technologies for a country with a horizon of up to 50/60 years. The dynamic behaviour of the energy system is obtained through maximising the consumer and producer surplus. Supply and demand clear the market through price fluctuations, taking into account any limit on emissions, resources or technological options.

The basic components in the database are the sources of supply and their associated cost and availability, the demand for energy services and the technologies linking the different elements through *energy carriers* and *material flows*. The sources of supply of energy or *resources* cover all means by which energy can enter or leave the system (other than to meet the demands): import, exports, extraction, and stockpiling of primary energy carriers. In Markal *resource technologies* are used to specify the cost of the different energy types, their origin, their environmental characteristics (e.g. sulphur content of coal) as well as their availability.

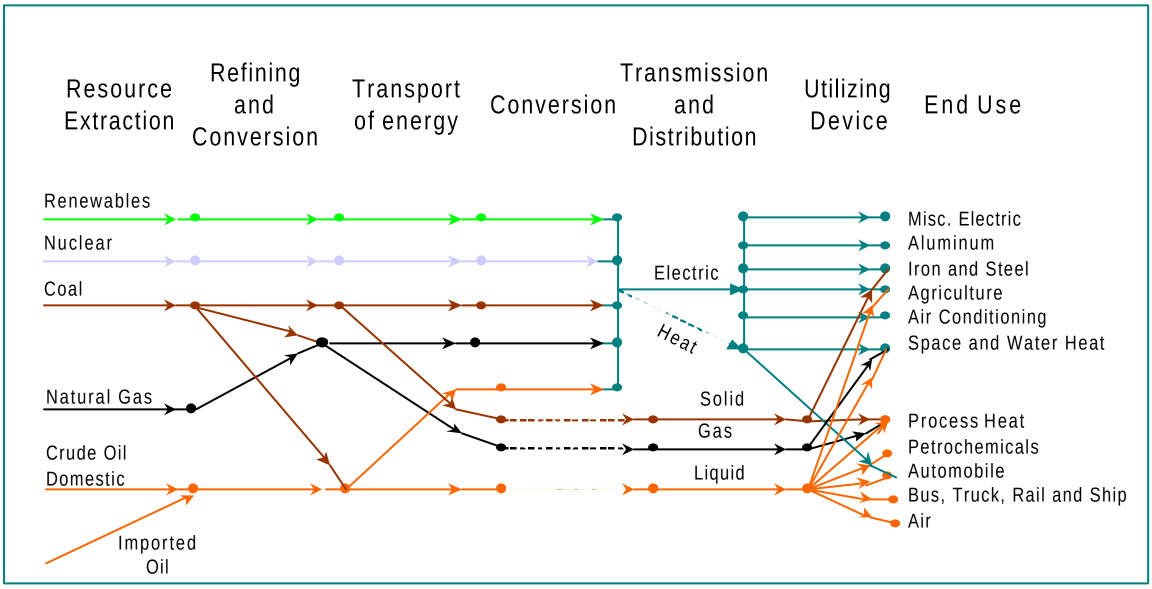
The *demand for energy services* or useful energy demands are price sensitive, depending on their marginal costs. The demand for energy services is separated in demand from the industrial sector, the residential sector and the transport sector and within these sectors there is a further disaggregation into subsectors.

Then there is the technology database, which contains the main energy transformation and energy use processes in the Belgian energy system. The typical Markal terminology distinguishes between different types of technologies:

1. *conversion technologies*: load dependent plants generating electricity or district heat
2. *demand technologies*: technologies consuming energy to meet demands for energy services
3. *process technologies*: all other transformation activities, load-independent

Different types of process technologies exist. They can represent real processes, including investment and capacity specifications, or they can be dummy technologies, which represent distribution and/or sectoral allocation of energy carriers. Another use of process technologies is to represent different environmental abatement options for conversion technologies.

In Markal the demand for energy services is linked to resources through a chain of processes, conversion and demand technologies. Processes are connected by energy carriers and material flows. The complete representation of all possible chains form primary energy supply to demand for energy services is called the *reference energy system.* The figure below represents a simplified reference energy system, on which structure the general description of the database below is based.


Resource Extraction
Refining and Conversion
Transport of energy
Conversion
Transmission and Distribution
Utilizing Device
End Use
Renewables
Nuclear
Coal
Natural Gas
Crude Oil Domestic
Imported Oil
Electric
Heat
Solid
Gas
Liquid
Misc. Electric
Aluminum
Iron and Steel
Agriculture
Air Conditioning
Space and Water Heat
Process Heat
Petrochemicals
Automobile
Bus, Truck, Rail and Ship
Air

2. POWER GENERATION AND FUEL CONVERSION

2.1. General structure

The reference energy system for the electricity sector is illustrated in Fig 1. On the left-hand side in Fig 1 one finds the primary energy resources for the sector.

imphc1 : imports of hard coal
minhc31 : mining of coal gasification
impnga1 : imports of natural gas
imphdl1 : heavy fuel imports
impldo1 : light distillate oil imports
imprce1 : recuperated coal from mine exploitation
implwr1 : nuclear fuel

Other primary energy sources are renewable energies.

Wind
Hydro-power
Municipal waste
Hay
Straw
Miscantus

For these energies no resources technologies are defined because they are free of charge. For municipal waste there is however a technology (with cost elements attached) to make the energy carrier suitable for electricity production.

On the right hand side in flowchart 1, one has the output products of the electricity sector.

ELC : Electricity
PSH : High temperature steam for industry
PSL : Low temperature steam for industry
LTH : Low temperature heat for centralised district heating
TER : Heat for decentralised district heating

2.2. Technologies for electricity generation

5 types of electricity production technologies are considered:

Nuclear power generation

For future investment, we consider the Pressurised Water Reactors (PWR), which have been put in operation Belgium for some 20 years and the Modular High Temperature Gas-Cooled Reactor (MHTGR).

Classic central power generation

Using coal

- Ultra Super Critical coal power plants
- Fluidised bed combustion plants
- Integrated Gasification Combined Cycle plants

Using natural gas or kerosene

- Gas turbine
- STAG (Steam And Gas) power plants
- Mixed plants on gas or kerosene (Turbojets)

Classic local power generation

- Gas turbines for cogeneration (high and low temperature steam)
- STAG power plants for cogeneration
- Gas engines for cogeneration
- Diesel engines for cogeneration

New technologies for power generation.

Different kinds of fuel cells for cogeneration (low and high temperature).

Renewables

Wind turbines, power plants on biomass, hydro power plants

Table 1 presents an overview of the main characteristics of the different types of power plants. The residual capacities of existing power plants were adapted to those proposed in the electricity sector equipment plan 1995-2005. Also the power plants under construction are included. Of course these input data are surrounded by a lot of uncertainties of which some are emphasised hereafter.

2.2.1. Nuclear

For **existing nuclear** the average availability factor and the technical lifetime are very important parameters because these plants produce 60% of all electricity and do this without CO2 emissions. The availability factor used in Markal is 85%, the Belgian historical average for this type of plants. It is assumed that the decided investment on existing nuclear plants will allow maintaining this high availability factor in the future.

The lifetime is set equal to 40 years and this is 15 years more than initially anticipated in the original equipment plans. These 40 years means that the major decisions on the replacement of the existing nuclear plants can be postponed from 1995 (= 1980 + 25 year - 10 year decision delay) to at least 2005 - 2010.

There is for the moment a nuclear moratorium on **new nuclear plants**. In order to evaluate the cost of this moratorium the cost of new nuclear power stations is important. Whether these new power stations will consist in some retrofitting of existing nuclear reactors or will entail the use of a new reactor type is unknown. In the database we consider that the nuclear capacity can be extended from 5500 MW to 8000 MW by using existing sites.

2.2.2. *Coal Power Plants*

Two types of coal power plants are considered in the model: an ultra super critical coal power plant (USC) and integrated coal gasification combined cycle (IGCC). These types of power plants can become the main base load technology in the longer run when natural gas becomes more expensive. Because of the large range found in the literature for the investment cost of the ultra super critical coal power plant, a gradual decrease of this cost has been assumed until 2005. IGCC is a technology, which is still at the demonstration level: important technical progress has been foreseen in the energy efficiency (from 42 % in 1995 to 51 % in 2030). Both technologies are, at least at the end of the horizon, in close competition with the cost and efficiency figures assumed here.

2.2.3. *Cogeneration technologies*

In the industrial sector, gasturbines of 4MWe and of 35MWe and STAG of 30MWe are considered for high temperature steam and a backpressure turbine (20MWe) for low temperature steam. STAG units of 30 and 100 MWe and gas turbines and diesel engines of 30MWe for cogeneration in the residential and tertiary sector are modelled. A number of gas turbines on biomass, as well as fuel cells for cogeneration have recently been included in the model. Small gas engines of 1MWe for decentralised cogeneration in this sector are also considered. Limits have been imposed on the penetration of cogeneration in the different sectors, based on the technological potential evaluated in the study by Econotec and VITO, 1994.

Table 1: General characteristics for types of power plants

	Markal-Code	First year available	Availability factor (%)	Lifetime (Years)	Electric efficiency (%) Start	2030	Invest.cost (BF/kW)	Fixed O&M (BF/kW/Year)	Var. O&M (BF/kWh)	Fuel type
Central production										
Pulverised coal (USC)	E11	2000	82 → 84	30	40	47	38421	1320	0.100	coal
Pulverised coal (exist)	E10	1990	83 → 85	30	37	40	47920	2200	0.090	coal
Coal gasification Combined Cycle (IGCC)	E12	2010	83 → 84	25	42	51	54770	1700	0.070	coal
In-Situ Coal STAG power plant	E13	2005	75.	25	48	48	23837	2501	1.320	coal
Pulverised coal power plant	E14	2010	85	30	47	52	40873	1320	0.100	coal
Mixed fossil	E33	1990	84	30	39	44	27120	1274	0.070	Mix[1]
Oil & Gas conventional	E34	1990	84	30	38.5	44	27120	1274	0.070	Mix[2]
Gas turbine (kerosene)	E41	1990	89.9	25	30	38	12262	299	-	kerosene
Gas turbine (gas)	E31	1990	91.	25	40	40	19941	299	-	nat. gas
STAG power plant, early	E32	1995	85	20	55	60	16349	990	0.060	nat. gas
STAG power plant, standard	E35	2010	85	20			16349	990	0.060	nat.gas
PWR nuclear plant	E21	1990	85	40	38.5	38.5	58040	1490	0.072	nuclear
MHTGR nuclear plant	E22	2010	85	30	45	45	98930	2129	-	nuclear
Wood gasification power plant	E61	2000	80	25	38	45	46000	2070	0.079	wood
Hydro power	E52	1990	88.8	40	38.5	38.5	99700	140	-	hydro
Hydro pumped storage	E51	1990	88.8	40	75.3	80	49853	1595	-	electricity
Wind turbine onshore at seaside	E53	1990	25	20	38.5	38.5	32700	1196	-	wind
Wind turbine onshore in polder	E54	1990	18	20	38.5	38.5	32700	1196	-	wind
Wind turbine offshore	E55	2000	37	20	38.5	38.5	57223	1525	-	wind
Wind turbine inland	E56	1990	16	20	38.5	38.5	32700	1196	-	wind
Municipal waste incinerator	E81	1990	84	30	38.5	44	27120	1274	0.070	mun.waste
Local production										
Autoproduction mixed fossil	EC0	1990	89	25	28	28	19941	299	-	mix
Coal fluidised bed	EA1	1995	80	20	37	37	69228	3368	-	coal
Gas turbine PSH	EC1	1990	80	20	23	28	44160	165	0.223	nat.gas
Back pressure turbine PSL	EC3	1990	80	25	22	22	50000	840	0.167	nat.gas
STAG for cogeneration PSH	EC6	1995	80	25	38	40	27600	1050	-	nat. gas
Slow Diesel engine for cogen.	ED1	1990	68	20	37	42	16300	163	0.180	gas oil
Gas engine cogen. (< 1MW)	EC4	1990	68	15	33	36	21000	210	0.400	nat gas
Gas engine cogen. (1 MW) PSL	EC7	1990	50	15	34	38	18000	180		nat.gas
Wood gasification for cogen.	ECW	2000	46	15	25	26.5	62000	4670	0.069	wood
Hay/Straw/Miscanthus gasific. For cogen.	ECT	2005	46	15	22	24	70000	6720	0.192	hay/straw/miscanthus
Fuel cells(MC/SO/PA) hydrogen PSH	EG1	2015	80	10	53	54	47800	1327	0.442	hydrogen
Fuel cells(MC/SO/PA) hydrogen TER	EG2	2005	50	10	51	51	53800	1495	0.374	hydrogen
Fuel cells(MC/SO/PA) natural gas PSH	EG4	2015	80	10	50	51	48866	1327	0.442	gas
Fuel cells(MC/SO/PA) natural gas TER	EG5	2005	50	10	40	40	55000	1495	0.374	gas

Stag for cogeneration LTH	EW1	1995	50	20	43	48	30100	1100	-	gas
Fuel cells cogeneration plant (hydrogen) LTH	EW2	2015	50	15	54	55	48000	1333	0.241	hydrogen
Fuel cells cogeneration plant (natural gas) LTH	EW3	2015	50	15	50	55	48000	1333	0.241	natural gas

(*) Cost of the wet gypsum desulphurization process and the selective catalytic reduction denitrification process included in the cost figures

2.3. Environmental process technologies in the electricity sector

Process technologies represent different environmental options for SO2, NOX and CO2 emissions. For other pollutants, which are generally less relevant for this sector (PM, VOC, etc.) no alternatives are considered in the electricity sector). In general, one basic options and one or two alternatives are considered.

Options to reduce SO2 emissions

SO2 environmental options	Available	Emission	Lifetime	Invest. Cost	Fixed O&M	Var. O&M
Markal Code		Kg/GJ		BF/GJ	BF/GJ/year	BF/ GJ
SAA	1990	0.685	No abatement			
SAB	1995	0.114	25	85		15
SA2	2005	0.09	Standard for new coal power plant			
SA3	2010	0.038	25	63.81		8.97
SA6	2000	0.076	25	19.94		4.99

Options to reduce NOX emissions

NOX environmental options		Emission	Lifetime	Invest. Cost	Fixed O&M	Var O&M
Markal Code		Kg/GJ		BF/GJ	BF/GJ/year	BF/ GJ
SBA		0.3	No abatement			
SBB		0.145	25	10		3
SB3		0.04	Standard for new power plant			
SB4	2005	0.02	25	13.56		
SB6		0.06	Standard for new power plant			
SB7		0.02				2
SB8		0.135		18.5		1
SB9		0.02		40		6
SE7		0.135				
SE8	2000	0.06	25	21.4		2.75
SE9	2005	0.02	25	21.4		4.63
SEA		0.15				
SEB		0.07		3.2		
SEC	2010	0.03	25	18.9		4
SEB1		0.15				
SEB2		0.07		3.2		
SEB3	2010	0.03		18.9		4
SE1		0.15	No abatement			
SE2		0.07	25	3.2		4
SE3	2010	0.03	25	18.9		4
SE4		0.068	No abatement			
SE5		0.03	25	21.38		2.75
SE6	2005	0.01	25	21.38		4.63
SED		0.068	No abatement			
SEE		0.03	25	21.38		2.75
SEF	2005	0.01	25	21.38		4.63

Options for CO2 storage in acquifers

CO2 storage option Markal Code		Reduction efficiency	Lifetime	Invest. Cost BF/GJ	Fixed O&M BF/GJ/year	Var O&M BF/ GJ
SCA	standard option - no CO2 storage					
SCB	2000	90%	25	422	5.7	14
SC0	standard option - no CO2 storage					
SC2	2000	90%	25	211	5.7	14
SC3	standard option - no CO2 storage					
SC5	2005	25	90%	120	5.15	0
SA7	2005	25	90%	140	5.15	5
SCK	standard option - no CO2 storage					
SCM	2000	25	90%	21	5.7	14
SCN	standard option - no CO2 storage					
SCO	2000	25	90%	211	5.7	14

2.4. Other processes

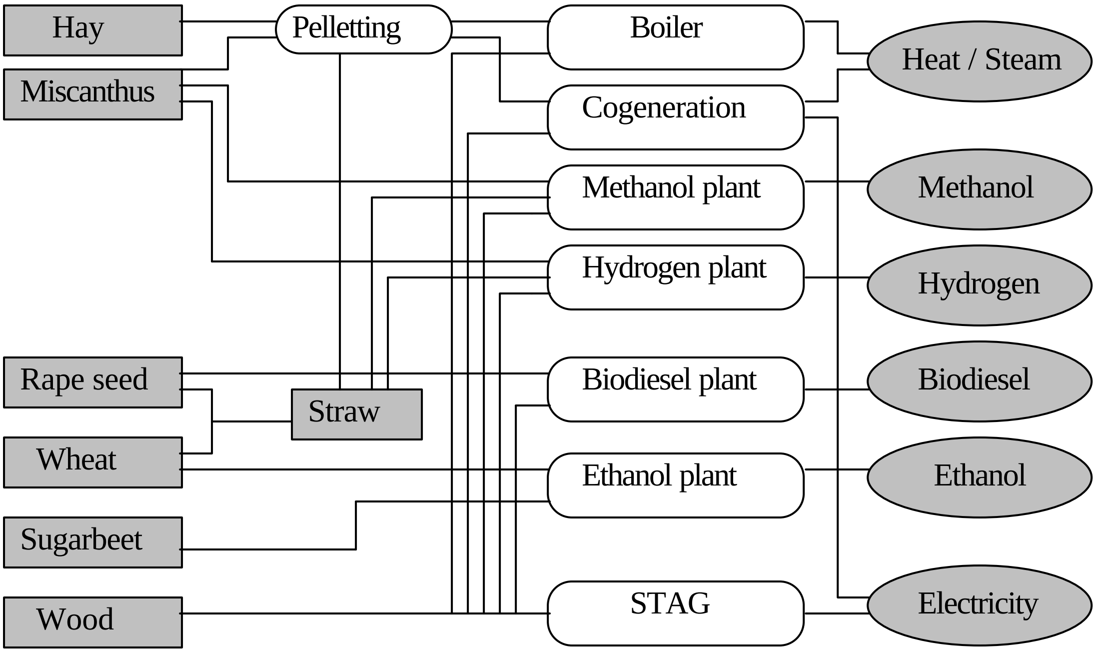
2.4.1. Dummy processes for environmental accounting and energy distribution

Processes in flowchart 1 with Markal codes starting with Pxx and Dxx are dummy processes for environmental accounting for other pollutants and distribution of energy carriers. These distribution "technologies" are used to allocate specific distribution costs to each sector.

2.4.2. Biomass conversion processes.

Biomass conversion processes have Markal codes starting with Bxx. A description of biomass is found in 'Energy from biomass in Belgium, an assessment of the possibilities', B. Van Hoof (1995). Figure 1 gives a simplified overview of biomass conversion as it is modelled in Markal.

Figure 1: Biomass conversion



Derived fuels from biomass include biodiesel (from rape seed or from wood), hydrogen (from wood, miscanthus or straw), methanol (from wood, miscanthus or straw) and ethanol (from wheat or sugarbeet). The costs associated with the conversion processes are given in Table 2.

2.4.3. Fuels derived from fossil sources

Conventional processes can produce hydrogen and methanol. Furthermore hydrogen and ethanol can be imported. The costs associated with these technologies are also given in Table 2.

Table 2: General characteristics for conversion processes

	First year available	Lifetime (Years)	Conversion efficiency (%)		Invest.cost (BF/GJ/y)	Fixed O&M (BF/GJ/y)	Var. O&M (BF/GJ)
			1990	2030			
BIOMASS CONVERSION							
Rape seed to Biodiesel	1995	20	62	62	545	32.7	10.5
Wheat to Ethanol	2000	20	52	52	1988	129.2	9.9
Sugarbeet to Ethanol	2000	20	55	57	2196	142.7	22.0
Straw to Methanol	2000	20	52	54	2015	110.8	50.4
Straw to Methanol (improved)	2015	20	86	86	2216	121.9	55.4
Straw to Hydrogen	2005	20	57	57	1940	97.0	38.8
Straw to Hydrogen (improved)	2015	20	70	74	2015	100.7	40.3
Wood to Biodiesel	2000	20	56	56	2142	317.1	18.0
Wood to Methanol	2005	20	54	56	2761	151.8	69.0
Wood to Methanol (improved)	2015	20	63	63	2790	139.5	69.8
Wood to Hydrogen	2005	20	59	59	2611	130.6	53.3
Wood to Hydrogen (improved)	2015	20	72	76	2723	136.2	54.5
FOSSIL FUEL CONVERSION							
Coal to Methanol	2005	20	59	63	798	71.8	-
Coal to Hydrogen (and natural	2005	20	53 (18)	53 (18)	798	79.8	-
Natural gas to Methanol	2000	20	71	75	319	33.9	-
Natural gas to Hydrogen	2000	20	75	80	239	22.0	-
Electricity to Hydrogen	2000	30	76	80	499	39.9	-

3. THE INDUSTRY

3.1. General structure

Industrial energy demand is split up into sector specific demand, representing the demand from energy intensive industries and supra-sectoral demand representing non-specific energy uses.

The energy intensive sectors are iron and steel production and steel processing, cement, flat and hollow glass, glass fibres, limes and limestone, other construction materials and basic inorganic chemicals (chlorine electrolysis and ammonia synthesis).

For the supra-sectoral demands the main categories are process heat (high temperature), steam (high temperature), heat (low temperature) and electricity which is further split up into electrothermal, continuous power, variable power and lighting demand.

The technologies in the industrial sector to satisfy these demands follow the same classification:

- Sector specific technologies
- Supra-sectoral technologies for the supra-sectoral demand of heat, steam and electricity.

3.1.1. *Sector specific technologies*

For each sector at least one conventional end use technology is modelled which represents the present mix of installations. In addition one or more alternative processes or savings options are provided. The savings options allow energy savings from 2 to 7% at increasing cost. These savings increase the overall efficiency of the technologies without substitution between energy vectors. These options are not cost effective at the prevailing energy prices.

The sector specific technologies are:

Iron & steel production	Blast furnace with basic oxygen converter Electric scrap iron Direct reduction process
Cement	Dry and wet cement process
Flat and hollow glass, fibre glass	Conventional furnace
Lime & limestone	Rotating furnace Vertical furnace
Inorganic chemicals	Chlorine electrolysis Mercury cell Diaphragm cell Membrane cell Ammonia synthesis

3.1.2. *Non sector specific technologies*

For the different categories of electricity demand, two steps of saving options of 5% each are modelled (at increasing cost), with the exception of electrothermal where the first step is 10%.

The heat demand can be satisfied by conventional technologies, alternative processes (e.g. direct steam rising from hydrogen), savings and/or cogeneration technologies. The model distinguishes process heat (high temperature heat), steam (intermediate temperature heat) and low temperature heat. Heat from cogeneration is constrained by the limits imposed on the capacities of CHP technologies (cf. Table 4). The technological potential is based on a study by ECONOTEC and VITO[1].

Fuel substitution possibilities for the technologies in the industrial sector are included when relevant and they take into account efficiency changes and additional costs due to fuel switching.

3.2. Detailed specifications

Industrial demand categories and related energy demand technologies are listed in **Error! Reference source not found.**.

Table 3: Industrial demand categories and related technologies

Description	Markal code	Unit	level 1990	level 2030	Related Technologies
Cement	IC	Kton/year	6102	9167	ICA, ICB, ICC, ICE, ICF
Construction materials	ID	PJ	7.2	10.8	IDA, IDB, IDC
Glass flat	IG	Kton/year	741	1114	IGA, IGB, IGC, IGD
Glass hollow (packaging)	IH	Kton/year	296	445	IHA, IHB, IHC, IHD
Glass fibres	II	Kton/year	170	254	IIA, IIB, IIC
Lime	IJ	Kton/year	1691	2542	IJA, IJB, IJC, IJD
Industry Continuous power	IK	PJ	29.9	46.9	IK1, IK2, IK3
Industry variable power	IL	PJ	38	60	IL1, IL2, IL3
Industry electrothermal	IM	PJ	6.9	11.6	IM1, IM2, IM3
Industry Lighting	IN	PJ	14	19	IN1, IN2, IN3
Chemical industry ammonia synthesis	IO	PJ	5.9	9.8	IOA
Chemical industry steam	IP	PJ	37.1	56.8	IPA, IPB, IPC, IPD, IPE, IPH, IPI, IPJ
Chemical process heat	IQ	PJ	18.5	28.6	IQA, IQB, IQC
Chemical chlorine electrolyse	IR	PJ	7.9	10.1	IR1, IR2, IR3, IR4
Steel	IS	Kton/year	11340	12044	ISA, ISB, ISC, SP1, SP2, SP3, SP4, SP5, F11, F12
Iron & Steel processing	IT	PJ	47.1	54.3	ITA, ITB, ITC, ITD
Other industry low temp steam & heat	IY	PJ	25	43.3	IYA, IYB, IYC, IYE, IYI, IYJ
Other industry	IZ	PJ	44.1	76.3	IZA, IZB, IZC

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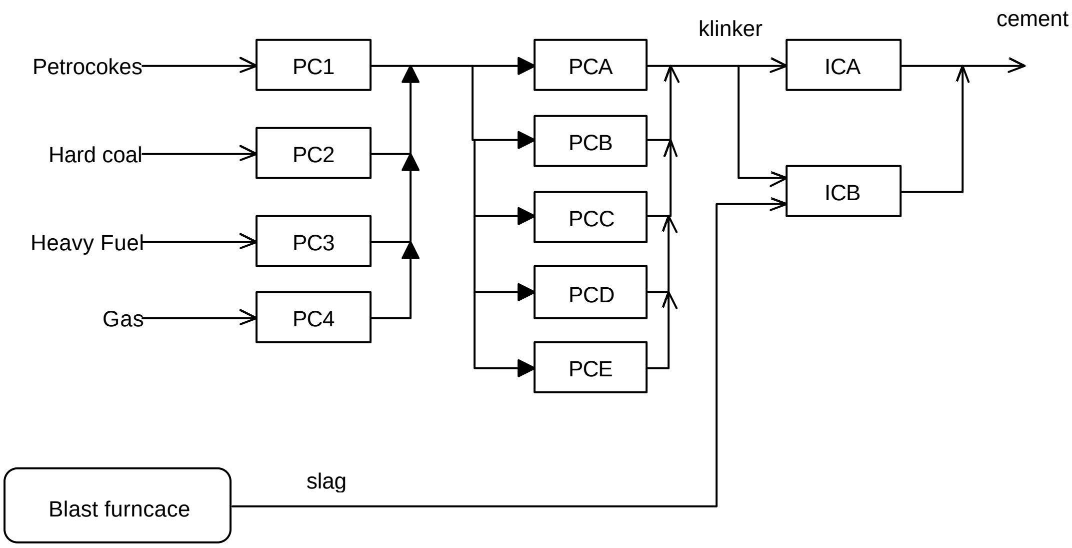
[1] “Rapport de synthèse concernant la cogénération en vue de l’élaboration au niveau fédéral des mesures à prendre pour réaliser et promouvoir la cogénération”, ECONOTEC et VITO, 26 mai 1994

3.2.1. Cement industry

Flowchart 1 : Cement industry in Markal



Characteristics for 5 alternative processes for clinker production are given in the following table. Fuel consumption mix (PC1...PC4) is controlled by adratios to limit petrol-cokes and coal consumption.

Table 4: Processes for clinker production

Description		Availability	Energy cons. GJ/t		Lifetime	Invest cost	Resid
			first	2030		Mil. BF/ kton cap	Cap. 1990
Dry process	PCA	1990	3.4	3.4	15	2.5	
Dry B.A.T.	PCB	2005	2.9	2.9	15	3.8	
Wet	PCC	1990	5.5		15	2	1250
Dry 10 % energy savings	PCD	1995	2.9	2.6	15	4.2	
Dry 20 % energy savings	PCE	1995	2.6	2.3	15	5.2	

The wet process (PCC) is applied when the moister content of the base minerals is high. As this process is the energy intensive, it is fazing out. Actually some capacities still exist.

Clinker production can be based on a variety of fuels. The processes PC1, PC2, PC3 and PC4 represent this.

In ICB clinker is partially replaced by blast furnace slags. Actually, all slag's from Belgian industry is used in cement industry.

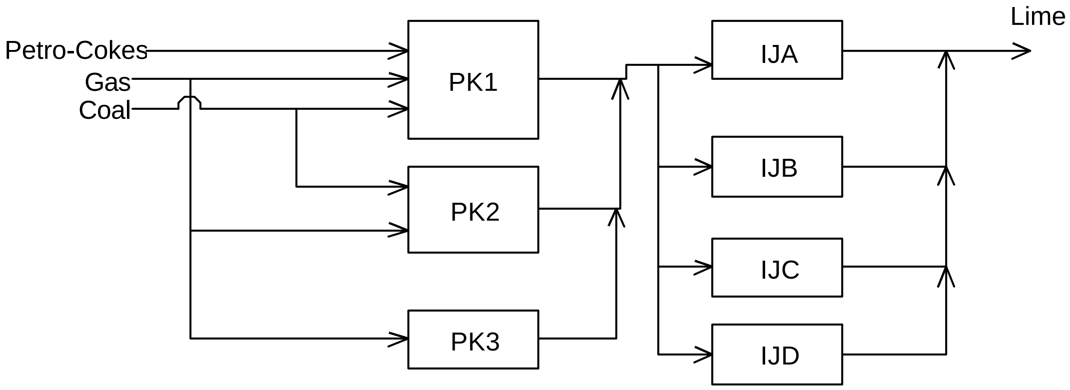
3.2.2. *Glass industry*

Technological options for the glass industry are given in the following table.

Table 5: Technologies for the glass industry

Glass industry		Availability	Energy cons. GJ/t		energy	Lifetime	Invest cost	Resid
			first	2030			Mil. BF/ kton cap	Cap. 1990
Flat glass	IGA		6.91	6.91	Heavy fuel	15	18.65	400
	IGB		6.82	6.82	gas	15	18.65	270
Optimal	IGC	2005	5.96	5.96	Heavy fuel	15	20.52	
Optimal	IGD	2005	5.88	5.88	gas	15	20.52	
Hollow	IHA		9.17	6.9	Heavy fuel	15	18.65	80
	IHB		9.03	6.78	gas	15	18.65	180
Optimal	IHC	2005	5.92	5.92	Heavy fuel	15	20.52	
Optimal	IHD	2005	5.83	5.83	gas	15	20.52	
Fibres	IIA		9.9	8.7	gas	15	18.65	
	IIB	2005	7.17	7.17	gas	15	23.67	
Savings	IIC	1995	7.17	7.17	gas	15	29.2	

3.2.3. *Lime industry*



Lime		availability	Energy cons. GJ/t		Energy	Lifetime	Invest cost	Resid
			first	2030			Mil. BF/ kton cap	Cap. 1990
Rotating	IJA	1990	6.13	5	Mix	20	2	1500
Vertic	IJB	1990	3.77	3.77	Mix	20	2	
Vertic BAT	IJC	2000	3.25	3.25	Mix	20	2.65	
Lime savings	IJD	1995	2.92	2.92	Mix	20	5.33	

Similar as in cement industry, lime industry has flexible fuel substitution possibilities. In processes PK1, and PK2 energy carriers are mixed in fixed ratios. For other environmental reasons, (not for Kyoto) an amount of gas is used in lime industry. This bottom limit is fixed on PK1, whereas in PK2 and PK3 the amount of gas is higher.

3.2.4. *Chemical industry*

The chemical industry is characterised by numerous processes, which can not be modelled in detail. However, from an energy point of view many chemical processes have similar energy requirements. Based on this, the chemical industry is clustered into four main categories: ammonia synthesis, process steam, and high temperature process heat and chlorine production. As energy demand is expressed in PJ, relative efficiencies, compared with a base technology are given in Table 6

Table 6: Energy demand technologies in chemical industry

Chemical industry		availability	relat. eff.	energy	Lifetime	investment cost	delivery
Ammonia synthesis							
	IOA	1990	1	gas	20		
Process steam							
Gas boiler	IPA	1990	0.92	gas	20	114	
Condensing boiler	IPB	1990	1	gas	20	140	
Heavy distillate boiler	IPC	1990	0.85	heavy fuel	20	200	
Heat exchanger PSH	IPD	1990	1	PSH	20		69
Heat exchanger PSL	IPE	1990	1	PSL	20		69
Direct Hydrogen steam boiler	IPH	2000	0.97	Hydrogen	20	114	
10 % energy savings	IPI	1995			20	2000	
Add. 10 % energy savings	IPJ	1995			20	3000	
Chemical Process heat							
	IQA	1990		gas			
5 % energy savings	IQB	1995		gas	20	57	
10 % energy savings	IQC	1995		gas	20	167	
Chlorine							
Chlorine electrolysis	IR1	1990	1	electricity	20	3165	
Chlorine diaphragm	IR2	1990	0.9	electr/gas	20	3425	
Chlorine membrane	IR3	1990	1.2	electr/gas	20	3790	
Chlorine max 10 %savings	IR4	1995				8900	

Ammonia synthesis is based on one process for which no alternatives exist. For process steam, three conventional boiler types on gas and heavy fuel, and two CHP heat exchangers are considered. Investment cost for heat exchangers are included in the price of the CHP technology.

3.2.5. *Steel production and steel processing*

Steal production is a very energy and GHG intensive industry. The following processes are modelled in Markal:

F11 and F12 Cokes factory: technologies for the production of coke. An alternative is the import of cokes

SP5 Sinter plant: the production of sinter with iron ore and cokes as main input materials

SP1 Blast furnace reduction: the classical process for the reduction of iron ore to raw iron

SP2 Direct reduction from gas: direct reduction with gas

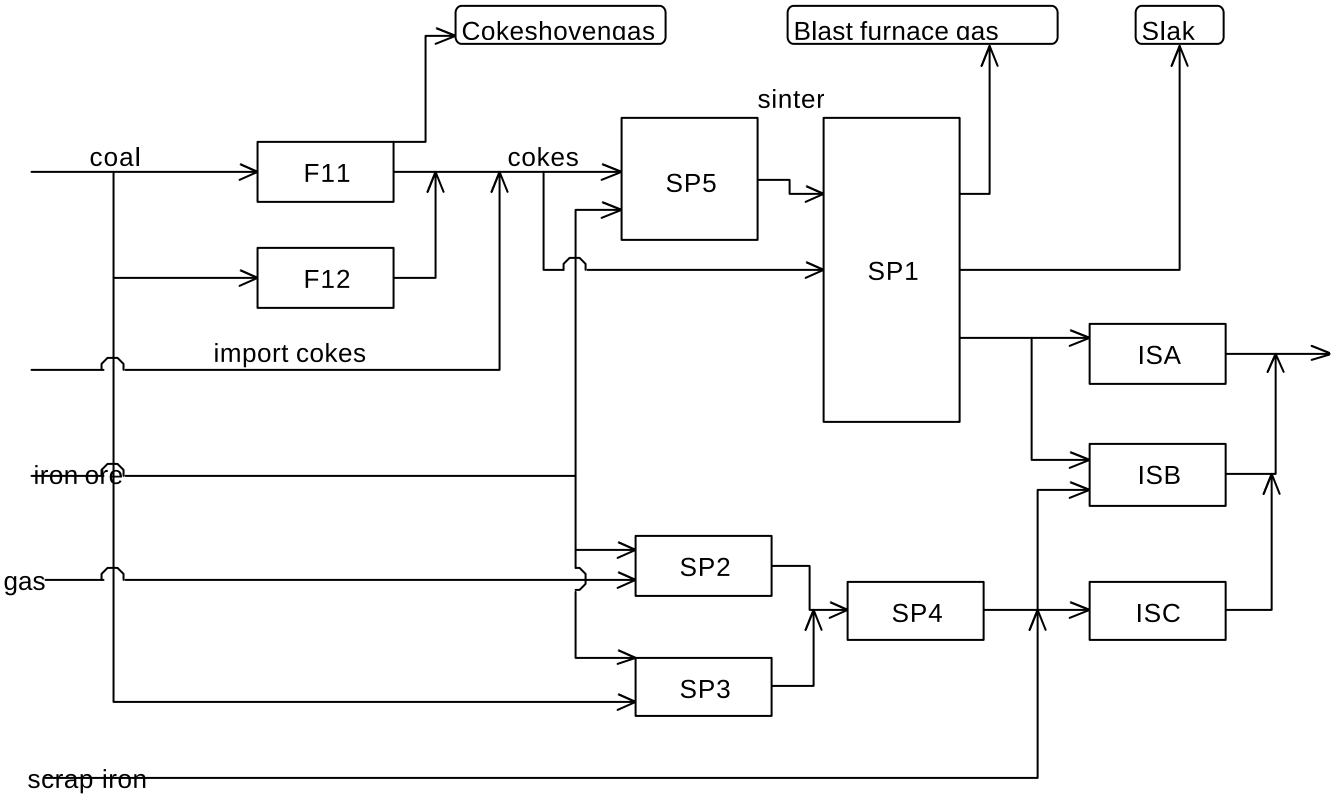
SP3 Sidcomet direct reduction with coal

ISA: Steal production from blast furnace iron. An amount of scrap iron is used for cooling

ISB: Steal production form blast furnace iron, direct reduction iron and/or scrap iron. The amount of direct reduction or scrap iron raises up to 1/3 of total iron used.

ISC: Electric arc furnace steel, mainly based on scrap iron. The amount of electric arc furnace steel is limited to 20 % of total steel production

Flowchart 2: Steal production



On the supply side, the following actions will reduce GHG emissions from steel industry:

Increase amounts of import cokes and reduce own cokes production. However on a worldwide level, this action will not decrease GHG emissions.

Reduce blast furnace activity and increase direct reduction processes. This means a shift from ISA to ISB. As the direct reduction process does not require cokes and sinter, these processes are more efficient.

Increase the amount of scrap iron.

Table 7: Steel processing options

Steel processing		availability	relat. eff.	Elect. Cons	Gas cons	Inv. cost
Cont. Casting	ITA	1990	1	0.27	0.73	
Ingot casting	ITB	1990	0.69	0.23	0.77	
Cont. Casting bat	ITC	1995	1.045	0.23	0.77	306
Cont. Casting savings	ITD	1995	1.1	0.23	0.77	406

3.2.6. *Other industry steam requirements*

These techniques are very similar to the chemical industry.

Table 8: Steam processes

Other industry steam requirements		availability	relat. eff.	energy	Lifetime	investment	deliv
Process steam							
Gas boiler	IYA	1990	0.92	gas	20	114	
Condensing boiler	IYB	1990	1	gas	20	140	
Heavy distillate boiler	IYC	1990	0.85	heavy fuel	20	200	
Heat exchanger PSH	IYD	1990	1	PSH	20		69
Max 10 % energy savings	IYI	1995			20	2000	

3.2.7. *Non sector specific technologies.*

Table 9 : Non sectoral specific energy technologies

Functional industrial classification		Elec.	Gas	H. Dist.	coal	Cons	Lifetime	Invest mil. BF/PJ
Construction materials other	IDA	0.15	0.35	0.1	0.4		20	14300
	IDB	0.135	0.315	0.09	0.36	0.1	20	16360
	IDC	0.12	0.28	0.08	0.32	0.2	20	17164
Continuos power	IK1	1						
	IK2	0.95				0.05		2777
	IK3	0.75				0.25		13136
Variable power	IL1	1						
	IL2	0.98				0.02	10	3963
	IL3	0.75				0.25	15	3484
Electro-thermal	IM1	1						
	IM2	0.9				0.1	10	499
	IM3	0.8				0.2	15	1388
Lighting	IN1	1						
	IN2	0.9				0.1		499
	IN3	0.8				0.2		1388
Base technology other industry	IZA	1	0.58	0.28	0.14			
	IZB	1.05	0.58	0.28	0.14		20	50.8
	IZC	1.1	0.58	0.28	0.14		20	205

4. RESIDENTIAL AND SERVICE SECTOR

Due to the differences in the evolution of demand for energy services and in the availability of technological options this sector is divided:

- by subsector: residential (rural dwellings, urban dwellings and apartments), small and large service
- by type of use of energy: heating, warm water, food preparation and electricity use

The demand categories, with the related technologies, are listed in Table 10.

Table 10: Demand categories in the residential and service sector

Description	Code	Demand in 1990 (PJ)	Demand in 2030 (PJ)	Related demand technologies
Residential space heating, rural	R1	72.9	91.6	20 heating technologies (R11.. R1R), 6 insulation levels (R1T-R1Y)
Residential space heating, urban	R2	95.6	120.9	20 heating technologies (R21.. R2R), 6 insulation levels (R2T-R2Y)
Residential space heating, appartments	R3	59.6	87.6	17 heating technologies (R21.. R2R), 6 insulation levels (R2T-R2Y)
Small service sector	R4	26.5	40.5	12 heating technologies (R41.. R4QR), 1 insulation levels (R4S)
Large service sector	R5	79.9	150.0	12 heating technologies (R51.. R5Q), 1 insulation levels (R5S)
Warm water residential, rural	RF	8.9	11.1	7 technologies (RF1..RFS)
Warm water residential, urban	RG	11.4	16.4	7 technologies (RG1..RGS)
Warm water residential, apartments	RH	7.4	13.0	7 technologies (RH1..RHS)
Warm water, small service sector	RI	2.1	3.6	7 technologies (RI1..RIS)
Warm water, large service sector	RJ	5.0	8.5	3 technologies (RJK1..RJS)
Food preparation	RK	15.7	23.9	3 technologies (RK1..RKL)
Residential electricity use	RL	30.7	66.4	1 technology, 1 savingsoption
Small service sector electricity use	RM	10.5	23.1	1 technology, 1 savingsoption
Large service sector electricity use	RN	24.5	53.9	1 technology, 1 savingsoption
Public lighting	RV	3.5	7.9	2 technologies

The construction of the datas for the demand for energy services starts from the data on the energy consumption of the sector, as there are no data on this type of demand. The computation is based on the following steps:

1. allocation of energy demand in 1990 between residential and service sectors
2. allocation of energy demand between the four demand categories
3. computation of demand for energy services in 1990 and 1995

A first section describes the first two steps. The next two sections are devoted to the third step. The residential sector is separated from the service sector, because the approach for the data construction is different. The last section covers the data for the technologies in both sectors.

4.1. Allocation of total energy consumption between residential and service sector and between demand categories

The primary source is the energy balance from the Energy Administration. Some correction is applied on the EA allocation between the two sectors. It is based on figures computed at CES and VITO. Also the public lightning figure is isolated.

The allocation between each demand category is based on computation made at CES and on datas from Electrabel and VITO. All the computations are made per fuel and the figures are normalised for an average temperature.

This gives the demand of energy per sector and per category, which is used to calibrate the demand for energy services.

4.2. Demand for energy services in the residential sector

In the residential sector, the basic unit for the demand for energy service is the house. Therefore the starting point is an evaluation of the existing housing stock in Belgium and its evolution over time.

After this first step we will evaluate the demand for heating per house, following a methodology outlined by Prof. Hens (KUL Laboratorium Bouwfysica). The results of this modelling exercise will then be compared to actual data. Finally, we will look at the demand for the other categories: warm water, cooking and electricity.

4.2.1. The house stock in Belgium

The number of houses in Belgium in 1990

Two sources were used to obtain the data on the Belgian house stock needed for Markal:

- the NIS data, based on the population survey of 1991
- data from Prof. Hens, KUL Laboratorium Bouwfysica.

We will be looking at the following characteristics of the house stock: age, type, heating system (centralised or local) and insulation level.

The constructions years considered are:

- before 1945
- between 1946 and 1970
- between 1971 and 1980
- between 1981 and 1990
- after 1990

In this text and in the model, houses built until 1990 are referred to as the *existing stock*, while houses built after 1990 are called *new houses*. Following Prof. Hens methodology, the construction year determines the level of insulation that is built-in in the house or flat. Implicitly, it is assumed that there was no upgrade of the insulation level after construction[2]. Insulation of houses will be looked at in a later section.

The types of dwellings considered are:

- open
- half-open
- closed
- flat

These types will be afterwards aggregated in the three types considered in Markal:

- R1, family house in rural site (open houses)
- R2, family house in an urban site (half open & closed houses)

---

[2] As all the houses are not necessarily built with the assumed insulation level, both assumptions might compensate each other on average.

- R3, apartment in building with at least 3 apartments

The NIS data gives the number of houses in 1991, disaggregated by construction year, type and size. However cross data are only available for type and construction year and not for size (Table T.40.12.A). A further disaggregation by heating system either centralised (CV, centraal verwarming) or local (LV, lokaal verwarming) was obtained from Prof. Hens. We used Prof. Hens' shares and applied them to the NIS figures, as totals did not exactly matched. As a result, we obtain the number of houses per construction period, type and heating system in 1990 (assumed to be the same than in 1991). The total number of houses (a generic term that here includes all types of dwellings) in 1990 was 3.748 millions. These results are shown in Table 11.

Table 11: The Belgian house stock in 1990

	open	halfopen	Closed	flat	Total
Before 1945	358,566	219,579	529,187	282,207	1,389,539
1945-1970	379,657	243,135	280,375	402,497	1,305,663
1971-1980	276,243	100,893	82,255	234,821	694,212
1981-1990	190,421	49,032	34,226	85,070	358,750
Total	1,204,887	612,639	926,044	1,004,595	3,748,164

Evolution of the number of houses from 1990 to 2030

The evolution of the number of houses is given through assumptions regarding

- the evolution of the population and of the size of the households,
- the number of demolition,
- the number of conversion from local to central heating in each type of houses.

The evolution of the population is taken from the study by the Statistical Office and the Federal Planning Office, 'Bevolkingsvooruitzichten 1995-2050'. Belgian population was 9.967 million in 1990, and will reach 10.3 millions in 2030.

The number of persons per household is based on the reference scenario in 'Huishoudens en Gezinnen – Monografie n°4, 1997' by the Statistical Office and the Federal Planning Office for the period 1991 – 2011. It goes from an average of 2.49 persons per household in 1991 to 2.28 in 2011. The trend was extrapolated until 2030 assuming the declining trend would continue, though at a slower pace (-0.02 persons per household every 5 years), to reach 2.2 persons per household in 2030. As a result, the number of households grows from 4 millions in 1990 to 4.682 millions in 2030.

To forecast the total number of houses, we have assumed that the ratio of households over house stock would remain constant. We then reach a total number of houses in 2030 of 4.384 millions.

In the past, the number of demolition remained fairly constant in Belgium, at about 16,000 houses demolished per year (as recorded by the Statistical Office for 1990). We have assumed that this figure would stay constant in the future. We also assumed that all houses demolished in 1990 have been built before 1945. After 1990, houses of the next generation (built between 1945 and 1970) can also be demolished.

Demolitions are split between the various house types following the observed shares of the different categories in the house stock built between before 1945 and still existing in 1990. These shares have been kept constant over time (open 28%, half-open 16.6%, closed 37.4%, flats 18%).

The number of new constructions is then computed as the balance between houses remaining from the previous period and the total number of houses desired for the period. New constructions are allocated between the types of houses considered with the coefficients in the table below. They take into account the fact that in the future there will be more flats and one-person households and less open construction.

Table 12: Allocation of houses per type

	New houses			
	Open	Half open	Closed	Flat
1990	19%	5%	40%	36%
1995	17%	3%	42%	38%
2000	14%	3%	43%	40%
2005-2030	11%	3%	43%	43%

Conversions from local to central heating systems are computed in the same way as demolitions, assuming that only houses built before 1981 can be converted. The shares of houses being converted in the number of houses available for conversions (built before 1981, and with a local heating system) is held constant, and in each category, the number of houses converted is proportional to the number of houses in that category.

Moreover, the following assumptions are also taken:

- all new buildings have central heating
- demolished buildings have local heating installation
- conversion occurs without any specific insulation measure

This gives then the number of houses per building year, per type and per heating system over the entire horizon 1990-2030.

4.2.2. The demand for heating

The heat demand per house

The demand of heating is computed per type of house based on the data of Prof. Hens, given an assumption on the average size of the houses. As there are no crossing data between size and type of house in the NIS data, one average size was assumed for the houses and one for the flats:

Houses: 114.5 m^2

Flats: 84.5 m^2

Following Prof. Hens, we have assumed that all houses were built on a square plan.

In sheet *Energievraag Hens*, we present the data received from Prof. Hens on heat demand per detailed house type. The heat demand per house/flat was computed as the average of the heat demand for one and two storied houses and for 3/4/5 storied flat building. For the flats, the average was computed with the weighing coefficients, used by Prof. Hens: 20% for 3 storied, 30% for 4 storied and 50% for 5 storied buildings.

The heat demand per house/flat is given in the next table.

Table 13: Heat demand per house/flat (MJ/year)

	open	**Halfopen**	**closed**	**flat**
Before 1945	60698	56968	51419	61213
1945-1970	53535	50940	46376	50138
1971-1980	27975	25630	22280	23161
1981-1993	23296	20976	17666	17757

To obtain total heat demand, it would suffice, in a simplistic world, to multiply the number of houses by the heat demand per house. However, to arrive at the actual energy demand for heating, one has to take into account the losses that occur at various stages of the heating system. These losses are modelled in the next section on the efficiency of the heating system.

Efficiency of heating system

Total heat efficiency of a heating system (eff_{inst}) can be divided into four components, as described in 'Wonen, verwarmen: energie en emissies', by H. Hens, B. Verdonck (1997): production (the boiler), heat delivery (e.g. losses through the chimney), distribution (from boiler to heating units) and regulation (the system is not 100% flexible to the demand).

$$\text{eff}_{\text{inst}} = \text{eff}_{\text{prod}} * \text{eff}_{\text{distr}} * \text{eff}_{\text{del}} * \text{eff}_{\text{reg}}$$

where:
eff_{prod} : efficiency of the boiler
eff_{del} : efficiency of heat delivery
$\text{eff}_{\text{distr}}$: efficiency in the heat distribution
eff_{reg} : efficiency of the regulation

Table 14: Parameters for heat demand per house/flat (MJ/year)

		Coal	Oil	Gas	But/prop	Electricity
Local	Effproduction	0.80	0.80	0.85	0.80	1.00
	Effregulation	0.90	0.90	0.90	0.90	0.80
	Effdelivery	0.85	0.87	0.90	0.90	0.96
	Effdistribution	1.00	1.00	1.00	1.00	1.00
	Effinst	**0.612**	**0.626**	**0.689**	**0.648**	**0.768**
Central	Effprod (<71)		0.779	0.843	0.784	0.900
	Effprod (71/80)		0.795			
	Effprod (>81)		0.840			
	Effregulation		0.870	0.870	0.870	0.870
	Effdelivery		0.900	0.900	0.900	0.900
	Effdistribution		0.900	0.900	0.900	0.900
	Effinst (<71)		**0.549**	**0.594**	**0.552**	**0.634**
	Effinst (71/80)		**0.560**			
	Effinst (>81)		**0.592**			

Total heat demand by the houses must thus be divided by the efficiency of the system to estimate the actual demand of energy by the houses (or, conversely, energy demand has to be multiplied by efficiency to compute heat demand). Total efficiency, averaged over the house types, is 0.623. Total heat demand, computed as demand per house times the house stock equals 169.8 PJ. Corrected for the efficiency, this gives us a total residential energy demand for heating of 272.6 PJ in 1990.

Total heat demand

This would be the heat demand of 1990, if the weather in 1990 had been average. However, we must add another correction, to take account of the fact that heat demand is lower in years with mild winters. This is done in the following way.

We first define the number of degree-days (DD) of a year as the difference between 15°C and the average day temperature (when below 15°C), summed over the days of the year. The average temperature of the day is the average of lowest and highest temperature recorded that day. These data are published by the Royal Meteorological Institute.

The demand for heat is then assumed to be proportional to this quantity. Computed energy demand for residential heating must be divided by the following adjustment factor to arrive at actual demand.

Adjustment factor = 1.000127276 - 0.0004791 * DD

The winter was particularly mild in 1990, and the adjustment factor is 1.175. We thus arrive at an estimated energy demand for residential heating of 272.6 / 1.175 = 232 PJ. The observed figure in 1990 was 252.4 PJ (an 8% difference).

It is to be noted that in Markal, the efficiency of the heating system is spread between demand and production. On one side, heat demand is increased (by 1/0.81) to take account of the efficiency of distribution and delivery. On the other side, the technologies used for residential heating embed the production and regulation efficiency. To take account of the efficiency of the regulation, the efficiency in Markal database, coming from VITO, and which contained information on efficiency of boilers and other equipment, have been corrected for the regulation efficiency: 0.9 for local heating technologies and 0.87 for central heating.

In computing demand from houses with local heating, we assumed the same efficiency as for central heating. Actually, local heating is more efficient, as can be seen from Table 4.

The efficiency of heating demand (the distribution and delivery components), taken as an average of the data from Prof. Hens (Table 4), are 0.9 for local heating and 0.81 for central heating. As no distinction is made between local and central heating at the demand stage, it is assumed that every local heating technology delivers for free 10% additional heat, to compensate for the 10% difference in efficiency between both systems.

The evolution of the heat demand

The computation of the evolution of the heat demand starts again on a per house base: the heat demand changes with income and energy prices, given a price elasticity of -0.3 and an income elasticity of 0.5. Then the total heat demand is computed by multiplying the heat demand per house by the number of houses and this for each period, type of house and construction year.

The residual capacity

The residual capacity is computed for each technology based upon the disaggregation of the energy demand per fuel, the life duration of the equipment and their efficiency.

4.2.3. Insulation measures, potential and cost

As far as the coding in Markal is concerned, insulation, rather than reducing the heat demand, is considered as a technology that produces heat without any primary inputs (oil, gas, electricity, etc.). In practice, it thus means that the demand of heat to the conventional heat producers will be reduced by the amount produced by the insulation. And the virtual heat produced by insulation is not counted to the final balances. It is thus equivalent to the usual way of thinking of insulation, but much easier to code into Markal. It implies that heat demand is not affected by insulation in Markal, but that some of it is diverted towards the insulation technologies.

Insulation measures

The availability of insulation measures and their cost depends on the construction year of the building. The different levels considered and the possibilities for additional insulation are given hereafter:

A0 Houses built before 1945

Full wall, no insulation.

Additional possibilities are roof/wall insulation and double-glazing.

B0 Houses built between 1945 and 1970:

Hollow wall (4cm), no further insulation.

Additional possibilities are roof/wall insulation and double-glazing.

C0 Houses built between 1971 and 1980

Hollow wall (4cm) filled with insulation, roof-insulation (8cm) and double-glazing**.**

Additional possibilities are roof insulation (16/23cm), wall insulation (8/12cm) and more advanced double-glazing (argon filling and low emission coating).

D0 Houses built between 1981 and 1990

Hollow wall (4cm) filled with insulation, roof-insulation (8cm), double-glazing and floor-insulation (6cm).

Additional possibilities are roof insulation (16/23cm), wall insulation (8/12 cm) and more advanced double-glazing (argon filling and low emission coating).

New houses, built after 1990

New houses (i.e. built after 1990) are built on the D0 standard: hollow wall (4cm) with insulation, roof-insulation (8cm), double-glazing and floor-insulation (6cm).

Options for additional insulation measures are: roof insulation (16/23cm), wall insulation (8/12 cm), floor insulation (9/12 cm) and more advanced double-glazing (argon filling and low emission coating).

These measures allow reaching the K55 level of insulation on new houses. We have estimated that this level could be attained by the following insulation measures: D0 + wall (12 cm), roof (16 cm). In addition, we have considered two other insulation measures for new houses: using better double glazing (argon filled, low emission coatings), and better insulation of the floor (12 cm).

Potential of insulation measures

To compute the potential for heat demand saving, we use a simplified formula to compute the heat demand per house as a function of the characteristics of their shell (wall/roof/glass/floor), based on Prof. Hens study. By changing the parameters affected by the insulation measure, one can then compute the impact on the heat demand of a "typical" house for different insulation measures. Details can be found in sheets *U-waarden* (parameter values) and *reductie in EV* (impact on heat demand).

Characteristics of the Houses

U-values give for the different types of surfaces the energy losses through the surface, in watt per squared metre and per difference in Kelvin between the inside and the outside temperature ($W / m^2 / K$). U values are given in sheet *U waarden*. They take into account the type of material and the type of insulation of each surface. Computing the sum of the U-values times the surface of the different shell gives the building constant C (loss in W/K). This constant allows computing the conduction losses:

$$\text{Conduction losses} = C^*(T_{in} - T_{out}) * \text{year conversion factor}$$

The building constant is in watt per Kelvin (W/K), i.e. in Joule per second and per Kelvin (J/s/K). The year conversion factor is needed to convert the conduction loss per second in conduction loss per year. It is equal to $60 * 60 * 24 * 365 = 3.1536\ 10^7$.

The ventilation factor (VV, measured in J/m^3) represents the loss through inside/outside flow of air. It depends on the type of building (open, half-open, …) and on the age of construction. It varies between 1.5 and 0.7 (see table 3). The ventilation losses are computed as:

$$\text{Ventilation losses} = 0.34 * VV * \text{Volume} * (T_{in} - T_{out}) * \text{year conversion factor}$$

The average volume of a house has been taken as 340 m^3. Following Hens, the average inside temperature asked for is assumed to be 15.7 Celsius. This figure is rather low but takes into account that the heating season does not last the whole year. It will however vary with the average U-value of the house (U_m) (indeed, the more isolated the house, the higher the demand of heat, representing a kind of rebound effect) and the total surface of the building (A_t). Note that $U_m A_t$ is equal to the building constant.

$$T_{in} = 15.7 - 0.00435 * U_m A_t$$

As outside temperature, we took 9.25, a bit higher than what Prof. Hens considered, but it allows a better calibration to his figures using our simplified model.

Free and sun gains are computed in a very simplified way, using the figures below.

Table 15: Parameters for heat demand per house/flat (MJ/year)

	Open	Half open	Closed	Flat
VV value (J/m^3)	1.5	1.3	1.1	0.7
Free gains (GJ/house/year)	15.4	15.4	12.4	15.4
Sun gains (GJ/house/year)	18	15	12	8

The heat demand for the different types of houses, given their characteristics and their insulation, is then computed as

Heat demand = Conduction loss + Ventilation loss – free & sun gains

Varying the insulation measures allows then computing the reduction in heat demand induced by the measure. Computations of heat demand for various types of houses are performed in sheet *Reductie in EV*. For example, we computed here that the heat demand of an open house built before 1945 is 60.5 GJ per year.

4.2.4. Cost of insulation

To define insulation measures in Markal, one must considered the cost per energy saved and not the measure taken in the house, especially as the cost per energy saved varies with the type of house and the installed insulation capacity.

We will consider the following insulation categories. Per insulation category, we need a cost and an energy saving potential. Based on standard house size, the cost (in constant 1990 BF) of the various insulation measures for each type of house is computed in sheet *Insulation Cost*. We also know the annual heat demand of each type of house, with any given type of insulation. We can thus obtain, for each insulation measure, a cost per GJ saved per year.

We will consider three levels of insulation for existing houses. These levels may correspond to different measures for different type/age of houses, as it is the cost per GJ saved that is the relevant variable.

- Level 1: measures with a cost lower than 10,000BF per GJ saved in the different categories of houses and lower than 3,000BF for flats.
- Level 2 measures with a cost between 10,000 and 20,000 BF per GJ saved for houses and between 3,000 and 5,000 BF for flats.
- Level 3: measures above 20,000 and 5,000 BF per GJ saved.

Attaining the level 3 on existing houses is roughly equivalent to the K55 level in new houses. For new houses, we also consider three levels of insulation.

- The first (called level 3, but with no structural link with the level 2 for existing houses) is K55, and costs about 10,000BF/GJ saved (5,000 BF for flats).
- The second (called level 4) corresponds to the addition of high performance double-glazing (argon filled, and with low emission coating). It cost about 15,000 BF/GJ saved.

- The third (level 5) measure give the maximum insulation possible with the techniques considered here. It increases the floor insulation to 12 cm. The cost is very high at about 60,000 BF/GJ saved.

Several assumptions are worth noting:

- Old houses with decentralised heating (built before 1945) will not be isolated
- New buildings always use central heating. (with the exceptions of direct electricity).
- The extra thick roof insulation (23 cm) is not used for the new buildings. We used this restriction because we had to have well-defined and non-overlapping measures. We could have introduced it at the K55 level, but it was not necessary to reach the K55 standard. Anyway, the gains between 16 cm and 23 cm of roof insulation are somewhat limited.

Local heating systems are on average cheaper than central heating system. All else being equal, based purely on costs, Markal would only select local heating in new houses. However, we assume that they will not be installed in new buildings, for comfort reasons. In addition, a number of houses are converted form local to central heating each year (see section II on house stock). To limit the use local heating, It is therefore bounded by the existing capacity in 1990 and the evolution of this capacity through the assumptions about conversion and demolition.

4.2.5. Potential of insulation measures

The potential for energy savings due to insulation measures is limited by the size of the house stock and potential savings per house. To reflect these limits, two sets of constraints have been introduced in Markal. The first is an upper bound on the investment (IBOUND(BD)) for insulation measures on new buildings. It corresponds to the fact that such measures can only be implemented in houses that are actually being built.

The second is an upper bound on the capacity of insulation measures on the existing stock of houses. New houses being built in the current period, can be insulated or not (subject to the constraint in the above paragraph). If they are not insulated at construction time, they can be later. They will then be counted as existing houses, and be subject to the measures to insulating existing (D0) buildings. This will be at a higher price, though, as it is easier to make the necessary works while the house is in construction than afterwards.

However, a house cannot be insulated twice. A set of additional constraints (RAT1l3, RAT2l3 and RAT3l3) fix an upper bound on what can be done with level 3 insulation (which can be achieved both on existing and new building).

This assumes that if level 4 and 5 are not chosen at construction time, they cannot be chosen later. This is not unreasonable, as these measures would then become very expensive (or virtually unfeasible, in the case of floor insulation).

4.2.6. Other demand categories

In addition to heating, demand for energy services from the residential sector comes from three categories: cooking, warm water and electrical equipment (non-heating equipment: lighting, appliances, etc.). See sheet *Warm water and other demand* for details.

Data for 1990 has been collected from CC, *Energie in België 1990* by fuel category (electricity, gas, oil, LPG (butane/propane)), and used to compute a demand per person and per house. A forecast of demand is computed using energy price and private consumption forecast from a GEM-E3 scenario, with the following elasticities:

Table 16: Elasticities of non-heating residential energy demand

	Energy price elasticity	Private cons. elasticity
Warm Water	-0.3	0.5
Cooking	-0.2	0.5
Light & Elec.	-0.3	1.0

4.3. Demand for energy services in the service sector

The procedure for computing the demand for energy services is rather simple. Given the energy demand per category and an average efficiency for existing technologies delivering this type of energy demand, a demand for energy services is computed for 1990 and 1995. A forecast of demand is computed using a forecast from a GEM-E3 scenario for the energy price and the activity of the service sector, with the following elasticities:

Table 17: Elasticities of energy service demand in the service sector

	Energy price elasticity	Activity elasticity
Heating	-0.3	0.8
Warm Water/Cooking	-0.3	0.8
Electricity Specific	-0.3	1

4.4. The technologies in the residential and service sector

A whole range of technologies for heating are modelled for the different subsectors. Heating devices for urban dwellings and rural dwellings are the same devices with the exception of central district heating, but the investment and operation cost for rural dwellings are approximately 25% lower. In addition to heating devices, insulation possibilities are also taken into account. There is a distinction between retrofitting of existing buildings and applying insulation measures on new houses. Central district heating can, at maximum, cover 6% of total heat demand in urban dwellings. For apartments, the same technologies with the same characteristics as for urban dwellings are modelled. Decentralised cogeneration is added to these technologies. Centralised and decentralised cogeneration together can, at maximum, cover 40% of total heat demand in apartments and this maximum can only be reached after 2010.

There are fewer possibilities for investment in heating technologies in services buildings than in the residential sector. The technologies for large and small service sector are nearly the same, but the cost for the small service sector are higher. As for urban dwellings and apartment buildings, there is a limit imposed on district heating: 35% of heat demand of the large service sector and 9% in the small service sector.

The characteristics for demand technologies are listed in Table 18 to Table 27. If space heat and hot water are produced by the same technology, this is indicated in the column "other demand categories". For some technologies bounds on activities or investment are introduced. This is generally the case for energy savings by different insulation levels. Only figures for 2000 are listed for indicative reasoning.

Table 18: Characteristics of demand technologies for heating in category R1 (rural dwellings)

Demand technology		First year available	Efficiency (%)	Energy	Lifetime (years)	Investment (BF/GJ inst)	F O&M (BF/GJ)	V O&M (BF/GJ)	Resid (1990)	Deliv (BF/GJ)	Other DM	bound	Ibound (2000)
Electric heating convectors	R11	1990	0.98	electr.	20	1207	5.6		2.35	758			
Electric heating accum.	R12	1990	0.83	electr.	20	2404	21.3		1.57	0			
Electric heat pump	R13	2000	2.48	electr.	20	4051	11.3		0	758			
Ground source heat pump	R14	2000	2.87	electr.	15	5078	22.6			708			
Airwater bivalent heat pump	R15	2000	2.61	electr.	15	2815	29.6		0	0			
Heat pump + oil boiler	R16	2000	2.09	electr.	15	3644	80.0				RF		
Heat pump + gas boiler	R17	2000	2.11	electr.	15	3778	95.6				RF		
Coal stove	R1A	1990	0.72	coal	15	677	11.3		5.07				
Nat. Gas stove	R1B	1990	0.77	Gas	15	1546	40.6						
Nat gas boiler - old	R1C	1990	0.68	Gas	20	1207	74.5		6.09				
Nat gas boiler	R1D	1990	0.73	Gas	20	1207	74.5						
Nat gas cond. Boiler	R1E	1990	0.83	Gas	20	1444	74.5						
Absorption Heat pump	R1F	2000	1.10	Gas	20	4291	214.0						
Propane Gas stove	R1L	1990	0.85	Propane	15	1639	32.7						
Propane gas boiler	R1M	1990	0.74	Propane	20	1072	26.4		0.17				
Propane gas cond boilier	R1N	1990	0.80	Propane	20	1309	26.4						
Light distillate stove	R1O	1990	0.72	Light dist.	15	1704	32.7		4.10				
Gasoil boiler old	R1P	1990	0.62	Light dist.	20	1907	58.7				RF		
Gasoil boiler	R1Q	1990	0.74	Light dist.	20	1535	58.7						
Gasoil boiler with water heating	R1R	1990	0.74	Light dist.	20	1907	58.7				RF		
Insulation level K55	R1T	1990	1		50	12211						x	
Insulation level 4	R1U	1990	1		50	15711						x	
Insulation level 5	R1V	1990	1		50	66060						x	
Insulation level 1	R1W	1990	1		50	7612						x	
Insulation level 2	R1X	1990	1		50	13133						x	
Insulation level 3	R1Y	1990	1		50	28191						x	

Table 19: Characteristics of demand technologies for heating in category R2 (urban dwellings)

Demand technology		First year available	Efficiency (%)	Energy	Lifetime (years)	Investment (BF/GJinst)	F O&M (BF/GJ)	V O&M (BF/GJ)	Resid (1990)	Deliv (BF/GJ)	other DM	bound	Ibound (2000)
Electric heating (convectors)	R21	1990	0.98	Electr.	20	1577	7.4		1.78	758			
Electric heating accum	R22	1990	0.83	Electr.	20	3139	27.9		0.8				
Electric heat pump	R23	2000	2.49	Electr.	20	5290	14.7						
Ground source heat pump	R24	2000	2.87	electr.	15	6681							
Airwater bivalent heat pump	R25	2000	2.61	electr.	15	3704	39.0			708	RG		
Heat pump + oil boiler	R26	2000	2.09	electr./gasoil	15	4795	105.3			708	RG		
Heat pump + gas boiler	R27	2000	2.11	electr./gas	15	4971	125.3				RG		
Central district heating	R28	1995	0.83	LTH	20	6114					RG	yes	
Coal stove	R2A	1990	0.80	coal	15	884	14.7		7.44				
Nat. Gas stove	R2B	1990	0.85	gas	15	2019	53.1		11.74				
Nat gas boiler old	R2C	1990	0.61	gas	20	1577	97.2		15.8				
Nat gas boiler	R2D	1990	0.74	gas	20	1577	97.2						
Nat gas condensation boiler	R2E	1990	0.80	gas	20	1886	97.2						
Absorption Heat pump (gas)	R2F	2000	1.10	gas	20	5603	279.0						
Propane Gas stove	R2L	1990	0.85	propane	15	2140	42.7		0.8				
Propane gas boiler	R2M	1990	0.74	propane	20	1400	34.1		0.16				
Propane gas cond boilier	R2N	1990	0.80	propane	20	1709	34.4						
Light distillate stove	R2O	1990	0.80	gasoil	15	2225	42.7		5.59				
Gasoil boiler (with water heating) old	R2P	1990	0.62	gasoil	20	2490	76.6		17.7		RG		
Gasoil boiler	R2Q	1990	0.74	gasoil	20	2004	76.6						
Gasoil boiler with water heating	R2R	1990	0.74	gasoil	20	2490	76.6				RG		
Insulation level 3 (K55) new constr.	R2T	1990	1		50	12782							0.84
Insulation level 4 new constr.	R2U	1990	1		50	14208							0.53
Insulation level 5 new constr.	R2V	1990	1		50	59018							0.13
Insulation level 1 existing constr.	R2W	1990	1		50	5703						14.15	
Insulation level 2 existing constr.	R2X	1990	1		50	13008						7.1	
Insulation level 3 existing constr.	R2Y	1990	1		50	22.69						4.9	

Table 20: Characteristics of demand technologies for heating in category R3 (apartments)

Demand technology		First year available	Efficiency (%)	Energy	Lifetime (years)	Investment (BF/GJinst)	F O&M (BF/GJ)	V O&M (BF/GJ)	Resid (1990)	Deliv (BF/GJ)	other DM	bound	Ibound (2000)
Electric heating convectors	R31	1990	0.98	electricity	20	1577	7.37		1.4	758			
Electric heating accumulation	R32	1990	0.83	electricity	20	3139	27.8		1.4				
Electric heat pump	R33	1990	2.48	electricity	20	5290	14.7			758			
Central district heating	R38	1995	0.83	LTH	20	6114	100				RH	6.6	2.69
Decentral district heating	R39	1995	0.85	TER / gas	20	1337	24			58	RH		2.6
Coal stove	R3A	1990	0.8	coal	15	884	14.7		0.76				
Natural gas stove	R3B	1990	0.85	gas	15	2019	53.5		6.42				
Natural gas boiler-old (tariff B&C)	R3C	1990	0.61	gas (GR3 & GR4)	20	1577	97.2		16				
Natural gas boiler (tariff B)	R3D	1990	0.752	gas (GR3)	20	1577	97.2						
Natural gas boiler (tariff C)	R3E	1990	0.752	gas (GR4)	20	1577	97.2						
Absorption heat pump	R3F	2000	0.87	gas (GR3)	20	5603	279						
Propane gas stove	R3L	1990	0.85	propane	15	2140	42.7		0.16				
Propane gas boiler	R3M	1990	0.75	propane	20	1400	34.4		0.08				
Light distillate stove	R3O	1990	0.8	light fuel	15	2225	42.7		0.4				
Gasoil boiler (with water heating) old	R3P	1990	0.62	Gasoil	20	2490	76.6		12.4				
Gasoil boiler new	R3Q	1990	0.76	Gasoil	20	2004	76.6						
Gasoil boiler (with water heating) new	R3R	1990	0.76	Gasoil	20	2490	76.6				RH		
Insulation level 3 (K55) new	R3T	1990	1		50	5180							0.78
Insulation level 4 new	R3U	1990	1		50	8093							0.76
Insulation level 5 new	R3V	1990	1		50	32927							0.05
Insulation level 1 existing	R3W	1990	1		50	2174						9.7	
Insulation level 2 existing	R3X	1990	1		50	4802						12.3	
Insulation level 3 existing	R3Y	1990	1		50	10783						8.8	

Table 21: Characteristics of demand technologies for heating in category R4 (small service sector)

Demand technology		First year available	Efficiency (%)	Energy	Lifetime (years)	Investment (BF/GJinst)	F O&M (BF/GJ)	V O&M (BF/GJ)	Resid (1990)	Deliv (BF/GJ)	other DM	bound	Ibound (2000)
Electric heating	R41	1990	0.98	electricity	20	1577	7.4		0.2	708			
Electric heating accumulation	R42	1990	0.95	electricity	20	3139	27.9		0.1				
Electric heat pump	R43	2000	2.86	electricity	20	5290	14.7			708			
Ground source heat pump	R44	2000	5.89	electricity	20	6681	29.2			708			
Air water bivalent heat pump	R45	2000	3.00	electricity	15	3704	39.0			708			
Heat pump + oil boiler	R46	2000	2.40	electr./ gasoil	15	4795	105.3				RI		
Heat pump + gas boiler	R47	2000	2.43	electr./ gas	15	4971	125.7				RI		
Central district heating	R48	1995	0.95	LTH	20	4080	100.0				RI		
Natural gas boiler	R4D	1990	0.85	gas	20	1577	97.2						
Natural gas condensation boiler	R4E	1990	0.92	gas	20	1886	97.2						
Absorption heat pump	R4F	2000	1.26	gas	20	5603	279.0						
Gasoil boiler	R4Q	1990	0.85	gasoil	20	2004	76.6						
Insulation & heat recovery	R4S	2000	1		25	5783	120.0						

Table 22: Characteristics of demand technologies for heating in category R5 (large service sector)

Demand technology		First year available	Efficiency (%)	Energy	Lifetime (years)	Investment (BF/GJinst)	F O&M (BF/GJ)	V O&M (BF/GJ)	Resid (1990)	Deliv (BF/GJ)	other DM	bound	Ibound (2000)
Electric heating	R51	1990	0.98	electricity	20	1207	5.6		0.5	282			
Electric heating accumulation	R52	1990	0.95	electricity	20	2404	21.3		0.2				
Electric heat pump	R53	2000	2.18	electr/ gas	20	2114	60			282	RJ		
Central district heating	R58	1995	0.96	LTH	20	3012	74						6
Decentral district heating	R59	1995	0.98	TER /gas	20	360	18				RJ		6
Nat. Gas condensation boiler	R5D	1995	0.92	gas	20	529	24				RJ		3
Nat gas boiler	R5E	1990	0.86	gas	20	441	24		20				
Absorption heat pump	R5F	2000	1.50	gas	20	1725	52					10	
Compressed heat pump	R5G	2000	1.63	gas	20	1597	80					10	
Gasoil boiler	R5Q	1990	0.88		20	564	40		38				
Insulation & heat recovery	R5S	2000	1		25	5783	120					10	

Table 23: Characteristics of demand technologies for category RF (warm water in rural dwellings)

Demand technology		First year available	Efficiency (%)	Energy	Lifetime (years)	Investment (BF/GJinst)	F O&M (BF/GJ)	V O&M (BF/GJ)	Resid (1990)	Deliv (BF/GJ)	other DM	bound	Ibound (2000)
Electric water heating at night (R1)	RF1	1990	0.70	electricity	20	3051	30		1.4				
Electric heat pump water heating	RF2	2000	1.87	electricity	20	7039	100						
Natural gas geiser	RFB	1990	0.60	gas	15	2014	141		2.3				
Solar water heating	RFG	1990	0.45	sol / gas	20	8315	299						3.14
Solar water heating electricity	RFH	1990	0.45	sol/electr.	20	9452	251						
Propane gas geiser	RFL	1990	0.45	propane	15	2014	141		0.6				
Solar boiler for R1	RFS	2000	1	sol	15	18000	300				R1		

Table 24: Characteristics of demand technologies for category RG (warm water in urban dwellings)

Demand technology		First year available	Efficiency (%)	Energy	Lifetime (years)	Investment (BF/GJinst)	F O&M (BF/GJ)	V O&M (BF/GJ)	Resid (1990)	Deliv (BF/GJ)	other DM	bound	Ibound (2000)
Electric water heating at night	RG1	1990	0.70	electricity	20	3051	30		1.8				
Heat pump water heating at night	RG2	2000	1.87	electricity	20	7039	100						
Nat. Gas geiser	RGB	1990	0.60	gas	15	2014	141		2.9				
Solar water heating	RGG	1990	0.45	sol /gas	20	8315	299			708			
Solar water heating / electricity	RGH	1990	0.45	sol/electricity	20	9452	251						
Propane geiser	RGL	1990	0.45	propane	15	2014	141		0.8				
solar boiler	RGS	2000	1	sol	15	18000	300				R2		

Table 25: Characteristics of demand technologies for category RH (warm water in apartment buildings)

Demand technology		First year available	Efficiency (%)	Energy	Lifetime (years)	Investment (BF/GJinst)	F O&M (BF/GJ)	V O&M (BF/GJ)	Resid (1990)	Deliv (BF/GJ)	other DM	bound	Ibound (2000)
Electric water heating at night	RH1	1990	0.70	electricity	20	3051	30		1.17				
Heat pump water heating at night	RH2	2000	1.87	electricity	20	7039	100						
Nat. Gas geiser	RHB	1990	0.60	gas	15	2014	141		1.92				
Solar water heating	RHG	1990	0.45	sol /gas	20	8315	299						3.14
Solar water heating / electricity	RHH	1990	0.45	sol/electricity	20	9452	251			708			
Propane geiser	RHL	1990	0.45	propane	15	2014	141		0.5				
solar boiler	RHS	2000	1	sol	15	18000	300				R3		

Table 26: Characteristics of demand technologies for category RI (warm water in small service sector)

Demand technology		First year available	Efficiency (%)	Energy	Lifetime (years)	Investment (BF/GJinst)	F O&M (BF/GJ)	V O&M (BF/GJ)	Resid (1990)	Deliv (BF/GJ)	other DM	bound	Ibound (2000)
Electric water heating at night	RI1	1990	0.70	electricity	20	3051	30		0.2				
Heat pump water heating at night	RI2	2000	1.87	electricity	20	7039	100						
Nat. Gas geiser	RIB	1990	0.60	gas	15	2014	141		0.98				
Solar water heating	RIG	1990	0.45	sol /gas	20	8315	299						3.14
Solar water heating / electricity	RIH	1990	0.45	sol/electricity	20	9452	251			708			
Propane geiser	RIL	1990	0.45	propane	15	2014	141		2.2				
Solar boiler	RIS	2000	1	sol	15	18000	300				R4		

Table 27: Characteristics of demand technologies for category RJ (warm water in large service sector)

Demand technology		First year available	Efficiency (%)	Energy	Lifetime (years)	Investment (BF/GJinst)	F O&M (BF/GJ)	V O&M (BF/GJ)	Resid (1990)	Deliv (BF/GJ)	other DM	bound	Ibound (2000)
Electric water heating	RJ1	1990	0.7	electricity	20	3051	30		0.47	282			
Natural gas geiser	RJA	1990	0.6	gas	15	2000	62		2.3				
Solar boiler	RJS	2000	1	sol	15	18000	300						

Table 28: Characteristics of demand technologies for category RK (cooking)

Demand technology		First year available	Efficiency (%)	Energy	Lifetime (years)	Investment (BF/GJinst)	F O&M (BF/GJ)	V O&M (BF/GJ)	Resid (1990)	Deliv (BF/GJ)	other DM	bound	Ibound (2000)
Electric Cooking	RK1	1990	1	electricity	15	7279			2.65	708			
Natural gas cooking	RKB	1990	1	gas	15	6780			3.95				
Propane gas cooking	RKL	1990	1	propane	15	6780			3				

Table 29: Characteristics of demand technologies for other demand categories (electricity use)

Demand technology		First year available	Efficiency (%)	Energy	Lifetime (years)	Investment (BF/GJinst)	F O&M (BF/GJ)	V O&M (BF/GJ)	Resid (1990)	Deliv (BF/GJ)	other DM	bound	Ibound (2000)
Electricity use in residential	RLA	1990	1	Electricity						708			
Savings electricity residential	RLB	1990			5	5000						2.7	
Electricity use in small service s.	RMA	1990	1	Electricity						708			
Savings electricity small service s.	RMB	1990			5	5000						0.7	
Electricity use in large service s.	RNA	1990	1	Electricity						263			
Savings electricity large service s.	RNB	1990			5	5000						3.6	
Public lighting	RV1	1990	1	Electricity									
Public lighting BAT	RV2	1995	1.43	Electricity	10	1247							

5. THE TRANSPORT SECTOR

The transport sector[3] is divided in passenger and freight transport, subdivided in sub-categories depending on the transport mode. The category passenger transport by car is further split into short distance and long distance travel.

Table 30: Demand categories in the transport sector

Demand category	Markal code	Unit	Level 1990	Level 2030
Short distance private transport by car	T1	billion veh km	40.6	79.8
Long distance private transport by car	T2	billion veh km	32.9	86.7
Transport by bus	T3	billion veh km	1.7	2.3
Freight transport by truck	T4	billion veh km	7.0	13.2
Passenger rail transport	T5	Million veh km	70.0	122.4
Freight rail transport	T6	Million veh km	19.7	39.6
Inland transport by ship	T7	Million veh km	10.0	17.3
Aviation bunker	T8	PJ	40.1	107.0
Marine bunker	T9	PJ	179.0	198.6

Each demand category can be served by a number of different technologies (e.g. the demand for car transport can be satisfied by gasoline fuelled cars, diesel fuelled cars, hydrogen fuelled cars, etc.). The technologies are characterised by the following parameters: investment cost, operating cost, fuel-type, delivery cost of the fuel, efficiency, year of availability, and eventually maximum market potential. Emission abatement technologies (e.g. catalysts) to comply with environmental regulations have been included.

5.1. Passenger transport by car (short distance & long distance)

The 1990 "average" gasoline car is used as reference, considering an average yearly mobility demand per car of 14400 km for the “short distance” category and 22000 km for the "long distance" category. Ten basic of cars are modelled: gasoline car, diesel car, LPG car, CNG car, hydrogen combustion car, hydrogen fuel cell car, electric city car, electric battery module car, ethanol cars, methanol cars. For gasoline, diesel and LPG cars, euro 0 ... euro 4 environmental types are considered.

For well-established technologies like the gasoline and the diesel cars, investment cost is projected to remain constant at its 1990 level. The same is true for cars running on new fuels, like ethanol and methanol, which do not require drastic changes to engine technology like ethanol and methanol. They are expected to be available by the year 2000 at a slightly higher price than the traditional technologies because the corrosiveness of ethanol and methanol imposes the use of more costly materials for the fuel tank and fuel lines. Hydrogen combustion cars have still higher prices, because the fuel tanks have to be constructed from high cost composite materials to be able to withstand the high pressure (some 650 bar) under which the hydrogen is stored. For technologies requiring changes in the engine technology, the investment costs are expected to decrease with time. For electrically powered vehicles, with changeable battery or fixed battery, this would be mainly due to improvements in battery technology, both for the classic lead battery and for the new types of batteries ($ZnBr^-$ or NaS) which are undergoing further development and entering in the stage of mass production.

The most substantial reductions in investment cost are expected in the fuel cell powered car. Fuel cell powered cars are a very novel technology and are expected to enter the market somewhere around

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[3] Aviation and Marine bunkers, though modelled in Markal, are not included in this analysis.

2005, at relatively high prices. Learning effects in the production of fuel cells will reduce investment cost to a level more comparable with the other technologies towards the end of the forecasting horizon.

The delivery costs of energy carriers are expressed in BF/GJ, i.e. BF per unit of energy delivered. The delivery costs for gasoline, diesel and LPG are taken as reference. For the other technologies/fuels the cost above this reference cost are taken into account. The higher delivery cost of methanol is the result of the lower energy density of methanol compared to gasoline and the higher cost of the delivery truck due to a more costly tank. The increase is smaller for ethanol because its energy density is higher compared to methanol. For compressed natural gas, the delivery cost as such is lower because it is delivered via pipelines instead of trucks, but due to the danger involved when filling up with CNG, it is assumed that this will require qualified personnel. This offsets the advantage of the lower cost of distribution of the CNG and the cost will be 160 BF/GJ higher compared to gasoline, diesel and LPG (approximately 5BF/l). The same is true for hydrogen which may be delivered partly through the gas pipelines. The delivery costs for a changeable battery powered car are low because it concerns only the depreciation of the loading devices. For an electric city car, the delivery cost is higher because the use of electric vehicles in the urban areas will impose a heavy strain on the electricity grid, which will need some investment. As said before, the prices do not include taxes or excises.

Table 31: Car technologies

Type	14400 km /year	22400 km /year	energy	availability	Km/MJ	Cost	F O&M	Lifetime
Gasoline car euro 0	T1A	T2A	gasoline	1990	0,3662	420	30	10
Gasoline car euro 1	T1B	T2B	gasoline	1990	0,3662	420	30	10
Gasoline car euro 2	T1C	T2C	gasoline	1995	0,3754	420	30	10
Gasoline car euro 3	T1D	T2D	gasoline	2000	0,3849	420	30	10
Gasoline car euro 4	T1E	T2E	gasoline	2005	0,3946	420	30	10
Gasoline car euro 4 eff	T1F	T2F	gasoline	2010	0,4713	471	30	10
Diesel Euro 0	T1G	T2G	Diesel	1990	0,4077	460	44	10
Diesel Euro 1	T1H	T2H	Diesel	1990	0,4077	460	44	10
Diesel Euro 2	T1I	T2I	Diesel	1995	0,418	460	44	10
Diesel Euro 3	T1J	T2J	Diesel	2000	0,428	460	44	10
Diesel Euro 4	T1K	T2K	Diesel	2005	0,439	460	44	10
Diesel Euro 4 eff	T1L	T2L	Diesel	2010	0,525	513	44	10
LPG car euro 0		T2M	LPG	1990	0,357	510	30	10
LPG car euro 1		T2N	LPG	1990	0,357	510	30	10
LPG car euro 2		T2O	LPG	1995	0,357	510	30	10
LPG car euro 3		T2P	LPG	2000	0,357	510	30	10
CNG car	T1S	T2S	gas	2000	0,394	510	30	10
Ethanol car	T1T	T2T	ethanol	2000	0,394	510	35	10
Hydrogen fuel cel car	T1U	T2U	hydrogen	2000	0,9009	1417	30	10
Hydrogen combustion	T1V	T2V	hydrogen	2000	0,4098	560	60	10
Methanol car	T1W	T2W	methanol	2000	0,398	510	35	10
Electric battery	T1X		electricity	2000	1,006	800	30	10
Electric city car	T1Y		Electricity	2000	1,06	685	30	10
Biodiesel car	T1Z	T2Z	Biodiesel	1995	0,408	472	30	10

Table 32: Bus technologies

Type	Markal key	energy	availability	km/Mj	1000 BF/pc	F O&M	Lifetime	Capacity (10^6km/year)
Diesel bus euro 0	T3G	Diesel	1990	0.1336	3500	80	20	0.0402
Diesel bus euro 1	T3H	Diesel	1990	0.1336	3550	80	20	0.0402
Diesel bus euro 2	T3I	Diesel	1995	0.1336	3600	80	20	0.0402
Diesel bus euro 3	T3J	Diesel	2000	0.1336	3650	80	20	0.0402
Diesel bus euro 4	T3K	Diesel	2005	0.1336	3700	80	20	0.0402
Diesel bus euro 5	T3L	Diesel	2010	0.1336	3800	80	20	0.0402
LPG bus	T3M	LPG	2005	0.1242	3800	80	20	0.0402
CNG bus	T3S	CNG	2005	0.0782	3500	80	20	0.0402
Electric trolley bus	T3T	electricity	1990	0.3861	5250	80	20	0.0402
Fuel cell battery bus	T3U	electricity	1990	0.153	6720	100	20	0.0402
Methanol bus	T3W	methanol	1990	0.1336	3500	80	20	0.0402
Electric battery bus	T3X	electricity	2005	0.4032	5250	80	20	0.0402

Table 33: Truck technologies

Type	Markal key	energy	availability	km/Mj	1000 BF/pc	F O&M	Lifetime	Capacity (10^6km/year)
Diesel truck euro 0	T4G	Diesel	1990	0.0782	3500	80	20	0.038
Diesel truck euro 1	T4H	Diesel	1990	0.0782	3550	80	20	0.038
Diesel truck euro 2	T4I	Diesel	1995	0.0782	3600	80	20	0.038
Diesel truck euro 3	T4J	Diesel	2000	0.0782	3650	80	20	0.038
Diesel truck euro 4	T4K	Diesel	2005	0.0782	3700	80	20	0.038
Diesel truck euro 5	T4L	Diesel	2010	0.0782	3800	80	20	0.038
CNG truck	T4S	CNG	2005	0.0782	3500	80	20	0.038
Ethanol truck	T4T	Ethanol	1990	0.0782	3500	80	20	0.038
Hydrogen truck	T4V	hydrogen	2005	0.0782	4000	100	20	0.038
Methanol truck	T4W	methanol	1990	0.0782	3500	80	20	0.038
biodiesel truck	T4Z	biodiesel	2000	0.0782	3650	80	20	0.038

Table 34: Train & Inland waterways technologies

Type	Markal key	energy	availability	km /Mj	Million BF	F O&M	Lifetime	Capacity (10^6km/year)
Diesel passenger train	T5G	Diesel	1990	0.0067	250	25	25	0.1233
Electric passenger train	T5X	Electricity	1990	0.025	250	25	25	0.1233
Diesel goods train	T6G	Diesel	1990	0.004	250	25	25	0.1233
Electric goods train	T6X	Electricity	1990	0.01	250	25	25	0.1233
Inland diesel ship	T7D	Diesel	1990	0.0029				

5.2. Transport by bus

Demand is expressed in million vehicle km/year. As for cars the european environmental legislation has been introduced. The reference technology for transport by bus is the traditional diesel bus. Alternative types considered are the diesel cumulo bus (which stores the energy from braking), the CNG bus, the hydrogen fuel cell/battery bus, the LPG-bus, the electric battery bus and the electric trolley bus.

The diesel cumulo bus is subject to additional investment cost compared to the reference diesel bus for the storage system of the braking energy. For the investment cost of CNG and LPG fuelled buses the same reasoning as for CNG-trucks applies. The fuel cell bus is equipped with a battery for additional power during acceleration. The battery will be loaded using the braking energy. The investment cost of battery buses is modelled using the same assumptions as for the battery cars.

For the diesel cumulo buses the O&M cost is the same as for the reference diesel bus. Though additional maintenance will be required for the braking energy storage system, the cost will be offset by the lower use that is made of the diesel engine and consequently the lower maintenance cost of the diesel engine compared to the traditional diesel bus. The lifetime of the batteries for battery buses is estimated to be some three years. CNG and LPG buses are subject to more safety controls which increase the operations and maintenance cost. The operations and maintenance cost of trolley buses decreases over the years because more and more of the electric network will be completed, thus imposing a lower charge on the operations and maintenance cost as the years go by.

The lower efficiency of CNG and LPG buses are a consequence of the lower performance of the otto engine powering CNG and LPG buses compared to diesel buses. A cumulo/diesel bus has an efficiency approximately 8% higher than a diesel bus, through the storing of braking energy. Methanol and diesel buses compare well in efficiency.

5.3. Transport by truck.

The reference technology for the category "transport by truck" is the diesel truck. Alternative technologies are CNG-trucks, ethanol trucks, methanol trucks, methanol/diesel trucks and hydrogen trucks. Diesel trucks are equipped with oxidation catalysts.

Diesel, ethanol and methanol trucks have the same investment cost. The methanol/diesel trucks require however additional investment, because in order to work properly, the methanol has to be dissociated into CO and H2 through a catalytic reaction at a temperature of 300°C. The cost of the catalyser/heating unit and the cost of an extra fuel tank explain the higher investment cost of methanol/diesel trucks. The investment cost of a CNG truck is higher because of the ignition system that has to be built in, the cost of the CNG-tank and the loss of useful cargo capacity. The investment cost of a hydrogen truck is still higher because the hydrogen is stored in high pressure cylinders. The loss of cargo capacity is comparable to the CNG truck.

Since all the technologies considered in the truck transport category are based on a normal combustion engine, the investment costs are assumed to remain constant over the entire horizon.

The slightly higher O&M cost of methanol and methanol/diesel trucks is attributable to the corrosiveness of methanol (cf. private cars). The higher O&M cost of CNG and hydrogen trucks results from the necessity to build and maintain tank stations and from safety controls. All O&M costs remain constant over time.

5.4. Rail & inland waterways transport

Electric and diesel technologies are used for rail transport, both for passenger and goods train. Although the technologies are the same, energy consumption is higher for goods transport, which is mainly due to the choosen dimension (train-km)