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MATTER 1.0

A MARKAL Energy and Materials System Model Characterisation

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Framework of the study

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Abstract

This report discusses the MATTER 1.0 model, a MARKAL systems engineering model for Western Europe. This model will be used for development of energy and materials strategies for greenhouse gas emission reduction in the framework of the MATTER study and the BRED study. The report discusses first the general model structure. Next, it discusses the options to decrease greenhouse gas emissions in the life cycle of materials that are considered in the model calculations.

CONTENTS

SUMMARY

This report discusses the MATTER 1.0 model, a MARKAL systems engineering model for Western Europe. This model will be used for development of energy and materials strategies for greenhouse gas emission reduction in the framework of the MATTER study and the BRED study. The report discusses the general model structure. This includes the definition of (groups of) materials, waste materials, products, and the demand scenarios 1990-2050. A full list of all processes in the MATTER 1.0 model is provided. The following options to decrease gas emissions related to the life cycle of materials are considered in the model calculations:

- Increased energy efficiency: alternative materials production processes, based on new technology.
- Increased materials efficiency: increased materials quality.
- Increased materials efficiency: product re-design.
- New recycling technologies.
- Waste separation and product re-use.
- New energy recovery technologies.
- Substitution of energy carriers.
- Substitution of natural resources.
- Substitution of materials.
- End-of-pipe technology.

1. INTRODUCTION

This report describes the current materials systems module in the MARKAL-MATTER1.0 model (status 1/6/1998). The materials system encompasses the whole life cycle of materials (materials production, product assembly, product use and waste handling). The model is a representation of the complete Western European energy and materials system. This model has been developed for greenhouse gas emission reduction studies (e.g. [1,2,3]).

Chapter 2 focuses on the general materials system module characteristics (materials and products). Chapter 3 discusses the strategies to reduce GHG emissions related to the life cycle of materials, the so-called improvement options, that are considered in the model calculations.

The MARKAL model

The MARKAL linear programming model was developed 20 years ago within the international IEA/ETSAP framework (International Energy Agency/Energy Technology Systems Analysis Programme). More than 50 institutes in 27 countries use nowadays MARKAL [4,5]. MARKAL is an acronym for MARKet ALlocation.

The model was originally developed for energy systems analysis. In recent years, the model has been extended for materials systems analysis. The extended model can be used to analyse the whole materials life cycle 'from cradle to grave'.

A MARKAL model is a representation of (part of) the economy of a region. The economy is modelled as a system, represented by processes and physical and monetary flows between these processes. These processes represent all activities that are necessary to provide products and services. Many products and services can be generated through a number of alternative (chains of) processes. The model contains a database of several hundred processes, covering the whole life cycle for both energy and materials. The model calculates the least-cost system configuration which meets a certain energy, materials and products demand. This system configuration is characterised by process capacities, activities and flows.

Processes and the model constraints are model input data that must be provided by the model user. Constraints are determined by the maximum introduction rate of new processes, the availability of resources, environmental policy goals, etcetera.

Processes are characterised by their physical inputs and outputs of energy and material, by their costs, and by their environmental impacts. The greenhouse gases carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and perfluorocarbons (PFC) are considered. Waste volumes and land requirements are other environmental impacts that are considered. Emissions are accounted for in physical units. They are also accounted for in the MARKAL optimisation that is based on costs: all environmental impacts are endogenised in the process costs and the costs of energy and material flows. Emissions are valued in financial terms on the basis of a CO_2-

equivalent penalty level which is set by the model user. Upstream emissions are in the MARKAL methodology transferred in the process chain through the increased shadow prices (or marginal costs) of energy, materials and products.

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Figure 1.1 *Materials system model structure [6]*

MATTER: Western European MARKAL

Approximately one third of all GHG emissions can be attributed to the materials system. Changes in material flows can influence the GHG emissions significantly. The Western European MARKAL model has been developed within the MATTER project (MATerials Technologies for GHG Emission Reduction) in order to study these strategies in more detail. MATTER is a joint project of 5 Dutch institutes in the framework of the National Research Programme on Global Air Pollution and Climate Change (NOP-MLK).

The model covers more than 25 energy carriers and 125 materials. More than 50 products represent the applications of these materials and 30 categories of waste materials are modelled. The following GHG emission reduction strategies have been considered in the materials system:

- industrial process improvements,
- CO_2 removal from industrial plants and storage in depleted gas fields and aquifers,
- reduction of non-CO_2 GHG emissions through end-of-pipe technology and process substitution,
- reduction of materials consumption through product substitution (e.g. re-useable packaging),
- materials substitution,
- renewable biomass feedstocks,
- improved waste collection and separation systems,
- waste recycling, cascading and energy recovery.

Improvement options in the energy system are considered simultaneously. Integrated assessment of improvements in the energy system and the materials system is important because different reduction strategies influence each others efficiency. For example if the reference electricity production becomes less CO_2 intensive due to introduction of renewables, electricity production in waste incineration plants becomes a less attractive option for GHG emission reduction. As a consequence of such interactions, the assessment of the potential and the cost-effectiveness of reduction strategies requires an integrated systems approach. A dynamic approach is required because of the time lag between materials consumption and waste release beyond the product life. For example changing materials consumption in one year can influence the recycling potential in future years. Moreover, GHG emission reduction will take decades. Changing technology, changing consumption patterns, changing resource prices and changing environmental policy goals are issues that must be considered in such a dynamic analysis.

2. MODEL STRUCTURE

2.1 Materials and Energy Model

The MATTER 1.0 energy and materials system model covers the whole life cycle of energy and materials that are consumed in Western Europe. The energy system model structure and energy system model input data are discussed in separate volumes [7,8,9]. The following materials model discussion is on an intermediate level of detail, focusing on the system structure. Model input data and background information for these data are provided in separate reports (Table 2.1). Information regarding input data and some analysis results can also be found on Internet [10].

Table 2.1 *Documentation for the MATTER1.0 model input parameters*

Topic	Report
Metals	[11,12]
Ceramic and inorganic materials	[13]
Natural organic materials	[3,14]
Synthetic organic materials	[15,16]
Buildings and infrastructure	[17]
Packaging	[18]
Road vehicles	[19]

2.2 Materials and Waste Materials

The selection of materials is based on the analysis in [20,21]. The selection covers all key groups of materials from a GHG emission point of view: ceramic materials, inorganic materials, metals, natural organic materials, plastics and other synthetic organic materials. These groups of materials are further desegregated in this analysis. A list of materials that are separately modelled is shown in Table 2.2. A list of all waste materials is provided in Table 2.3.

The code for the materials and waste materials in Table 2.2 and in Table 2.3 represents the materials group. The code starts with an M (for materials) or with a W (for waste materials). The second character represents the materials group:

C = ceramic materials
I = inorganic materials
M = metals
N = natural organic materials
P = plastics
S/T= other synthetic organic materials

This structured coding facilitates data management.

All material flows are modelled in megatons (Mt). Not all materials are actually included in products; some are intermediates in the production of other materials (e.g. many synthetic organic materials).

The level of detail for materials and products is to a large extent determined by their relevance from a greenhouse gas emission point of view. The general rule that has been applied is that all material flows with an upstream GHG emission that equals at least 0.1% of the total Western European GHG emission are separately modelled (which corresponds to approximately 5 Mt CO_2 equivalents per year).

The selection of materials is further based on the uniformity of the production process, the uniformity of the applications and the availability of statistical data regarding material flows.

From a CO_2 emission point of view, the energy intensity has been used as an important indicator for the selection process. From a CH_4 emission point of view, the natural organic materials (paper and board, wood products, other natural fibres) deserve special attention because of CH_4 formation during their decomposition in landfill sites. Regarding N_2O, industrial production processes of nitric acid, adipic acid and caprolactam have been modelled separately. Finally PFC emissions related to primary aluminium smelting have been considered.

The model does not include the emissions from agriculture for food production. Food production accounts for a significant part of the N_2O emissions (from natural fertiliser use) and part of the CH_4 emissions (from ruminants and manure storage). HFC emissions and SF_6 emissions are also not considered. The latter two have been omitted because they are of minor importance. Emission reduction strategies for these substances are still in their infancy.

A list of all waste materials that are separately modelled is shown in Table 2.3. Three types of materials from Table 2.2 have no waste material equivalent. Intermediates have no waste equivalent. Second, some materials are consumed during their use phase. Examples of such materials are fertilisers. A third group consists of waste materials that are irrelevant from a GHG emission point of view, because they can neither be recycled (with significant GHG benefits) nor be used for energy recovery. For example used concrete is not separately modelled. Its recycling as concrete filler is not relevant from a GHG emission point of view. Its disposal has been accounted for through a disposal fee.

Other materials have one or several waste material equivalents. Several waste materials have been modelled if the quality of the waste material limits the recycling potential. The waste quality depends on the product category where the material is applied. For example the bulk of papers ends up in separately collected waste paper, while cardboard beverage packagings end up in MSW. For example the technological potential and the economics of plastic waste recycling are highly dependent on the quality of the waste flow. For wood waste, impurities and size limit the recycling potential. Recovery of metals from Municipal Solid Waste (MSW) is generally more expensive than the collection and recycling of large scrap segments.

Waste materials are modelled that are characterised by their fixed chemical composition, instead of modelling of aggregated waste streams such as MSW, shedder waste, of demolition waste. This approach provides some insight into the changing waste flow composition. Especially over a period of decades, this composition will change significantly. As a consequence, its potential for energy recovery and for recycling will change. The disadvantage of the waste material approach is that waste policies generally focus on waste streams. A translation of modelling results from the waste material level to the waste stream level is generally required.

Table 2.2 *Materials in the Western European MARKAL model*

Code	Material	Code	Material
MCA	CONCRETE BUILDING BLOCKS [T]	MPA	CELLOPHANE [T]
MCB	BRICKS [T]	MPB	PHB/PHV (BIOPOL) [T]
MCC	CEMENT [T]	MPC	BUTADIENE RUBBER (BR) [T]
MCD	READY MIX CONCRETE [T CONCR. EQUIV.]	MPE	POLYETHYLENE [T]
MCE	PREFAB CONCRETE [T CONCR. EQUIV.]	MPF	ACRYLONITRILE BUTADIENE STYRENE [T]
MCH	HIGH STRENGTH CEMENT [T CONV. CEM. EQUI]	MPG	STYRENE BUTADIENE RUBBER [T]
MCK	PORTLAND CEMENT CLINKER [T]	MPM	NYLON 6.6 [T]
MCL	SAND-LIME BRICKS [T]	MPN	NYLON 6 [T]
MCM	MARBLE AND GRANITE STONES [T]	MPP	POLYPROPYLENE [T]
MCQ	QUICKLIME (CaO) [T]	MPR	UF RESINS [T]
MCS	FLOOR TILES + STONEWARE [T]	MPS	POLYSTYRENE [T]
MCT	GLASS [T]	MPT	POLYETHYLENE TEREPHTHALATE [T]
MCY	GYPSUM [T]	MPU	PVC [T EXCL. ADDITIVES]
MCZ	KAOLIN [T]	MPV	PVC [T INCL. ADDITIVES]
MIA	NITRIC ACID [T]	MPW	PUR [T]
MIC	CHLORINE [T]	MSA	ASPHALT [T]
MIF	AMMONIA [T NH3 EQUIV.]	MSB	BENZENE [T]
MIK	POTASH [T K2O EQUIV.]	MSC	CAPROLACTAM [T]
MIN	NAOH [T]	MSD	DETERGENTS [T]
MIP	PHOSPHORIC ACID [T P2O5 EQUIV.]	MSE	ETHYLENE [T]
MIS	SODA [T]	MSF	PROPYLENE [T]
MIZ	SODIUM CHLORIDE [T]	MSG	C4-FRACTION [T]
MMA	ALUMINIUM [T]	MSH	BUTADIENE [T]
MMB	COPPER CATHODE [T]	MSI	BUTYLENE [T]
MMC	CAST IRON [T]	MSJ	BTX [T]
MMD	DRI QUALITY STEEL [T]	MSK	TOLUENE [T]
MMF	DIRECT REDUCED IRON [T]	MSL	LUBRICANTS [T]
MMH	HIGH QUALITY CRUDE STEEL [T]	MSM	CYCLOHEXANE [T]
MMI	IRON [T]	MSN	CUMENE [T]
MML	LOW QUALITY CRUDE STEEL [T]	MSO	DIETHYLENE GLYCOL [T]
MMM	MEDIUM QUALITY CRUDE STEEL [T]	MSP	PAINT [T PAINT EQUIVALENTS]
MMN	REINFORCEMENT STEEL [T]	MSQ	XYLENES (MIXED) [T]
MMO	HOT ROLLED SECTION STEEL [T]	MSR	NATURAL ELASTOMERES (RUBBER) [T]
MMP	HOT ROLLED COIL STEEL [T]	MST	ETHYLENE OXIDE [T]
MMQ	COLD ROLLED COIL STEEL [T]	MSU	ETHYLENE GLYCOL [T]
MMR	COLD ROLLED COIL AT&F STEEL [T]	MSV	PROPYLENE OXIDE [T]
MMS	COLD ROLLED COIL F&P STEEL [T]	MSW	ACRYLONITRILE [T]
MMT	HEAVY PLATE STEEL [T]	MSX	P-XYLENE [T]
MMU	WIRE ROD STEEL [T]	MSY	O-XYLENE [T]
MMV	ALLOY STEEL [T]	MSZ	XYLENE RESIDUE [T]
MMW	GALVANIZED/TINPLATE STEEL [T]	MTA	TEREPHTHALIC ACID [T]
MMX	COPPER CONCENTRATE [T]	MTB	BUTANOL [T]
MMY	SEMI-FINISHED COPPER [T]	MTC	ACETONE [T]
MNA	COMPOST (15% H2O) [T]	MTD	PHENOL [T]
MNB	ROUNDWOOD (15% H2O) [T]	MTE	PHTHALIC ANHYDRIDE [T]
MNC	CHIPBOARD [T]	MTF	STYRENE [T]
MNF	FIBER BOARD [T]	MTG	VINYL CHLORIDE MONOMER (VCM) [T]

Table 2.2 (continued) *Materials in the Western European MARKAL model*

Code	Material	Code	Material
MNG	GRAVEL AND SAND [T]	MTH	FORMALDEHYDE [T]
MNK	PALM KERNEL OIL [T]	MTI	UREA [T]
MNL	MARIGOLD FLOWER OIL [T]	MTJ	ANILINE [T]
MNM	HIGH QUALITY WASTE PAPER PULP [T]	MTK	ACETIC ACID [T]
MNN	LOW QUALITY WASTE PAPER PULP [T]	MTL	HEXAMETHYLENEDIAMINE [T]
MNO	MECHANICAL PULP [T]	MTM	NITRO-BENZENE [T]
MNP	PACKAGING PAPER AND SANITARY PAPER [T]	MTN	METHYL ETHYL KETON (MEK) [T]
MNQ	GRAPHIC PAPER [T]	MTO	ADIPIC ACID [T]
MNR	NEWSPRINT [T]	MTP	I-PROPANOL [T]
MNS	WOOL [T]	MTQ	TOLUENEDIISOCYANATE [T]
MNT	SAWN TROPICAL HARDWOOD (15 % H2O) [T]	MTR	2-ETHYLHEXANOL [T]
MNU	CHEMICAL PULP [T]	MTS	CARBON BLACK [T]
MNV	VISCOSE/RAYON [T]	MTU	SURFACTANT (AES) [T]
MNW	OTHER SAWN WOOD/PLYWOOD (15 % H2O) [T]	MTV	ACETIC ANHYDRIDE [T]
		ORE	IRON ORE [T]
		OXY	OXYGEN [T]
		PEL	PELLETS [T IRON EQUIV.]
		SIN	SINTER [T IRON EQUIV.]

Table 2.3 *Waste materials in the Western European MARKAL model*

Code	Waste material
WCC	BLAST FURNACE SLAG [T]
WCF	FLY ASH [T]
WCT	WASTE GLASS [T]
WMA	ALUMINIUM SCRAP [T]
WMB	COPPER SCRAP [T]
WMF	STEEL SCRAP [T]
WMM	STEEL SCRAP IN MSW [T]
WMN	ALUMINIUM SCRAP IN MSW [T]
WND	DEMOLITION WOOD [T]
WNF	WASTE NATURAL TEXTILE FIBER [T]
WNK	KITCHEN WASTE (30% H2O) [T]
WNP	WASTE PAPER, SEPARATELY COLLECTED [T]
WNQ	WASTE PAPER, WRAPPINGS ETC. IN MSW [T]
WNR	MIXED WOOD WASTE (15% H2O) [T]
WNS	WOOD PROCESS WASTE (15% H2O) [T]
WP1	POLYOLEFINE WASTE CLEAN [T]
WP2	POLYOLEFINE WASTE MIXED [T]
WP3	POLYOLEFINE WASTE MSW [T]
WP5	POLYSTYRENE WASTE CLEAN [T]
WP6	POLYSTYRENE WASTE MIXED [T]
WP7	POLYSTYRENE WASTE MSW [T]
WPA	PVC WASTE CLEAN [T]
WPB	PVC WASTE MIXED [T]
WPC	PVC WASTE MSW [T]
WPF	PET WASTE CLEAN [T]
WPG	PET MIXED [T]
WPH	PET WASTE MSW [T]
WPJ	NYLON WASTE MIXED [T]
WPX	BIOPLASTICS WASTE [T]
WSA	ASPHALT WASTE [T]
WSL	WASTE LUBRICANTS [T]
WSR	ELASTOMERES WASTE [T]

The waste material approach with different waste qualities allows modelling of waste cascades. It is generally no problem to use clean waste materials in processes that can handle mixed waste materials. However the other way around is only possible if expensive separation and upgrading processes are applied. An example of a cascade within the model is shown in Figure 2.1. The figure shows a waste cascade for plastics. Three types of plastic waste are modelled. The first one is high quality waste (HQ), representing pure plastics that can be re-extruded to yield polymers. This type of waste arises from production residues and from e.g. industrial packaging. The second type is mixed plastic waste. Mixed plastics, e.g. shredder residues, can only be recycled to high-grade polymers after separation. They can however be downcycled (back-to-monomer recycling, i.c. pyrolysis and back-to-feedstock recycling, i.c. hydrogenation). The third type is plastic in municipal solid waste (MSW), e.g. food packaging. Grate incineration and disposal are options for treatment of this waste stream. Upgrading of this waste type to the mixed plastic quality is possible, but requires extensive and expensive collection and separation.

Title: WASTE1.EPS
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Figure 2.1 *Example of materials cycle modelling including a waste quality cascade (MTO = Methanol To Olefins process; ox. Coupling = oxidative coupling)*

Similar cascades are modelled for wood products. For steel and aluminium, scrap in MSW has been modelled separately. Recovery and upgrading costs for these scrap types are significantly higher than for other scrap types. The waste modelling approach should be considered as a simplified approach. In real scrap markets, a division is made into much more scrap grades with different upgrading requirements and different prices (see e.g. [22,23]). It is basically possible to model such detail in MARKAL. However for a time horizon of five decades, the much higher level of uncertainty in other variables does not warrant such a level of detail. Moreover detailed modelling complicates the analysis of the key relations in the model. The analysis of these relations is one of the most important issues of the modelling study.

2.3 Product service categories and product alternatives

The list of product service categories has been developed from the aggregated list of 12 groups of product services that is discussed in [24]:

- residential buildings,
- other buildings,
- roads,
- other infrastructure,
- passenger cars,
- other transportation equipment,
- machinery and other production equipment,
- furniture and interior decoration,
- consumer durables,
- packaging,
- other non-durable products,
- auxiliaries/residual demand.

These product groups have been selected because the materials consumption - from a GHG emission point of view - is evenly distributed among these product groups. Moreover, the product life is significantly different. The product life affects the system dynamics.

Table 2.4 *Product service categories and product alternatives in the Western European MARKAL model*

Product service	Code	Product alternatives	No. of alternatives
Residential buildings			
Single family dwellings (2 types)	R1/5/6/8	Materials substitution	3 for 4 groups[1]
Multi family dwellings	R2/4/7	Materials substitution	3 for 3 groups[2]
Cellars [100 million m^2]	JV	Materials substitution	2
Window frames [1000 million frames]	JT	Materials substitution	4
Outside wall cladding [1000 million m^2]	RM	Materials substitution	4
Other buildings			
Service sector buildings	C0/1/2/3	Materials substitution	3 for 4 groups[3]
Industrial/agricultural buildings type 1	RJ	Materials substitution/re-design	3
Industrial/agricultural buildings type 2	RK	Materials substitution/re-design	3
Roads			
High volume roads	TH	Materials substitution	2
Low volume roads	TL		
Other infrastructure			
Railway tracks	TR	Materials substitution	2
Waterworks	TS	Materials substitution	4
Electr./telecomm. wire [Mt copp. wire e]	JR	Materials substitution	2
Pipes and ducts [Mt PVC equiv.]	JS	Materials substitution	2
Pipelines [Mt steel equiv.]	KC		
Passenger cars			
Passenger car (2 types)	T0	Materials substitution	4 for 2 types
6 Other transportation equipment			
Van	T1	Materials substitution	4
Truck	T2	Materials substitution	3
Machinery and production equipment			
Machinery	IM		
Industrial pressure vessels [pcs]	KA		
Nuts, bolts, nails etc. [Mt steel equiv.]	KB	Materials quality	2
Capital equipment	IZ		
Furniture and interior decoration			
Furniture (chests)	RP		
Desks	CG	Materials substitution	3
Interior wall cladding [1000 million m^2]	RZ	Materials substitution	4
Floor cladding [1000 million m^2]	RV	Materials substitution	4
Consumer durables			
Appliance materials use dummy	RQ		
Textiles	RU	Materials substitution	2

[1] North, 2 Central, South
[2] North, Central, South
[3] North, 2 Central, 1 South

Table 2.4 (continued) *Product service categories and product alternatives in the Western European MARKAL model*

Product service	Code	Product alternatives	No. of alterna-tives
Packagings			
Beverages, carbonated [Gl]	P1	Materials substitution/product re-use	7
Beverages, non-carbonated [Gl]	P2	Materails substitution/product re-use	6
Dairy products, no milk [Mt]	P3	Materials substitution	2
Wet food [Gl]	P4	Materials substitution/materials effi-ciency	3
Dry food, non-susceptible [Gl]	P5	Materials substitution/materials quality	8
Dry food, susceptible [Gl]	P6	Materials substitution/materials quality	6
Non-food liquids [Gl]	P7	Materials substitution	4
Dry non-food [Gl]	P8	Materials substitution	6
Carrier bags [10^9 bags]	P9	Materials substitution/product re-use	4
Industrial bags [Mt]	PA	Materials substitution/product re-use	4
Transport packaging [Gl]	PB	Materials substitution	5
Pallet wrapping [10^9 trip units]	PC	Materials substitution	2
Pallets (1000 million pcs)	TU	Materials substitution	2
Other non-durable products			
Compost	RX	Feedstock substitution	2
Non Energy Use: Lubricants + Bitumen	N1	Feedstock substitution	2
Residual paper	IV		
Auxiliaries/residual demand			
Fertilisers	IR		
Residual aluminium	IA		
Residual bricks	IB		
Residual chlorine	IC		
Residual glass	ID		
Residual sodium chloride	IK		
Residual petrochemicals	IS		
Residual cement clinker	IU	Materials quality	2
Residual wood	IX		

For some materials, detailed data are available regarding their application in specific product groups. These data is supplemented with estimates. These estimates are based on data for product quantity, multiplied with the materials composition of products. Another approach is based on monetary flows. Materials sales (in monetary units) divided by the materials price result in an estimate for the physical materials flows. However, the materials price can significantly differ per product group and per time period, so this approach is likely to result in less reliable estimates. The latter approach has only been used in cases where physical material flow data were not available.

The aggregated product groups have been further detailed. For some materials, detailed data are available regarding the consumption of important materials within these groups (mainly from branch organisations). Other data for products within product groups are based on LCA studies and other engineering studies. The products are considered to be characteristic products within a certain product group. A list of products and product alternatives is shown in Table 2.4. The product life span is indicated in Table 2.5.

Table 2.5 *Assumptions regarding product life span*

Product category	Life span [years]
Residential buildings	70-80
Other buildings	35-60
Roads	80
Other infrastructure	25-50
Passenger cars	12.5
Other transportation equipment	10-15
Machinery and other production equipment	25
Furniture and interior decoration	10
Consumer durables	10
Packaging	1
Other non-durable products	1
Auxiliaries/residual demand	1

2.4 Processes

Seven types of processes are modelled in the materials life cycle:

- primary materials production,
- materials recycling,
- product assembly,
- product use,
- waste product removal and separation,
- energy recovery,
- disposal.

For products with direct energy use (during the product use phase), direct energy use dominates generally indirect energy use (during production and waste management). Consequently, the use phase is the most important process from a CO_2 emission point of view. These products (e.g. cars, buildings, electric appliances) have already been included in the energy system module.

The processes with the highest GHG emissions in the materials life cycle (excluding the product use phase) are generally involved with primary materials production (including upstream emissions in electricity production) and waste management (recycling, energy recovery, and disposal). For this reason, these processes are modelled in more detail than the other ones. The other processes in the life cycle (product manufacturing and waste product collection and separation) are relevant because they determine the materials production and waste management.

Complex process routes in materials production, such as steel production or plastic production, are split into a number of separate steps. Each material and each product alternative is at least characterised by one (chain of) production processes. For some materials, a number of different production processes are currently applied. These processes are separately modelled if they show very different energy and/or GHG balances. The data for these processes represent the Western European average for historical years. Significant energy efficiency improvements (to basically unchanged processes) have not been modelled as separate processes. Instead, they are considered to be part of an autonomous energy efficiency improvement (AEEI) of a specific process. Changing energy efficiencies for subsequent time periods represent the AEEI.

Literature data for efficiency improvement potentials, data regarding the current best practice energy efficiency, historical energy efficiency improvements and data regarding the maturity of the process have been used to generate a forecast for future energy efficiency. Economic data and data regarding labour productivity have not been adjusted for future years unless very considerable improvements are documented in literature. In reality, significant labour productivity gains have occurred in the last decades due to a shift to more capital intensive production technology and due to technological development. Because labour costs do often constitute a more significant part of the process costs than energy costs, there is more incentive to increase labour productivity than there is to increase energy productivity (or energy efficiency). It seems likely that further gains will be achieved in the next decades. In case of competition between labour intensive processes and capital intensive processes, this simplification should be borne in mind.

2.5 Treatment of Temporal and Spatial System Boundary Effects

System boundaries in this study are based on the end-use of energy and materials by Western European consumers in the period 1990-2070. Model results for the period beyond 2050 are not reported because of potential effects of the system boundary on the system configuration. Waste materials that are released beyond the time horizon may affect the modelling results in the last two decades. Data for material flows in the period 1990-1995 and forecasts for the year 2000 have been used to calibrate the model [24].

The GHG emissions related to imports into Western Europe and exports out of Western Europe are also accounted (Table 2.6). Upstream emissions abroad (‘rucksacks’) are accounted for all net imports of energy and materials. For net exports of materials, emissions within Western Europe are deducted (‘credits’). The GHG-value of net imports and exports has been based on the GHG impact of the current Western European production processes. With regard to the net imports and net exports, no changing emissions due to emission reduction policies are considered. Imports and exports are constrained by upper and lower bounds. Constraints for the year 2030 are shown in Table 2.6. A proper analysis will require a regionalized world model, beyond the scope of the current optimisation.

Net imports and exports of finished products have not been considered. For net exports of waste products (such as trucks) and waste materials (such as steel scrap) to countries outside Western Europe, no GHG credits for foreign recycling are attributed to the system. It is difficult to estimate the GHG impact of waste handling, because it requires a detailed analysis of different materials chains. Moreover, MARKAL results where credits are attributed to waste exports result in export/accounting strategies to 'solve' environmental problems. This effect is caused by the fact that emissions in primary materials production decline rapidly in a scenario with emission penalties. As a consequence, the emission benefits of recycling within the system decline. However the emission credits for exports remain the same. Consequently it becomes attractive to export waste to reduce the systems emissions. This is thought to be no sensible policy option. For this reason, no credits are accounted for waste exports.

Table 2.6 *The GHG credits and rucksacks for net exports and imports, respectively*

	Material	Credits/rucksacks [Mt CO_2/t]	Cost [ECU/t]	Lower bound 2020 [Mt/year]	Upper bound 2020 [Mt/year]
Imports	Tropical timber	3.5	250	-	-
	Rubber	1.0	875	0.5	-
	Copper concentrate	0.5	100	0.75	2.0
	Copper cathodes	1.0	3500	-	-
	Alumina	1.5	200	-	-
	DRI	0.7	150-200	0	10
	Chipboard	0.5	1000	-	-
	Renewable sawn timber	0.3	500	-	-
	Polypropylene	3.0	1500	-	-
	PVC	2.0	1500	-	3.8
Exports	Sodium hydroxide	-1.0	50	-	1.0
	Steel coils	-1.5	0	22.5	-
	Benzene	-4.0	100	1	-
	Caprolactam	-4.0	200	-	-
	Ethylene	-4.0	100	-	2
	Propylene	-4.0	100	-	1
	Butylene	-4.0	200	-	1
	Butadiene	-4.0	200	-	1
	Toluene	-4.0	100	-	1.25
	Cyclohexane	-4.0	150	-	2
	Cumene	-4.0	150	-	2
	Diethylene glycol	-4.0	200	-	2
	Ethylene oxide	-4.0	150	-	2
	Ethylene glycol	-4.0	150	-	2
	Propylene oxide	-4.0	250	-	2
	Acrylonitrile	-4.0	250	-	-
	O-Xylene	-4.0	300	-	2
	Terepthalic acid	-4.0	300	-	2
	Butanol	-4.0	150	-	1
	Acetone	-4.0	150	-	1
	Phenol	-4.0	200	-	1
	Phthalic anhydride	-4.0	200	-	1
	Urea	-2.0	100	0.5	1.5

MARKAL does not calculate the specific GHG emissions per unit of product by addition of process emissions. A different accounting practice is applied for CO_2. The CO_2 emission account is largely based on the energy input of the system instead of an account of the process-specific emissions. The bulk of the CO_2 emissions is proportional to the use of fossil energy carriers. The CO_2 emissions from energy use are calculated on the basis of net imports and mining of fossil fuels and the storage of carbon and CO_2, following the IPCC emission accounting guidelines [25]. Contrary to the IPCC approach, wood use in buildings is modelled as carbon storage during the product life. All other greenhouse gas emissions are modelled as process-specific GHG emissions (proportional to the process activity).

2.6 Final Demand for Product and Material Services

The demand scenario in this study is derived from the ‘rational perspective’ scenario that has been developed previously for the energy systems model [7]. A discount rate of 8% has been applied for all investments in all sectors, representing an average of low discount rates in the public sector (utilities etc.) and higher discount rates in the private sector (e.g. industry and households). In this scenario the growth in demand for services, with important negative external effects on environment and health, is limited. Energy demand in the commercial sector and transport sector has been related to growth in GDP. The demand in the residential sector is driven by the number of households and the penetration level of products and services. Energy prices rise moderately (e.g. the crude oil price increases gradually by 30-40% to 4.4 ECU_{1995}/GJ in 2050, coal prices are virtually stable at 1.8-2 ECU_{1995}/GJ).

In order to find key demand parameters for sensitivity analyses, the impact of (groups) of demand categories on the total GHG emissions in 2030 has been analysed. This is not a straightforward calculation in MARKAL, because the model provides only a value for the emissions on a systems level. The model does not produce an emission value for individual products or demand categories. As a consequence, a method has been developed to estimate this emission. The result is shown in the last column of Table 2.6. These emission values have been obtained by calculation of the difference in GHG emissions between two runs without any GHG emission constraints (base-case runs). One run encompassed all demand categories as indicated in Table 2.7. In the other run, the end use of one (group of) demand categories was set to zero. The difference in GHG emission between both runs represents the contribution of this individual demand category to the total GHG emission.

One should add that this is a measure for the *marginal* impacts. The totals for all demand categories, treated in such a way, will not add up to the total emissions. For example, the marginal electricity production (the most costly option that is applied to satisfy total electricity demand) may be based on renewables with zero CO_2-emissions, while a significant fraction of the total electricity production is based on coal (with high CO_2 emissions). Each time one demand category is set to zero and electricity demand decreases, the same renewable energy based electricity production will be excluded in the cost minimisation approach (with limited GHG consequences). As a consequence, the total impact for all demand categories, calculated according to this method, can not equal the total emission for the whole system.

The results show the importance of the categories buildings (code C0..Rk) and transportation equipment (T0..T2). Their importance is so high because these end use parameters also determine the direct energy use (heating and cooling, and transportation fuel demand, respectively). Assuming that 15-20% of the CO_2 equivalents for buildings and for transportation can be allocated to materials, the total impact of materials is 1200-1300 Mt CO_2 equivalents. For some product groups such as infrastructure the net impact is very small due to the carbon storage effect (i.c. bitumen storage in asphalt). The results indicate that the transportation demand and the building demand are key parameters for sensitivity analyses.

Table 2.7 *Product service demand trends in the Western European MARKAL model (index)*

Code	Demand category	Unit	1990	2020	2050	Contribution 2030 [Mt CO_2 equiv.]
C0/1/2/3	Service sector buildings	[m^2]	100	147	164	629
R1/5/6/8	Single family dwellings (2 types)	[m^2]	100	122	128	
R2/4/7	Multi family dwellings	[m^2]	100	160	228	
RJ	Industrial/agricultural buildings type 1	[m^2]	100	109	119	
RK	Industrial/agricultural buildings type 2	[m^2]	100	108	116	
P1	Beverages, carbonated	[10^9 litres]	100	117	131	127
P2	Beverages, non-carbonated	[10^9 litres]	100	120	139	
P3	Dairy products, no milk	[10^9 litres]	100	132	163	
P4	Wet food	[10^9 litres]	100	152	204	
P5	Dry food, non-susceptible	[10^9 litres]	100	112	125	
P6	Dry food, susceptible	[10^9 litres]	100	152	204	
P7	Non-food liquids	[10^9 litres]	100	151	203	
P8	Dry non-food	[10^9 litres]	100	111	123	
P9	Carrier bags	[10^9 bags]	100	115	130	
PA	Industrial bags	[Mt]	100	157	213	
PB	Transport packaging	[10^9 litres]	100	142	185	
PC	Pallet wrapping	[10^9 trip units]	100	175	250	
TU	Pallets	[10^9 pieces]	100	125	150	
T0	Passenger car (2 types)	[pieces]	100	144	193	1207
T1	Van	[pieces]	100	123	131	
T2	Truck	[pieces]	100	138	170	
IA	Residual aluminium	[Mt]	100	134	150	215
IB	Residual bricks	[Mt]	100	50	50	
IC	Residual chlorine	[Mt]	100	71	71	
ID	Residual glass	[Mt]	100	267	300	
IK	Residual sodium chloride	[Mt]	100	106	112	
IM	Machinery	[pieces]	100	110	119	
IS	Residual petrochemicals	[Mt]	100	155	175	
IZ	Capital equipment	[pieces]	100	115	130	
IR	Fertilisers	[Mt]	100	120	120	150
IV	Residual paper	[Mt]	100	186	200	53
N1	Non Energy Use: Lubricants + Bitumen	[PJ]	100	100	100	7
CG	Desks	[pieces]	100	134	175	33
JS	Pipes and ducts	[Mt PVC equiv.]	100	175	250	
JT	Window frames	[10^9 frames]	100	119	138	
JV	Cellars	[10^8 m^2]	100	119	137	
RM	Outside wall cladding	[10^9 m^2]	100	138	175	
RV	Floor cladding	[10^8 m^2]	100	125	150	
RZ	Interior wall cladding	[10^9 m^2]	100	125	150	
IU	Residual cement clinker	[Mt]	100	100	100	49
IX	Residual wood	[Mt]	100	138	144	
JR	Electr./telecomm. wire	[Mt copper wire equiv.]	100	121	143	203
KA	Industrial pressure vessels	[pieces]	100	100	100	
KB	Nuts, bolts, nails etc.	Mt steel equiv.]	100	119	138	
KC	Pipelines	[Mt steel equiv.]	100	138	175	
RP	Furniture (chests)	[pieces]	100	113	125	113
RQ	Appliance materials use dummy	[pieces]	100	125	150	
RU	Textiles	[Mt]	100	125	150	
RX	Compost	[Mt]	100	100	100	
TH	High volume roads	[m^2]	100	137	175	20
TL	Low volume roads	[m^2]	100	113	118	
TR	Railway tracks	[km]	100	121	143	
TS	Waterworks	[Mt THW equivalents]	100	100	100	

3. IMPROVEMENT OPTIONS

3.1 Introduction

This chapter discusses the following options to reduce energy requirements and greenhouse gas emissions:

- Increased energy efficiency in materials production: alternative materials production processes, based on new technology.
- Increased materials efficiency: increased materials quality.
- Increased materials efficiency: product re-design.
- New recycling technologies.
- Waste separation and product re-use.
- New energy recovery technologies.
- Substitution of energy carriers in materials production.
- Substitution of raw materials for materials production.
- Substitution of materials.
- End-of-pipe technology.

They cover both improvements in materials production and improvements in materials use.

3.2 Increased energy efficiency: alternative materials production processes, based on new technology

New processes can be significantly more energy efficient due to new technology. Promising process designs that are considered in the calculations are listed in Table 3.1. The list includes only processes that have not been used in the past and that are currently not yet applied on a large scale. The list is not exhaustive, but represents a cross-section of important developments that are considered in the model calculations. The data are based on the sector studies (see Table 2.1) and additional information (e.g. [26,27,28]). The efficiency gains are for individual materials in the range of 10-25 %.

One important guideline for the assessment of energy efficiency potentials in the materials producing industry is the thermodynamic minimum energy requirement for materials production. This minimum is determined by the minimum chemical energy requirement and by the minimum thermal losses. For most materials, the current energy consumption (for a set resource quality) exceeds this minimum by 25-50%. This is a measure for the theoretical potential for energy efficiency gains.

In reality, a certain gap will remain between the theoretical minimum and the day-to-day practice. Breakthrough energy efficiency gains for materials that require significant amounts of chemical energy (steel, aluminium, ammonia) seem not very likely in the next 50 years, unless radical changes such as increased recycling (steel, aluminium) or changing product services (e.g. biological nitrogen fixation instead of synthetic nitrogen fertilisers) are considered. Such improvements are not included in the category energy efficiency improvements. Moreover, their potential is limited by resource availability and technological constraints.

Table 3.1 *Energy efficient processes for the production of primary materials*

Technology	Product	Primary energy efficiency increase compared to current BAT [GJ/t product]	Time horizon for development	Status
CCF	Liquid iron	5	2015	Promising/pilot plant
Near net shape casting	Steel sheet	5	2020	R&D/labscale
Bipolar cell	Aluminium	10-20	2015	Problematic/pilot plant
Membrane reactor	Ammonia	5	2020	R&D/labscale
Roller kiln	Bricks	0.5	2010	Promising/pilot plant
Biopulping	Mechanical pulp	2-4	2010	Promising/pilot plant
Impulse/condensing belt drying	Paper	2-4	2015	R&D/pilot plant
Nickel coated membrane cell	Chlorine	3-5	2010	Promising/pilot plant

3.3 Increased materials efficiency: increased materials quality

A proper analysis of materials quality requires a case-by-case approach for individual product parts. Such data are only available for a limited number of cases. The modelling of materials efficiency is complicated by the pervasiveness and diversity of materials use.

Not all materials characteristics have the same relevance from a GHG emission point of view. For the metals, synthetic organic materials and for ceramic materials, different quality criteria apply. Materials strength has been considered for steel and for concrete. In situations where strength determines the minimum amount of material, stronger materials can reduce materials requirements. The potential savings are in the range of 10-20 % in situations where these materials can be applied.

Improved steel qualities have been considered in the transportation sector, for packaging (beverage cans), and in machinery (product groups pressure vessels and nuts, bolts, nails etc., see Chapter 2). For concrete, high strength concrete has been considered as an improvement option for 25% of the total concrete market. Both for steel and for concrete, the actual material savings can significantly differ among different applications. Data should be considered averages with a spread of 100%. Finally for plastics, the development of new polyolefin qualities for packagings has been included in the calculations.

In principle, the same strategy could be applied to other sectors and other materials. For a number of products, materials efficiency gains through improved materials quality and improved processing are included in the autonomous development of the product weight.

Further improvements have not been modelled in detail because sufficiently accurate data have not been encountered. Moreover, the modelling of these options in

MARKAL is very data intensive. The production, use and waste handling of each product made with a different materials quality must be modelled separately in order to account the consequences of changing materials consumption for future waste composition. This is a promising research area where much more basic data must be collected in order to deepen the insight.

3.4 Increased materials efficiency: product re-design

Re-design of products shows a strong relation with increased materials quality (Section 3.3), materials substitution (Section 3.10), and product re-use (Section 3.6). These strategies will generally result in product re-design. The meaning of re-design in the sense of this section is limited to re-design that is not based on any of these improvements. It includes re-design based on the same materials mix and design for disassembly. The latter type is closely related to product re-use, but focuses on the beginning of the economic product life cycle instead of the end section.

Re-design of products using the same materials that are currently applied in the specific products has been modelled for a number of packaging types (e.g. stretch foil instead of shrink foil) and for cars (the ultra light steel automobile body design ULSAB). Re-design based on different materials (e.g. an aluminium car instead of a steel car) has been included in the category materials substitution (see Section 3.10).

Product re-design includes design for disassembly. A number of case studies indicate the potentials of product part re-use through improved product design for disassembly (e.g. [29,30]). However re-design for increased product part reuse has not been considered extensively in the calculations because its potential is limited to certain segments of some product groups. It is not considered a key strategy for GHG emission reduction, but may in certain cases generate significant financial profits. The well established re-use practice of copying machines is a good example. This practice includes designs of copying machines that allow easy disassembly and standardised product parts for different types and subsequent designs of copying machines.

3.5 New recycling technologies

Recycling rates are for most materials already fairly high, compared to the amount of waste material that is released. Existing recycling technologies are modelled for steel, aluminium, copper, paper, lubricants, asphalt and glass. Plastics are the only major materials group where new conversion processes can increase recycling rates and decrease GHG emissions. The example of plastics will be discussed because it exemplifies how complicated quality cascades and competing technologies can be modelled in MARKAL.

A number of new plastic waste recycling technologies have been developed in the last decade, especially in Germany because of the packaging legislation that specifies certain recycling rates. This has resulted in the development of a number of new recycling technologies.

Eight types of plastic waste management options are modelled, each capable of handling a cartain waste quality (see Figure 5.1):

- re-extrusion (clean plastic waste input),
- solvent separation (mixed plastic waste input),
- pyrolysis DRP process (mixed plastic waste input),
- hydrogenation VEBA process (mixed plastic waste input),
- plastic waste injection in blast furnaces (mixed plastic waste input),
- plastic waste incineration in cement kilns (mixed plastic waste input),
- incineration grate firing (MSW input),
- disposal (MSW input).

High-quality waste can be processed with technologies that require low-quality waste inputs (e.g incineration), but the other way around is impossible without an upgrading effort. This is modelled like a cascade, represented by ‘dummy’ processes that convert high quality waste into mixed plastic waste and that convert mixed plastic waste into plastics in MSW. Upgrading is modelled as a sorting process that converts plastics in MSW into ‘mixed plastic waste'. The costs for this sorting process step in the German DSD (Duales System Deutschland): DEM 2.61 per kg mixed waste [31]. Future costs will probably decrease. 50% lower costs are assumed by the year 2000, and further cost reductions beyond 2000.

Re-extrusion

Re-extrusion technology is only applicable for high-quality plastic waste types. The plastic is ground and extruded. The material output quality depends largely on the waste input quality, compatibilizers can improve the output quality [32,33]. If mixed plastics are used as input, the resulting material is only suited for a limited number of applications.

Solvent separation

The process is based on the difference in solvability of plastics in organic solvents. The process uses selective dissolution at increasing temperatures and flash devolatilization to separate mixed plastics into component polymers with pigments and fillers predominantly removed. The process has been developed on a pilot plant scale, it is uncertain what results will be achieved on industrial plant scale [34,35].

Pyrolysis DRP process (mixed plastic waste input)

Pyrolysis is the process where hydrocarbons are heated in an oxygen-free atmosphere. At a temperature of several hundred ^{0}C, the hydrocarbons decompose to yield a mixture of solid, liquid, and gaseous products. The product composition depends on temperature and pressure. The higher the temperature, the more gaseous products. An important fraction of this gaseous product is ethylene. Pure ethylene is a valuable product, that can be used for plastics production. The ethylene yield results vary considerably. Literature references indicate yields of up to 40%. Such a high value is not yet proven on a large scale. In this study, a lower ethylene yield value has been applied. 25% of the LHV of the plastic waste is estimated to be used for process heating purposes. Plastic pyrolysis technology is tested on pilot plant scale.

Coke and oil by-products faced quality problems in the past, the present status is unclear [36].

Hydrogenation VEBA process (mixed plastic waste input)

Plastics can be treated with hydrogen to produce feedstock such as a naphta-type product and a hydrogenation residue, that can be used in cooking processes. In Germany, a pilot plant exists and the construction of a large-scale plant is on it's way. The technology can be characterised as a thermal hydrocracking/hydrogenation process. The reactions take place in a liquid phase reactor and a gas phase reactor at temperatures of 400-450 ^{0}C and a pressure of up to 250 bar. The main problem is currently the feeding of plastics into the reactor. Data for hydrogen consumption are still uncertain, but seem to be significantly higher as might be expected on the basis of the plastics chemical structure [37].

Plastic waste injection in blast furnaces (mixed plastic waste input)

Plastic waste injection into blast furnaces is currently practised on pilot plant scale in Germany [38,39]. Cost data have not been encountered. Because the additional equipment is similar to the equipment for incineration in cement kilns, the same cost data have been applied.

Plastic waste incineration in cement kilns (mixed plastic waste input)

Incineration of waste types in cement kilns is widely spread over Europe. Plastic waste incineration in cement kilns has been developed in Italy. The application of plastic waste requires special waste injection equipment due to its light weight. Investment costs for storage, transportation, and injection equipment are approximately 40 ECU/t plastic waste capacity. Annual costs for labour etc. are additionally 10 ECU/t [40].

Incineration grate firing (MSW input)

Current grate firing systems achieve an efficiency of 20-22%. Higher efficiencies are possible if the incineration plant is coupled to combined cycle power plants. LT steam from the incineration plant is further heated in the power plant and subsequently used in a steam turbine. Such combined plants can achieve a 28% efficiency for the incineration section. One such plant has been built in the Netherlands and is currently operating [41].

Disposal (MSW input)

Disposal costs are largely determined by government intervention. Large differences exist between countries. In the calculations, it is assumed that the disposal costs increase from 50 ECU/t in 1990 to 150 ECU/t in 2010 and subsequently to 200 ECU/t in 2040.

The advantage of recycling technologies from a GHG emission point of view depends on the reference technology (incineration or disposal) [42,43]. The main saving is the feedstock energy of the plastics, which constitutes two thirds of the energy input into primary plastics production. If renewable feedstocks are applied in plastics production, the GHG emission reduction becomes negligible.

3.6 Waste separation and product re-use

Re-use has been modelled for a number of packagings and for one building type (see Table 2.4). Waste separation has been modelled for used cars (disassembly) and for plastics, paper, steel, and aluminium from MSW.

3.7 New energy recovery technologies

A number of new energy recovery technologies for waste materials are included in the model. They cover the whole spectrum from anaerobic digestion to gasification, pyrolysis, and conventional grate incineration. Co-combustion has been modelled for plastics in blast furnaces and for tyres, wood, and plastics in cement kilns. For wood waste, a number of dedicated and co-combustion options for electricity production have been included (see [44] for a data description).

3.8 Substitution of energy carriers in materials production

Substitution of energy carriers in primary materials production has already been included in the energy system model. Combined heat and power generation (CHP) for steam generation, substitution of coal and oil by natural gas, by renewable energy, and by nuclear energy are examples of such substitutions. For a discussion, one is referred to the energy model description [7].

3.9 Substitution of raw materials for materials production

Substitution of naw materials can be split into substitution of fossil fuel feedstocks and substitution of inorganic resources. The first type applies to iron production, petrochemical production (ethylene, BTX, carbon black), methanol and ammonia production. In all these cases, biomass has been modelled as a renewable alternative (see [3])

The second type, substitution of inorganic resources, is important for cement production. Alternatives that have been considered are slags from iron production, fly ash from coal fired power plants, volcanic ashes (Pozzolan and Trass cement types) and so-called ‘geopolymeric cement’, based on substitution of calcium carbonate by sodium carbonate (see [13,45]).

3.10 Substitution of materials

Substitution of materials has been modelled for a number of products that are listed in Table 2.4. The types of materials that are competing depend on the product group. For transportation equipment, the competition is between steel, aluminium, and plastics. For packaging, the competition is between different types of plastics, paper and board, glass, wood and metals. For structural building elements, competition is between concrete, bricks, sand-limestone, wood, and steel. Substitution of materials implies generally new processing possibilities. As a consequence, materials substitution results generally in new product design.

From a modelling point of view, the substitution is characterised by discrete product alternatives. For example, a passenger car designed in steel competes with an ‘aluminium’ passenger car and a ‘plastic’ passenger car. The latter two are designed for maximum steel substitution. The product alternatives represent extremes. For many products, data for competing product designs are derived from LCA studies.

3.11 End-of-pipe technology

End-of-pipe technology has been modelled for CH_4 from landfill sites, for N_2O from the chemical industry and for CO_2 from a number of sources. These emissions will be discussed separately.

CH_4 emissions from landfill sites are related to the decomposition of organic waste. The decomposition rate depends on the waste type. Kitchen waste decomposes rapidly. Paper and wood require more time. Plastics and other synthetic organic materials do not decompose within a period of 100 years. Cellulose and hemicellulose decompose, while the decomposition of lignin is more difficult. Landfill gas is produced for 20-30 years after the closure of the landfill site. One must add that the current emission accounting practice for methane in different Western European countries does not account the actual emissions but the potential emissions: an emission coefficient (kg CH_4/t disposed waste) is applied to the waste that is annually disposed of. This coefficient represents the emissions for this waste during the whole period beyond disposal. Significant differences exist regarding national CH_4 emission factors for landfilling [46]. For example the emission factor in Germany is ten times higher than the emission factor in the UK. The Netherlands pose an exception compared to the other Western European countries because instead of potential emissions, actual emissions are accounted. These emissions are based on dynamic simulation models for methane emissions from landfill sites.

Two major routes exist for reduction of methane emissions. The first one is the reduction of organic waste disposal. The second option is recovery of landfill gas from disposal sites. A different accounting practice has consequences for the relevance of emission reduction options. If the potential emission approach is applied, reduction of waste disposal will result in a more rapid decline of emissions than in case an actual emission approach is applied.

Two options have been considered for reduction of CH_4 emissions from landfill sites. The first one is the reduction of waste disposal. The second one is the recovery of landfill gas. Nowadays waste disposal is declining in many Western European countries because of waste policies that favour prevention, recycling and incineration. This results in an autonomous decline of the methane emissions. This trend could be further accelerated, e.g. though higher waste disposal fees. One can argue whether this is really an 'end of pipe' strategy or a prevention strategy. In this study, it has been allocated to the former category. Regarding landfill gas recovery, 50-80% of the landfill gas can be recovered and used for energy purposes, depending on the recovery technology that is applied. The costs of this type of emission reduction option are well below 10 ECU/t CO_2 equivalent [47].

In the model, an emission coefficient is applied to individual waste materials that are disposed of (potential emission approach) [3]. Landfill gas recovery has been modelled as an option to reduce these emissions.

N_2O emissions from the chemical industry can be split into emissions from nitric acid (HNO_3) production, from adipic acid production and from a number of other nitrification processes. These emissions can be reduced through thermal or catalytic destruction. The N_2O concentrations are higher in adipic acid production compared to nitric acid production, requiring different process equipment. The major adipic acid producers agreed to a voluntary reduction of their emissions by 90% by the end of 1998 [48, pp. 50-52]. N_2O decomposition for HNO_3 production is also a proven technology. A pilot plant in Norway resulted in a 70% emission reduction. Further research is aimed at the development of catalysts that can achieve an even further emission reduction [48, pp. 55]. N_2O conversion technology is cost-effective from a GHG emission reduction point of view (below 10 ECU/t CO_2). These technologies are forecast to be introduced on a large scale before 2010, based on current policy plans [47].

An third important type of end-of-pipe technology is CO_2 removal from flue gases and subsequent underground storage. CO_2 removal is currently already applied in a number of industrial processes such as ammonia production and production of Direct Reduced Iron (DRI). The reason CO_2 removal is applied in these cases is a clean gas flow without CO_2 that can be used for further processing. The CO_2 is generally vented or sold for other purposes. The technology can also be applied in all industrial processes that constitute major CO_2 emission sources. In the model calculations, CO_2 removal has been modelled for iron and DRI production, for Portland cement clinker production, and for ammonia production. In electricity production, CO_2 removal has been considered for gas fired power plants and for coal fired power plants (ICGCC). Literature indicates that CO_2 removal from refineries (residue gasification/flexi-coker process) and from petrochemical plants (ethylene oxide production) may also be attractive. The letter two options have not been modelled. Processes where CO_2 removal is applied have been selected because of high CO_2 concentrations in the off-gases and the significant emission reduction potential on a European scale. In all these cases, the plant capacity is well above 0.5 Mt CO_2 per installation. Smaller scale plants are technologically viable, but the removal and storage costs will be significantly higher The removal technology that is applied depends on the gas composition and the CO_2 concentration. A combination of a watergas-shift reaction and a physical absorption system (Selexol) or a chemical absorption system (amines) seems attractive for most gas types [49]. A number of recovery options based on membrane technology require still considerable development [50]. CO_2 removal costs are in the range of 10-50 ECU/t CO_2.

CO_2 storage poses more of a problem than CO_2 removal. These problems are more of a legal character and a social acceptance problem than a technological or environmental problem. CO_2 injection into depleted oil fields is a proven technology for enhanced oil recovery. At one offshore oil platform in Norway, CO_2 is removed from a gas flow and injected into an underground water reservoir (aquifer). Both depleted oil and gas fields and aquifers can be used for CO_2 storage. CO_2 could also be injected into the deep ocean, but the environmental consequences of such a disposal may be serious. Storage in the ocean soil at depths of 10-15 metres may be a viable option, but it requires more research and the costs are still unclear [51]. Storage in the oceans has not been considered in the model. For underground storage below land and below the continental shelf, the storage capacity may pose a constraint. Estimates regarding the storage potential depend on the specifications for the aquifer (aquifer depth, the presence of trapping structures, the efficiency of use of the aquifer volume etc.) [52]. For the emission calculations it has been assumed that the annual storage potential for the period 2000-2050 is 500 Mt per year (a total of 25 Gt CO_2 for the whole period). This potential includes both technological and social constraints. In a sensitivity analysis, the storage potential is reduced to 2.5 Gt CO_2 for the whole period. CO_2 transportation and storage costs are below 10 ECU/t CO_2. However these costs are to some extent dependent on the transportation distance. Especially the electricity costs for transportation distances of more than 25 kilometres can exceed the capital costs. The electricity consumption for the compression is for distances below 25 kilometres in the range of 0.2-0.3 GJ/t CO_2. Longer transportation distances have not been considered. The emissions during the electricity production is accounted for proper assessment.

4. SUGGESTIONS FOR FURTHER RESEARCH

The current model is a first version of the Western European integrated energy and materials model. Further research can focus on a number of issues:

Scenario studies:

- Develop and analyse a number of scenarios.

Model use:

- Facilitate the access to the model data, either through reports or through direct access, e.g. through Internet.
- Validate the model structure and the model data through a review by independent experts.
- Use the model for more detailed studies on a sectoral or materials level.

Model extensions:

- Add the missing GHG emissions (CH_4/N_2O from agriculture and PFCs from solvent use, HFCs and SF_6 emissions).
- Add a food demand and supply module for improved understanding of land availability and agricultural emissions.
- Add more product demand categories.
- MARKAL results cannot be compared to LCA results because environmental impacts are not reported for individual chains in the system. The model results will be more open for discussion if such chain analysis can be performed on the basis of the model results, in order to quantify the environmental impacts and life cycle costs of individual products and materials. It is recommended to enhance the chain analysis possibilities.
- More environmental impacts can be included. Topics such as acidic emissions, waste, resource depletion and dematerialisation can be added to the existing model structure. The synergy's and antagonisms between different environmental policy fields can be analysed.
- The potential for optimisation of energy and materials transportation should be analysed in more detail.
- Within the energy system, the MARKAL transportation module needs further enhancement with regard to the technology characterisation and the demand forecasts. The building module deserves more attention with regard to the delivery costs and the simulation of decision making.
- The model equations should be adjusted so different discount rates can be applied to different sectors.

Analysis of Materials Options

Further research into the potentials for increased materials efficiency is warranted. This study provides only limited insight into the associated emission reduction potentials. The research should focus on new design methods, improved materials processing technologies and systematic methods for materials design. The most promising research areas seem to be new materials and processes based on biomass feedstocks, new metal production technologies, new types of plastics and the development of new concrete products. The analysis of the materials quality improvement strategy for GHG emission reduction requires more research:

- Investigate materials quality potentials in more detail.
- Investigate product re-design potentials in more detail.
- Investigate waste separation and product re-use in more detail.
- Investigate potentials for extended product life in more detail.
- Investigate substitution potentials for other product groups than road vehicles, buildings and infrastructure, and packaging in more detail.

The development of the Dutch and the Western European models has shown that few statistical data are available regarding the final use of materials in products. More research is also warranted regarding the growing materials stock in products and regarding the product life.

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ANNEX OVERVIEW OF PROCESSES IN MATTER 1.0

The following tables provide an overview of processes in MATTER 1.0. The are split into four groups:

- electricity production,
- process technologies (that convert energy carriers and materials into other energy carriers and materials),
- demand technologies (that satisfy a final consumer demand),
- final demand categories.

Electricity production

SET CEN(CON) Centralised Power Plants

BE2 Biomass gasifier/STAG power plant
BE3 Biomass gasifier/dedicated STAG
BE4 Biomass gasifier/SOFC
EC2 Existing pulverised coal power plant
EC3 Existing lignite fired power plant
EC4 New pulverised coal power plant
EC5 Integrated coal gasification power plant
EC6 New lignite fired power plant
EC7 Integr. lignite gasification power plant
ED0 Existing oil fired power plant
ED1 New oil fired power plant
EG0 Existing gas fired power plant
EG1 Gas turbine peaking plant
EG2 Existing STAG power plant
EG3 New STAG power plant
EH0 Medium and high head hydro
EH1 Low head hydro
EH4 Hydro Iceland for Aluminium smelters
EI1 Waste to energy plant (incinerator)
EI2 Waste to energy plant (Lurgi gasifier)
EN0 LWR power plant
ES1 Solar PV in Middle Europe
ES2 Solar PV in South Europe
ES3 Solar PV from South Europe for rest Europe
ET1 Geothermal energy
EW4 Large onshore wind turbine
EW5 Large onshore wind turbine/storage
EW6 Large offshore wind turbine/storage
EW7 Existing capacity windturbines onshore

SET DCN(CON) Decentralized Power Plants

BD1 Lignine boiler/large ind. Cogeneration
BD2 Lignine gasifier/large ind. Cogeneration
BE1 Wood gasification/small ind. Cogeneration
ECA Coal FBC CHP plant
EGA Existing gas turbine CHP plant
EGB Existing STAG CHP plant
EGC Exist. gas engine generator set
EGD New gas turbine CHP plant
EGE New STAG CHP plant
EGF New gas engine generator set
EGG SOFC/gas turbine combination
EXA Steam turbine industry /

SET STG(CON) Storage Conversion Technologies

EH2 Hydro pumped storage
EH3 Hydro pumped storage (more expensive)/

Process technologies

G1	Biomass/RME from rapeseed
H1	Biomass/ethanol from cellulosis
H2	Biomass/ethanol from hemicellulosis
H3	Biomass/ethanol from sugars/starch
H4	Biomass/ethanol 95% to 99%
I1	Biomass/HTU oil production
I2	Biomass/HTU oil production from lignine
I3	Biomass/HTU oil conversion to diesel
J1	Biomass/biodiesel from lipids
K1	Lubricants production from rapeseed oil
O1	Dummy wheat to constituents
O2	Dummy sugarbeet to constituents
O3	Dummy straw to constituents
O4	Dummy wood to constituents
O5	Dummy sorghum to constituents
P1	Biomass growing rapeseed Middle
P2	Biomass growing wheat Middle
P3	Biomass growing sugarbeet Middle
P4	Biomass growing miscanthus Middle
P5	Biomass growing poplar Middle
P6	Biomass growing algae Middle
P7	Timber quality wood Middle
P8	Marigold flower Middle
P9	Timber quality wood Middle ex. forests
PA	Biomass/growing sorghum South
PB	Biomass/growing wheat South
PC	Biomass/growing sugarbeet South
PD	Biomass/growing miscanthus South
PE	Biomass/growing Eucalyptus South
PM	Timber quality wood North
PN	Carbon storage new forest areas
00	Gas boiler (N. Europe, comm)
01	Condensing gas boiler (N. Europe, comm)
02	Cond.boil.low-e glass (N. Europe, comm)
03	Cond.boil.low-e+heat recov. (N. Europe)
06	Oil boiler (N. Europe comm. Heat)
07	Oil boil+low-e (N. Europe)
08	Oil boil+low-e+heat recov (N. Europe)
0A	Coal boiler (N. Europe, comm. heat)
0B	Coal boil+low-e (N. Europe)
0C	Coal boil+low-e+heat recov (N. Europe)
0E	Electric heatpump (N. Europe)
0F	El.heatpump+low-e glass (N. Europe)
0G	El. resistance/boiler (N. Europe)
0H	El. resistance+low-e glass (N. Europe)
0I	El. resistance+low-e+heat rec. (N. Euro)
0K	District heat (N. Europe, comm. heat)
0L	COL+low emit. glass (N. Europe)
0M	COL+low emit. glass+heat rec. (N. Europ)
0P	TE heat (N. Europe)
0Q	TE heat+low-e glass (N. Europe)
0R	TE heat+low-e glass+heat rec. (N. Europ)
10	Gas boiler (M. Euro, small office heat)
11	Cond. gas boiler (M. Euro, small office)
12	Cond. boil+low-e glass (M. Euro, sm.off)
13	Cond.boil+low e+heat rec (M.Eur.,sm.off)
16	Oil boiler (M.Eur.,small bldg.)
17	Oil boiler+low e (M.Eur.,small bldg.)
18	Oil boiler+low e+heat rec (M.Eur.,sm.of)
1A	Coal boiler (M. Europe, small off.)
1B	Coal boiler+low e (M. Europe, sm. off)
2B	Coal boiler+low e (M. Euro. lg.off)
1C	Coal boil+low e+heat rec (M. Eur, s.of)
1E	El. heatpump (M. Euro, small off.)
1F	El. heatpump+low e (M. Euro, small off.)
1K	District heat (M. Euro, sm. Off.)
1L	District heat+low e (M. Euro, sm. off.)
1M	Dis heat+low e+heat rec (M. Euro, s.of)
1P	TE heat (M.Euro, s.of)
1Q	TE heat+low e (M.Euro, s.of)
1R	TE heat+low e+heat rec (M.Euro, s.of)
2C	Coal boil+low e+heat rec (M. Euro. lg o)
2G	El. heatp. (M. Euro, lg.off)
C2I	El. heatp.+low e (M. Euro, lg.off)
C2K	Dist. heat (M. Euro, lg.off)
C2L	Dist. heat+low e (M. Euro, lg.off)
C2M	Dist. heat+low e+heat rec (M. Euro, l.o)
C2P	TE (M. Euro. lg.off)
C2Q	TE+low e (M. Euro. lg.off)
C2R	TE+low e+heat rec (M. Euro. lg.off)
C30	Gas boiler (S. Euro. lg. off)
C31	Cond. gas boiler (S. Euro. comm. heat)
C32	Cond. boil+low e (S. Euro. comm. heat)
C33	Cond. boil+low e+ht rec (S. Euro. comm)
C36	Oil boiler (S. Euro. comm)
C37	Oil boiler+low e (S. Euro. comm)
C38	Oil boiler+low e+heat rec (S. Euro. com)
C3A	Coal boil. (S. Euro. comm)
C3B	Coal boil.+low e (S. Euro. comm)
C3C	Coal boil.+low e+heat rec (S. Euro. com)
C3E	El heatp. (S. Euro. comm)
C3F	El heatp.+low e (S. Euro. comm)
C3G	El heatp.+low e+heat rec (S. Euro. comm)
C3H	El.res.+low e (S. Euro. comm)
C3I	El.res.+low e+heat rec. (S. Euro. comm)
DAA	Methane recovery from disposal sites
DAB	Dummy methane emission disp. sites
DCC	Disposal blast furnace slag
DCF	Disposal fly ash
DCT	Disposal waste glass
DMA	Disposal aluminium scrap
DMC	Disposal copper scrap
DMS	Disposal steel scrap
DND	Disposal demolition wood
DNF	Disposal waste fiber
DNK	Disposal kitchen waste
DNP	Disposal waste paper
DP1	Dummy clean po waste to mixed po waste
DP2	Dummy mixed po waste to MSW po waste
DP3	Disposal polyolefin waste MSW
DP4	Separation po waste from MSW
DP5	Dummy clean to mixed ps waste
DP6	Dummy mixed to MSW ps waste
DP7	Disposal polystyrene waste MSW
DP8	Separation ps waste from MSW
DPA	Dummy clean to mixed pvc waste
DPB	Dummy mixed to MSW pvc waste
DPC	Disposal pvc waste MSW
DPD	Separation pvc waste from MSW
DPF	Dummy clean to mixed other pl. waste
DPG	Dummy mixed to MSW other pl. waste
DPH	Disposal other plastic waste MSW
DPI	Separation other plastic waste from MSW
DPX	Disposal bioplastics
DSA	Disposal waste asphalt
DSL	Disposal waste lubricants
DSN	Disposal waste nylon
DSR	Disposal waste elastomeres
DSU	Disposal waste tyres
DXA	Aerobic digestion kitchen waste
DXK	Anaerobic digestion kitchen waste
IAA	Aluminium production Hall-Heroult
IAB	Aluminium Hall-Heroult+point feeders
IAC	Aluminium production inert anodes
IAD	Al Hall-Heroult+point feeders Iceland
IAE	Al production inert anodes Iceland
IAR	Aluminium production recycling
IBA	Brick production tunnel kiln
IBB	Brick production roller kiln
IBD	Floor tile + stoneware production
IBF	Granite + marble ornamental stone prod.
ICA	Chlorine prod. membrane electr.
ICB	Chlorine prod. adv. membrane electr.
IDA	Glass production gas/oil fired primary
IDB	Glass production electric primary
IDR	Glass recycling gas/oil fired

IDS	Glass recycling electric furnace
IEA	Copper production (concentrate to cath.)
IEC	Copper recycling (to cathode)
IED	Copper finishing
IG1	Continuous casting
IG2	Hot strip mill
IG3	Plate mill
IG4	Wire rod mill
IG5	Heavy section mill
IG6	Rebar mill
IG7	Cold rolling mill
IG8	CRC annealing & tempering
IG9	CRC finishing & packaging
IGA	Iron prod. BF max coal inj.
IGB	Iron prod. COREX
IGC	Iron prod. CCF
IGD	Coke oven
IGE	Sponge iron prod. DRI
IGF	Sponge iron prod. DRI -CO_2
IGG	Dummy cokes for iron production
IGH	Dummy cokes for iron production -CO_2
IGI	Dummy coal for iron production
IGJ	Dummy coal for iron production -CO_2
IGK	Dummy residual gas from steel industry
IGL	Dummy residual steam from steel industry
IGM	Dummy residual steam from steel ind. HP
IGN	Steel prod. hot rolling advanced
IGO	Electro galvanizing
IGP	Hot dip galvanizing
IGQ	Steel prod. BOF+additional scrap
IGR	Steel prod. scrap/EAF
IGS	Steel prod. BOF
IGT	Steel prod. DRI/EAF
IGU	Sinter production
IGV	Pellet production
IGW	Dummy DRI steel to high quality steel
IGX	Dummy mixing DRI/scrap based steel
IGY	Dummy high to medium quality steel
IGZ	Dummy medium to low quality steel
IHA	Charcoal production for steel industry
IHB	Dummy wood to coal/iron production
IHC	Dummy wood to coal/iron prod. -CO_2
IHD	Waste plastic for steel industry (extr.)
IHE	Waste plastic for steel industry -CO_2
IHW	Alloy steel preparation&finishing
IHX	Cast iron production (Cupola)
IJB	Lubricants from refinery
IJD	Lubricants re-refining
IKA	Sodium chloride leaching
IKB	Sodium chloride from sea water
IKD	Potash production
IKP	Phosphoric acid production
IKQ	Phosphoric acid production from phosphor
ILA	Soda production light
ILB	Soda production heavy
INA	Petroch. Naphtha cracker
INB	Petroch. Gas oil cracker
INC	Petroch. Ethane cracker
IND	Petroch. Oxydative coupling
INE	Petroch. MTO
INF	Petroch. LPG cracker
ING	Ethanol dehydrogenation
INH	Flash pyrolysis wood
INI	Butane dehydrogenation to i-butylene
INJ	C4 fractionation
INK	Ethylene oxide production
INL	Propylene oxide production
INM	Cumene production
INN	Cumene oxydation
INO	Cyclohexane production
INP	Caprolactam production
INQ	Phthalic anhydride
INR	TPA production
INS	Ethylene glycol production
INT	Acrylonitrile production
INU	Styrene production
INV	VCM production
INW	MTBE production
INX	BTX separation
INY	Xylenes separation
INZ	Xylene residue isomerisation
IO0	Caprolactam production incl. N_2O mitig.
IO1	Adipic acid production incl. N_2O mitig.
IO2	UF resin production
IO3	Viscose production
IO4	Cellophane production
IOA	Formaldehyde production
IOB	Urea production
IOC	Aniline production
IOD	Acetic acid production
IOE	Caprolactam production
IOF	Nitro-benzene production
IOG	MEK production
IOH	Adipic acid production
IOI	I-propanol production
IOJ	TDI production
IOK	Ethanol production from ethylene
IOL	2-ethylhexanol production
IOM	Carbon black production
ION	Acetic anhydride production
IOO	Detergent production (AES) synthetic
IOP	Acetic acid production from biomass
IOQ	Butanol/acetone prod. from biomass
IOR	I-propanol from biomass
IOS	Butadiene through flash pyrolysis
IOT	Phenol through lignine hydrotreatment
IOU	Carbon black production from biomass
IOV	Detergent prod. (AES) from palm oil
IOW	Dummy paint production
IOX	Paint production from Marigold oil
IOY	Biopol (PHB/PHV) production
IOZ	Butene recovery from refineries
IP1	Polypropylene prod. polymerisation
IP2	Polyethylene prod. polymerisation
IP3	PVC production
IP4	PS production
IP5	PET production
IP6	ABS production
IP7	SBR production
IP8	PUR production
IP9	Nylon 6 production
IPA	Nylon 6.6 production
IPB	BR production
IPC	PUR production from lignine
IPF	Polyolefin re-extrusion
IPH	PVC re-extrusion
IPI	Polystyrene re-extrusion
IPJ	Other thermoplast re-extrusion
IPK	Polyolefin solvent separation
IPM	PVC solvent separation
IPN	Polystyrene solvent separation
IPO	Other thermoplast solvent separation
IPP	Polyolefin pyrolysis
IPR	PVC pyrolysis
IPS	Polystyrene pyrolysis
IPT	Other thermoplast pyrolysis
IPU	Polyolefin hydrogenation
IPW	PVC hydrogenation
IPX	Polystyrene hydrogenation
IPY	Other thermoplast hydrogenation
IPZ	Nylon hydrolysis
IQA	Gypsum production
IQD	Kaolin production
IQM	Sand-lime brick production
IRA	Ammonia prod. conventional
IRB	Ammonia prod. advanced

RC Ammonia prod. conventional -CO_2
RD Ammonia prod. advanced -CO_2
RH Nitric acid conventional
RI Nitric acid including N2O mitigation
SX PVC production
UA Cement clinker dry process
UB Cement clinker wet process
UC Cement clinker dry process -CO_2
UD High strength concrete/cement
UE Dummy common to high strength cement
UF Portland cement production
UG Fly ash cement production
UH Blast furnace cement production
UI Activated slag cement production
UJ Geopolymeric cement production
UK Pozzolanic cement production
UM Quicklime production
UP Ready mix concrete production
UQ Prefab concrete element production
UR Concrete building block production
VA Paper production newsprint n-int.
VB Paper production graphic n-int.
VC Paper production packaging etc. n-int.
VD Paper production newsprint integrated
VE Paper production graphic integrated
VF Paper production packaging integrated
VN Chemical pulp production
VP Mechanical pulp production
VQ Mechanical pulp biopulping
VR Recycling pulp production deinking
VS Recycling pulp production no deinking
WA Asphalt production
WB Asphalt recycling
XA Sawn wood production
XB Chipboard production
XC Acetylated wood production
XD PLATO wood production
YA Tyre production synthetic rubber
YB Tyre production natural rubber
A1 Reference residence construction
A2 Wooden frame residence construction
A3 Steel frame residence construction
A4 Reference residence demolition
A5 Wooden frame residence demolition
A6 Steel frame residence demolition
B1 Reference appartment construction
B2 Wooden frame appartment construction
B3 Steel frame appartment construction
B4 Reference appartment demolition
B5 Wooden frame appartment demolition
B6 Steel frame appartment demolition
C1 Small steel car production
C2 Small aluminium car production
C3 Small plastic car production
C4 Small standard car production
C5 Small steel car shredding MY
C6 Small aluminium car shredding MY
C7 Small plastic car shredding MY
C8 Small standard car shredding MY
CA Small steel car shredding HY
CB Small aluminium car shredding HY
CC Small plastic car shredding HY
CD Small standard car shredding HY
D1 40-T Steel truck production
D2 40-T Aluminium truck production
D3 40-T Standard truck production
D4 40-T Steel truck shredding MY
D5 40-T Aluminium truck shredding MY
D6 40-T Standard truck shredding MY
E1 Reference office building construction
E2 Wooden frame office bldg. construction
E3 Steel frame office building construction
E4 Reference office building demolition
JE5 Wooden frame office building demolition
JE6 Steel frame office building demolition
JF1 Reference ind./agr. bldg. construction
JF2 Wood frame ind./agr. bldg. construction
JF3 Steel frame ind./agr. bldg. construction
JF4 Reference ind./agr. bldg. demolition
JF5 Wood frame ind./agr. bldg. demolition
JF6 Steel frame ind./agr. bldg. demolition
JG1 Ref. ind./agr. bldg. type2 constr.
JG2 Impr. I ind./agr. bldg. type2 constr.
JG3 Impr. II ind./agr. bldg. type2 constr.
JG4 Ref. ind./agr. bldg. type 2 demltn.
JG5 Impr. I ind./agr. bldg. type 2 demltn.
JG6 Impr. II ind./agr. bldg. type 2 demltn.
JH1 Brick residence construction type 2
JH2 Solid wood residence construction type 2
JH3 Wood frame resid. construction type 2
JH4 Used brick residence demolition type 2
JH5 Used solid wood residence demol. type 2
JH6 Used wood frame resid. demol. type 2
JI1 Foundation construction/weak soil
JJ1 Swedish ref. resid. construction
JJ2 Swedish concr. resid. construction
JJ3 Swedish high eff. resid. construction
JJ4 Swedish ref. resid. demolition
JJ5 Swedish concr. resid. demolition
JJ6 Swedish high eff. resid. demolition
JM1 Low volume asphalt road construction
JN1 High volume asphalt road construction
JN2 High volume concrete road construction
JO1 Reference appliance construction
JO2 Plastic appliance construction
JO3 Reference appliance shredding
JO4 Plastic appliance shredding
JP1 Reference machinery construction
JP2 Max. plastic machinery construction
JP3 Reference machinery disassembly
JP4 Max. plastic machinery disassembly
JQ1 Plywood desk construction
JQ2 MDF desk construction
JQ3 Steel desk construction
JQ4 Plywood desk demolition
JQ5 MDF desk demolition
JQ6 Steel desk demolition
JR1 Copper wire assembly
JR2 Aluminium wire assembly
JR3 Disassembly copper wire
JR4 Aluminium wire disassembly
JR7 Pyrolysis copper wire
JT5 PVC window frame assembly
JT6 Wood window frame assembly
JT7 Tropical wood window frame assembly
JT8 Aluminium window frame assembly
JTA PVC window frame disassembly
JTB Wood window frame disassembly
JTC Tropical wood window frame disassembly
JTD Aluminium frame disassembly
JU1 Wood parquet production
JU2 Tile floor production
JU3 Synthetic carpet production
JU4 Wool carpet production
JU5 Wood parquet demolition
JU6 Tile floor demolition
JU7 Synthetic carpet disassembly
JU8 Wool carpet disassembly
JV1 Concrete cellar construction
JV2 Sand-limestone cellar construction
JW1 Concrete railway track construction
JW2 Wood railway track construction
JW3 Concrete railway track demolition
JW4 Wood railway track demolition
JX1 THW waterworks construction
JX2 Steel waterworks construction

JX3 Concrete waterworks construction
JX5 THW waterworks demolition
JX6 Steel waterworks demolition
JX7 Concrete waterworks demolition
JY1 Wooden pallet production
JY2 Plastic pallet production
JY3 Wooden pallet disassembly
JY4 Plastic pallet demolition
JZ1 Aluminium ext. wall. production
JZ2 Staal ext. wall. production
JZ3 Stone ext. wall. production
JZ4 Concrete ext. wall. Production
JZ5 Aluminium ext. wall. demolition
JZ6 Staal ext. wall. demolition
JZ7 Stone ext. wall. demolition
JZ8 Concrete ext. wall. demolition
KA5 Industrial pressure vessel construction
KA8 Industrial pressure vessel demolition
KC5 Pipeline construction
KC8 Pipeline demolition
KD1 Large steel car production
KD2 Large aluminium car production
KD3 Large plastic car production
KD4 Large standard car production
KD5 Large steel car shredding MY
KD6 Large aluminium car shredding MY
KD7 Large plastic car shredding MY
KD8 Large standard car shredding MY
KDA Large steel car shredding HY
KDB Large aluminium car shredding HY
KDC Large plastic car shredding HY
KDD Large standard car shredding HY
KE1 Steel van production
KE2 Aluminium van production
KE3 Plastic van production
KE4 Standard van production
KE5 Steel van shredding MY
KE6 Aluminium van shredding MY
KE7 Plastic van shredding MY
KE8 Standard van shredding MY
KF1 20-t Steel truck production
KF2 20-t Aluminium truck production
KF3 20-t Standard truck production
KF4 20-t Steel truck shredding MY
KF5 20-t Aluminium truck shredding MY
KF6 20-t Standard truck shredding MY
OCR Catalytic reformer
OFC Fluid catalytic cracker
OFX Flexi coker
OH1 Refinery heavy crude
OHC Hydrocracker
OHF Hydrocracker for fuel oil
OHY Hycon
OL1 Refinery light crude
OME Methanol from natural gas
OVS Visbreaker
R1A District heat exchanger
R1B District heat+floor insul.+heat recov.
R1C Gas boiler
R1D Condensing gas boiler
R1E R1D + floor insulation
R1F R1E + PU foam + heat recovery
R1G R1F + coated glass
R1H R1F + coated and gasfilled glass
R1I R1F + 3-double coated and gasfilled glas
R1J Total energy heat
R1K R1J + floor insulation + heat recovery
R1L R1J + maximum insulation
R1M Petroleum products
R1N Electric appliances
R1O Coal stove
R1P Wood stove
R2A District heat exchanger
R2B R2A + coated glass
R2C R2B + heat recovery
R2D District heat + maximum insulation
R2E Gas boiler
R2F Condensing gas boiler
R2G R2F + coated glass
R2H R2G + heat recovery
R2I R2F + coated glass
R2J Petroleum products
R2K Electric resistance
R2L Coal stove
R2M Wood stove
R3A District heat exchanger
R3B District heat+floor insul.+heat recov.
R3C Gas boiler
R3D Condensing gas boiler
R3E R3D + floor insulation
R3F R3E + PU foam + heat recovery
R3G R3F + coated glass
R3H R3F + coated and gasfilled glass
R3I R3F+3*coated and gasfilled glass
R3J Total energy heat
R3K R3J + floor insulation + heat recovery
R3L R3J + maximum insulation
R3M Petroleum products
R3N Electric resistance
R3O Coal stove
R3P Wood stove
R4A District heat exchanger
R4B R4A + coated glass
R4C R4B + heat recovery
R4D District heat + maximum insulation
R4E Gas boiler
R4F Condensing gas boiler
R4G R4F + coated glass
R4H R4G + heat recovery
R4I R4F + maximum insulation
R4J Petroleum products
R4K Electric resistance
R4L Coal stove
R4M Wood stove
R5A District heat exchanger
R5B District heat+floor insul.+heat recov.
R5C District heat+maximum insulation
R5D Conventional gas boiler
R5E Condensing gas boiler
R5F R5E+floor insulation
R5G R5F+heat recovery
R5H R5G+coated glass
R5I R5G+coated and gasfilled glass
R5J R5G+3*coated and gasfilled glass
R5K Electric heatpump: heat + water
R5L R5K+floor insulation
R5M R5L+coated glass
R5N R5L+coated and gasfilled glass
R5O R5K+triple glass+impreg. wall insulation
R5P Total energy heat
R5Q R5P+floor insulation+heat recovery
R5R R5P+maximum insulation
R5S Petroleum products
R5T Electric resistance
R5U Coal stove
R5V Wood stove
R6A District heat exchanger
R6B District heat+fllor insul.+heat recov.
R6C Gas boiler
R6D Condensing gas boiler
R6E R6D+floor insulation
R6F R6E+PU foam+heat recovery
R6G R6F+coated glass
R6H R6F+coated and gasfilled glass
R6I R6F+3*coated and gasfilled glass
R6J Total energy heat

6K R6J+floor insulation+heat recovery
6L R6J+maximum insulation
6M Petroleum products
6N Electric resistance
6O Coal stove
6P Wood stove
7A District heat exchanger
7B R7A+coated glass
7C R7B+heat recovery
7D District heat+maximum insulation
7E Gas boiler
7F Condensing gas boiler
7G R7F+coated glass
7H R7G+heat recovery
7I R7F+maximum insulation
7J Petroleum products
7K Electric resistance
7L Coal stove
7M Wood stove
AT Ethanol to transport sector
BA Dummy ethanol addition to gasoline
BB Dummy methanol to gasoline
BE Lignite to electricity generation
CA Coal to agricultural sector
CC Coal to commercial sector
CE Coal to electricity generation
CF Coal to fuel conversion sector
CH Coal to households
CI Coal to industry
CS Coking coal to industry
CT Dummy industry coal to coal for cement
CU Dummy industry petcoke to cement kilns
DT Diesel to transport sector
FA Residual fuel oil to agricultural sector
FC Residual fuel oil to commercial sector
FE Residual fuel oil to electricity sector
FH Residual fuel oil to households
FI Residual fuel oil to industry
FT Residual fuel oil to transport sector
GA Gas to agricultural sector
GC Gas to commercial sector
GE Gas to electricity generation
GF Gas to fuel conversion sector
GH Gas to households
GI Gas to industry
HC Total energy heat to commerce
HH Total energy heat to households
HT Hydrogen to transport sector
IA Dummy separate steel scrap to MSW
IB Magnetic separation steel scrap in MSW
IC Magnetic separation aluminium scrap MSW
ID Dummy separate aluminium scrap to MSW
KT Kerosene to transport sector
LI LPG to industry
LT LPG to transport sector
MT Methanol to transport sector
NI Naphtha to industry
OA Gas oil to agricultural sector
OC Gas oil to commercial sector
OH Gas oil to households
OI Gas oil to industry
OT Gas oil to transport sector
PH Petroleum products to households
PI Petroleum coke to industry
QA Dummy coal for IGCC
QB Dummy coal for IGCC -CO_2
QC Dummy gas for STAG
QD Dummy gas for STAG -CO_2
RB Dummy bitumina to oil for electricity
RF Dummy petrocoke to oil for electricity
RM Dummy gasoline to diesel
RN Dummy diesel to kerosene
RO Dummy kerosene to naphtha
SRP Dummy naphtha to gasoil
SRQ Dummy gasoil to residual fuel oil
SRR Dummy residual fuel oil to bitumen
SRS Dummy ethylene to fuel gas
SRT Propylene recovery from refineries
SRU Benzene recovery from refineries
SRV Xylene recovery from refineries
SSA Gasoline to agricultural sector
SSH Gasoline to households
SSI Gasoline to industry
SST Gasoline to transport sector
STH Dummy high to low temperature steam
STI Industrial LT steam production from LPG
STL Industrial LT steam production
SUA Dummy tyre incineration in cement kilns
SUC Dummy demol. wood inc. in cement kilns
SUD Dummy plastic inc. in cement kilns
SVA Dummy wood proc. waste to mixd wood wste
SVB Dummy mixd wood waste to demol wood wste
SVC Dummy timber qual. wood to proc. waste
SVE Dummy demol. qual. wood to energy wood
SVF Dummy hq waste paper to lq waste paper
SVG Lq waste paper separ. collection+upgrading
SVH Dummy hq waste paper pulp to lp wp pulp
SVI Dummy mechanical pulp to hq waste pulp
SWH Wood to households
SWI Wood to industry (only energy, no waste)
SXA Hydrogen production from natural gas
SXB Hydrogen production from fuel oil
SXC Hydrogen production from petrocokes
SXD Hydrogen production from electricity
SZU Oxygen production
T01 Gasoline car partly IIC
T02 Gasoline car IIC
T03 Diesel car partly IIC
T04 Diesel car IIC
T05 Fuel cell car RB
T06 Methanol car IIC
T07 Ethanol car IIC
T08 Electric car mid term RB
T09 Electric car long term RB
T0A Ethanol car partly IIC
T0D Diesel standard car
T0E Electric car short term RB
T0F Fuel cell car
T0G Gasoline car standard
T0M Methanol car partly IIC
T11 Diesel van, IIC
T12 Diesel van, IIC, CVT
T13 Gasoline van, IIC
T14 Gasoline van, IIC, CVT
T15 Fuel cell van, RB
T16 Electric van, mid term, RB
T17 Electric van, long term, RB
T18 Hybrid van, RB, CVT
T1D Diesel van, standard
T1E Electric van, short term, RB
T1F Fuel cell van
T1G Gasoline van, standard
T1H Hybrid van, RB
T21 Diesel truck with IIC
T23 Fuel cell truck
T2D Diesel truck standard
T2M Methanol truck, IIC
T2T 20-t Standard truck use
T2U 20-t Steel truck use
T2V 20-t Aluminium truck use
T2W Dummy truck use conversion GJ to tonkm
T2X 40-t Steel truck use
T2Y 40-t Aluminium truck use
T2Z 40-t Standard truck use
UA1 Incineration polyolefines in MSW
UA2 Incineration PS in MSW

UA3 Incineration PVC in MSW
UA4 Incineration other plastics in MSW
UA5 Incineration waste paper in MSW
UA6 Incineration waste elastomeres in MSW
UA7 Incineration wood waste in MSW
UA8 Incineration kitchen waste in MSW

Demand technologies

D1	Dummy agricultural diesel demand
E1	Dummy agricultural electricity demand
G1	Dummy natural gas to agricultural sector
0X	Reference office building North Eur.
0Y	Wooden frame office building North Eur.
0Z	Steel frame office building North Eur.
1X	Reference office building Mid Eur. small
1Y	Wooden frame off.bldg Mid Eur. small
1Z	Steel frame off.bldg Mid Eur. small
2X	Reference office building Mid Eur. large
2Y	Wooden frame off.bld Mid Eur. large
2Z	Steel frame off. bldg Mid Eur. large
3X	Reference office building South Eur.
3Y	Wooden frame office building S. Eur.
3Z	Steel frame office building S. Eur.
ES	Other commercial electric appliances
G1	Plywood desk use
G2	MDF desk use
G3	Steel desk use
1A	Gas boiler/LTH/large industry
1B	Fuel oil boiler/LTH/large industry
1C	Coal boiler/LTH/large industry
1D	Hydrogen boiler/LTH/large industry
1E	Electric heatpump/LTH/large industry
1F	Heat exchanger/LTH/large industry
2A	Gas burner/HTH/large industry
2B	Fuel oil burner/HTH/large industry
2C	Coal burner/HTH/large industry
2D	Hydrogen burner/HTH/large industry
2E	Electric heating/HTH/large industry
2F	LPG burner/HTH/large industry
3A	Gas boiler/LTH/small industry
3B	Gas oil boiler/LTH/small industry
3C	Coal boiler/LTH/small industry
3D	Hydrogen boiler/LTH/small industry
3E	Abs. heatpump/LTH/small industry
3F	Compr. heatpump/LTH/small industry
3G	Electric heatpump/LTH/small industry
3H	Heat exchanger/LTH/small industry
3T	Straw boiler/LTH/small industry
3W	Wood boiler/LTH/small industry
4A	Gas boiler/HTH/small industry
4B	Gas oil boiler/HTH/small industry
4T	Straw boiler/HTH/small industry
4W	Wood boiler/HTH/small industry
5A	El. appl.&light/ELE/large industry
5M	Electric drive/ELE/large industry
5N	Adv. electric drive/ELE/large industry
6A	El. appl.&light/ELE/small industry
6M	Electric drive/ELE/small industry
6N	Adv. electric drive/ELE/small industry
A0	Aluminium use dummy
B0	Brick use dummy
C0	Chlorine use dummy
D0	Glass use dummy
K0	Sodium chloride residual use dummy
MX	Reference machinery use
MY	Plastic machinery use
P0	Polyolefin residual use dummy
R0	Ammonia use dummy
S0	Petrochemical residual use
U0	Cement clinker use dummy
V0	Paper/board use dummy
X0	Sawn wood use dummy
Y0	Tyre use dummy
ZX	Capital equipment use
ZY	Capital equipment use improved quality
R5	Copper wire use
R6	Aluminium wire use
S1	Copper pipe use
S2	PVC pipe use
T1	PVC window frame use
T2	Wood window frame use
JT3	Tropical timber window frame use
JT4	Aluminium window frame use
JV3	Concrete cellar use
JV4	Sand-limestone cellar use
KA1	Industrial pressure vessel use
KB1	Use of nults, bolts, nails etc.
KB2	Use of nults, bolts, nails etc. HQ steel
KC1	Pipeline use
N1A	Dummy residual non-energy use
P11	Steel can carbonated beverages
P12	Aluminium can carbonated beverages
P13	All steel can carbonated beverages
P14	One-way PET bottle 1.5 l
P15	25-way PET bottle 1.5 l
P16	25-way PET bottle 1.5 l improved
P17	Glass bottle 0.3 l one-way
P21	Liquid board pack
P22	One-way PET bottle 1.5 l
P23	25-way PET bottle 1.5 l
P24	25-way PET bottle 1.5 l improved
P25	Glass bottle 1 l one-way
P26	PE pouch 1 l one-way
P31	PS cup (yoghurt,margarine etc.)
P32	PP cup (yoghurt,margarine etc.)
P41	Steel can wet food
P42	Steel can wet food honeycomb can
P43	Glass jar 0.5 l one-way
P51	Cardboard box dry food
P52	Cardboard box + bag dry food
P53	Plastic box + blister
P54	LDPE film
P55	PP film
P56	Metallocene film
P57	Paper
P58	Aluminium foil
P59	Cellophane film
P61	PP-laminate
P62	PET laminate
P63	Metallocene laminate
P64	PP-laminate coated
P65	PET laminate coated
P66	Metallocene laminate coated
P71	HDPE-bottle
P72	HDPE-bottle recycled material
P73	HDPE-Pouch
P74	Cardboard refill package
P75	Biopol PHV/PHB bottle
P81	Cardboard box
P82	PE box
P83	Cardboard blister
P84	LDPE-film
P85	PP-film
P86	Paper
P87	Cellophane film
P91	PE bag
P92	Paper bag
P93	Recycled bag
P94	Multiple use bag
PA1	PE bag
PA2	Paper bag
PA3	FIBC one way
PA4	FIBC multiple use
PB1	Plastic crate
PB2	Wooden crate
PB3	Corrugated board crate
PB4	Corrugated board box
PB5	Plastic shrink foil
PC1	Shrink-covers
PC2	Stretch films
R1X	Reference SFD North
R1Y	Concrete SFD North
R1Z	High efficiency SFD North
R2X	Reference MFD North

R2Y Wood frame MFD North
R2Z Steel frame MFD North
R3X Dummy SFD Middle Europe existing
R4X Reference MFD Middle Europe
R4Y Wood frame MFD Middle Europe
R4Z Steel frame MFD Middle Europe
R5X Reference SFD Middle Europe new type 1
R5Y Wood frame SFD Mid. Europe new type 1
R5Z Steel frame SFD Middle Europe new type 1
R6X Reference SFD South Europe
R6Y Wood frame SFD South Europe
R6Z Steel frame SFD South Europe
R7X Reference MFD South Europe
R7Y Wood frame MFD South Europe
R7Z Steel frame MFD South Europe
R8X Brick SFD Middle Europe new type 2
R8Y Solid wood SFD Mid. Europe new type 2
R8Z Wood frame SFD Mid. Europe new type 2
RA0 Combined heating and hot water
RA1 Gas boiler water heater
RA2 Combi boiler water heater
RA3 Electric water heater
RA4 Electric heatpump boiler
RA5 Petroleum products water heater
RA6 Coal water heater
RA7 Wood water heater
RA8 Solar boiler; electric heatpump backup
RA9 Solar boiler; gas backup
RB0 Combined heating and hot water
RB1 Gas boiler water heater
RB2 Combi boiler water heater
RB3 Electric water heater
RB4 Electric heatpump boiler
RB5 Petroleum products water heater
RB6 Coal water heater
RB7 Wood water heater
RB8 Solar boiler; el.heatp.backup; ex.house
RB9 Solar boiler; gas backup; existing house
RBA Solar boiler; el.heatp.backup; new house
RBB Solar boiler; gas backup; new house
RC0 Combined heating and hot water
RC1 Gas boiler water heater
RC2 Combi boiler water heater
RC3 Electric water heater
RC4 Electric heatpump boiler
RC5 Petroleum products water heater
RC6 Coal water heater
RC7 Wood water heater
RC8 Solar boiler; electric heatpump backup
RC9 Solar boiler; gas backup
RD1 Conventional dishwasher
RD2 Dishwasher (enzymatic detergent)
RD3 Dishwasher (enzym.; ASD; optical sensor)'
RES Other existing electric appliances
RF1 Gas cooker
RF2 Electric cooker
RF3 Infrared jet impingement cooker
RF4 Petroleum product cooker
RF5 Coal cooker
RF6 Wood cooker
RJ1 Reference ind./agr. building
RJ2 Wood frame ind./agr. building
RJ3 Steel frame ind./agr. building
RK1 Ref. ind.agr. building type 2
RK2 Impr. I ind.agr. building type 2
RK3 Impr. II ind.agr. building type 2
RL1 Incandescent lamp residential
RL2 Halogen lamp residential
RL3 Fluorescent lamp residential
RLA PL/SL lamp (>350 hours/year)
RLB PL/SL lamp (300-350 hours/year)
RLC PL/SL lamp (200-300 hours/year)
RM1 Use aluminium wall cladding
RM2 Use steel wall cladding
RM3 Use stone wall cladding
RM4 Use fiber concrete wall cladding
RNS Other new electric appliances
RO1 Steel food containers
RO2 Glass food containers
RP0 Furniture (chest) dummy
RQ1 Reference appliances
RQ2 Plastic appliances
RR1 Old type refrigerator
RR2 Standard refrigerator (3 cm insulation)
RR3 Better insulated absorption refrigerator'
RR4 Improved absorption refrigerator
RR5 Stirling refrigerator (krypton panels)
RR6 Stirling refrigerator (soft vac. panels)'
RT1 Tumble drier (conventional)
RT2 Tumble drier (improved)
RT3 Heat pump drier (improved)
RT4 Tumble drier (improved; high speed spin)'
RT5 Heat pump drier (impr.; high speed spin)'
RU1 Synthetic textiles
RU2 Textiles natural fiber substitute
RV1 Use wood parquet
RV2 Use tile floor
RV3 Use synthetic floor cladding
RV4 Use wool floor cladding
RW1 Conventional washing machine
RW2 Washing machine (ASD; optical sensor)
RX0 Compost use
RZ1 Use wall paper
RZ2 Use wall tiles
RZ3 Use wall plaster
RZ4 Use wall wood cladding
T0S Large standard car use
T0T Large aluminium car use
T0U Large steel car use
T0V Large plastic car use
T0W Small standard car use
T0X Small aluminium car use
T0Y Small steel car use
T0Z Small plastic car use
T1W Standard van use
T1X Aluminium van use
T1Y Steel van use
T1Z Plastic van use
T20 Truck use
T31 Diesel bus with MF and IIC
T32 Diesel bus with MF, IIC and CVT
T33 Electric bus long term with MF and RB
T3D Diesel bus standard
T3E Electric bus mid term with MF and RB
T3F Fuel Cell bus with MF and RB
T4D Diesel rail transport
T4E Electric rail transport
T5D Diesel inland ships
T5F Hydrogen inland ships
T6K Kerosene aircraft
T71 Dummy bunker demand
TH1 Asphalt high volume roads
TH2 Concrete high volume roads
TL1 Asphalt low volume roads
TR1 Use concrete railway tracks
TR2 Use wood railway tracks
TS1 Use THW waterworks
TS2 Use steel waterworks
TS3 Use concrete waterworks
TU1 Use wooden pallets
TU2 Use plastic pallets

Demand categories

D Agricultural diesel demand
E Agricultural electricity demand
G Natural gas to agricultural sector
0 North Eur. service sect. space heat
1 Middle Eur. service sect. small building
2 Middle Eur. service sect. large building
3 South Eur. service sect. space heat
E Commercial other electricity demand
G Desks
1 LTH large industry
2 HTH large industry
3 LTH small industry
4 HTH small industry
5 ELE large industry
6 ELE small industry
A Aluminium
B Bricks
C Chlorine
D Glass
K Sodium chloride (cryst. incl. Cl2 prod.)
M Machinery
P Polyolefine
R Ammonia
S Petrochemicals
U Cement clinker
V Paper
X Sawn wood (15% water content)
Y Tyres [Mt]
Z Capital equipment
R Electr./telecomm. wire [Mt copp. wire e]
S Pipes and ducts [Mt PVC equiv.]
T Window frames [1000 million frames]
V Cellars [100 million m^2]
A Industrial pressure vessels [pcs]
B Nuts, bolts, nails etc. [Mt steel equiv]
C Pipelines [Mt steel equiv]
1 Non Energy Use: Lubricants+Bitumen
1 Beverages, carbonated [Gl]
2 Beverages, non-carbonated [Gl]
3 Dairy products, no milk [Mt]
4 Wet food [Gl]
5 Dry food, non-susceptible [Gl]
6 Dry food, susceptible [Gl]
7 Non-food liquids [Gl]
8 Dry non-food [Gl]
9 Carrier bags [10^9 bags]
A Industrial bags [Mt]
B Transport packaging [Gl]
C Pallet wrapping [10^9 trip units]
1 SFD use - North Europe
2 MFD use - North Europe
3 SFD use - Middle Europe existing
4 MFD use - Middle Europe
5 SFD use - Middle Europe new type 1
6 SFD use - South Europe
7 MFD use - South Europe
8 SFD use - Middle Europe new type 2
A Water heating - North Europe
B Water heating - Middle Europe
C Water heating - South Europe
D Dishwashers
E Other existing electric appliances
F Food preparation
J Industrial/agricultural buildings type 1
K Industrial/agricultural buildings type 2
L Lighting
M Outside wall cladding [1000 million m^2]
N Other new electric appliances
O Solid food containers
P Furniture (chests)
Q Appliance materials use dummy
R Refrigerators and freezers
T Tumble driers
RU Textiles (excl. cotton)
RV Floor cladding [1000 million m^2]
RW Washing machines
RX Compost
RZ Interior wall cladding [1000 million m^2]
T0 Passenger car
T1 Van
T2 Truck
T3 Bus
T4 Rail Transport
T5 Water Transport Inland
T6 Air Transport
T7 Bunkers
TH High volume roads
TL Low volume roads
TR Railway tracks
TS Waterworks (THW equivalents)
TU Pallets (1000 million pcs)

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