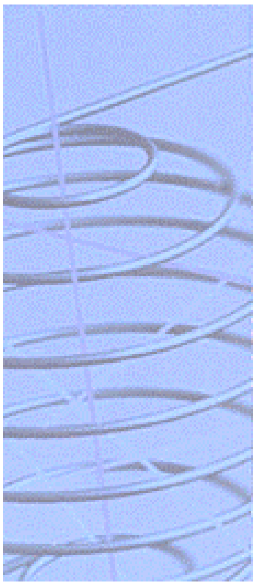
Greenhouse gas emissions reduction and material flows

Final report

IDD – Institut Wallon - VITO



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GREENHOUSE GAS EMISSIONS REDUCTION AND MATERIAL FLOWS

Final report

June 2001

For

the "Prime Minister's Office

Federal Office for Scientific, Technical and Cultural Affairs"

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VLAAMSE INSTELLING VOOR TECHNOLOGISCH ONDERZOEK
INSTITUT POUR UN DEVELOPPEMENT DURABLE

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Summary

Ongoing climate policies intend to promote energy efficiency within all the different activity sectors. Domestic sector especially is one of those sectors where energy use efficiency is a major goal of the policies, including energy equipment efficiency improvement, better thermal insulation of buildings,…

A priori it seems however interesting to extend at least the reflection around consumer behaviour to consumer goods in general. Measures aiming at tackling the consumption of products should promote those that generate the lowest levels of greenhouse gas emissions throughout the life cycle, namely from cradle to grave. Such a reflection necessarily implies to take into account technology improvements within the production system.

In order to illustrate and quantify the impact of such an approach, we have analysed three product categories and their product system : housing, beverage packaging and livestock products.

The aim is to evaluate the life cycle emissions related to these three product systems as well as the ways to reduce these emissions through measures both addressed to the consumer and to the production system.

This life cycle and dynamic approach has been undertaken through a systematic analysis of :

- Material flows for materials involved in the product systems studied,
- Technologies used to process and produce these materials as well as the different waste treatment options,
- Life cycle emissions of greenhouse gas by the different products studied
- Emissions reduction potential of these emissions both at the product levels and at the level of the Belgian demand for the three product categories. Costs have also been studied.

Different methodological developments have been undertaken in order to achieve the goals of the project :

Demands for all three product categories have been modelled : a bottom-up econometric model has been developed for the whole consumption pattern for breeding and packaging and a stock-flow model has been developed for the housing demand.

While material flows received very few attention in Belgium up to now the study constituted a first attempt to analyse the relevant material flows for the three product systems. The analysis has led to different conclusions for the three product systems : while foreign trades plays a small role for most of building materials, the meat system and especially the beverage packaging system involves significant import and export both for intermediary materials and end-use products..

Quantifying the greenhouse gas reduction potential related to the end use of specific product groups in Belgium, presented the challenge of finding a way between the development of a global and complex model such as the MATTER MARKAL model and product-specific LCA approaches.

Linking projections on demand with technical improvement options and specific emission factors enabled to give some insights on the possible impact of policies addressing consumption patterns and their environmental impacts. This macro-level quantification of the reduction potential gives relevant additional information in policy discussions, as compared to the results of LCA studies.

MARKAL provides a structured framework for evaluating costs taking into account categories studied (housing and beverage packaging) technical evolutions over a long time period. MARKAL models were developed for two of the products. Costs analyses were undertaken on an independent econometric analysis for the meat system.

The research has evaluated the life cycle greenhouse gas (GHG) emissions related to three product categories to levels of less than 1% to 4% of the Belgian 1990 GHG emissions. In relative terms, product substitutions only within each product category may represent significant reductions of the life cycle emissions resulting from the Belgian demand for each of the product systems, suggesting that in theory product substitutions may offer non negligible contributions to the fulfilment of the Belgian Kyoto target.

However given the low absolute levels of these potentials as compared to the total emissions reduction that Belgium has to achieve, the important question is whether these specific product-related emission reduction potentials can be extrapolated to other products categories and other consumption patterns.

Furthermore the costs analysis undertaken in the project indicate that while the theoretical potential from product substitution is significant at the level of the product-related demand, this substitution seems to be less cost-efficient than technology improvements available within the production system itself.

The level of confidence in this conclusion is however low given the high uncertainty level that we experienced with regard costs data for the different technologies and products.

Considering the weak data quality it can be questioned if an optimisation based on total system cost as applying in MARKAL-type models is the most efficient and most transparent way of taking into account the cost aspect. An approach based on fixed scenarios and associated cost calculations, eventually using cost ranges, seems more appropriate. At least both approaches should be combined as mutually complementing tools.

Finally the examples studied also indicated that both the necessary instruments and the geographical level for implementing them in order to achieve these potentials have to take into account the specificity of each product category : this specificity relates to uncertainty but also to the openness of the Belgian economy which is more or less important from one material to the other and hence from one product to the other.

Indeed, the European level could be more appropriate for some product categories. In general product-related measures also require European co-ordination. The Integrated Product Policy presently under discussion could offer such a framework.

Finally this project as also shown the importance of systematically recording consumption figures of key product groups in physical terms as a condition for properly assessing the environmental benefits of changes in consumption patterns (e.g. towards sustainable consumption).

1 Introduction

1.1 The context

In the framework of the Kyoto Protocol, Belgium, as part of the European Union, has committed itself to reduce its annual greenhouse gas emissions by 7.5% in the period 2008-2012 compared to the 1990-1995 levels.

With regard to the substantial carbon dioxide (CO_2) emissions in Belgium (more than 80% of total greenhouse gas (GHG) emissions), additional improvements in energy efficiency have to be pursued by all the activity sectors. Due to the addition of other greenhouse gases (CH_4, N_2O, SF_6, HFC's and PFC's) in the Protocol, efforts should also be extended at the level of the industrial processes, products consumption and agriculture. Besides this, the reports from the Intergovernmental Panel on Climate Change (IPCC) (especially its recent Third Assessment Report) show the need to develop strategies for the longer term to be continued beyond 2010.

As a result, considerable work is required to develop new options for GHG emissions mitigation as well as effective instruments that create synergies between the different actors involved.

1.2 The aims of the project

The project « Greenhouse gas emissions reduction and material flows », undertaken by IW, Vito and IDD and co-ordinated by IW, aims at identifying supplementary long-term options of GHG emissions reduction.

The starting point of the project was the fact that demand for products by households represents a demand for various materials. The resulting material flows on their turn represent energy flows and greenhouse gas emissions as materials are subject to successive transformations and transportation. However, except for final energy consumption, the influence of consumer choices is not really taken into account in present climate change policies.

The present study aims at answering the following three basic questions about the environmental impacts of the consumer patterns simultaneously with a consideration of production side with its technological evolution, including environmental performance improvements :

1. What is the impact of consumer choices on GHG emissions, namely through the product-related life cycle emissions? Especially what can be the impact of changes in product choices and in materials contained in products?

2. What is the impact of process substitutions on GHG emissions?

3. What can be the contribution of consumption pattern changes to the GHG reduction emissions efforts for the first commitment period of the Kyoto Protocol (2001-2012) but also for the subsequent commitment periods?

1.3 The approach

The analytical approach that has been followed is an **end-use approach**, which means that the Belgian final demand for the three product categories (or for their function) was a starting element to be analysed in the project.

Moreover due to the “indirect” effect of consumer choices on resource consumption and environmental impacts, **a life cycle approach** imposed itself : this means that the environmental impacts to be considered in relation to the demand for defined products are those produced from cradle to grave (from the extraction of raw materials to waste treatment).

At the same time, while the consumer demand was the main driving force considered, it was important to evaluate both life cycle environmental impacts and potentials to reduce them, taking into account possible technological improvements within the upstream production system and downstream waste treatment system. For this reason we adopted **a dynamic approach,** which means that evolution of technologies and improvements in their environmental performance are taken into account.

Finally we sought to meet a double concern, namely :

- to give an exhaustive picture of the three product systems, from the demand side to the production side and the waste treatment side, in order to draw the most realistic conclusions,

- to develop consistent insights on GHG emissions evolution and potentials for emissions reduction, including consistent cost evaluations.

For this purpose we have implemented **a double analytical work**: a detailed description of each product system and the application of MARKAL for two of the three product groups. Both approaches are mutually supporting.

1.4 The methodology

In order to implement this original approach, different steps were followed as explained below :

1. The **demand** for the three product categories was analysed: based on various data sources (notably statistical data), the existing products and their recent evolution were depicted and analysed. Then econometry was used by IDD to develop scenarios for the future trends.

2. Then the main materials involved in the product systems were identified. The different **material flows**, namely imports, exports, domestic production and consumption (including, in some cases, flows of waste materials) were quantified on the basis of statistical data from industry federations and official statistics. This part of the study allowed evaluating the importance of the total domestic production compared with total domestic consumption of these materials, especially materials consumption that can be attributed to the products studied.

3. Another step was the **analysis of production processes** as currently existing but also as potentially developing in the future. The GHG emissions and costs of the technologies were analysed. It is to be noted that this sub-task was more or less focused on the Belgian production system depending on the importance of the domestic production compared to the national consumption.

4. The previous steps allowed calculating the **life cycle emissions** for the different products, both at the level of the product and at the level of the Belgian demand.

5. The last step consisted in the **evaluation of GHG emission potential reductions** at the different levels of the product life cycles. This evaluation was performed both with simplified scenarios resulting in theoretical emissions reduction potentials and with MARKAL applications. The latter allowed a dynamic, integrated and economic evaluation of the potential.

1.5 Three illustrative cases

Three product categories were selected to illustrate this approach: livestock products, packaging and residential housing.

The application of this approach and methodology for the three selected product categories was justified by the fact that all three products represent **an important part of the day-to-day consumption.** They are also complementary with respect to the needs they relate to, the materials they involve and the GHG they emit (see Table 1) and by the fact that these product categories offer possibilities for reducing the GHG emissions during their life cycle. This selection also covers **different sectors**. Wood as a building material makes it possible to include the **carbon sinks** issue in the analysis. Finally, livestock allows including **non-CO_2 GHG** emissions in the analysis.

Partner	*IDD*	*Vito*	*IW*
Product category	**Livestock products**	**Packaging**	**Residential housing**
Products	Meat	Beverage packaging	Single family houses
"Materials" involved	Animals, fertilizers, fodder…	Plastic, paper, glass, steel, aluminium	Steel, cement, concrete, glass, bricks, wood
Main greenhouse gas emitted	CH_4, N_2O, CO_2	CO_2	CO_2

Table 1: Main features of the product categories studied and the author of their evaluation

1.6 Structure of the report

This report is a joint report by IW, VITO and IDD aiming at describing the common methodology followed through the project and at describing the different main results and conclusions for each specific product system. General conclusions are also drawn with regard to the general approach and the basic questions as listed in paragraph 1.2). Detailed descriptions and analyses of all three product categories can be found in the specific report by each partner (IW, 2001[1], [2], IDD, 2000[3] and VITO, 2001[4,5]).

Before presenting the different results of the project, the existing literature on "Material flows and GHG emissions" and the general approach followed in the project are discussed in chapters 2 and 3 respectively.

Then results are presented on :

- The Material flows analysis that has been done in relation with the materials involved in the product systems studied, especially for the housing system and the beverage packaging system.
- The description of the technology processes involved in the three product systems.
- The results related to the three product systems (housing system, packaging system, and meat system).

Then a comparison of the three sets of results is presented and finally some conclusions are drawn.

2 Material flows and greenhouse gas emissions: overview of literature[6]

Several tools have been developed for the analysis of energy and material flows or the chain analysis of products. In some analysis quantification of material use or material flows is an end in itself. In others it is a step in the assessment of environmental impacts related to material use.

2.1 Material flow studies

Three large groups of material flow studies can be distinguished according to their level of aggregation and the way 'materials' are defined.

- In a first group the Direct Material Input (DMI) and the Total Material Requirement (TMR) of an economy are estimated. DMI and TMR comprise all raw materials or primary resources (including energy carriers) required for the production and consumption of an entire economy. These highly aggregated indicators are used as indicators for environmental impacts and sustainability. The implicit assumption is that all material flows are carriers of environmental burdens and that any decrease in materials use is a step towards sustainability.

- In a second group the material is a *commodity produced by industry* or a *base material* (e.g. plastics, steel, paper and cardboard). The imports, exports, production and consumption of these materials are traced at all intermediate and final production and consumption stages. Methods have been developed to estimate the material flows related to components and packaging and to relate them to final use.

- Finally, substance flow analyses (SFA) focus on flows of one specific substance (often one element, such as Cd, N, P). The link between the studied substance and the potential impact is stronger than for the other types of material flow studies. Substances are analysed because they are considered to be inherently dangerous or harmful.

None of these studies look at environmental impacts directly.

Material flows studies often are confined to territorial boundaries: the material flows induced by all the (production and consumption) processes in a country are studied. Most claim a life cycle perspective, but in practice few of them link the material flows to specific functions or to final consumption.

2.2 Life cycle analysis

In life cycle analysis (LCA) the potential environmental impacts related to specific products or functions are studied. LCA is used to identify the improvement potential in the product system for a specific product or to compare competing products or processes.

However, to assess the total effect of specific policy measures, the results of LCAs have to be completed with analyses of the total technical, sociological and economic potential of these changes. Results of a life cycle assessment can also be hard to translate to regional or national policies because parts of the life cycle take place outside the territorial boundaries.

2.3 Greenhouse gas emissions and material (and energy) flows

Patel *et al*[7] studied fossil carbon use for materials in Germany. They look at how much the production and waste management of synthetic organic materials contribute to the release of CO_2 emissions and to what extent these emissions could be reduced by improved material management. Material flows are analysed up to the level of final products. Alternatives for plastics use and energy use during the use phase of plastic products are not considered. The model uses mixed boundaries "reflecting the German situation".

In the MATTER and BRED projects[8,10] a comprehensive West European materials and energy system model, combining a life cycle approach with the MARKAL energy system optimisation model was developed. System boundaries were chosen on the basis of the end use of products. The model allowed estimating the potential contribution of materials strategies to reduction of greenhouse gas emissions. It was concluded that approximately one third of all greenhouse gas emissions could be attributed to the materials system.

Its dynamic nature, the optimisation of the entire system and the fact that costs are taken into account are clear strong points of the model. However, some of these advantages are no longer valid in an open economic system, or in a system that does not represent the entire economy of a region or country. Even before the MATTER project ECN developed a Dutch energy and materials model in a similar way and acknowledged this difficulty.[9]

The advantage of developing such a comprehensive model with complex interactions is somehow counteracted by the fact that the results are difficult to interpret in terms of significant insight for policy making. Also, the underlying assumption of rational decision-making based on full foresight and full transparency is not realistic. The model is suitable for analysis of broad strategies but not for decisions on specific technologies.

2.4 Conclusions

Many of the material flows studies mentioned above have the objective of looking at ways of diminishing environmental impacts related to production and/or consumption patterns. However, many of them do not consider environmental impacts explicitly. Approaches in which total materials use is calculated are not very helpful in analysing specific environmental impacts and ways to reduce them.

Specific material flow analyses, especially those including the final use of materials in products, can be helpful in quantifying the magnitude of actual and future flows (including waste flows) of specific materials. As such, they do not give any information on specific emissions or impacts, but they can be helpful in identifying the importance of these flows, and they can give an idea of the relation between the final consumption of specific materials (in products) and the domestic production system for these materials.

The life cycle concept (*cradle to grave*) is necessarily linked to a specific function or to the final use or consumption of an end product. Two different perspectives can be taken for evaluating emissions:

- a *life cycle emissions from end use perspective*, in which the life cycle emissions related to the end use of specific products (functions) within a specified region are studied;

- a *direct emissions from processes perspective* in which the impacts caused by the transformation and end use processes within a specified region are studied.

The evaluation of both life cycle emissions from end use and actual emissions from processes within one comprehensive model was possible in the MATTER study because Western Europe was considered as a relatively closed economy. However, as illustrated further by the analyses of material flows, the Belgian economy is extremely open. Moreover, the focus in this research is on specific end uses (packaging, housing, livestock products). Hence, the model does not represent the entire economy, and becomes even more 'open'.

We can conclude that the development of a comprehensive Belgian energy and materials model is not useful, and that specific approaches have to be developed for each of the product groups studied in this project.

3 General approach: description

3.1 Definitions of the system studied

Substantial methodological work has been done in relation to the definition of the system(s) that was (were) intended to be modelled with MARKAL. This work and its conclusions are described in paragraph 4.3.

Methodological aspects described here are related to the detailed system description. In order to ensure a harmonised scheme for the three product systems and a coherence in the analysis to meet the assigned aims of this project, the three teams have adopted a common nomenclature such as a set of **concepts and definitions** and a **common framework** as described below.

3.1.1 Concepts and definitions

The definitions adopted in the project are mainly based on two types of sources :

- The PhD thesis of D. Gielen on the Dutch integrated energy and materials MATTER MARKAL model (Gielen, 1999)[10]. It contains a glossary comprising terms frequently used in LCA or stemming from the domain of materials flows studies and terms defined for use in the model description
- LCA studies, especially the network action on LCA in forestry (partially based on ISO and SETAC definitions)

The following terminology has been adopted :

- ***function*** = ***functional unit*** : quantified performance of a product system for use as a reference unit in a life cycle assessment study (ISO/SETAC, 1996/1997)
  - equivalent to ***product service*** : utility of the product for the consumer
  - one product can have more *functions*, e.g. for packaging : bringing content to the consumer, preserving, carrying information, …; often one speaks of the ***primary function***
- ***product*** : materials in their final physical shape that is delivered to the consumer (equivalent to the ***final product*** in LCA terminology)
- ***product alternatives*** : different products performing the same function. Also designated as ***functional group*** (group of products performing comparable *functions) or* ***product category***
- ***product use*** : relates to the phase in which the product is performing its *function*, is delivering its service (corresponding to the ***product life span*** in LCA terminology)
- ***product system*** : collection of materially and energetically connected unit processes which performs one or more defined *functions* (ISO/SETAC, 1996/1997). Also designated as **chain**

- ***life cycle*** : consecutive and inter-linked stages of a *product system*, from raw material acquisition or generation of natural resources to the final disposal (ISO/SETAC, 1996/1997).

3.1.2 Common framework

The analysis of the different elements has been performed at different narrowing levels : global study, function, functional group, product. At each level a clear definition and description of what is studied and a justification of this choice (statistical significance, relevance according to an end-use standpoint, GHG relevant materials and processes, etc…) have been given. The process of definition, boundary setting and description was iterative.

Each product system is then described according to the following scheme :

1. Backgrounds

2. System definition and boundaries

2.1. Functions

2.2. Functional group

2.3. Products

3. Detailed system description (including all product systems relating to the products defined under 2.3).

3.1. **Product system description according to levels** (from natural resources extraction of raw materials involved to treatment of disposed products) and subsystems/processes.

- Types and quantification of global flows involved : inventory at national level , data on production, consumption, import, export, …
- Main existing processes, their importance (in terms of flows) and their characteristics (technical and economical)
- For each process/flow: actual situation, relevant historical data, expected developments.

3.2. **Environmental and socio-economic performances per product**

Energy balance, GHG emissions balance, other impacts

3.3. **Discussion of the possible improvements of the GHG emissions balances**

- In the production chain : energy efficiency, material efficiency, new recycling ways, energy recovery during waste treatment, energy substitution, material substitution, end of pipe technologies
- At the product level : product reuse, increased product life time, increased efficiency of product use, development of multifunctional products, product re-design with less material or more efficient materials
- At the function level : consumption pattern changes

3.4. Evaluation of the demand and socio-economic impacts

3.2 Demand modelling

IDD elaborated a bottom-up econometric model for the whole consumption pattern based on socio-economic variables for breeding products and packaging. A brief survey of econometric modelling systems has been done in order to select the most appropriate for the project objectives. This survey was realised considering the long-term perspective of the project and the need to reproduce structural modifications of the consumption patterns. For this purpose, traditional top-down systems would have been misleading. The Houthakker-Taylor demand system was retained and the behavioural econometric equations were encompassed inside a bottom-up model. Demand was modelled in physical terms and all aggregated prices were endogenously computed (as well as the CPI, of course) in function of the elementary prices (of each goods and services categories) and the structure of private consumption (budget shares). The bottom-up model enabled to translate physical data into monetary data, both in current prices and constant process. All the demand equations were simultaneously simulated. The overall model for consumer demand consisted of about 130 simultaneous equations and distinguishes 60 categories of goods and services, of which 18 were considered in physical terms (kg or litres per capita). The econometric results were discussed among the partners as well as preliminary simulations.

For residential housing materials, a special stock-flow model was proposed based on data gathered by IW on housing (new houses, demolition and renovation). For this system, both econometrics and socio-demography were used to ground behavioural equations. The model works as a stock-flow matrix that simulates the evolution of existing houses and the need for new single family houses. Econometric was used to capture socio-economic behaviours. Demography was used to take into account the long-term modifications of the structure of the Belgian population and their impact on housing demand (preference for single family houses). For a given population, the model determines both the average surface for new houses and the number of houses needed to equilibrate the housing market (from a dwelling point of view). Both econometric results and simulation results were discussed among the partners.

As far as socio-economic impacts of alternative scenarios are considered, their evaluation requires data about production, employment and productive investments, external trade and a description of the chain from a productive point of view (sub-sectors, deliveries, external trade…). This data collection was achieved under the responsibility of each partner for its own chain. Furthermore, a sectoral model based on the input-output table was developed to quantify the indirect effects on the activity sectors. Through intermediate deliveries, this system describes the indirect modifications of effective production for each of the 60 sectors considered with respect to any alteration of the demand addressed to one of them.

3.3 Description of MARKAL

MARKAL (MARKet Allocation) is a dynamic technico-economic energy system optimisation model developed in the framework of the "Energy Technology Systems Analysis Programme" (ETSAP) of the International Energy Agency (IEA). The Linear Programming model selects the least cost combination of processes and flows that satisfies the exogenously defined demand for energy services over a given time period (typically several decades) under given exogenously defined constraints, starting from an existing exogenously defined transformation system. It calculates the resulting total system cost, total or specific emissions, energy flows, process activities, and shadow prices for produced goods.

In that time period, demand will change, costs and technical parameters of technologies will change, existing capacity will gradually be replaced, new technologies will become available. As a consequence, the least cost combination of technologies will also evolve.

MARKAL optimises the system over the entire time period and the entire system. It supposes rational decision making based on full foresight and full transparency.

Although MARKAL allows imports and exports, the implicit assumption in MARKAL is that the productive system changes according to (changes in) the demand. In fact, imports and exports are defined as processes that are part of the system and provide an alternative to transformation within the system. If no constraint (minimum, maximum, fixed, ratio) is put on import and export, they will be evaluated according to the same criterion of least cost combination for the entire system.

MARKAL allows the evaluation of GHG emission reduction policies. Emissions can be associated with processes or with fuel consumption. A constraint or a cost can be put on these emissions.

In the present Belgian MARKAL model, the Belgian energy system is studied. This includes all energy flows and related air emissions (notably CO_2, SO_2 and NO_x) occurring in Belgium, resulting from primary energy production, energy transformation and final energy consumption in the different activity sectors.

A new MARKAL version has been developed in the framework of the MATTER project for the analysis of integrated energy and materials systems. MARKAL was adapted to allow modelling material flows (allowing substitutions between materials and between processes). The most important structural difference is that storage of materials in products had to be modelled by including a time lag between input and output of the products during the use phase. Like with the demand for energy services demand for product services has to be defined exogenously. The integrated model is also used to extend the analysis of GHG emissions mitigation within energy transformation and use processes to substitution between production processes and between materials. The materials system includes industrial processes, products use and waste treatment (collection, disposal, recycling and energy recovery).

The MARKAL energy and material flows model has some clear strong points :

1. The dynamic nature of the model allows taking into account changing energy and product service demand, resource availability and resource prices, assessing (long term) improvement potentials and taking into account the time lag between production and disposal.

2. Optimisation of the entire system allows selecting the most cost-effective technologies as a function of constraints, comparing improvement options in different sectors and analysing interactions between changes in the energy system and changes in the materials system. Recycling and reuse are integrated in the entire system. Outcomes (costs, emissions) are given for the entire system, thus no allocation problems arise.[1]

3. Finally, costs are taken into account in evaluating emission reduction options.

However, it became clear in the course of this project that some of these theoretical advantages are no longer valid in an open economic system, or in a system that does not represent the entire economy of a region or country (mainly because the assumption that the productive system changes according to (changes in) the demand is no longer valid).

Moreover the underlying assumption of rational decision making based on full foresight and full transparency has decisive implications on the results.

4 Results

4.1 Material flows analysis

No systematic efforts in analysing material flows in physical terms have been undertaken in Belgium up to now. The efforts made in this project represent a first contribution in this sense. A quantification of the main flows of some materials that characterise the Belgian economic system has been done as well as a preliminary evaluation of the GHG emissions that are associated with these flows. The analysis has been limited to the materials that potentially are part of the products studied in the project : residential housing, beverage packaging. Such an analysis for the meat system has less relevance because of the specificity of this system. For this system, as a result of the system defined for this product category, materials involved (as understood in a very general term) are meat itself, fertilizers, and pesticides. The different flows for these materials are described in the specific report prepared by IDD[3].

Data collected for the material flow analysis have been used for different purposes in other parts of the project :

- To quantify the part of imports for satisfying domestic demand for these materials,

- To quantify the part of the products studied in the project (residential housing, food packaging and breeding products) in the domestic consumption,

[1] multiple inputs and outputs, costs and benefits of recycling, reuse or energy recovery

- To quantify the exogenous residual demand to be introduced in MARKAL.

The work has been done for cement, concrete, bricks, glass, steel, non ferrous metals, wood, lime, plastics, paper and cardboard. Data sources were industry federation's reports, statistical data and internal data from different surveys from Institut Wallon and VITO.

The analysis has lead to the following conclusions regarding the quality and availability of data :

- For some materials, data are not complete enough to analyse all types of flows : while productions are generally reported for Belgium, export and import data are frequently given for Belgium and Luxembourg together and apparent consumption can not be evaluated from these flows; some data are not reported in the official statistics for reasons of confidentiality. Flows are often expressed in monetary values, which is not relevant for the project purposes.
- Inconsistencies exist between different data sources (for instance between national statistic data and industry federation data); in some cases data in official production statistics are not consistent with actually installed production capacities; sometimes calculated apparent consumption of specific intermediates does not match with the production of related products (as shown in more detail for plastics production and intermediates for plastics production);

The main results are summarised in next table showing the magnitude of the mains flows production, consumption, import and export.

The evaluation of the part of the two product systems, housing and beverage packaging, in the domestic demand for the different materials has also partly been made.

Caution has to be taken when interpreting the data in Table 2. Most production data shown there refer to the production of the primary materials; the corresponding consumption data refer to the consumption of materials by primary processors. Sometimes different processing steps still have to be carried out before these (transformed) materials reach the final consumer. At each of these intermediate production steps often quite important imports and exports occur. Hence, the consumption of the base material by the Belgian transformer is quite different from the consumption of the transformed material by the Belgian final consumer. This is illustrated for plastics, for paper and cardboard and for aluminium in the corresponding detailed reports.[5] A specific difficulty in tracing the material flows up to the level of the final consumer is the quantification of materials used for packaging or for components. Packaging and components are imported and exported as parts of products, and do not appear as such in the foreign trade statistics.

Important cross-boundary flows also exist for selectively collected waste materials, that have been sorted according to grades and qualities and that are internationally traded as secondary raw materials. E.g. the Belgian export of waste paper is more than twice the use of recovered paper pulp for paper and board production in Belgium.

kt material	Year	production	import	export	consumption			
					total	building construction	*of which SFH residential building*	packaging
Bricks	1997	2,510	85	462	2,133	95%	*65%*	0%
cement	1998	6,803	679	1,982	5,500	87%	*52%*	0%
flat transformed glass	1998	307	-	-	~307	65%	*3%*	0%
wool glass	1998	111	-	-	<65	95%	*ND*	0%
sawn wood	1997	577	1,006	236	1,347	ND	*11%*	19%
wood-based panels	1997	1,548	504	1,523	529	ND	*3%*	0%
steel	1998	12,780	-	-	4,176	13%	*6%*	3%
copper	1992	373	-	328	107	23%	ND	0%
aluminium (semi-manufactured products)	1997	380	151	331	200	35%	ND	20%
zinc	1992	63	23	41	45	28%	ND	0%
lime	1998	1,982	0	0	1,982	ND	*ND*	0%
plastics [a]								
Polyethylene	1998	1591	882	1842	636	5%		65%
Polypropylene	1998	1317	541	1143	918	3%		48%
PET	1998	-	210	73	136	0%		94%
PVC	1998	769	234	426	92	65%		15%
polystyrene	1998	789	147	638	258	38%		41%
polycarbonates	1997	ND	ND	ND	166			
total plastics					*2040*	*19%*		*41%*
paper and cardboard (non-coverted)	1998	1,545	2,773	1,053	3,265	0%	*0%*	40%

[a] *Consumption data reported here are calculated from production and foreign trade statistics. They differ however quite a lot from data given by APME/TN Sofres. Data that are clearly not consistent with actual production capacities have been marked with a question mark.*

Table 2: Order of magnitudes for the different material flows

Another important conclusions that can be drawn are the following :

- The relative importance of Belgian production with respect to the domestic demand is important for most building materials. However, the weight of imports is important for wood and steel products.

- The situation is reverse for packaging : the analysis has particularly emphasised the complexity of flows all along the product system. For all packaging materials important trade flows exist at all levels of the production chain (base materials, intermediates, semi-manufactured products, finished packaging, and finally, packed products). As an example polyethylene flows for packaging were analysed in detail. It was concluded that the part of the Belgian final domestic consumption of polyethylene packaging that is directly related to the Belgian production of polyethylene is very small and almost impossible to quantify. The same can be concluded for the other plastics , hollow glass, paper and cardboard used for packaging.

4.2 Process description : overview and trends

This study contains a description of the production system and presents industrial technologies involved in the product systems studied. This information identifies the production characteristics, the points form which emissions may be produced through these processes and materials and energy use both under the current situation and under future developments in technology and capacity. Details of the analysis will be found in separate reports (see IW[2] and VITO[6]).

For building materials (cement, lime, bricks, steel, glass and wood), the report presents successively :

- a brief characterisation of the materials and products processed.

- the main production routes in the Belgian industry, the fundamental processes and their relevant characteristics.

- Alternatives for production and energy consumption existing world-wide (New and emerging technologies).

- an overview of the current and future capacity in the main Belgian industries. This section incorporates data compiled from Institut Wallon and Vito through annual and punctual surveys of individual manufacturing plants to analyse the current situation and data from the activities reports of the largest companies to estimate future investments in technology and capacity.

- background information on the greenhouse gas (GHG) releases and mitigation options. In this section, GHG emissions are quantified by process using the Intergovernmental Panel on Climate Change (IPCC), Corinair and/or calculated emission factors for Belgium. The main sources of information are data from recent literature and the Belgium energy inventories which focus primarily on the on-site energy and materials consumption reported by each industry. Then GHG emissions mitigation options are discussed using the next list of improvement options : "fuel switch", "increased energy efficiency", "CO_2 removal and storage", "recycling and reuse" and "dematerialization and materials substitution". Potential technologies that will reduce GHG emissions are included in the "increased energy efficiency and cleaner technologies" topic. Finally, other environmental impacts are presented.

Information within each topic and each industry sector was searched from a variety of sources, and was usually condensed from more detailed sources pertaining to specific topics. The reports provide a synopsis of each issue and references where more in-depth information can be found are listed at the end of the report.

Table 3 summarises an estimation of the energy consumption and the CO_2 emitted in Belgium by tonne of material and by industrial process as well as alternative technologies existing world-wide for the main building materials.

Industrial sector	Unit of material	Production routes in Belgium	Fuel combustion GJ/t	Electricity GJ/t	Process emissions t CO_2/t	CO_2 emissions t/t	New and emerging technologies
Iron and steel	Steel	79% blast furnace (BF)	10,1	1,46	0,24	1,7	Ironmaking technologies: ➢ Direct Smelting: COREX, CCF, SIDCOMET ➢ Direct Reduction: Midrex and Hyl Casting technologies: ➢ Thin slab casting ➢ Direct strip casting Growth of EAF plants
		21% electric-arc-furnace (EAF)	4,5	2,99	0,05	0,7	
Cement	Clinker	38% wet process	5,6	0,20	0,55	1,07	Grinding process: ➢ Roller mills Growth of dry process with preheaters and precalciners
		21% dry process	3,3	0,25	0,55	0,87	
		41% dry process with precalciner	3,0	0,27	0,55	0,85	
Glass	Commercial flat glass	Fuel fired furnace	8,0	0,78	0,17	0,8	Recuperative and regenerative preheating systems Increased glass recycling
Bricks	Brick	Mainly continuous tunnel kiln	2,3	0,25	---	0,16	Roller kiln

Table 3: Belgian main industrial energy consumption and CO_2 emissions for building materials

For some of the packaging materials another approach was used. Because of the predominant foreign trade flows no direct links exist between the final use of packaging products and the Belgian production of packaging materials. E.g. a detailed analysis of the specific features of the Belgian petro-chemistry or of the paper and board sector would not give the required results for an analysis of life cycle greenhouse gas emissions related to the use of plastics or cardboard for beverage packaging. In the case of aluminium, the most important contribution to greenhouse gas emissions is found in the production of primary aluminium. However, there is no production of primary aluminium in Belgium.

Hence, for the analysis of the production processes for plastics, and cardboard or aluminium, European state-of-the-art technology was considered rather than the specific features of the Belgian production. Major information sources were the European Reference documents on Best Available Techniques (BREF) and the different sector studies that provided the basis for the input data for the MATTER model.

The production of plastics, and of the necessary intermediate organic chemicals, is a part of the much larger, highly integrated petrochemical complex. Crucial petrochemical processes, such as the production of ethylene or aromatics, have multiple inputs and outputs. Due to the complexity of the petrochemical processes calculating greenhouse gas emission factors for plastics is tedious. This is clearly shown by the striking differences in CO_2 emissions in the older and the more recent versions of the APME ecoprofiles, which in their turn differ quite a lot from other detailed studies.[7,11,12] In the context of this project it was not possible to analyse these contradicting results in depth.

kg CO_2 equivalents/ton		CO_2		
		Patel, 1999	APME, 1993-1995	APME, 1999
PE	LDPE	1240	1250	1900
	HDPE		940	1700
PP		-	1100	1900
PET		2070	2330	4300

Table 4 : Gross CO_2 emissionsfor plastics production

Another source of uncertainty on the greenhouse gas emissions related to the use of plastics is the treatment of plastics waste. The plastics waste sector is in full development. Many recycling processes are in a development stage and have not yet passed the test of full scale application. In the case of plastic beverage packaging mono-plastic waste streams can be separated, and mechanical recycling seems to offer the largest potential environmental benefits.

When considering reductions in greenhouse gas emissions in pulp and papermaking, energy use is the basis issue. The use of recycled paper pulp provides an important potential for reducing energy use. However, the choice of system boundaries is essential for the evaluation of greenhouse gas emissions. Energy use in pulp and paper production from wood is to a large extent biomass based (burning of bark and black liquor), whereas papermaking from recovered pulp might have to rely on external fossil energy sources. The final greenhouse gas emission balance depends on the possible alternative uses for this biomass.

Both for plastics and for paper and cardboard production only gross estimates based on general assumptions can be given for future energy use and/or emission factors.

4.3 MARKAL modelling choice

The conceptual framework adopted within the MATTER study (see Gielen , 1999[10]) as well as the usual implementation of MARKAL for energy system analysis were the departure points for the definition of the system that the project intended to model. An overall system definition was initially searched in the perspective of a comprehensive simultaneous modelling of the three product systems inter-linked with the whole Belgian production system driven by the domestic demand. This last includes both the product demand and the “residual material demands” (materials consumed by products not studied in the current project) and material exports.

In the current project the system was to be delimited on the basis of a "end-use" and life cycle approach which means that all materials used for products had to be taken into account. This consequently should include production outside the region (imports), transport as well as waste recycling and recovery.

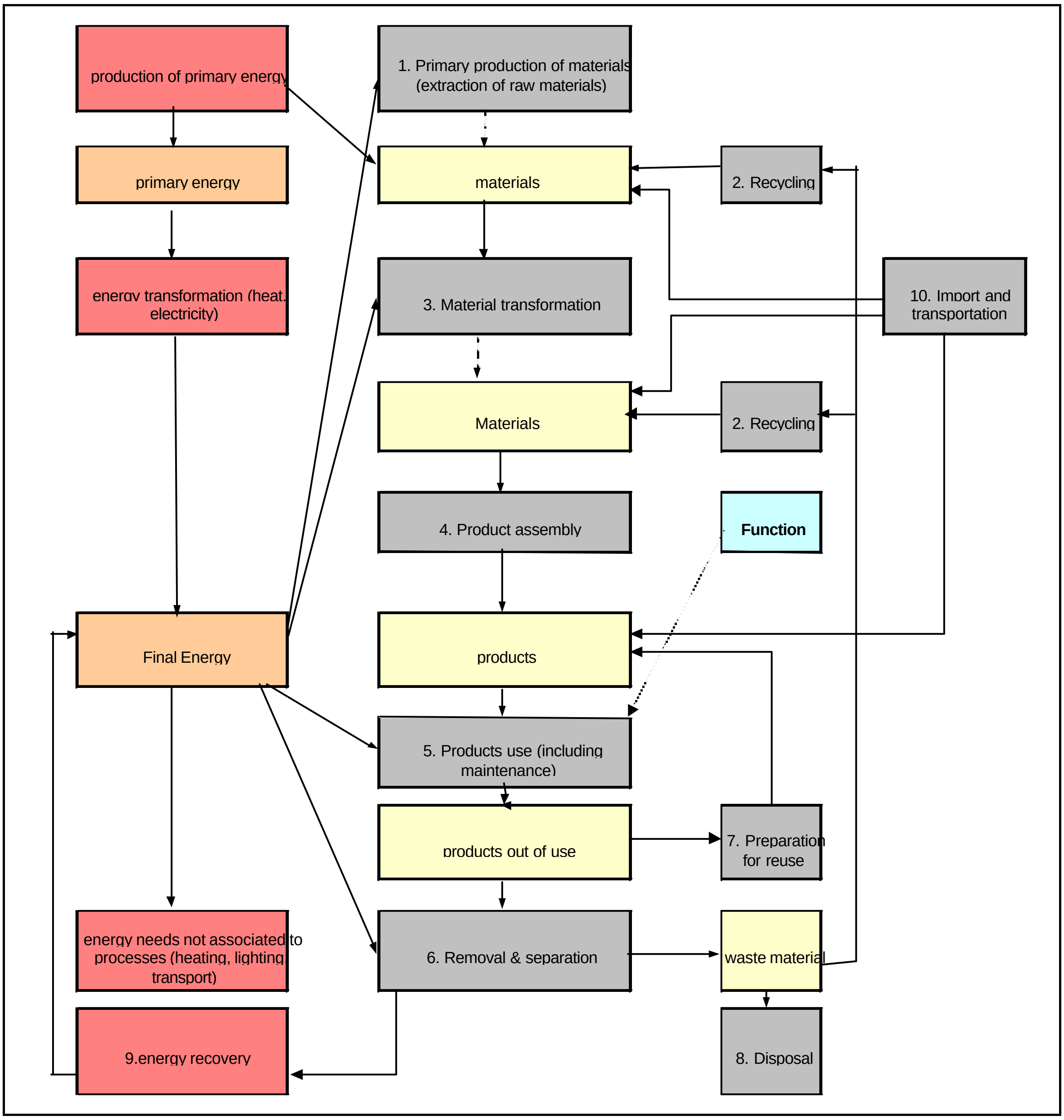


Figure 1 : Description of the system initially delimited for the project

Therefore the system would have included detailed modelling and analysis of improvement options for processes not only taking place in Belgium, but more generally, all of these used in the production, use and post-use treatment of the products studied that are used/consumed in Belgium, from cradle to grave.

Reaching such a comprehensiveness of the model is however a challenge. It is not feasible to represent in detail all the different options between upstream processes for imports (this is also the case for downstream processes for export). A way to overcome this huge complexity could be to characterise imports by fixed emission coefficients per unit. In the case of exports these emission coefficients would be defined as negative values[2]. 'Belgian' emissions and 'imported' emissions may also be distinguished.

[2] *to correct for the GHG emissions caused by the import and transformation processes related to the exported good (these emissions are not related to Belgian end use)*

Figure 2 illustrates the consequences of such a system definition for a MARKAL implementation : Optimisation over the system defined is based by the fact that technological options are restricted to the Belgian territory so underestimating improvements outside.

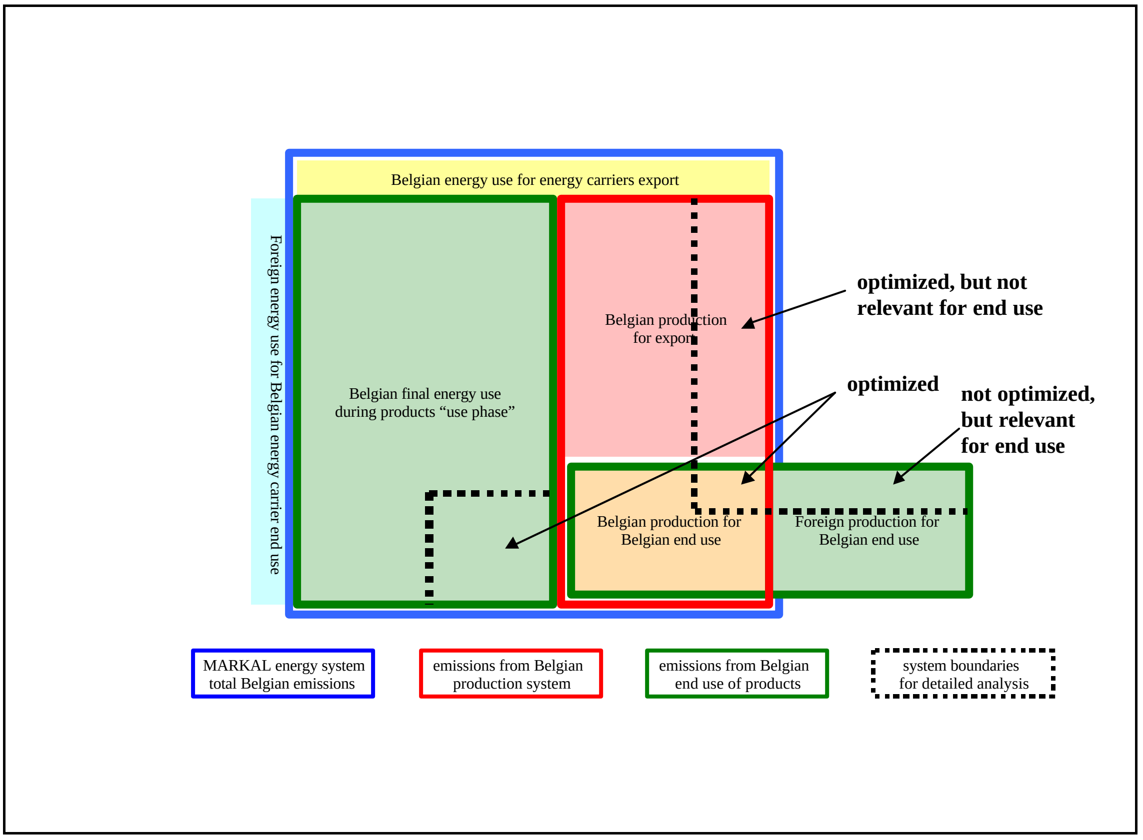


Figure 2: : Initial system boundaries

- For analysis of the total Belgian emissions the system boundaries are shown in blue.
- For analysis of emissions caused by the Belgian production system the system boundaries are shown in red.
- For analysis of emissions caused by the Belgian end use the system boundaries are shown in green.

An in-depth analysis of the MARKAL MATTER model and the material flows lead to the conclusion that the system boundaries as defined above, had to be adapted for the current project.

The MARKAL MATTER model that was developed for Western Europe enabled to envisage simultaneously two perspectives for evaluating GHG emissions at the same time :

- a life cycle emissions / end use perspective, in which the life cycle emissions related to the end use of specific products groups (functions) are studied;

- an actual emissions / processes perspective in which the emissions occurring during the transformation[3] and end use processes within a specified region are studied.

Both perspectives are valuable and sensible. Both perspectives correspond to specific policy options (the former would provide a basis for acting on consumer responsibility, e.g. product taxes; the latter corresponds to the concept of national production responsibility as currently in use for evaluation of national GHG emission levels). The evaluation of both perspectives within a comprehensive and unique model was possible in the MATTER study as a consequence of the system studied namely Western Europe. For a relatively closed economy like Western Europe it can be stated that GHG

[3] *We will use 'transformation' to cover not only production processes but also post-use treatment of used products.*

emissions taking place abroad due to the production and transportation of the main imported materials (mainly oil, tropical timber and most metal ores), are of minor importance.

However, the most important specificity of the present project, compared to the MATTER study, arises mainly from the geographical scale adopted : The MATTER project studied Western Europe while the present project focused on Belgium. In an open model (imports, exports) both perspectives lead to different system boundaries. In an open economy as Belgium, there is a weak link between production and consumption and changes in consumer behaviour in order to reduce life cycle GHG emissions will not automatically lead to changes in production as a large part of the life cycle emissions takes place abroad. Even more difficulties arise if the model does not represent the entire economy (sectorial, only specific materials / products / product groups, …).

This problem proved to be different from one product system to the other because materials involved are not the same as shown for the "Residential housing" and "Beverage Packaging" systems (Table 5) and the role of imports and the share in the use of specific materials for the considered end use differ. For instance, significant transportation costs makes the building materials a closer market at national level. However, one of the functions of packaging is to ensure the transport of goods and in a small country like Belgium, huge flows of this product category arise.

	Residential housing	Food packaging	Model as originally defined for housing??
Share of material imports in the product system	Small	Large	Upstream improvement options for imports not considered in the optimisation
Share of Belgian production in the product system	Large	Small	Improvement options considered
Energy use during use phase of final products	Large	Small	Improvement options considered

Table 5 : Differences between the product systems "Residential housing" and "Food packaging"

Furthermore, the experience acquired within the MATTER project shows that the advantage of developing a comprehensive model, including the three product systems and their interaction with the overall productive system, is counteracted by the fact that the more global and comprehensive the model is, the more difficult is the interpretation of the results in terms of significant insight for policy making.

On the other hand, the overall solution given by the model assumes rational decision making (system cost optimisation) based on full foresight and full transparency. The more complex the model and the interactions are, the less plausible this assumption is. In the MATTER and the BRED projects many scenario and sensitivity analyses have been carried out to assess the impact of several assumptions (e.g. on technical and cost coefficients, on macro-economic parameters). However, the influence of this basic and very crucial assumption on the final results is not analysed.

For these reasons, it was decided to develop separate models for residential housing and beverage packaging. The structure of the two models are compared in Table 6.

	Residential housing	Beverage packaging
Horizon	2030 (however results are significant for a 2020 horizon)	
General definition of the system and its boundary	Product use, product elimination, material production processes and transport involved in the product preparation	
Representation of the demand	Demand for new single family houses, renovated houses, demolished houses and house maintenance expressed in total surface	Demand for beverages, grouped according to the potential packaging options
Level of description of the Belgian production system	Detailed description of most the processes encountered in Belgium and alternative technologies taking into account the industry investment plans. Exception for plastic production for which technologies are standard technologies.	Industrial processes are described on the basis of European standard technologies.
Imports representation	Explicitly distinguished from Belgian processes	No distinction between import and domestic production
Material exports representation	Represented through a defined separate demand for the material	No export considered
The level of detail of the energy system	Not explicitly described. Input data are based on scenarios performed with the Belgian energy MARKAL model.	Simplified energy system based on average energy efficiencies and emissions factors
Interrelation with the overall system	Exogenous demand for materials involved in the product production but consumed by other products expressed as a residual demand	No interaction
Waste treatment	Incomplete accounting due to the fact that the horizon is not far enough to take into account the demolition of houses built during the period studied	Detailed description of the technologies which enables a dynamic analysis of the down stream processes

Table 6 : Structure of the product system models "Residential housing" and "Beverage packaging"

With respect to the meat system, the following different elements lead us to decide not to use MARKAL model and to evaluate GHG emissions reduction potential in another way:

- the difficulty to find reliable cost data for the different processes of the system.
- the specificity of this system in terms of environmental impacts. In fact, the BRED study, especially the modelling of the livestock chain in MARKAL, lead to the conclusion that one of the most cost effective measures to reduce methane and N_2O emissions from livestock was to increase productivity through changes in the fodder composition by addition of concentrates .In view of the different crises that occurred in Belgium and Europe during the last years, this kind of mitigation measure is incompatible with healthy production and/or with other environmental concerns.

As a result, cost optimisation for the livestock system is less relevant than for the other two systems studied.

4.4 Housing system

4.4.1 Background

Buildings, especially residential buildings, play a major role in satisfying human needs : the primary function, i.e. sheltering people is primordial for the satisfaction of other needs (heating, private life, leisure, aesthetic, space, health…).

On the other side, building construction, which implies the use of different materials like cement, steel, glass, bricks, plastic,…, is an important sector from the bulk of materials consumption point of view, involving at the same time high levels of energy consumption per ton produced and the existence of potential options to reduce these emissions. The potential role of wood in building poses also the carbon sink problem, which is a great issue in the Kyoto Protocol. Waste is also a significant issue regarding building materials.

4.4.2 System definition

The **function** studied is the "residential housing" in its primary role of providing shelter. For this function, one functional group is analysed in particular, namely "single family houses". This choice is justified in terms of quantitative significance (single family houses represent more than 65% among all new residential buildings) but also on an end-use standpoint : single family houses are more characterised by individual behaviours than multi-family houses in Belgium.

A more precise definition of the relevant **products** to study was made on the basis of a preliminary analysis from statistical data on residential housing in Belgium. This analysis was also a complementary tool for the creation of a demand modelling performed by IDD (see paragraph 4.4.3.1.2). Construction rates, average built surfaces and their evolutions, demolishing rates, renovation rates and types, cost prices data…, were analysed.

Both new houses and renovated houses (especially with surface increases) represent significant material consumption and hence life cycle energy consumption and GHG emissions. Taking into account the importance of both options and they mutually possible substitutions, the analysis focused on them. Renovation of separate elements has also been included in the analysis.

With regard to architectural types, both with respect to the shape and to the materials involved, the huge diversity within the Belgian market couldn't obviously be taken into account. Consultation of experts from the sector (architects and entrepreneurs), technical documentation and observation lead to a build up of a simplified market representation:

- On one side, a limited set of houses differing in the <u>materials</u> used has been selected, going from so-called "conventional houses" (brick or concrete/brick) to wooden houses (either with brick facing or with wood facing), also including intermediary cases like expanded clay or cellular concrete. <u>All options were calculated to have the same thermal insulation level in order to exclude energy consumption during the use phase</u>. The analysis was also restricted to the shell.
- On the other side, based on three actual cases of new constructions for which precise quantified surveys were provided by architects, extrapolation curves were built in order to represent the different building elements size as a function of total <u>built surface</u>, so allowing to estimate the influence of surface on material consumption and hence life cycle emissions. This extrapolation was based on a limited set of architectural parameters.

4.4.3 Detailed description

4.4.3.1 The present demand and its evolution

4.4.3.1.1 Present demand

Housing is intensively described by statistical data (National Statistic Institute). All these data have intensively been used in the project. Every year about 20 000 new houses are built. The exact amount depends on different factors and there is no clear trends during the last years. On the opposite, there is an obvious increasing trend of total surface built per house (see Figure 3 and Figure 4).

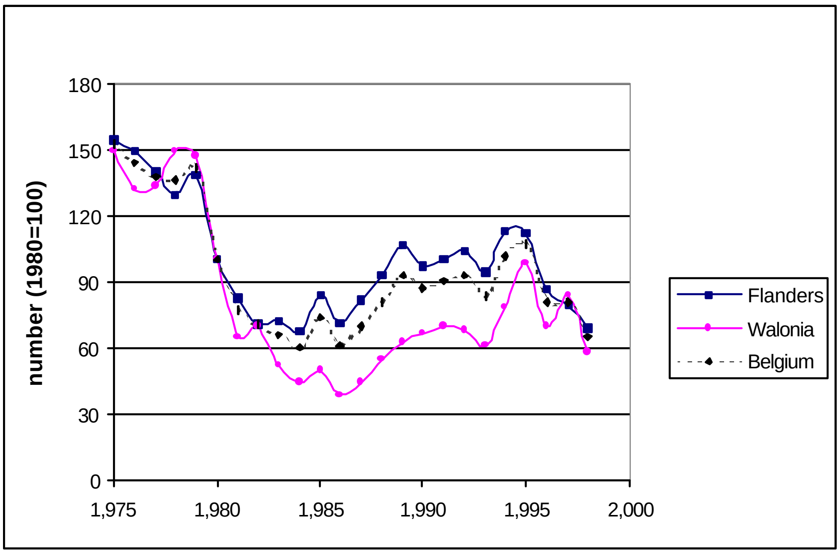


Figure 3 : Evolution of the number of new SFH
Source : INS

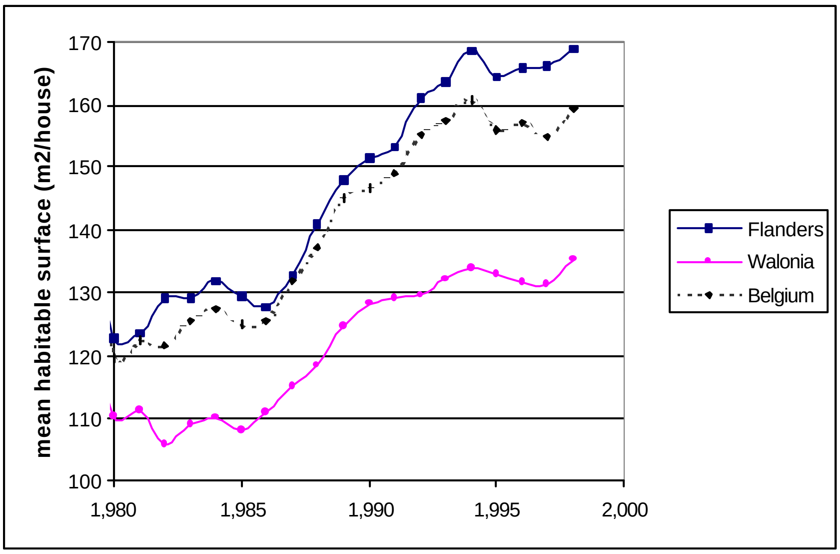


Figure 4 : Evolution of mean living surface of new SFH
Source : INS

Besides new construction, renovation also plays an important place in the building sector: among all renovations with transformation, renovation with surface increases account for more than 80%.

4.4.3.1.2 Evolution of the demand

Housing demand has been modelled inside the LOCATELLI model (IDD, 2000) only for single-family houses, both in terms of desired average surface and the number of houses to fulfil household's demand. Demography plays a key role in the model: the structure of the Belgian population into five kinds of households influences the demand for single family houses (with respect to other type of housing). Taking into account the current rates of demolition and renovation (both increasing or not the surface), the number of new constructions needed to satisfy household's demand results in around 23 000 in 2020. This figure tends to fluctuate over the simulation period. The number of constructions per year would increase from 22 050 in 2000 to 22 600 in 2005, then it would decrease slightly to 22 160 by 2015 and increase again until the end of the period. This profile results from the influence of demographic behaviours and the demolition rate. The average surface for new houses is 175 m^2 today. It would be around 215 m^2 in 2020, reflecting the increase in disposable income and relatively low real interest rates.

4.4.3.2 Description of the products : existing and new products

A description of representative houses has been made through a description of the most relevant options for building elements :

For **foundations**, three types can been considered : sole, slab and pile foundations. The latter is however encountered very exceptionally for bad structure soils. The sole foundation technique is the most usual and the less expensive as it requires less material. Slab foundation is implemented for less favourable soils.

For **exterior walls** existing techniques are generally based on "empty walls", namely with a loading layer (masonry) and a facing layer. Both are separated by insulating material and a empty layer that allows ventilation of humidity transmitted through the facing layer.

- In most usual constructions, the facing layer is made of bricks and the loading wall is made of bricks or concrete.

- In more recent constructions, other materials like expanded clay, composite materials (like poroton), cellular concrete are used.

- Wood construction is currently in development, even if the rate is not easily quantified. The most current technique in Belgium is the wood skeleton construction system with a loading structure made of a wooden uprights. The inside facing may be made of wood or plaster. The outside facing is made of bricks or wood. Brick facing is the most usual in Belgium due notably to urban planning constraints. For these reasons, wood construction is very scarce in the country.

Interior walls are generally made of concrete blocks. Expanded clay, poroton and cellular concrete are more and more used. Like for external walls, wood construction of internal walls is made of wood skeleton.

Roof skeleton is made of wood in most cases. Slates are one of the more common roofing material especially in some areas in Belgium while tiles (artificial and natural tiles) are used in the other parts.

Table 7 describes the different house types considered in the analysis with respect to their material composition.

<table>
<tr><th></th><th>brick&concrete house + cellar</th><th>brick&concrete house</th><th>terraced brick&concrete house</th><th>brick house</th><th>stone & concrete house</th><th>Argex house</th><th>Cellular concrete house</th><th>wood & brick house</th><th>Wood house</th><th>renovated conventional house</th><th>renovated wood house</th></tr>
<tr><td>foundation</td><td colspan="6">strong sole foundation</td><td colspan="3">light sole foundation</td><td>strong sole foundation</td><td>light sole foundation</td></tr>
<tr><td>external walls</td><td colspan="3">Brick&concrete wall + reinforc.</td><td>brick wall</td><td>Stone + concrete wall</td><td>Brick & argex</td><td>Cellular concrete + roughcast</td><td>Brick & wood</td><td>Wood</td><td>Brick&concrete wall + reinforc.</td><td>Wood</td></tr>
<tr><td>interior walls</td><td colspan="3">concrete wall</td><td>brick wall</td><td>concrete wall</td><td>argex wall</td><td>cellular concrete wall</td><td>wood wall</td><td>wood wall</td><td>concrete wall</td><td>wood wall</td></tr>
<tr><td>roof</td><td colspan="4">tile roof + RW</td><td>natural slates + RW</td><td colspan="2">artificial slates + RW</td><td colspan="2">natural slates + RW</td><td>tile roof + RW</td><td>natural slates + flax</td></tr>
<tr><td>soil</td><td colspan="7">concrete floor</td><td colspan="2">wood floor</td><td>concrete floor</td><td>wood floor</td></tr>
<tr><td>windows</td><td colspan="4">PVC window frame</td><td>Wooden window frame</td><td>PVC window frame</td><td colspan="3">Wooden window frame</td><td>PVC window frame</td><td>Wooden window frame</td></tr>
</table>

Table 7 : Description of the different representative houses studied

4.4.3.3 Environmental impacts of the product and related demand

Environmental impacts of products on a life cycle perspective include all environmental impacts from technologies involved in the overall product system as well as emissions due to transportation and waste treatment.

In the study, the analysis of the environmental impacts focused on indirect GHG emissions (IGEP), namely life cycle GHG emissions excluding emissions from heating[4]. Other environmental impacts were discussed more qualitatively.

For GHG emissions, process and transport emissions are the most important for most building materials.

From the description of the **technology processes** involved in the housing system, it was shown that amongst the GHG emissions, CO_2 emissions (either from energy consumption, either from the process itself) are the most significant. Average emission factors have been assessed for all building materials.

For **transport** an estimation of distances covered for the different materials was made and averaged CO_2 emissions estimated for these representative paths. Depending on the densities of the materials and their distance for transportation, averaged CO_2 emissions were estimated from 0.02 to 0.07 t CO_2 per ton transported. Compared with process emissions this may represent from 2% (for plastic) to more than 100% (for stone). As for process emissions, compared with the CO_2 emissions, N2O and CH4 emissions are much smaller.

4 Houses analysed in the study were supposed to have the same thermal insulation levels which allows to neglect the emissions from heating in the comparison.

Wood products merit a special attention with respect to CO_2. Wood products use may have two impacts : Increased use of wood products can both stimulate the carbon sequestration and increase the carbon storage effect, while decreasing the emissions through material substitution. The impact depends on the type of wood production : a neutral effect of wood products on the atmosphere can only be reasonably assumed for wood from sustainable forest management. Our analysis has lead to the conclusion that if wood originates from deforested lands life cycle emissions are much more unfavourable and wood as a building material would result in an increase of life cycle emissions compared with more conventional practices.

The comparison presented below is based on the assumption that wood is logged from sustainable managed forests.

From the analysis of production processes, transport, product use, we can conclude that CO2 emissions coincide with GHG emissions. For this reason, both terms will be used here below with the same meaning.

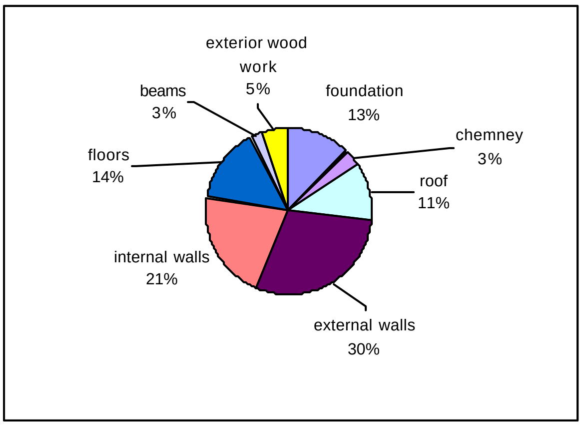
4.4.3.3.1 GHG emissions at the product level

The material intensity and the indirect GHG emissions[5] have been estimated for each of the houses selected in Table 7 based on GHG emissions calculations for the materials involved. This has been done for each building element (foundations, walls, soils, roof, windows,…).

Being one of the most usually built[6], the conventional house with brick&concrete walls can be considered as a reference.

For this reference house with a 200 m^2 total surface and without cellar, the total material consumption has been estimated at 220 ton, of which 68% are concrete blocks. This concrete consumption is distributed mainly between foundation (15%), walls (65%) and floors (19%). Walls and foundations are the most important elements in the total material consumption and bricks and mortar are the second ones (9% for both). Finally, plaster, steel and tiles intervene each for 2% to 3% of the total.

With this material composition, indirect CO_2 emissions are dominated by concrete, cement (contained in mortar) and bricks. The total emissions results in around 47 ton CO_2. Figure 5 gives the distribution of indirect CO2 emissions between building elements on one side and between materials on the other side.



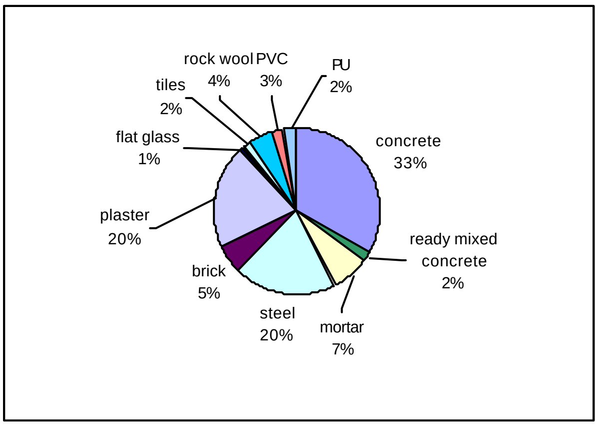


Figure 5 : Importance of the different materials for each building element for a conventional house in the **total indirect CO_2** emission between building elements (left) and between materials (right)

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[5] As mentioned, the analysis didn't explicitly calculate the complete life cycle GHG emissions of buildings as GHG emissions due to heating (so-called "direct" emissions). This is why we use the term "indirect emission" to refer to the GHG emissions related to the life cycle of the material component of the building and material intensities were evaluated under the hypothesis that thermal insulation was the same for all buildings.

[6] It is however to be noted that brick houses are also commonly built.

These results allow identifying the walls as the main elements of the building where material and design changes may result in significant environmental performance improvements over the whole building.

Then Figure 6 depicts the influence of the total surface of the house on the material consumption and on the indirect CO2 emissions. It shows that an increase in 50% of the total surface results in a 38% increase of indirect CO2 emissions.

For a similar house with a cellar, the concrete consumption is still higher : from 330 t to 460 t and the indirect CO2 emissions vary from 59 to 83 t CO_2. This represents an increase of 24% and 13% compared with the house without cellar over the surface interval considered.

When an terraced conventional house is built CO_2 emissions vary from 43 t to 60 t which is slightly lower than for the detached house. The small difference is explained by a small difference in concrete and brick consumption for the common walls.

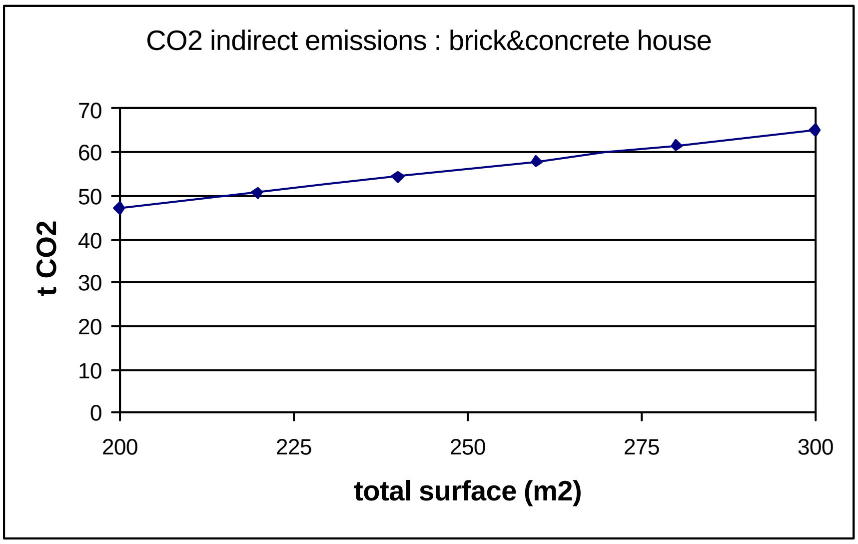

Figure 6 : Indirect CO_2 emission for a brick&concrete house as a function of the total surface

Material intensities and life cycle GHG emissions as calculated for different types of houses (200 m^2 total surface) in the same way as for the conventional house are represented in Figure 7.

The figure shows that the construction of new conventional houses implies indirect GHG emissions ranging from 40 to 50 t CO_2 depending on the construction of a cellar. This represents from **7% to 14% of the direct emissions** (house heating) during the whole life of the house. This percentage depends on the lifetime of the building and on the fuel that is used (natural gas or oil).

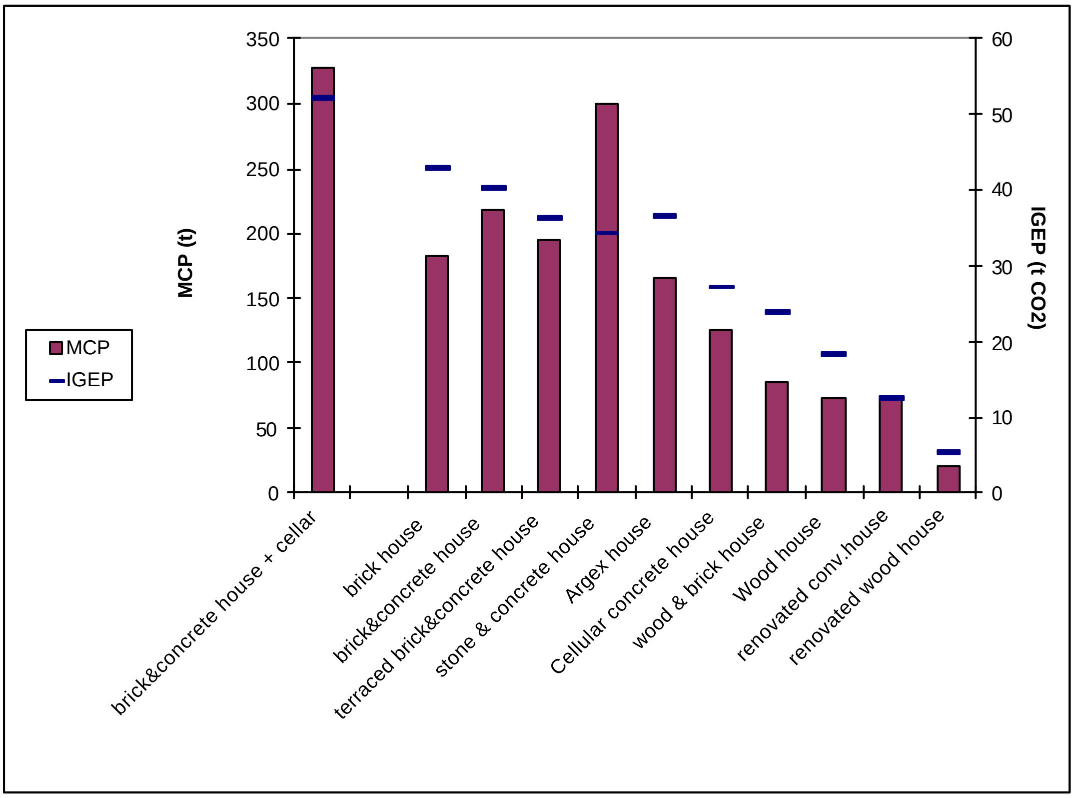

Figure 7: Comparison of material intensities and indirect CO2 emissions values for the different houses cases studied for a 200 m^2 total surface.

It also reveals a similar trend between material intensity and indirect CO2 emissions. Two exceptions are observed : brick house and stone&concrete house.

The figure suggests that compared with the reference house construction large environmental performance improvements can be gained from material substitutions : indirect CO2 emissions can be reduced by 10 to 15% if materials like cellular concrete, stone or expanded clay are used for new construction. Further decrease may be obtained if wood is used (from 40% to 50%).

Compared with new construction, renovation allows to reduce the IGEP by 70% to 87%.

This comparison indicates an important technical potential for reducing CO2 emissions. However, this comparison has to be completed by a comparison with consideration of the respective possible lifetimes of the different types of houses. With that respect, a large uncertainty exists and is the largest for non conventional houses. For wooden houses especially, few experience exist in Belgium notably with respect to the weather conditions. Houses in Canada appear to have quite large lifetime but extrapolation to the Belgian context is tricky.

Different experiences in Belgium for complete wood houses indicate a possible lifetime up to 60 years. If brick facing is used this lifetime will possibly be extended to 70 years.

Assumptions on the lifetimes for the different types of houses are given in Table 8.

	life time (yr)
Brick house	100
Brick&concrete house	100
Terraced brick&concrete house	100
Stone & concrete house	120
Argex house	100
Cellular concrete house	90
Wood & brick house	70
Wood house	60
Conventional renovation	50
Wood renovation	40

Table 8 : Comparison of averaged yearly indirect emissions taking into account average lifetimes of different houses

Given these lifetimes, we calculated annual IGEP values (see Figure 8). Results are there compared with annual IGEP values calculated for a uniform lifetime for all houses (100 years). We see that the advantage of non conventional construction is smaller especially for wood construction. Compared with the brick&concrete house, the annual GEP is now 25%, 15% and 25% smaller for cellular concrete, wood&brick and wood houses respectively.

For renovation the advantage is also reduced and emissions reductions vary from 40% to 66% for conventional and wood renovations.

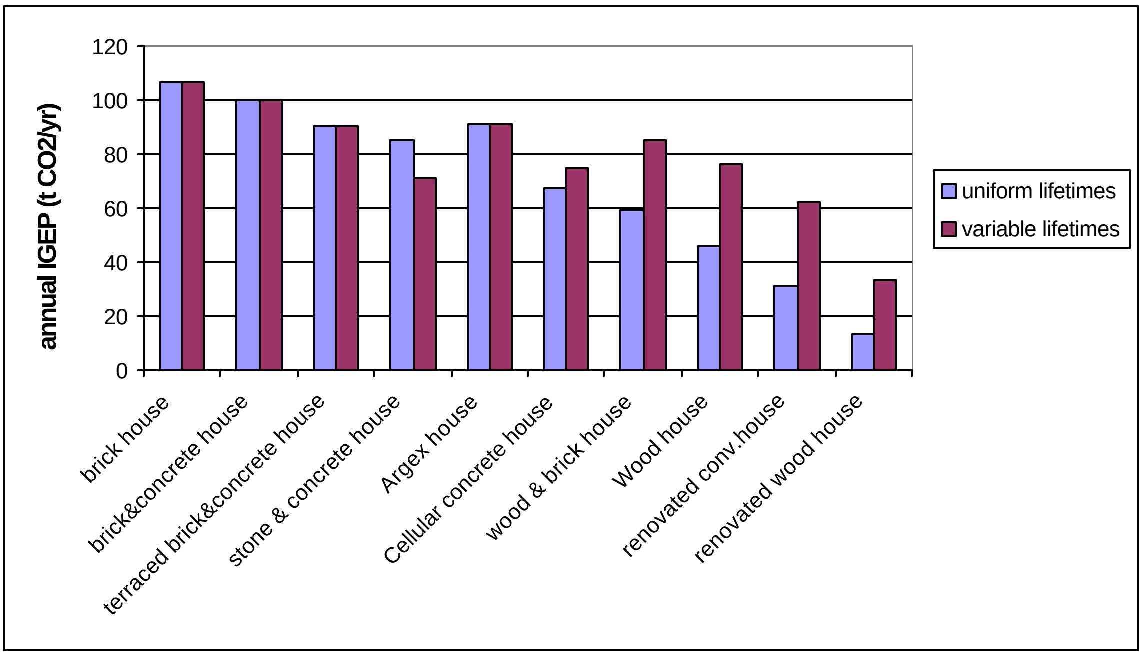

Figure 8 : Annual indirect CO2 emissions for two sets of lifetimes assumptions

Uniform lifetimes means that all houses are supposed to have a lifetime of 100 years while variable lifetimes refers to assumptions from Table 8.

4.4.3.3.2 On the whole consumption

Estimating the related indirect emissions at the level of Belgian demand for new construction and renovation requires to have an estimation of the present sharing of different types of houses in the market. Due to lacking statistical data we had to make own estimations based on expert judgements and observations. We considered that about 75% of new houses are conventional houses, that 15% are intermediary cases (expanded clay or cellular concrete) and that 4% are wooden houses. Given this share and also taking into account renovation (mostly of conventional type) the total indirect GHG emissions can be estimated to 1750 kt CO_2 .

4.4.4 GHG emissions scenarios

4.4.4.1 Introduction

Assessing the possible role of products, materials and technologies substitutions within the housing system in the fulfilment of the emissions reduction targets as agreed in the framework of the Kyoto Protocol, requires to develop emission scenarios up to 2010 at least.

Such scenarios have been developed under two different approaches described below :

- In a first approach scenarios were built in order to derive an estimation of a theoretical potential for reducing life cycle CO2 emissions resulting from product substitution at the level of consumption.

- In a second approach, a MARKAL model has been developed for the housing system in order to evaluate the technico-economic potential.

4.4.4.2 Results

As a first step we made a straightforward evaluation of the evolution of the life cycle CO2 emissions resulting from the demand for new construction and renovation of SFH under a static production system. According to this assumption, CO2 average life cycles emissions of all materials are constant and only two parameters influence the evolution of the total, namely the total demand and the contribution of the different types of houses to satisafy this demand.

Given the housing demand as projected in the reference scenario by IDD, two alternative GHG emissions curves have been calculated : the first one assumes a constant share of houses types (as estimated for the current situation), the second assumes an increasing contribution of intermediary houses types and wooden houses (respectively rising to 30% and 25%).

The resulting two GHG scenarios are represented in Figure 9.

The upper curve represents the first scenario and the lower the second. In the first case, GHG emissions should rise to 1900 kt while they reach 1550 kt in the second case a 18% decrease compared to the BAU scenario in 2010 and a 11% decrease compared with the 1990 emissions level.

These percentages represent a **theoretical potential** of life cycle GHG emissions from new construction and renovation of SFH.

However, they suppose that no technological evolution will occur over the period 1990-2010 and are estimated disregarding costs prices.

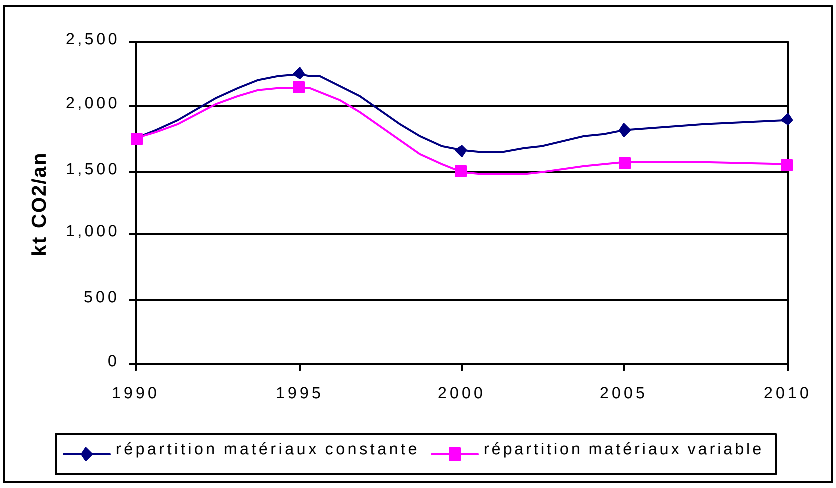

Figure 9 : Indirect CO2 emissions scenarios

To complement this picture, a MARKAL model has been developed allowing an assessment of the **technico-economic potential** of GHG emissions reduction through substitutions between SFH types for a given housing demand (and as a result, substitution between materials involved in the construction and the renovation of SFH) compared with emissions reductions achieved within the production system through eco-efficiency improvements of technologies used to produce the materials.

For the development of the modelling of the housing chain, the system has been delimited to :

- the demand for new SFH houses and renovation (including renovation with surface increase, light renovation with maintenance),
- the total residual demand for the most significant materials in the building sector (including domestic and foreign demand), so corresponding to the Belgian demand dedicated for all needs else than single family houses),
- the production technologies and primary materials involved in the life cycle of the materials used for the construction and renovation of houses.

The structure of the model is summarised in Table 9. All input data are based on the results from previous analysis especially on demand evolution, material flows and industrial processes.

	Residential housing
Horizon	2030 (however results will be significant for a 2020 horizon)
General definition of the system and its boundaries	Product use, product elimination, material production processes and transport involved in the product preparation
Representation of the demand	Demand for new single family houses, renovated houses and house maintenance expressed in total surface
Level of description of the Belgian production system	Detailed description of the main processes encountered in Belgium and alternative technologies taking into account the industry investment plans. Exception for plastic production for which technologies are standard technologies.
Imports representation	Explicitly distinguished from Belgian processes (however of few importance given the low level of imports for most of the main building construction materials)
The level of detail of the energy system	Not explicitly described. Input data are based on scenarios performed with the Belgian energy MARKAL.
Interrelation with the overall system	Exogenous demand for materials involved in the product production but consumed by other products expressed as a residual demand
Material exports representation	Included in the residual demand (which so represent the Belgian production not dedicated to SFH construction and renovation)
Waste treatment	Incomplete accounting justified by the fact that the horizon is not far enough to take into account the demolition of houses built during the period studied and also to the fact that it may influence only slightly the energy performance of the system.

Table 9 : Structure of the product system model "Residential housing"

Five scenarios have been built in this study :

- Scenario BASE : in this scenario only residual demands are considered without any constraint on the CO_2 emissions.

- Scenario BASEHOUS : in this scenario, both residual demand and demand for new construction and renovations are taken into account, again without any limitation on CO_2 emissions.

- KYOTO scenario : in this scenario, only residual demands are considered and an emission reduction target is assumed for 2010 (-7.5% compared to emissions in 1990) and for 2030 (-15% compared to emissions in 2030).

- KYOTOH scenario : in this scenario, residual demands and demand for new construction and renovation are taken into account, with the same limitation as in the KYOTO scenario.

- KYOTOP scenario : same as KYOTOH but with constraints on the share between the different houses types.

The choice of these scenarios is to :

- Evaluate the scale of the life cycle emissions attributed to the SFH construction and renovation compared with the emissions produced by the residual demands.

- Estimate the cost of emission reduction resulting from process technology substitutions only.

- Estimate the possible influence of material substitution (through product – houses types – substitutions) on the overall system considered and the cost of emission reduction under such possible (free or drastic) substitutions.

Results from this modelling indicate that for the system modelled, shift in technologies as a CO2 mitigation measure is more cost effective than shift in product types (here shift in construction type). In both scenarios KYOTO and KYOTOH where the model chooses freely the technologies that allow to minimise the total cost, the same technology evolutions are observed. For the KYOTOH scenario we observe that the additional emission reduction to be achieved compared with the KYOTO scenario is accomplished through additional technology shifts and that no change is made on the product side.

Next table gives the resulting costs for the reduction scenarios KYOTO, KYOTOH and KYOTOP. It indicates that the cost slightly increases when reduction efforts cover a larger volume of emissions. When a constraint is put on the share of construction types, the costs is more than three times the costs without any constraints.

Scenario	Reduction cost (Euro/t CO2)
KYOTO	28
KYOTOH	37
KYOTOP	128

Table 10 : Cost of CO_2 emissions reduction

This is due to the higher estimated price of “low emitting” houses (cellular concrete, brick&wood and wood houses) compared with the price of the more conventional houses (especially brick&concrete house). Stone houses are about two times more expensive than conventional houses. Cellular concrete houses appear to be 10% more expensive while brick houses as well as wooden houses (brick&wood or full wood) are 20% more expensive.

As a result, the emission reduction potential from only product shifting is estimated as negligible compared with the potential offered by technology improvements within the production system.

The result itself is however questioned by three major facts :

- The experience gained with this analysis indicated a substantial uncertainty on costs of technologies found in the literature. Despite these costs were adjusted in order to better reflect the market prices and better reproduce the comparative price of the different houses considered, there remain an unsolved gap between cost of technology shifts and cost of product shifts as CO2 emissions reduction measures. Cost of technology shift depends on the comparative costs of competing technologies that may be subject to high uncertainty.

- Results may have been influenced by the choice of the system boundaries. However, it is very uneasy to check this possibility.

- Assumed costs data do not take into account a possible influence of the market development on technology costs.

Further analysis of the uncertainty of results would be fruitful. However, a proper treatment of uncertainty is not straightforward with MARKAL and an intensive work should be made to overcome this limitation which is out of the scope of this study.

4.4.5 Conclusions

In the framework of this detailed analysis of the housing system we performed an detailed analysis of the SFH system in order to evaluate the life cycle emission reduction potential of construction and renovation of SFH in Belgium.

The analysis has been made through different steps, going from the description of the current houses demand, through the description of different houses types, of the relevant material flows and industrial processes to the evaluation of the indirect GHG emissions and the potential for emission reductions both on a technical and restricted product perspective and on an economic perspective.

The evaluation of the demand has shown that residential housing, especially SFH represents an important demand in Belgium with some increasing trends, notably with respect to living surface.

Different building practices with respect to material composition have been described and material consumption has been quantified. This evaluation has shown the primacy of a limited set of materials in the total material intensity, especially concrete and bricks.

The analysis of the building material flows in Belgium has allowed to highlight the low levels of international trades for the most important materials (cement, concrete, brick). The situation is more complicated for steel, wood and glass as intermediary flows are more important. We could also estimate the consumption of these materials for SFH construction and renovation compared with the total domestic consumption.

The estimation of material intensities and indirect emissions indicated a high possible emission reduction potential from shifting from conventional houses to cellular concrete and wooden houses (up to 25% emission decrease). Such a potential also exists if shifting from construction to renovation (up to 66% emission decrease).

At the level of the overall Belgian market given the possible evolution demand for construction and renovation we estimated that an increase of the share of non conventional houses by up to 25% of the market, may help to reduce the indirect emissions in 2010 resulting from this demand by 6% compared with 1990 levels.

Then a technico-economic analysis carried out with MARKAL lead to the conclusion that, for the product system studied, technology improvements at the supply side offer more economically efficient measures to reduce GHG emissions reductions than material and product shifting. This conclusion is largely based on technology and material costs where uncertainty is high.

4.5 Packaging system

4.5.1 Background

Packaging is an activity with a rather high visibility for the public. It is expected that in future it will still gain importance. It has been associated with some direct and indirect environmental impacts (i.e. the waste problem), and has been subject to specific legislation.

The European Directive 94/62/EG on Packaging and Packaging waste has been translated into Belgian law in the *Co-operation agreement on the prevention and management of packaging waste*[13]. The Co-operation agreement gives the *party responsible for packaging* the duty to reach specific targets for recycling and valorisation of waste packaging. This is a major driving force in packaging and recycling technology development.

Especially beverage packaging has received a lot of attention, in legislation (e.g. ecotax legislation) and in LCA studies. Partially this can be explained by the relative uniformity and comparability of the packed products, which makes beverage packaging more suitable for a simplified and standardized approach. Another reason is probably the fact that waste statistics are often given in tons. Because glass and metal are important packaging materials for beverages, and because their weight per unit of packed product is high, they represent a proportionally large fraction in the total waste quantity ().

Therefore, it seems *a priori* interesting to look at the total contribution of beverage packaging to specific emissions or environmental pressures, and the reduction in these emissions or pressures that can result from measures addressing the use and the composition of packaging, to see if the attention given to beverage packaging can result in significant environmental benefits. These benefits should then be weighed against eventual increases in costs related to changes in the use and the composition of packaging.

4.5.2 System definition

This analysis deals with the Belgian end use of packaging by the final consumer, or, in other words, with packaging used for packed products brought on the Belgian market. This includes import of packed products for Belgian end use and Belgian production of packed products for Belgian end use. It excludes Belgian production of packed products for export and Belgian production of packaging for export.

Large discrepancies can exist between the end use of packaging, the intermediate use of packaging by packers of products and the packaging production.

The study area has been limited to household packaging. The detailed analysis of packaging options and alternatives will focus on beverage packaging only.

The function, or the *packaging service* that has been studied, is the quantity of specific goods to be packed in specific portions. In the case of beverage packaging two different markets (functions) can roughly be distinguished: large (family) packs and small (individual) packs.

According to this definition some packaging types (products) are perfect substitutes (e.g. one litre of milk can be packed in a one litre glass bottle, in a one litter PE bottle, in a one litre beverage carton). In reality however, the function is more complex than how it is defined here. These qualitative differences are taken into account when identifying packaging options that can substitute one another.

Final demand for packaging is determined in the first place by the demand for the packed product, in this case the demand for beverages. The demand for beverages induces a specific demand for packaging service, which can be fulfilled by different packaging options.

Therefore, we will first analyse the actual and future demand for packed beverages. Afterwards we will look at the actual use and potential evolutions for specific beverage packaging options.

4.5.3 Detailed description

4.5.3.1 The actual demand for beverages an its evolution

4.5.3.1.1 Present demand

The total consumption of packed beverages (excluding draught beer) in 1993 was estimated at 3600 million litre.[14] About one fifth of it was consumed in bars and restaurants. By 1999 this consumption has grown to about 3900 million litre.[15,3]

Milk and water are mainly packed in large bottles (family packs). Beer is mainly (more than 90 %) packed in individual packs. For fruit juices and soft drinks a 70/30 ratio applies.

Combining groups of beverages and portioning gives rise to the following demand categories (functions):

	% of total packed volume						
content	Carbonated water and soft drinks	Non-carbonated water	Milk and milk drinks	Beer	Wine and spirits	Fruit juices and nectars	Total
large	26	22	13	1	8	4	74
small	7	1	3	14		1	26

Table 11 : Estimated market shares for beverage packaging functions in 2000

Because of their small shares, the small packs of non-carbonated water and fruit juices, and the large beer packs will not be considered separately. The small packs for milk and milk drinks will not be considered further neither. The error made in this way is small because the same packaging options are available for small and large milk packs.

4.5.3.1.2 Evolution

The Corelli model (developed by IDD) provided a projection of the future demand for beverages. These data were used to calculate the demand for packed beverages (see Table 12). Total demand is expected to increase to 4380 million litres.

million litres	2000	2015
carbonated beverages	1260	1550
- water	330	440
- soft drinks	930	1110
non-carbonated water	980	1320
milk and milk drinks	620	500
fruit juices and nectars	210	270
beer (excl. draught)	590	450
wine and spirits	280	290
total	3940	4380

Table 12 : Demand for packed beverages in 2000 and 2015

4.5.3.2 The actual and potential use of (beverage) packaging

There is no direct statistical information on the quantities of packaging brought on the Belgian market. Data from the National Statistics Institute (NIS) or the Belgian Foreign Trade Board (BDBH) do not give information on the quantities of packaging brought on the Belgian market through import of packed products, or on the quantities of packaging used to pack products that eventually will be exported.

In the collaboration agreement, the same end use perspective as adopted in our study is used. Thus, data provided by FOST Plus and Val-I-Pac members can be used to estimate the Belgian end use of packaging.

Based on exact figures provided by FOST Plus, the amounts of one-way household packaging were extrapolated for the total market. The flows of reusable packaging (mainly glass bottles and plastic crates for glass bottles) were estimated separately (Figure 10).

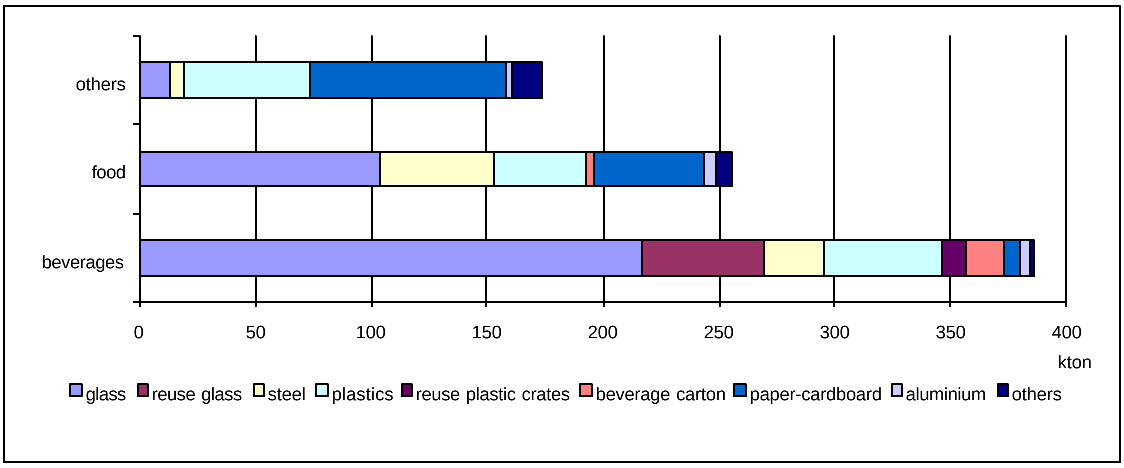

Figure 10: Household packaging brought on the Belgian market in 1999

Comparison with Val-I-Pac estimates for company packaging shows that total quantities of household and company packaging are roughly equal. However, the composition of both differs. Glass packaging dominates for household packaging; paper and cardboard dominate for company packaging. Wood is important for company packaging (crates and pallets), but represents less relevance for household packaging.

More than 75 % of the household packaging (by weight) consists of food and beverages packaging. Food and beverage packaging accounts for more than 90 % of all glass and steel and 2/3 of all plastics used for packaging. Paper and cardboard is more important for non-food-or-beverage applications.

Volumes of beverages packed in one way packaging were calculated from FOST Plus data, using assumptions on the average weight for each packaging material. Detailed analyses of data for the different groups of beverages lead to the following conclusions:

- Carbonated water and carbonated soft drinks: 2/3 is packed in PET bottles; the remainder is mainly packed in refillable glass. Cans represent the third important option for packaging carbonated soft drinks, but they receive competition from small PET bottles.

- Non-carbonated water: 2/3 is packed in PET bottles. The remainder is mainly packed in refillable glass. Non- carbonated water is mainly sold in 1 and 1,5 l bottles (95 %).

- Milk and milk drinks: 65% is packed in beverage cartons; the remainder is mainly packed in glass (14 %) or HDPE bottles (20 %). PET has already been introduced for some fresh milk products. In the milk packaging market it is expected that beverage cartons will lose market shares to plastic bottles (HDPE, PET?).
  The refillable PC bottle was introduced in March 1996 on the Dutch market to replace the glass bottle for fresh milk (pasteurised milk). The share of fresh milk in the total milk consumption in Belgium is less than 5 %.

- Beer: About 40 % of all the beer consumption is draught beer. The remainder is packed mainly in glass. More than 90 % is packed in small packs. Between 1987 and 1997 one way bottles have steadily been replaced by cans. Beer in PET bottles has a clear potential. It has been launched already on several markets.

- Wine and spirits are almost exclusively bottled in large size glass bottles (mainly one way glass). Probably the largest part of the market will also in future be packed in glass, but it can be expected that a rising share will be packed in alternative packages (beverage cartons, bag-in-box systems and PET bottles).

- Fruit juices and nectars: mainly packed in beverage cartons (88 %); the remainder is packed mainly in glass (large one way bottles and small refillable bottles), a very small quantity in cans. Recently fruit juices packed in PET bottles have been successfully introduced on the Belgian market.

PET has gained a share of more than 33 % of the beverage packaging market and 50 % of the market for one way beverage packaging. This is caused by the growth in soft drink and water consumption, and by the fact that this two groups of beverages are increasingly packed in PET bottles, replacing reuse glass bottles. PET bottles are also increasingly used for applications from which they were excluded until now because of technical constraints (beer, fruit juices, milk products). Also beverage cartons are being replaced by PET or HDPE bottles.

In the Netherlands refillable plastic bottles are used for packaging water and soft drinks (PET) and (fresh) milk (PC). They have almost entirely replaced the refillable glass bottle. On the Belgian market the use of refillable PET is however negligible. A technical obstacle to the use of ref-PET is the flavour transfer to the PET material.

4.5.3.3 Description of beverage packaging products

Table 13 and Table 14 give the options for beverage packages that are quantitatively important or could become so. Some questions remain regarding technical potential, e.g. for packaging fruit juices and milk in (refillable) PET bottles. It seems however that technical difficulties for these options will be overcome very soon.

	glass bottle		PET bottle		HDPE bottle	beverage carton
	one way	reuse	one way	reuse		
carbonated waters / soft drinks		A	A	P		
non-carbonated mineral waters		A	A	P		
fruit juices and nectars	A	(A)	R	(P)		A
milk and milk drinks		A	R	(P)	A	A
wine and spirits	A	A				(A)
A: actually commonly used; (A): actually used, but marginal; R: recently introduced; P: potentially used; (P): unclear potential						

Table 13: Packaging options for large size beverage packs

	glass bottle		PET bottle		can
	one way	reuse	one way	reuse	
carbonated waters / soft drinks		A	A	P	A
Beer	A	A	R	(P)	A
A: actually commonly used; R: recently introduced; P: potentially used; (P): unclear potential					

Table 14: Packaging options for small size beverage packs

For each of these options a representative standard packaging system (primary and secondary packaging) has been defined. Data from two surveys from 1992 and 1993 [14,16] were compared to more recent data, found in various literature sources[17,18,19] and to own data. From these data, the future evolution (i.e. the weight) was estimated. For each type of packaging a secondary packaging has been assumed. For these secondary packaging materials a standard weight reduction of 10 % in the period 2000 - 2015 has been assumed.

The data for energy use for packaging making and filling were derived from a comparison of different literature sources[20,18,21,22,19] and own data. The data that are found in the literature, differ very much.

Cost data for the different packaging options were taken from a recent Austrian study[21] and adapted for our purpose.

4.5.3.4 Packaging waste treatment

At the end of 2000 the FOST Plus collection scheme covered 76% of the Belgian population. Glass, paper and cardboard and PMD[7] are collected. Other plastic packaging (foils, cups, boxes, bags, …) are not collected. FOST Plus does not consider their collection and recycling economically or ecologically justified. Costs for collection of glass and paper and cardboard have been steady over the last years. The costs for PMD collection have constantly decreased since the start of the FOST Plus collection schemes. The costs for sorting have risen, but they have stabilised around 7800 BEF/T. Sorting costs can be reduced significantly through the introduction of automated sorting techniques.

The recycling rates for the areas covered by the FOST Plus collection schemes give an idea of the recycling rates that would theoretically be reached if the whole country was covered by a similar collection scheme. They suggest that considerable increases in collection and recycling are still possible.

The remaining quantities end up in the rest fraction of the domestic waste.

[7] *PMD: plastic bottles and flasks, metal packaging and beverage cartons*

4.5.4 Greenhouse gas emissions scenarios

4.5.4.1 Introduction

Two complementary approaches have been used to estimate the greenhouse gas emissions and the emission reduction potential related to the end use of beverage packaging in Belgium:

- a base model (PackBase) based on average emission factors for materials and energy production, and fixed scenarios for changes in packaging use and recycling rates;

- a MARKAL partial optimisation model (PackMark) in which the choice of packaging and recyling rates is optimised on cost basis.

The considered packaging options are based on Table 15. Table 15 summarises the end use scenarios that have been used in the PackBase model. Changes in packaging choices in the scenarios are based on a gradual replacement of packaging with higher emission factor (g CO_2 eq/l) with packaging with lower emission factor (§ 4.5.4.2.1), taking into account technical and sociological constraints.

BAU	further decrease in reuse glass, replaced by one-way PET - one-way PET partially replacing cans - beverage cartons and reuse glass for milk products partially replaced by HDPE
FR	no changes in packaging choice
NIR	no increase in reuse - replacement by "best option" (except for ± 5 %)
RU1	increase of reuse (mainly reuse PET) - moderate use of PET and reuse PET for beer - wine and spirits : 90 % glass; 20 % reuse
RU2	more drastic increase of reuse PET - increased use of (reuse) PET for beer - wine and spirits : 85 % glass; 20 % reuse
RU3	maximum reuse (large: 90 %; small: 80 %, exc. wine: 30 %) - wine and spirits : 80 % glass

Table 15: End use scenarios for the PackBase model

In the PackBase model different materials production and waste treatment scenarios have been combined with these end use scenarios (see Table 16).

FEF (fixed emission factors)	no changes in emission factor
M	decrease in materials use (weight) per packaging type
M+RW	increasing % waste recycling
M+RW+RP	increasing % recycled material in production

Table 16: Materials production and waste treatment scenarios for the PackBase model

Changes in weight per packaging type are based on the detailed analysis of the packaging options (§ 4.5.3.3). Actual and future recycling rates are based on the analyses of the packaging flows (§ 4.5.3.4) and the material flows (§4.1). Emission factors for the production of the materials found in literature were corrected for the use of recycled material in the production process. The benefits from recycling or from energetic recovery of used packaging were allocated partially to the packaging.

In the PackMark model the BAU end use scenario has also been used. In all other scenarios (see Table 17) the possible shifts in end use were confined within specified ranges according to the maximum substitution potential that is considered to be achievable.

BAU	fixed packaging end use
OPT	end use optimisation without greenhouse gas emission limit
RE-15	end use optimisation - greenhouse gas emission limit at 85 % of the level of 2000
RE-30	end use optimisation - greenhouse gas emission limit at 70 % of the level of 2000
RE-MAX	end use optimisation - greenhouse gas emission limit at minimum possible

Table 17: Scenarios for the PackMark model

To take into account the uncertainty on the cost data all scenarios were run also with a decrease in specific packaging costs of 15% for reuse options.

In the PackMark model the same changes in packaging weight were considered. The same future recycling rates were considered as the potential maximum for 2015. The actual recycling rates are the outcome of the optimisation.

In both models the same emission factors for electricity and transport have been used. For transport of the filled packaging from the filler to the retailer it has been considered that the beverage quantity transported is volume-restrained. Transport allocated to the packaging is the difference of the considered option and a hypothetical bulk transport (additional kilometres to be done because of the packaging choice). An average transport distance of 150 km has been assumed.

4.5.4.2 PackBase results

4.5.4.2.1 Greenhouse gas emissions for beverage packaging options

Greenhouse gas emissions were calculated for packing 1 litre of beverage in different types of packaging in 2000 and 2015 (Figure 11 and Figure 12). The results for 2015 include reduction in packaging weight and increased recycling (*M+RW+RP*). These results were used further to calculate the greenhouse gas emission reduction related to the entire packaging system, and the potential greenhouse gas emission reduction (§ 4.5.4.2.2).

In most cases reuse packaging perform better than one way packaging. The only one way packaging type that can compete with the reuse packaging for greenhouse gas emission reduction, is the beverage carton. The reuse PET bottle performs better than the reuse glass bottle.

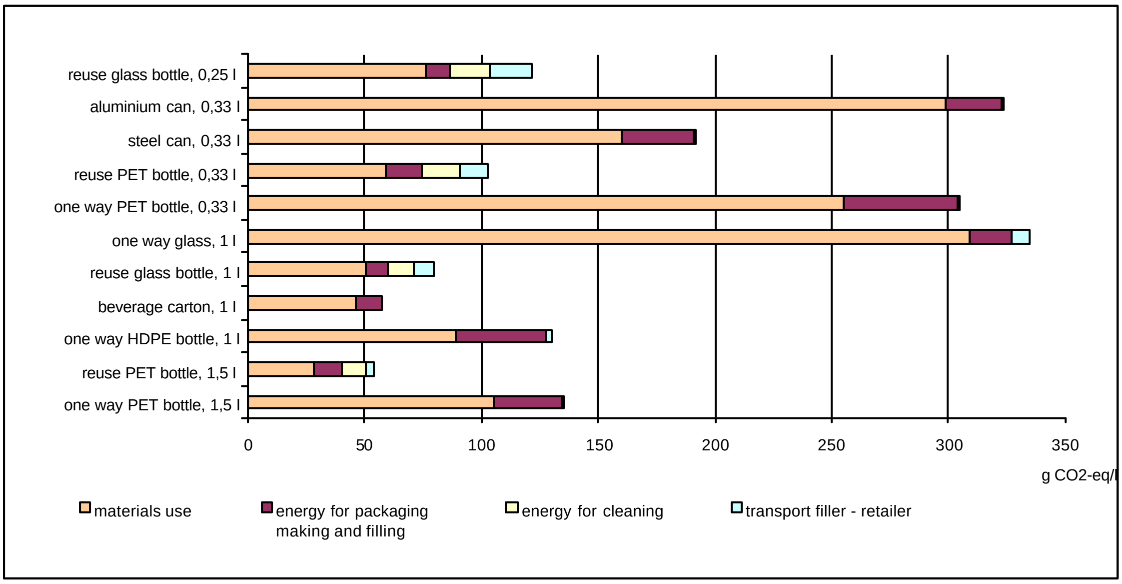

Figure 11: Greenhouse gas emissions for packaging 1 litre of beverage for different types of beverage packaging in 2000

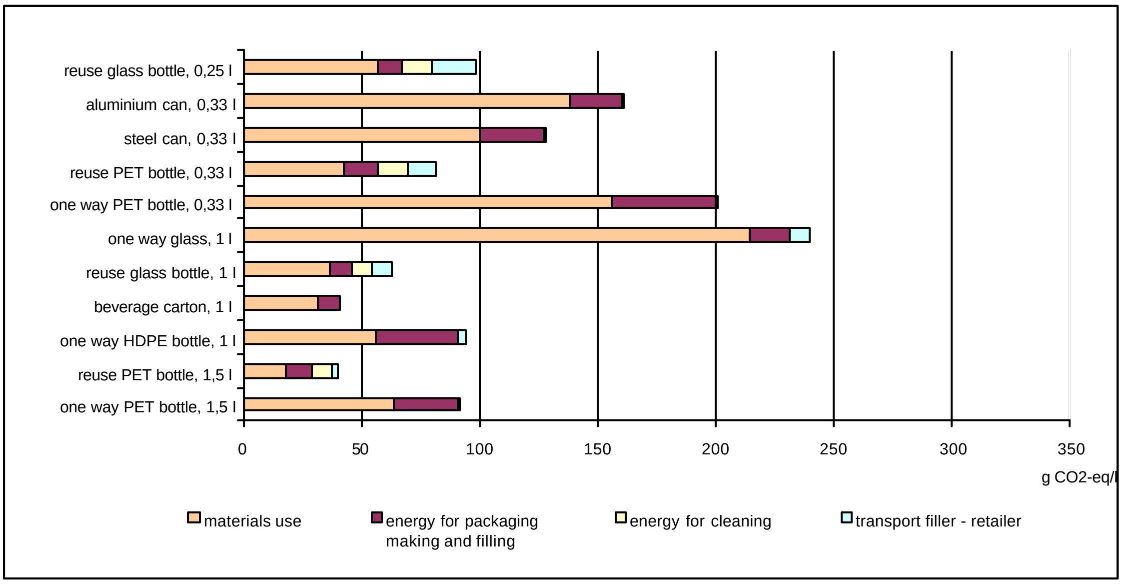

Figure 12: Greenhouse gas emissions for packaging 1 litre of beverage for different types of beverage packaging in 2015

The difference between the packaging is mainly caused by the materials use (including waste treatment), which largely outweighs differences in greenhouse gas emissions during the use phase of the packaging (making, filling, cleaning, transport). Comparison of the results for 2000 and 2015 shows that material related greenhouse gas emissions can be reduced significantly through decreases in packaging weight and increased recycling.

It has to be stressed that these results are intended to be used further in macro-scenarios on greenhouse gas emissions related to the total use of beverage packaging in Belgium. They do not apply to each specific case. Moreover, they only apply to greenhouse gas emissions. Other environmental aspects have not explicitly been taken into account.

4.5.4.2.2 *Greenhouse gas emissions and possible reduction for the entire beverage packaging system*

The actual amount of greenhouse gas emissions (over the entire life cycle) caused by the end use of all beverage packaging in Belgium was estimated at 581 kton CO_2-equivalents[8] per year.

When the choice of packaging, the weight per packaging and the rate of recycling remain unchanged (*FR-FEF*), emissions will rise to 643 kton in 2015 as a result of the increase in beverage demand. In the *BAU-FEF* scenario they will rise to 672 kton. Through decreases in packaging weight (*BAU-M*) this amount can be reduced by 48 kton. Increased recycling can lead to an additional reduction of 146 kton.

Figure 13 shows the greenhouse gas emission reduction that is realised in 2015 in the different scenarios compared to *BAU-FEF* scenario.

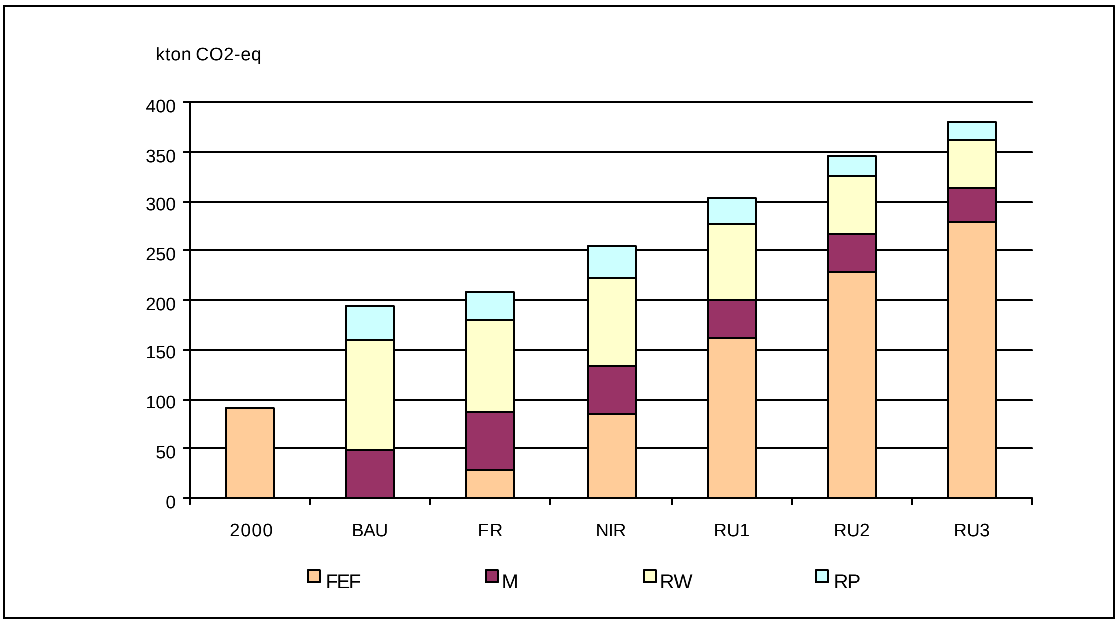

Figure 13: Greenhouse gas emission reduction of combined end use scenarios and materials production and waste treatment scenarios

Without increased use of reuse packaging the reduction potential in 2015 can rise to 133 kton as a result of changes in the choice of packaging (*NIR-M*) and to 254 kton if an increase in recycling rate[9] is also considered (*NIR-M+RW+RP*). With increases in reuse the reduction potential in 2015 can increase to 346 kton in a moderate scenario (*RU2- M+RW+RP*), and 379 kton in a more ambitious scenario (*RU3- M+RW+RP*). The latter means a decrease of 56 % compared to the *BAU-FEF* scenario.

The additional reduction that can be expected from changes in packaging use compared to a scenario in which only changes in packaging weight and recycling rates (*BAU-M+RW+RC*) occur, increases from 60 kton for the *NIR* scenario to 185 kton in the most drastic scenario. Even with increased recycling benefits, the reduction potential in the *BAU* scenario is only as high as what can be obtained from moderate changes in packaging use without any increase in recycling efforts (*RU1-M*).

[8] *When giving greenhouse gas emission figures further in the text,* kton CO_2-equivalent *will be shortened to* kton*.*

[9] *both an increase in the use of recycled material in the production of packaging, as an increase in the recycling rate of used packaging*

Hence, increased recycling leads to additional emission reduction, but it can not attain the same reduction as what can be obtained with changes in the choice of packaging (mainly reuse). Even when materials weight per unit of packaging is reduced and high recycling targets are obtained, changes in the choice of packaging can still lead to an additional emission reduction of 150 to 185 kton.

Table 18 summarises the reductions that can be realised compared to the 2000 emission level. Three strategies are compared: *packaging weight reduction* (M), *increased recycling* (M+RW+RP) and *changing end use* (RU2). Clearly, the three strategies interact. With reductions in packaging weight only, emissions will still increase. When adding an *increased recycling* strategy (without changes in end use) emissions can be reduced by 18 % compared to the 2000 level. When adding a *changing end use* strategy (without changes in recycling), emissions can be reduced by 30%. Finally, combining all three strategies, emissions can be reduced by 44 %.

	BAU	changes in end use (RU2)
no changes in packaging production and waste treatment (FEF)	+16%	-24%
packaging weight reduction (M)	+7%	-30%
increased recycling (M+RW+RP)	-18%	-44%

Table 18: Potential emission reduction of different strategies compared to the 2000 emission level

The influence of some crucial parameters on the results was tested.

- Using an emission factor for plastics production which is half way between the values proposed by APME and by Patel *et al* (see Table 4)) reduces the total emissions in 2000 by 60 kton (-10%). The reduction potential (compared to the BAU scenario) reduces by 22 kton (-6%).
- Increasing the emission factor for electricity production (marginal electricity production from gas in stead of an average emission factor, including nuclear) increases total emissions by 47 kton (+8%). The reduction potential is almost unaffected.
- Decreasing the recycling rates for used packaging in 2015 by 5% reduces the reduction potential by 10 kton (-3%)

4.5.4.3 PackMark results

4.5.4.3.1 Emissions

Emissions in 2000 are at 515 kton CO_2-equivalents. In the BAU scenario these emissions increase to 530 kton. This moderate increase is a combination of the increased packaging demand, the changing end use and changes recycling rates. Recycling rates increase for glass and cardboard, but not for plastics and steel (§ 4.5.4.3.3).

In the OPT scenario emissions are 89 kton higher than in the BAU scenario. The minimum emission level that can be achieved is 289 kton, a reduction of 241 kton compared to the BAU scenario and 329 kton compared to the OPT scenario.

4.5.4.3.2 Changes in packaging use

In the OPT scenario the decline in reuse packaging is more pronounced than what was put forward in the BAU scenario. The shift to one way PET packaging is more pronounced. Part of the reuse glass packaging is replaced by reuse PET.

When limiting greenhouse gas emissions in 2015 at 85% of the level in 2000, the use of reuse PET bottles will drastically increase (Figure 14). Again reuse glass disappears almost entirely. The use of one way PET also increases. It replaces HDPE for milk packaging to the extent possible.

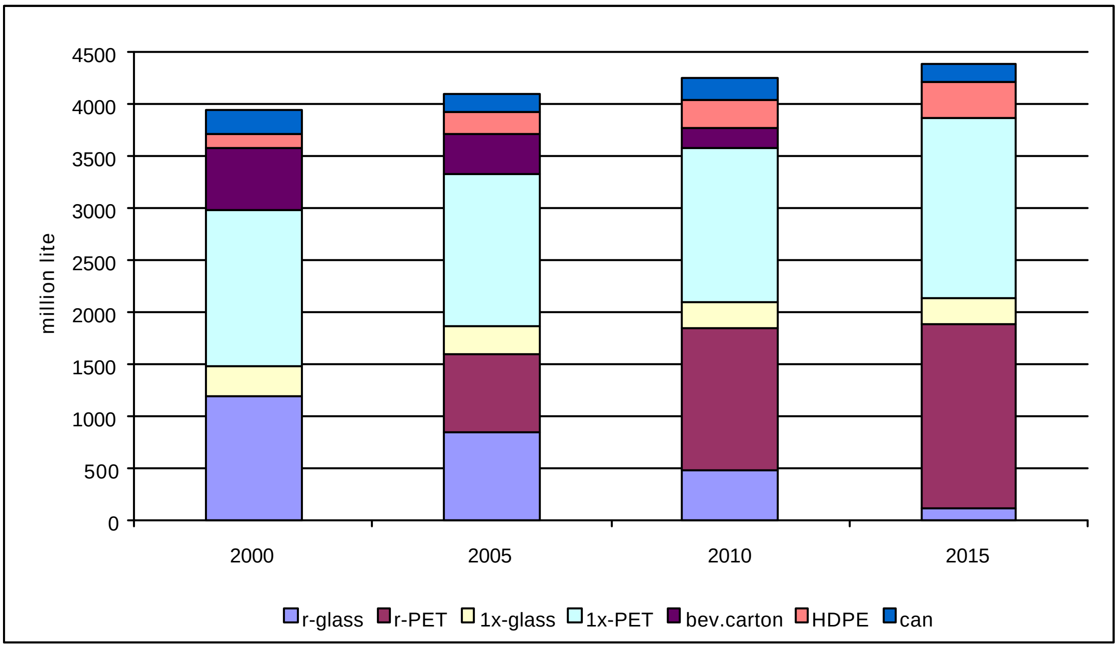

Figure 14: End use of beverage packaging – 15% reduction scenario

In case of a 30% reduction of the emission level (Figure 15) the use of reuse PET bottles increases further (further replacement of large one way PET bottles by reuse PET bottles; small reuse PET bottles replace cans and one way PET bottles for beer and soft drinks). Also in this case HDPE bottles replace beverage cartons, although emissions per litre packed are higher for HDPE bottles than for beverage cartons. Only in the maximal reduction scenario beverage cartons keep their market share. Cans also disappear in the more drastic reduction scenarios.

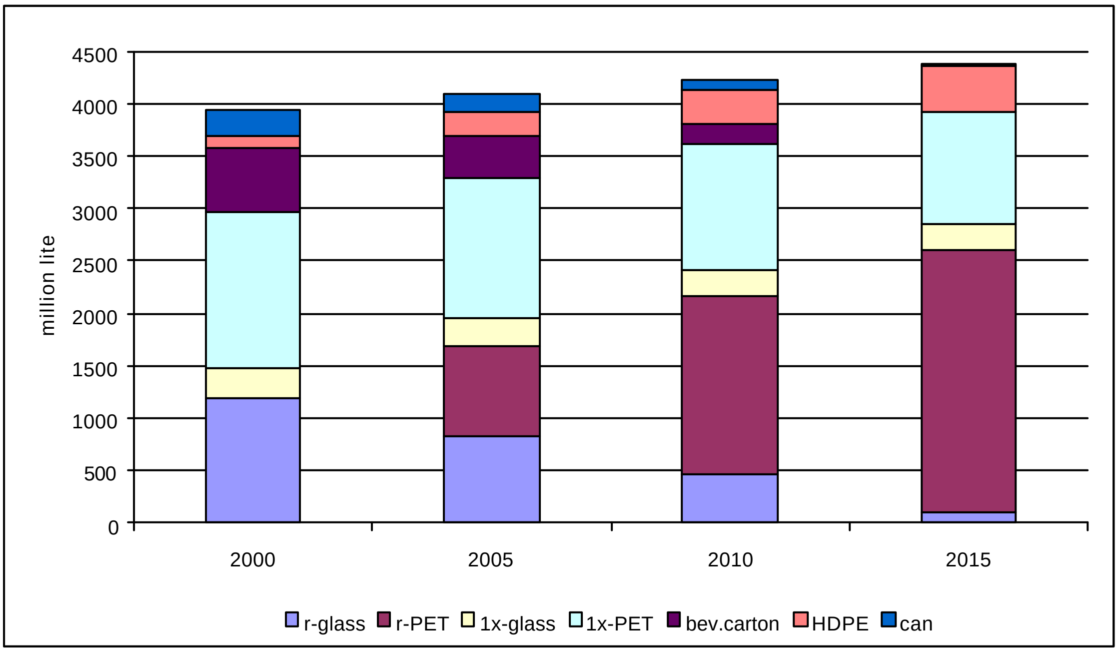

Figure 15: End use of beverage packaging – 30% reduction scenario

4.5.4.3.3 Evolutions of recycling rates

In the BAU and the OPT scenarios recycling rates only increase for cardboard packaging and for glass packaging. Both in the RE-15 and the RE-30 scenario recycling rates increase to the maximum level for all materials. The fact that already in the RE15 scenario the full potential of recycling for greenhouse gas emission reduction is exploited, indicates that increased recycling is a cheaper strategy for reducing greenhouse gas emissions than increased reuse.

4.5.4.3.4 Costs of greenhouse gas emission reduction

The average packaging cost (including costs for treating packaging waste) (Table 19) decreases between 2000 and 2015. Logically the decrease is more pronounced in the OPT scenario than in the BAU scenario. However, also in case of a 15 or 30 % reduction in greenhouse gas emissions (compared to the 2000 level) the packaging cost is lower than in the BAU scenario. These results suggest the BAU scenario is sub-optimal, both in cost terms and in terms of greenhouse gas emission reduction.

Therefore, the costs and the reductions of the reduction scenarios will be compared with the OPT scenario. However, it should be kept in mind that this is a scenario in which packaging use has been optimised for least costs without greenhouse gas emission reduction. Most probably it gives a too drastic view of the changes that might occur (see remarks on MARKAL, §3.3)

Euro/litre	2000	2015				
		BAU	OPT	RE-15	RE-30	RE-MAX
packaging cost	0.134	0.110	0.091	0.096	0.104	0.119

Table 19: Comparison of packaging costs for the different scenarios

Figure 16 shows both the average emission reduction cost and the packaging cost per litre when increasing greenhouse gas emission reductions are aimed for. Increases in packaging cost are in the order of 0.005 to 0.013 Euro/litre. The cost for emission reduction increases from 130 Euro/ton CO_2 eq in the 15% reduction case to 228 Euro/ton in the 30% reduction case, and finally to 371 Euro/ton in the maximum emission reduction case.

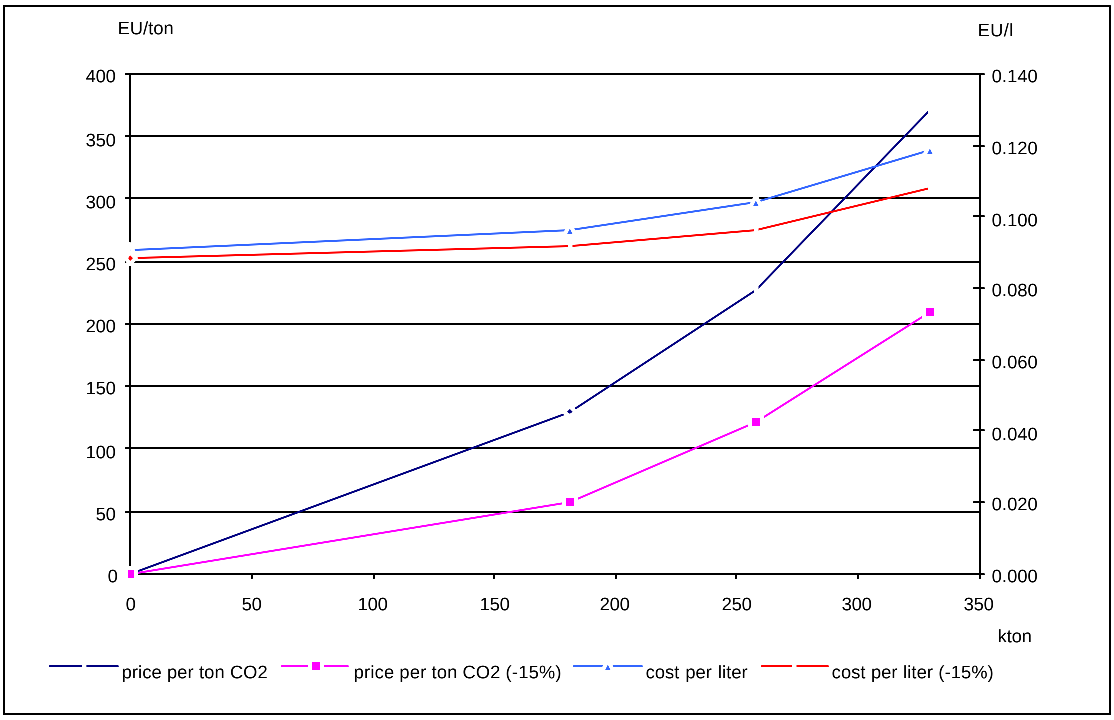

Figure 16: Cost of greenhouse gas emissions reduction (compared to OPT scenario)

To have an idea of the effect of the price differences between one way and reuse packaging, the specific costs of packaging use for the reuse options were decreased by 15 %, while all the other costs remained unchanged. In that case the cost for emission reduction decreases to 57 Euro/ton CO_2 eq in the 15% reduction case, to 121 Euro/ton in the 30% reduction case, and to 209 Euro/ton in the maximum emission reduction case.

4.5.4.4 Comparison of the results of both models

When comparing the results of both models some differences appear. Calculated emissions for 2000 are 66 kton lower for the PackMark model. This difference can partially be explained by differences in the choice of system boundaries (allocation of recycling credits). They can also be explained by the way both models have been set up and by their level of detail.

Emissions in the most drastic scenario in the PackBase model are comparable to the emissions in the PackMark scenario with maximum emission reduction. The reduction potentials calculated in both models are comparable.

4.5.4.5 Conclusions

Two complementary approaches have been used to calculate the life cycle greenhouse gas emissions and the emission reduction potential related to the end use of beverage packaging in Belgium. Although the results differ on some points, some general conclusions can be drawn.

Greenhouse gas emissions per packed litre of beverage are smaller for reuse packaging (glass and PET) than for all one way packaging options except beverage cartons. Greenhouse gas emissions related to materials use (including waste treatment) dominate greenhouse gas emissions during the use phase of the packaging (making, filling, cleaning, transport). They can be reduced significantly through decreases in packaging weight and increased recycling.

The **total greenhouse gas emissions** related to the end use of beverage packaging in Belgium can be estimated at 500 - 600 kton.

The reduced use of materials per packaging unit (reduced packaging weight) as well as some other changes , will lead to some reductions in greenhouse gas emissions. But on the whole greenhouse gas emissions will increase, because of the increase in beverage consumption and the gradual replacement of reuse packaging by one way PET bottles. In the absence of measures to reduce greenhouse gas emissions these emissions will increase by 50 to 100 kton.

Calculations of the **emission reduction potential** show a maximum reduction potential of 300 to 350 kton. However, this implies drastic changes in the use of beverage packaging. More realistic estimates show a reduction potential of 250 to 300 kton.

Increased recyling is a cheaper option for greenhouse gas emission reduction than changes in packaging choice, but it has a limited potential. Changes in packaging choice (i.e. increasing the use of PET reuse bottles) gives significant additional benefits compared to increased recycling only (up to more than 150 kton). However, the actual trend goes in the opposite direction. Only when imposing greenhouse gas emission limits, reuse PET becomes an attractive option.

The influence of some crucial parameters on the emissions and the emission reduction potential was tested. Although total emissions can change by 10%, the influence on the reduction potential is limited.

Compared to the actual situation and compared to the assumed BAU scenario, there is quite some potential for greenhouse gas reduction without additional **cost**. The changes in recycling rate and packaging use taking place in the 15% and 30% reduction scenarios, lead to a reduction in packaging cost.

However, when comparing emissions and costs of reduction scenarios to a scenario in which packaging cost is minimised (without emission limits), the average **emission reduction cost** was estimated at 130 Euro/ton in case of a 15% emission reduction (compared to the 2000 level), and 228 Euro/ton in case of a 30% emission reduction. This result is very sensible to the price difference between one way and reuse packaging options. If the specific costs for reuse are reduced by 15%, the emission reduction cost reduces by 45% to 55%. However, most probably, the average packaging cost will not fully reduce to the level of this minimised cost. Hence, these emission reduction costs should be interpreted as upper limits.

Life cycle greenhouse gas emissions related to the end use of beverage packaging in Belgium represent about 0,3 to 0,4% of the **total Belgian greenhouse gas emissions**. The calculated emission reduction potential corresponds to 1,1 to 1,4% of the total emission reduction effort that Belgium has to realise in the period 2000 – 2010 (approximately 22 Mton).

The comparison is however not fully correct because a significant part of the life cycle greenhouse gas emissions are related to imported materials or products, and will occur abroad. Hence, a significant part of the emission reduction potential will be realised abroad, and will not help Belgium in reaching its emission reduction targets. Similarly, Belgian production of (packaging) materials for export will contribute to the life cycle greenhouse gas emissions related to the end use of beverage packaging abroad.

It is not clear which part of the emission reduction will be realised in Belgium. Taking into account the large imports of intermediates in material production, materials and packaging itself, and the export of waste materials (see Part III[5]), the share of the "imported" emissions and "exported" emission credits will probably be at least 50 %.

4.5.5 Conclusions

4.5.5.1 Objectives and method

This study is a first attempt to quantify the effects of changes in beverage packaging use in Belgium on specific emissions (in this case greenhouse gas emissions), on a macro level and for a long time period, taking into account the possibilities and constraints for substitution of different packaging options for specific groups of beverages. This macro level quantification of the reduction potential gives relevant additional information for evaluating product policies as compared to the results of LCA studies.

The approach that has been developed for greenhouse gas emissions can also be used to quantify the effects on e.g. waste streams. It can also be used for other product groups.

To be able to take into account the cost factor, a MARKAL model was developed. MARKAL optimises the entire system based on cost minimisation, and provides a structured framework for evaluating costs, taking into account technical evolutions over a long time period. However, the system based on end use of beverage packaging is not a closed system, and an optimisation of all production processes based on the end use of beverage packaging only does not make sense.

Therefore, the focus of the optimisation was on the those parts of the packaging system that are really influenced by the choices in packaging: the choice of packaging type itself and the treatment of the waste packaging. For the treatment of the waste packaging the implicit assumption is that markets for recycled materials are not constrained.

4.5.5.2 Packaging flows

There is no direct statistical information on the quantities of packaging brought on the Belgian market. Estimating final use was only possible because the Interregional Co-operation Agreement compels producers and importers of packed products to declare the amounts they have put on the Belgian market.

If the environmental benefits of (changes in) consumption patterns (e.g. towards sustainable consumption) are to be assessed or evaluated quantitatively, systematically recording consumption figures of key product groups in physical terms (weights) seems a necessity.

More than 75 % of the household packaging (by weight) consists of food and beverages packaging. Food and beverage packaging accounts for more than 90 % of all glass and steel and 2/3 of all plastics used for packaging.

Beverage packaging represent more than 40 % of the total end use of household packaging in Belgium. This is mainly due to the fact that 67 % of all beverage packaging are glass bottles. Because their weight per unit of packed product is high, beverage packaging represent a proportionally large fraction in the total packaging waste quantity. In terms of packed volumes food packaging is more important.

Major trends in beverage packaging are a decline in reuse and an increase of the use of PET, also for applications from which it was excluded until now because of technical constraints (beer, fruit juices, milk). Reuse PET bottles have been developed, but are actually not in use in Belgium.

4.5.5.3 Greenhouse gas emissions related to beverage packaging

Except for beverage cartons, greenhouse gas emissions per litre of beverage packed are smaller for reuse packaging (reuse glass and reuse PET) than for one way packaging.

Greenhouse gas emissions related to materials use (including waste treatment) dominate greenhouse gas emissions during the use phase of the packaging (making, filling, cleaning, transport). They can be reduced significantly through decreases in packaging weight and increased recycling.

Life cycle greenhouse gas emissions related to the end use of beverage packaging in Belgium are small compared to the total Belgian greenhouse gas emissions: 500-600 kton CO_2-eq in 2000. In the absence of measures to reduce greenhouse gas emissions they will increase by 50 to 100 kton.

Decreases in packaging weight, increased recycling and changes in packaging choice (mainly shifts to reuse PET) lead to potential reductions in life cycle greenhouse gas emissions ranging from 250 to 300 kton CO_2-eq in 2015. Increased reuse gives significant additional benefits compared to increased recycling only.

The cost of these emission reductions have been calculated at 150 to 200 Euro/ton. However, cost data are quite uncertain. A decrease of 15% in specific packaging costs for reuse packaging reduces the emission reduction costs to 60 to 120 Euro/ton. In both cases costs were compared to a scenario in which packaging cost is fully minimised. Hence, they should be interpreted as an upper limit.

Compared to the total greenhouse gas emissions reduction effort needed to comply with the Kyoto protocol, the emission reduction potential from the Belgian end use of beverage packaging is small (1,1 to 1,4% of the total emission reduction effort). Moreover, a significant part of the life cycle emission reduction will be realised abroad. Calculating this share was not possible in the framework of this project. However, it can be estimated at least 50 % of the total emission reduction potential.

This analysis has only quantified the greenhouse gas emission reduction potential. In the case of packaging, strategies aiming at reducing greenhouse gas emissions seem to be the same as strategies aiming at reducing waste production. Hence, calculations of reduction potential should be broadened to other environmental impacts. Synergetic effects on other environmental impacts should also be taken into account when interpreting reduction costs.

4.6 Meat system

4.6.1 Background

The chain for breeding products is characterised by a high complexity and an important integration with other activities (industries and services). Moreover, agriculture plays a key role in the Belgian economy since the Second World War and must be considered within the European framework. Even if the share of agriculture in the GDP is declining, this sector still remains an important one due to its economic integration, employment (direct and indirect), value added and environment.

Some examples are needed to evaluate the contribution of this sector and the role of breeding activities. The total surface used for agricultural activities is around 1.38 millions ha : this represents 45% of the country. Almost 60% out of this is devoted to grass and fodder production. Direct and indirect employment accounts 120,000 persons, of which 60% are full-time workers. Finally, the value of the agricultural production is 262 billions BEF and breeding products represent 65% of this value. The value added of the sector represents 107 billions BEF or 1.1% of the GDP.

4.6.2 System definition

The function considered in the description is defined as quantity of meat per capita and per year. This means that all the different kinds of meat products are considered as able to satisfy this function. The possible substitutions between each kind of meat products are reflected by the socio-economic behaviours captured within the demand modelling framework (the CORELLI model).

From the demand point of view, nine meat products are considered and all the possible substitutions between these products are taken into account. Therefore, the chain description is carried out only for the three main categories, namely pork, beef and poultry. We shall see that they represent the main meat categories consumed in Belgium (89.9% in 1997) and capture the main structural phenomenon as far as meat consumption is concerned.

The frontiers of the system are defined as follows : first, the final demand within the Belgian frontiers was established; exports and imports were not considered. For the main categories, the analysis of material flows reveals that the main part of demand is satisfied with internal production. Crossed flows between imports and exports are nevertheless sometimes rather important (notably for poultry). From the bottom of the system, it was decided to exclude from the analysis to the production of engines, buildings. More important for our purpose, the production of fodder and fertilisers is included.

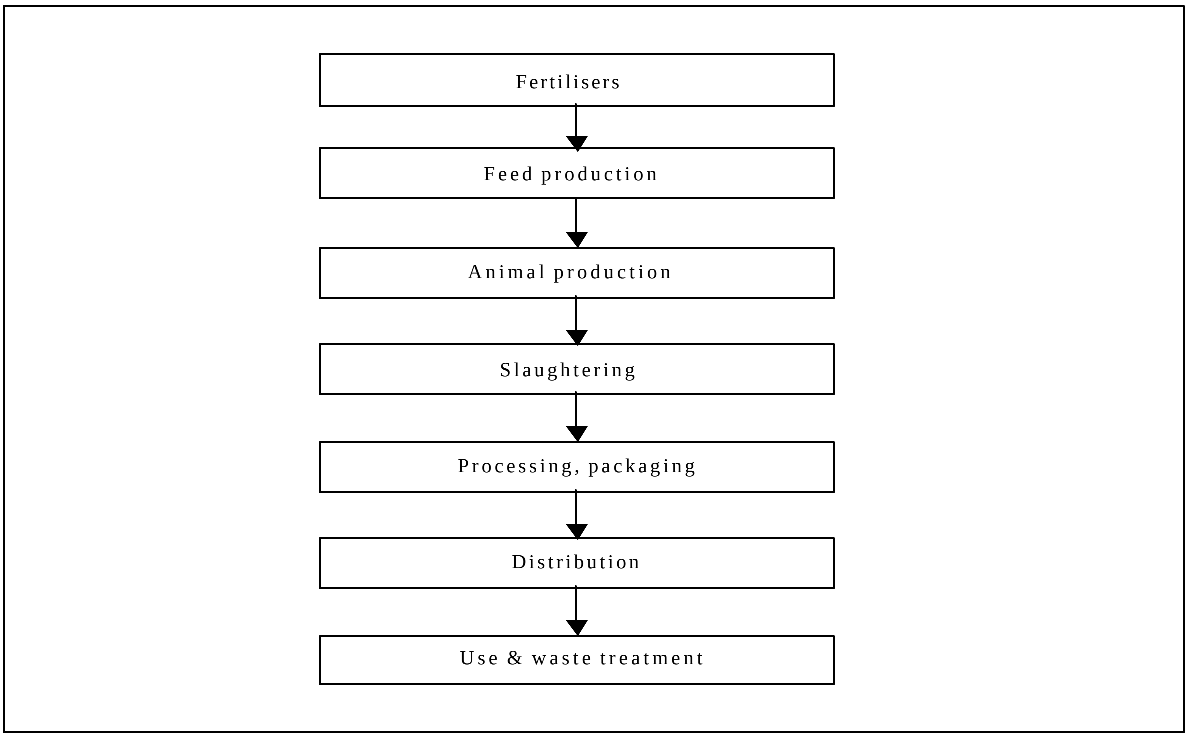

Figure 17 : System description for meat products

4.6.3 Detailed description

4.6.3.1 The actual demand and its evolution

4.6.3.1.1 Present demand

The meat consumption in Belgium and in Europe is displayed in the following table in kg par capita and per year. One can see that the pork represents the major part of consumption, especially in Belgium. Beef and poultry represent about 20% of the consumption each.

	kg / capita / year		% of total	
	EUR-12	Belgium	EUR-12	Belgium
Pork	41.3	48.8	44.5%	46.7%
Beef	19.0	22.3	20.5%	21.3%
Poultry	20.9	22.9	22.5%	21.9%
Other	11.7	10.6	12.6%	10.1%
Total	92.9	104.6	100.0%	100.0%

Table 20 : Meat consumption in Belgium and Europe
source : source : Eurostat, 1997

4.6.3.1.2 Evolution

The simulation undergone with the CORELI model show that overall consumption per capita for meat products is expected to rise very slowly in the forthcoming years, slower than overall private consumption: 102 kg/year in 1995 and 109 kg/year in 2015. As a result, the budget share for meat products is about 3.5% today; it would be about 1.8% in 2015.

However, the structure of this meat consumption is likely to change a lot. The share of veal, chicken and other poultry would increase sharply, from 25.4% in 1995 to 32.9% in 2015 (expressed in kg). Pork and beef would remain more or less constant around 59% of total meat consumption. One can notice that lifestyle effects are quite important and significantly alter consumption patterns.

The table below displays the complete results from the CORELLI model.

	Observations			Forecast				
	Kg per capita		Mean annual growth rate	Kg per capita				Mean annual growth rate
	1985	1997	1985 to 1997	2000	2005	2010	2015	1997 to 2015
Beef	21.67	16.92	-2.04	16.45	16.88	17.88	18.97	0.64
Veal	3.04	4.44	3.20	4.97	5.67	6.31	6.91	2.49
Pork	47.14	44.58	-0.46	45.40	46.01	46.43	46.72	0.26
Sheep	1.72	1.94	1.03	2.20	2.35	2.47	2.57	1.57
Horse	2.68	1.16	-6.73	0.87	0.55	0.34	0.21	-9.06
Chicken	13.84	17.63	2.04	18.19	19.87	21.90	24.27	1.79
Other poultry	2.51	3.50	2.81	3.87	4.32	4.71	5.05	2.06
Rabbit	2.39	2.95	1.76	3.10	3.31	3.50	3.68	1.25
Edible offals	7.26	3.43	-6.05	3.07	2.37	1.79	1.32	-5.16
Total	102.25	96.54	-0.48	98.12	101.32	105.33	109.71	0.71

Table 21 : Past and forecasted meat consumption in Belgium
Source : Source : CORELLI model

4.6.3.2 Environmental impacts of the product and related demand

4.6.3.2.1 On the product level

The indirect greenhouse gases emissions embodied in the production processes (considered from a LCA approach) are calculated at each step of the chain. These steps are the following : production and use of fertilizers, production and use of pesticides, feed production, animal production (breeding), slaughtering, transport (both between production and slaughtering and between slaughtering and consumption). The greenhouse gases considered are CO_2, CH_4 and N_2O. One of the main concern for this chain analysis is non-CO_2 greenhouse gases, of course. These gases are aggregated with their Global Warming Potential over 100 years with the IPCC coefficients.

The table below displays the indirect emission coefficient for the three gases considered and as a whole; they are always expressed in CO_2-equivalent. The first column gives the emissions per kg of meat product and the second column gives the repartition between the three gases considered. CH_4 is the main contributor for beef, but also for pork whereas N_2O is mainly concerned in the sheep production. Poultry production is mainly responsible for CO_2 emissions. Yet, the level of emissions is very high for beef and sheep (14 and 18 kg of CO_2-eq per kg of meat product) and is low (2 and 3 kg) for pork and poultry.

	Beef		Pork		Poultry		Sheep	
CO_2	3.4	23.2%	0.9	24.7%	0.8	37.4%	1.9	9.9%
CH_4	6.3	42.4%	1.7	46.2%	0.7	31.1%	7.6	40.5%
N_2O	5.1	34.5%	1.1	29.1%	0.7	31.5%	9.3	49.6%
Total	14.8	100.0%	3.6	100.0%	2.1	100.0%	18.8	100.0%

Table 22: Indirect GHG emissions : in kg CO_2-eq / kg of meat

The origin of the gases is very different from one meat to another, as it can be seen in the following table. For beef, as an example, breeding is the main source of emission, which concerns essentially methane. This is also the case for poultry, but mainly for heating and lighting, which entails direct and indirect CO_2 emissions.

	Beef		Pork		Poultry		Sheep	
Fertilisers production	2 380	16.1%	442	12.2%	261	12.46%	1 719	9.15%
Feed production	4 669	31.6%	707	19.5%	699	33.38%	2 593	13.80%
Breeding	7 422	50.2%	2 045	56.5%	816	38.96%	14 216	75.67%
Transport	154	1.0%	205	5.7%	151	7.23%	122	0.65%
Slaughtering	14	0.1%	14	0.4%	15	0.74%	13	0.07%
Transport	154	1.0%	205	5.7%	151	7.23%	122	0.65%
Total	14 795	100.0%	3 620	100.0%	2 094	100.0%	18 788	100.0%

Table 23 : Decomposition of indirect GHG emissions by source (in gr CO_2-eq / kg)

4.6.3.2.2 On the whole Belgian system

The analysis of material flows allows to calculate the contribution of these emissions in the global Belgian GHG emissions, considering imports at each level of the chain. These emissions represent around 4% of the total Belgian emissions of GHG (see table below).

	Beef		Pork		Poultry		Sheep		TOTAL	
		%		%		%		%	kt	%
CO_2	777.3	23.1	444.2	24.7	182.4	37.4	41.4	9.9	1 445.2	23.9
CH_4	1 421.4	42.4	830.0	46.2	151.7	31.1	169.5	40.5	2 572.6	42.5
N_2O	1 156.2	34.5	522.0	29.1	153.7	31.5	207.8	49.6	2 039.7	33.7
Total	3 354.9	100.0	1 796.2	100.0	487.8	100.0	418.7	100.0	6 057.5	100.0
%	55.4%		29.7%		8.1%		6.9%		100.0%	

Table 24 : GHG emissions due to meat consumption (kt CO_2-eq)

Considering the flows for domestic production and imports, the following table show that 87% of the emissions due to meat consumption comes from national production. However, this share is quite different from one meat to another. For sheep, imports are dominant; for poultry, imports represent 25% of the emissions; for beef and pork, national production is largely dominant with more than 90% of the indirect emissions.

	BEEF		PORK		POULTRY		SHEEP		TOTAL	
	kt	%	kt	%	kt	%	kt	%	kt	%
Production	5 624	91.4%	3 880	93.1%	623	75.5%	83	16.0%	10 210	87,5%
Imports (1)	532	8.6%	289	6.9%	203	24.5%	437	84.0%	1 459	12,5%
Total of supply	6 156		4 168		825		520		11 669	
Exports	2 062	38.1%	1 723	49.0%	494	50.3%	161	27.8%	4 441	42,3%
Consumption	3 355	61.9%	1 796	51.0%	488	49.7%	419	72.2%	6 058	57,7%
Total of demand (2)	5 417		3 519		981		580		10 498	
%	52.8%		35.7%		7.1%		4.5%		100.0%	

(1) with the same indirect emission coefficient as Belgium production

(2) without stock variations

Table 25 : Total GHG emissions (kt CO2-eq)

The table below gathers several studies carried out for the calculation of indirect GHG emission for meat products. This table shows that our figures are quite similar to others, except for the MATTER study. This comes from the fact that "[CO_2 emissions are] calculated on the basis of the food intake expressed in biomass energy units, multiplied by the CO_2 emission coefficient factor for oil (because the biomass could also be used to substitute oil)" (from : GREENHOUSE GAS EMISSION REDUCTION IN AGRICULTURE AND FORESTRY, D. Gielen *et al.*, ECN, May 1999, footnote page 5). If this method were applied to the Belgium consumption, this would result in CO_2 emissions representing more than 10% of national emissions, which is not realistic.

Authors(s)	Categories	Emission rates	Gas considered
…	Beef	9.1 kg CO_2-eq/kg (CH$_4$ = 40%)	CO_2. CH_4. N_2O
…	Pork Sheep	0.82 kg CO_2/kg 1.40 kg CO_2/kg 0.87 kg CH_4/kg	Only CO_2
Johnson *et al.* (1998)	Milk	1.56 kg CO_2-eq/kg (CH_4 = 38%. N_2O = 27%)	CO_2. CH_4. N_2O
Jarvis et Pain (1994)	Milk	1.40 kg CO_2-eq/kg (CH_4 = 55%)	CO_2. CH_4. N_2O
MARKAL-MATTER	Milk	0.62 kg CO_2-eq/kg (CH_4 = 62%)	CO_2. CH_4. N_2O
MARKAL-MATTER	Beef	34 kg CO_2-eq/kg (CO_2= 21 kg CO_2/kg)	CO_2. CH_4. N_2O
	Pork	11 kg CO_2-eq/kg (CO_2= 7 kg CO_2/kg)	CO_2. CH_4. N_2O
	Poultry	7 kg CO_2-eq/kg (CO_2= 5 kg CO_2/kg)	CO_2. CH_4. N_2O
	Sheep	50 kg CO_2-eq/kg (CO_2= 21 kg CO_2/kg)	CO_2. CH_4. N_2O

Table 26 : A comparison of GHG emission rates from literature

4.6.4 GHG emissions scenarios

4.6.4.1 A reference scenario for GHG evolution

The figure hereafter represents GHG emissions calculated from the evolution of meat consumption with the emission rates calculated in 1997. The evolution displayed only results from the modifications of the consumption patterns for meat products. From 1980 to 1998, observed data are used ; from 1999 onwards, simulation results from the CORELLI model are used (see above).

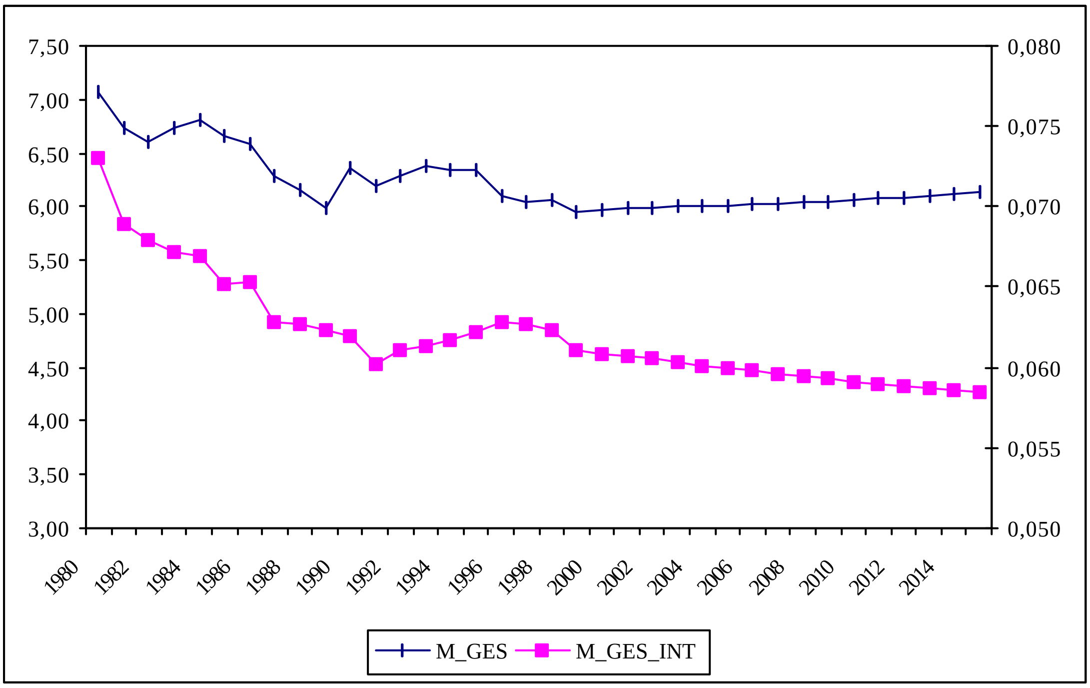

Figure 18 : GHG evolution with constant indirect emission coefficients
Emissions in kt CO_2-eq (*M_GES*, left scale, in Mt CO_2-eq)
Global emission coefficient (*M_GES_INT*, right scale, in MT CO_2-eq/t of meat)

This figure shows that the spontaneous evolution of consumption patterns for meat products tends to reduce the indirect GHG emissions, as well on the past period or in the future. As a result, from 1998 to 2015 emissions due to meat consumption are not expected to rise. The table hereafter displays the results for each gas. We can observe that, in spite of the fact that meat consumption is expected to increase by 0.46% per year, GHG emissions are expected to rise only by 0.18% per year.

	Mean annual growth rate (%)		Levels (Mt CO_2-eq)		
	1980 to 2000	2000 to 2015	1980	2000	2015
Meat consumption (kg/capita/year)	0.07	0.46	96.84	98.12	105.08
GHG emissions, of which :	-0.84	0.18	7.07	5.97	6.14
- CH_4	-0.36	0.29	1.91	1.78	1.86
- N_2O	-0.95	0.08	2.76	2.28	2.31
- CO_2	-1.13	0.21	2.40	1.91	1.97
Mean indirect emission coefficient (Mt CO_2-eq/kg)	-0.91	-0.27	0.073	0.061	0.058

Table 27 : Contribution to consumption patterns to the evolution of GHG emissions

4.6.4.2 Results

The alternatives on the consumer side rely on the opportunities to alter the patterns of meat consumption or to decrease overall meat consumption. We first evaluate the impact of a mere substitution between beef and poultry. Considering the indirect emission coefficients given above, a reduction of the consumption of beef by 1 kg per capita and per year entails a decrease of indirect GHG emissions by 12.9 kg CO_2-eq. This means that a reduction of the beef consumption by 10% compensated by an increase of poultry consumption so as to maintain the global meat consumption unchanged would reduce total GHG emissions by around 0.3 Mt CO_2-eq. This explains why any modification in the demand for meat product would have a significant impact on the global GHG emissions.

The imposition of a tax proportional to the content in GHG for each meat has also been considered in order to evaluate the possibilities for substitution among the consumption patterns. For example, the CORELLI model revels that a tax of 250 €/tCO_2-eq would reduce emissions from meat production by 8.9% on the long term (see table below). This impact is mainly due to a short decrease in beef consumption (-20%) whereas poultry is hardly affected by the tax (-0.7%). The global reduction represents about 0.5 Mt CO_2-eq. Methane would be the main contributor to this reduction. It is also interesting to notice that overall consumption would not really be affected by this tax. The impact on the consumer price index is quite weak (+0.6% in 2015) and the overall consumption is only decreased by 0.2%. This shows that consumption patterns are relatively flexible and that the burden of the tax can be partly avoided by the consumers thanks to this flexibility.

	2000	2005	2010	2015
Meat consumption				
Beef	-4.67	-16.63	-20.13	-20.77
Veal	-1.31	-1.29	-1.28	-1.27
Pork	-3.53	-3.21	-2.93	-2.69
Poultry	-0.89	-0.82	-0.75	-0.68
GHG emissions				
CH_4	-3.56	-8.79	-10.02	-9.99
N_2O	-3.31	-8.37	-9.52	-9.45
CO_2	-2.52	-6.12	-6.91	-6.83
All gases (in CO_2-eq)	-3.17	-7.85	-8.92	-8.86
Consumer price index	0.09	0.07	0.06	0.06
Overall private consumption	-0.11	-0.20	-0.21	-0.20

Table 28 : Impacts of a tax of 250€/tCO_2-eq on meat products
(*in % from the business as usual scenario)*

The figure below shows the impact of this GHG tax on the indirect emissions of meat products. The first line represents the business as usual scenario (our reference projection) and the dotted line the simulation with the tax. We can see that consumer patterns are gradually adjusted to the new relative prices system ; this adjustment is done after 5 or 6 years. This reveals that even if consumer patterns are flexible, time is necessary to adjust them.

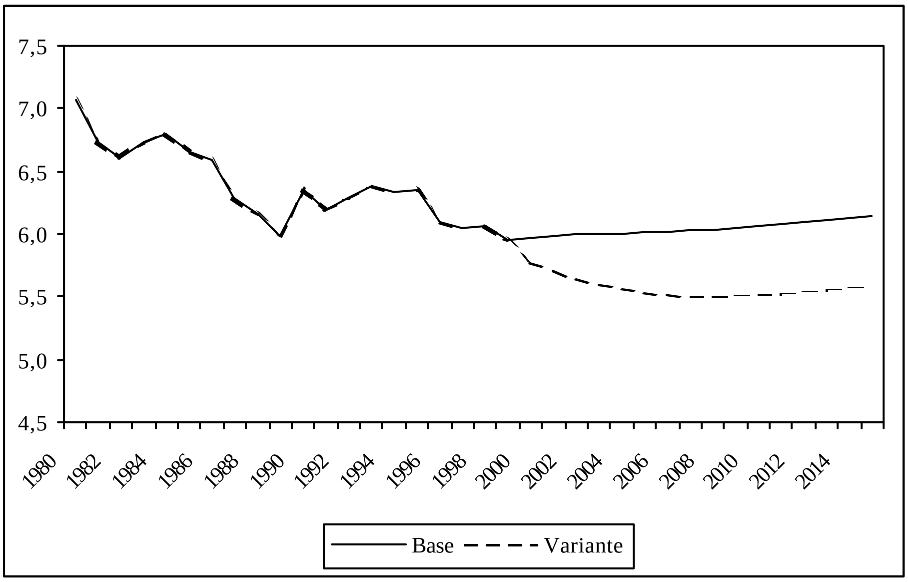

Figure 19 : BaU scenario and GHG tax simulation on GHG emissions (in Mt CO_2-eq)

As far as the production side is considered, the table below presents the alternatives considered. These alternatives are considered as technical potentials since no optimisation procedures have been applied. These potentials come from several studies undergone for different fields of the production system. As an example, ECOFYS has realised a comprehensive analysis of these potentials, for different types of GHG in the breeding systems in Europe.

The potentials differ from one gas to another. For CO_2, these potentials rely in the improvement of energy efficiency and processes, substitutions between energy products or a drop in energy demand (for fossil fuels), notably for transport. For CH_4, they consist on livestock reduction, increase of feed conversion efficiency (by adjusting animal diets), increase of animal production by adding chemical compounds and management of manure. For N_2O, the potentials mainly consist on optimisation of production processes for nitric acid, the use of end-of-pipe abatement technologies and the decrease in the use of fertilisers.

Each of these potentials has been evaluated for each chain production for the different kinds of meat products considered here. The individual potentials (that is to say for each individual measure in each chain production) are mainly based on the potentials identified by ECOFYS. The overall potential emission reductions are displayed in the table below.

	Reduction in %			Total reduction	
	CO_2	CH_4	N_2O	in %	in kt CO_2-eq
Livestock reduction by 10%	-5.1	-5.5	-1.3	-4.0	-242.6
Reduction of enteric fermentation	0.0	-5.4	-1.3	-2.8	-168.3
Modification of feeding composition	-1.9	-11.7	-2.3	-6.2	-377.9
Improvement in nitric acid production	0.0	0.0	-3.7	-1.2	-74.6
Reduction in fertilizers use	-15.7	0.0	-34.7	-15.4	-935.0
Transport rationalisation	-14.5	0.0	0.0	-3.5	-209.9

Table 29 : Potential reductions on the production side

All the studies, at one moment or another, consider the fact that the most efficient measure is always the livestock reduction. In another words, measures such as a decrease in demand or an improvement of feed conversion can induce a decrease in livestock. Of course, livestock reduction can not be considered as a measures *per se*. If a benchmark of 10% is considered, we can see that it would allows a reduction a GHG by 242 kt CO2-eq.

It appears clearly that one of the major potentials relies in the production and use of fertilizers, and notably in their use.

4.6.4.3 Socio-economic impacts

The socio-economic impacts have also been considered for this chain analysis. They are essentially evaluated on employment on the basis of direct and indirect impacts on activities. For any of the alternatives considered above from the demand or production side, these impacts can be evaluated.

Two examples can be given. The first one is a livestock reduction by 10%. This “measure” (we can recall that this is not really a measure but rather an “intermediate impact”) would entail the loss of 2,200 workers. Another example is the substitution between beef and poultry considered above. Since beef production is more labour-intensive than poultry production (and the same holds true for pock), such a substitution would entail a reduction in employment by around 1,200 persons on the term.

4.6.4.4 Conclusions

The main conclusion here lies in the fact that demand management should be considered along with production management: both of them are important and they generally reinforce each others.

When we consider that livestock reduction is the most efficient manner to reduce GHG emissions, it can not be consider without an exploration of the potential modifications of demand patterns. From this point of view, the simulations undergone with the CORELLI model reveal that potential modifications of the consumption patterns exist and should be used. But this must should be done along with a better use and production of fertilisers for animal breeding. The combination of both package measures would have a significant impact on indirect GHG emission in Belgium.

However, the analysis of this chain reveals that the uncertainties are very important, not only about the reduction costs but also for the emission rates. From this point of view, sensitivity analyses have been realised. They show that, considering the uncertainty on direct emission rates for CH_4 and N_2O, the indirect emission coefficients calculated on the whole chain are very uncertain. The level of uncertainty is such that the differences between beef and pork is hardly significant from a statistical point of view. This result confirms the need of further researches in this field.

5 Comparison of the three systems

5.1 Life cycle emissions compared to national emission

Life cycle emissions of the different products as well as emissions resulting from the demand at the Belgian level are compared in next table. At the product level, emissions are obviously the highest for houses, followed by meat.

On the opposite, annual life cycle emissions estimated at the level of the total Belgian respective demands (year 2000) are the highest for meat. For this demand, total emissions reach about 6 Mt eq-CO_2 corresponding to 4% of the total Belgian GHG emissions in 1998. Estimated life cycle emissions resulting from housing demand represent 1% of the Belgian GHG emissions. For beverage packaging this percentage is 0.4%.

The fraction of these emissions that comes from activities carried out in the national territory is also very different from one category to the other. The larger fraction is estimated for housing (~95%) and the lowest for beverage packaging (probably less than 50%).

		Housing	Meat	Beverage packaging
Life cycle emissions of the different products in 2000		For new constructions (200 m^2 total surface) : **from 18 t CO_2 to 52 t CO_2** For renovation (surface increase resulting in a 200 m^2 total surface): **from 5 t CO_2 to 14 t CO_2**.	**Beef: 14 kg eq-CO_2/kg** **Pork: 4 kg eq-CO_2/kg** **Poultry: 2 kg eq-CO_2/kg** **Sheep: 19 kg eq-CO_2/kg**	large packs: from 54 to 335 g CO_2 eq/l small packs: from 103 to 324 g CO_2 eq/l
Life cycle emissions resulting from the Belgian demand for the functional group in 2000	Absolute level	1.75 Mt CO_2.	6.1 Mt eq-CO_2. (of which 1.4 Mt CO_2)	0.5 - 0.6 Mt CO_2.
	Fraction of total GHG Belgian emissions	1.2%	4%	0.4%
	Average fraction being emitted in Belgium	95%	87%	<50%

Table 30 : Comparison of life cycle GHG emissions for the three product categories studied.

5.2 Emission reduction potentials

Scenarios on the evolution of life cycle GHG emissions induced by the demand for the three product categories have been developed. These dynamic, integrated assessments take into account product substitutions (changes in product choice) and (technological) changes in the upstream production system and downstream waste treatment system simultaneously.

However, in view of the possible role of the consumer choices on the life cycle emissions induced by the demand for goods and, more generally, the possible influence of product substitutions[10], it is interesting to compare for the three product categories the potentials of GHG emission reduction that may result simply from product substitutions, without taking into account changes in the production and waste treatment system. This potential may be designated as the "potential from product substitution". This is of course a theoretical estimation. A more realistic estimation would require to take into account technology improvements that may occur in the future and also the costs that such emission reductions would imply.

If demands evolve as in the base case projections built up by IDD[11], if for housing no shifts in product types are considered and if only slight changes in packaging choices are considered, the resulting life cycle emissions would increase over the period studied (1990-2010 for housing, 1997-2015 for meat, 2000-2015 for packaging) for all three product categories, however with different rates (see Table 31). On the other hand, if shifts in product types occur (shifts towards less emitting products) then significant emission reductions compared to the reference scenario would be observed.

For the three product categories the difference between this “product substitution scenario” and the reference scenario reveal a theoretical potential that would result from product shifting without any technological change within the upstream production system and downstream waste treatment system. In all three cases it shows that product shifting enables to reverse the increasing GHG emission trend as driven by the increase of the total demands.

	Housing	Meat	Packaging
Period studied	1990-2010	1997-2015	2000-2015
Life cycle emissions changes over the period studied if no change in product system occur	+8.5%	+2%	+16%
Life cycle emissions change over the period studied if change in product system occur	-116%	-6%	-24%

Table 31 : Evolution of life cycle emissions for the three product categories without any (or with slight changes for the packaging system) technological improvements within the upstream production system

For **each** of the three product categories the theoretical emission reduction potentials in **absolute values** are low compared with the total Belgian GHG emissions : for each of them at the end of the periods studied, from 0.1 to 0.3 Mt CO2-eq emissions would be avoided in the scenario through product shifting compared with the reference scenario.

In the same time , these theoretical emission reduction potentials represent from 6% to 24% of the base year emissions resulting from the demand. If similar emission reduction potentials could be proved for a more extended set of product categories, this would provide theoretical emission reduction potentials comparable to the overall emission reduction target (-7.5% of the total GHG emissions in 1990) to which Belgium has committed itself in the framework of the Kyoto Protocol.

A proper interpretation of this theoretical potential needs however a complementary cost analysis as well as a more integrated assessment which should take into account the role of technology changes in the evolution of life cycle emissions.

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[10] Product substitution may be driven through changes in consumer choices but also through changes in the marketing and the production system (resulting for instance from waste treatment improvements – for packaging especially – from ecodesign)

[11] It is to be reminded here that while for meat demand projections could be built for each type of meat, demand projections built for packaging and for housing are aggregated for all product types and make no assumption on the contribution from the different products to the overall demand.

For **meat**, estimations has shown that an emission reduction of 0.2 Mt CO2-eq (-10%) is possible with a marginal cost of 250 Euro/t CO_2-eq. This reduction comes from substitutions among the products considered (that is to say a reduction of beef consumption partly compensated by an increase of less-emitting meat products).

For housing and packaging, cost estimations were made with MARKAL. In these cases this enabled to complement previous scenarios with a more dynamic and integrated assessment : technology improvements over the period considered (1990-2030 for the housing system and 2000-2015 for the packaging system) were indeed taken into account.

For the **housing** system, the most cost efficient measures that fulfil the demand for construction and renovation by 2010 and allow a 7.5% decrease of life cycle CO2 emissions in 2010 ompared to the 1990 emissions, would result from technology improvements or substitutions. These measures offer emission reductions with a marginal 37 Euro/t CO2 cost price. On the opposite, measures aimed at reaching the Kyoto target through product substitutions, namely through shifting from conventional houses to wood houses, represent a cost up to 140 Euro/t CO2.

For **beverage packaging**, as described in §4.5.4, life cycle emission reduction may be achieved both through reductions in packaging weight and changes in recycling rates and through reinforced product reuse.

Emission reductions up to 18% (compared to the 2000 level) can be realised through reductions in packaging weight and changes in recycling rates. However, no detailed cost analysis has been done for scenarios without changes in choice of packaging.

Calculated total costs for a 15% reduction (compared to the 2000 level) are lower than the costs of the considered BAU scenario. However, compared to more drastic changes in beverage packaging (based on cost minimisation) reduction costs could be as high as 130 Euro/t CO2.

As a conclusion for all three product categories, product substitution offers significant emissions reduction potentials but reaching such potential would represent costs which are higher than technology improvements both for material production and for waste treatment.

5.3 Methodological uncertainties

One of the major difficulties encountered all along the three systems analysis has been the uncertainty that affected the different stages of calculations. In the framework of this project we were not able to make a complete analysis of all the uncertainty on the results regarding the evaluation of the emissions reduction potentials.

Besides the influence of the product demand projections (see IDD, 2000)3 we can list the different types of uncertainties and discuss their possible implications on the quality of the results :

- Representativeness of the products within their product category. For meat demand statistical data allow to estimate the actual demand for each products. For packaging some data could be used. For the housing system there is no available data about the representativeness of the different house types so that we had to make own estimations. This issue both refers to the material composition of houses and to the architecture of the houses.

- Uncertainty on life cycle emissions factors : Some emissions factors result from detailed analysis of the energy consumption by technologies, of which some standard technologies. For some of them literature provides convergent data and information from the industry sector allows to reach some confident estimates. Uncertainties from 10% to 20% may be assumed for building material productions. For the meat system, statistical tests have shown that the differences between emission factors between the meats considered are hardly significant. For packaging the high complexity of petrochemical processes and the role of waste treatment represent significant sources of uncertainties. The choice of the system boundaries for production of some materials may also have high implications on the estimated emissions factors. This was illustrated through the sensitivity analysis carried out for beverage packaging.

- Uncertainty on the material flows : for some materials (plastics, wood, glass) the analysis showed a high complexity of the intermediary flows and the resulting difficulty to assess the role of foreign trades in the total life cycle emissions.

- Uncertainty on costs : uncertainty on costs in general is high and has major implications on the conclusions that can been drawn about economic efficiency of the estimated technical potential improvements (see sensitivity analysis beverage packaging).This uncertainty, combined with the other sources of uncertainty above hamper to draw out evident conclusions on the cost of emissions reductions resulting from product and material substitutions compared with technology improvements.

6 Conclusions

The approach followed in this project aimed at giving insights in the greenhouse gas (GHG) emissions indirectly induced by the consumption of some product categories (SFH houses, meat and beverage packaging). The aim was also to assess the possible contribution of product substitution to the reduction of GHG emissions. The assessment has been made taking into account the possible future evolution of the technologies involved in the life cycle of the products considered. Costs analyses were also carried out.

A substantial amount of work has been carried out in order to collect the numerous data needed in this project : these data concerned the different flows of materials involved in the different product systems, the technology descriptions, the description of products and the market analysis.

Different methodological developments have also been undertaken in order to achieve the goals of the project :

A consistent modelling of the demand has been carried out for all three product categories : a bottom-up econometric model has been developed for the whole consumption pattern for breeding and packaging and a stock-flow model has been developed for the housing demand.

While material flows received very little attention in Belgium up to now the study constituted a first attempt to analyse the relevant material flows for the three product systems. The analysis has led to different conclusions for the three product systems : while foreign trade plays a small role for most building materials, the meat system and especially the beverage packaging system involves significant import and export both for intermediary materials and final products.

More fundamentally the ambition to quantify the greenhouse gas reduction potential related to the end use of specific product groups in Belgium, presented the challenge of finding a way between the development of a global and complex model such as the MATTER MARKAL model and product-specific LCA approaches.

Linking projections on demand with technical improvement options and specific emission factors enabled to give some insights in the possible impact of policies addressing consumption patterns and their environmental impacts. This macro-level quantification of the emission reduction potential gives relevant additional information in policy discussions, as compared to the results of LCA studies (e.g. in the discussion on reuse and one-way packaging).

To be able to take into account the cost factor, MARKAL models were developed for two of the product categories studied (housing and beverage packaging). MARKAL provides a structured framework for evaluating costs taking into account technical evolutions over a long time period. Costs analysis were undertaken on an independent econometric analysis for the meat system.

In absolute terms, the research has evaluated the life cycle GHG emissions related to three product categories to levels of less than 1% to 4% of the Belgian 1990 GHG emissions. In the same time it has revealed that, in relative terms, product substitutions within each product category may represent significant reductions of the life cycle emissions resulting from the Belgian demand for each of the product categories. The analysis suggested that in theory product substitutions could offer non negligible contributions to the fulfilment of the Belgian Kyoto target.

However given the low absolute levels of these potentials as compared to the total emission reduction that Belgium has to achieve, the important question is whether these specific product-related emission reduction potentials can be extrapolated to other products categories and other consumption patterns.

The cost analyses indicated that if the theoretical potential from product substitution is significant, this substitution seems to be less cost-efficient than technology improvements within the production and waste treatment system itself.

The level of confidence of this conclusion is however low given the high uncertainty level of the cost data for the different technologies and products.

Considering the weak quality of these data an optimisation based on total system cost and an approach based on fixed scenarios and associated cost calculations, eventually using cost ranges, could be combined as mutually complementing tools.

The examples studied also indicated that both the necessary instruments and the geographical level for implementing them in order to achieve these potentials have to take into account the specificity of each product category : this specificity relates to uncertainty but also to the openness of the Belgian economy which is more or less important from one material to the other and hence from one product to the other.

Indeed, the European level could be more appropriate for some product categories. In general product-related measures also require European co-ordination. The Integrated Product Policy presently under discussion could offer such a framework.

Finally this project has also shown the importance of systematic recording consumption figures of key product groups in physical terms as a condition for properly assessing the environmental benefits of changes in consumption patterns (e.g. towards sustainable consumption).

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