SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT POLICY

SPSD II

SUSTAINABILITY DEVELOPMENTS OF PRODUCT SYSTEMS, 1800-2000

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PART 1

SUSTAINABLE PRODUCTION AND CONSUMPTION PATTERNS

GENERAL ISSUES

AGRO-FOOD

ENERGY

TRANSPORT

SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT POLICY (SPSD II)

FINAL REPORT

Sustainability developments of product systems, 1800-2000

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TABLE OF CONTENTS

ANNEXES

ANNEX 1: Bibliography

ANNEX 2: Publications and presentations

ANNEX 3: Additional data and graphs for the environmental perspective for all cases

ANNEX 4: Additional data for the social and economic perspective for all cases

ANNEX 5: Data on electricity production in Belgium

ANNEX 6: Data on steel production

ANNEX 7: Illustrations

The annexes can be consulted at the www.belspo.be website

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

This scientific report presents the results of a four-year research project regarding (un)sustainability developments of four product systems (drinking water, bread, transport and heating of homes) in Belgium between 1800 and 2000. This project emerged from close collaboration between "two worlds": natural and human sciences.
This type of collaboration existed throughout the world since the 1970s, but it was utterly marginal. Although historians were sensitive to the environmental problems of their time, and started to question the impact of industrialization, urbanization and mass consumption on the environment, their research remained very much oriented toward 'traditional' history. And although some natural scientists took a historical outlook (sometimes covering hundreds of years), they primarily focussed on present-day problems, to propose solutions for the (near) future. In the course of the 1990s, things started to change. The launching of specialized reviews, for example *Environment and History* (1995) and *Environmental History* (1996), testified to this change. Today, this field is developing swiftly (but not always smoothly), as may be read in up-to-date review essays.[1] Recent literature in this domain pleads for full integration of general history with environmental history, and of history *tout court* with natural sciences.[2] This, of course, opens a wide field of investigation. We believe that such integration may alter the way natural scientists envisage present-day problems, as well as historians think about the past.

Our project aimed at contributing to this integration (regarding the methodology), adding to environmental theory (e.g. the concept of sustainability), and, especially, at increasing our knowledge of past, present (and, indeed) coming ecological, social and economic developments, problems and solutions.

Right from the onset, our project took some particular perspectives that may be characterized as original. The concept of sustainable development is most often studied at the macro-level (world, countries, regions), and sets of sustainability indicators are being developed for that level. At the micro-level (product systems) sustainability indicators are virtually non-existent. Our project focussed on the micro-level. In order to achieve progress towards more sustainable development, the actors at the micro-level within product systems (producers, consumers and policy makers) need a good understanding of how product systems may contribute to more sustainable development. We thus have, so to speak, *political* ambitions (taken in the broadest sense) as many decisions in practice are taken at the micro level. And finally, we wish to stress again the fact that we were and are convinced that historical insight may contribute to present-day and future problems with regard to sustainable production and consumption.

We did not wish to start from theory or commonly accepted views but, on the contrary, from a set of quite simple questions such as "Did bread baking pollute around 1850?", "What was the environmental cost of heating one's house around 1950?", or "How much CO_2 was sent into the air by an average car in 1960?". And especially, we wanted to know how these evolved through time. Our perspective, though, was not purely ecological: sustainability should be closely linked to economic and social factors. A judgement of "sustainable" production and consumption, thus, should consider ecological, economic and social features (i.e., the three

[1] For instance, John McNell, "Observations on the nature and culture if environmental history", *History and Theory*, 42 (2003), pp. 5-43.
[2] Stephen Mosley, "Common ground: integrating social and environmental history', *Journal of Social History*, Spring 2006, pp. 915-933.

dimensions of sustainability). So, other questions were asked, such as, “What was the price of bread in 1850?”, “Did the government interfere with the supply of grain in 1900?, or “What percentage of the population had access to the fulfilment of currently considered basic needs during the two centuries ?”.

The combination of historians and engineers proved to be a very successful one (despite some initial hitches with regard to language, approach, methodology, and expectations). As mentioned above, our research connects to rather new developments in both historiography and environmental studies. Our contribution is particular in yet another way too, in that it is based on an extensive empirical basis, within the context of one country. The latter is both an advantage and a disadvantage, although the advantage is, according us, much bigger than the disadvantage: this research does indeed deal with very concrete issues, people, policies, and developments.

During the project it became clear that not all information, we would ideally like to have, was available in a consistent way. Quite often socio-economic information needed to be retrieved via different sources that used different definitions. In the environmental dimension we also faced the problem of lack of historical information. For some cases, this lack could be solved by measuring the environmental emissions of existing old objects (though this was not possible anymore for emissions to water or soil). Furthermore product systems consist of many subsystems, and we were forced to limit the system boundaries and address just the most contributing subsystems. In the environmental dimension we were also forced to limit ourselves to emissions like $C0_2$, SO_2, NO_x and VOS which contribute significantly to wider environmental impacts and which are mainly caused by the use of energy carriers in several processes of the product system.
One has to keep into mind these limitations. Our intention was to explore and interpret some main trends in the three dimensions of sustainability in order to learn from the differences and similarities both between the three dimensions as well as between the four mentioned product systems.

More detailed information is enclosed in the yearly scientific reports available on www.belspo.be .

Finally, it is our great pleasure to thank warmly all the people that have been involved in this project: the five researchers, the nine members of the steering committee, the (to us innumerable) national and international experts who evaluated the different stages of the project, and the two members of the administration of *Belgian Science Policy*. It has been great (and pleasant) working together!

2 PROJECT OBJECTIVES

- To create a better understanding of long-term historical developments in each of the three dimensions of sustainability (social, economic and environmental), where the four product systems have gone through; to consider the developments in the three dimensions separately as well as combined.
- To gain insight into the factors that influenced the process of (un-)sustainable development on a micro level (for four basic needs) , in order to better interpret and steer recent and future developments.
- To get a better view of the concept of sustainability for product systems.

3 METHODOLOGY

3.1. General outline

Four case studies form the backbone of the project. They provide the basic data and background information in order to reflect on the (un-)sustainability of the trends. In each case study we retrieved quantitative data to develop indicators that show the progress or deterioration regarding environmental, economic and social relevant issues. Qualitative data were also retrieved to obtain a better understanding of the changes that occurred over the two centuries and to describe important changes that could not readily be quantified. The report structure is built upon the following sequential and related steps:

1. The research subjects we have selected are those basic needs we expect all persons on earth would have: water, food, the ability for mobility and heated accommodation. Because we use the life cycle assessment approach[3] for the environmental indicators we defined the functional unit for each basic need in order to allow for comparisons over time : 1 litre drinking water, 1 bread , a human trip of 1 km over land (on bicycle, by car or by train) and 1 cubic metre of heated accommodation during 1 year. The functional unit defines the functions of the system under study, serves as a basis for comparison and includes a clearly defined unit to which the environmental impacts are related.

2. Selection of "key years" in the past: 1800, 1850, 1900, 1950, 1975 and 2000. In the transport case the years 1925, 1960, 1975 and 2000 have been chosen.
   Based on historical research and available or retrievable data a qualitative and quantitative status description of the fulfilling of the four basic needs is made for each key year. We have examined the environmental, social and economic aspects on the production side as well as on the consumption side. We focus on Belgian sources[4] for data on production and consumption, unless production clearly occurred abroad (such as grain produced in the USA). The following aspects are quantitatively founded:
   - Environmental: integral environmental load per functional unit (to the extent possible);
   - Economic: real price, i.e. days (or hours) of labour needed to purchase a service or good, consumption of functional units per person, percentage of budget spent on basic need;
   - Social: percentage of people with access to basic need (degree of equality).

   This allows to show the environmental progress or decline per functional unit as well as for the total Belgian consumption.
   In this way we create a birds-eye view on historical developments. In the graphs the data-points are connected by dashed lines that are only intended as helpful lines for interpretation, the factual development in intermediary periods will have differed.

[3] ISO 14040 defines an LCA as follows : “ LCA studies the environmental aspects and potential impacts (damages) along the continuum of a product’s life (i.e. cradle-to-grave) from raw material acquisition through production, use and disposal. The general categories of environmental impacts needing consideration include resource use, human health, and ecological consequences”.

[4] Although Belgium can be regarded as representative for a more expanded geographical region (e.g. western Europe). It has an open economy (the nineteenth century politics of free trade probably were ‘exemplary’), the maritime harbor of Antwerp was one of the most important harbors of the nineteenth century, migration made of Belgium a ‘multicultural society’ and Belgium was the first country to industrialize (after Great Britain).

3. On macro level general indicators are retrieved on important social and economic aspects for the "key years" such as the total amount of consumers, average life expectancy, infant mortality or purchasing power.

4. Interpretation of the simultaneous developments in the social, economic and environmental dimension allows for concluding on the (un-)sustainable developments within the product systems and for reflecting on the concept of sustainability for product systems.

3.2. The concept of 'key years'

To create a long term view on 'sustainable development', it is imperative to cast a glance at the past : « No less important is the need for contemporary ecological management to include an historical dimension, especially if the goal is environmental sustainability. 'Sustainability' has little meaning without an understanding of long-term ecosystem trajectories and a knowledge of baseline conditions, if they ever existed »[5]. Bots[6] argues that it is an historian's duty to provide a scientific foundation for knowledge and diagnosis of the present and for prognoses. Therefore, a systematic ecological interpretation of the past is essential.

This research project wants to gain insight in the (positive and negative) elements that constituted (a part of) the (un)sustainable development over the past two centuries. It does not start from today's situation to propose scenarios for the future, since today's situation is the result of manifold factors of past influences. When looking at the past, a well-founded basic knowledge on (un)sustainable development over the past centuries can be constructed. A long term view is imperative to interpret, explain and steer recent and future developments.

In order to map the evolution over the past two centuries, six key years (1800, 1850, 1900, 1950, 1975, 2000) were chosen to represent specific changes in the development. We tried to set up the different analyses focussing on these key years, to make the search for data and the comparison between the four product systems more feasible. However, not all sources allow concentrating on these years only. Therefore, it is important to treat the key years as 'indicators' within a time period.

The key years each represent a period in time, that has specific characteristics:

- 1800 : the pre-industrial time (traditional production techniques, agrarian community, living and working functions are hardly separated).
- 1850 : 'industrial revolution' (capital growth in several sectors, mechanization, increasing trade, manufacturing industry, urbanization).
- 1900 : mature industrial community (electrical motor, colonialism, 'modern' labour organization, government interference e.g. education, labour legislation).
- 1950 : highly industrial community (electronics, plastics and nuclear energy, mass consumption, transport revolution).
- 1975 : post industrial community (growing environmental consciousness, internationalization, tertialization).
- 2000 : reference year.

[5] R.A. Butlin and N. Roberts ed. (1995), p. 1-14.
[6] A.C.A.M. Bots (2002).

The time span between key years was chosen in a way that made it possible to retrieve changes. Since changes (in every way) occurred faster while making headway to the twenty-first century, the second half of the twentieth century was divided in two parts of 25 years.
A remark has to be made concerning transport. Seeing that in 1950 transport modes still followed the same pattern as in the pre-war period, it was decided that the key year 1950 would be replaced by 1960[7]. The year 1925 was added to capture relevant developments like the T-Ford and the foundation of Belgian railways. This way, changes that occurred in the first half of the twentieth century could be retrieved more easily.

3.3. Choice of relevant environmental indicators

Our ambition is to quantify as much environmental impacts as possible according to modern LCA studies. We started with the years 2000 and 1800 in order to understand the main differences and to know which processes within the product systems contribute the most to the environmental impact. Infrastructure (such as roads, production plants) are usually not taken into account in LCA studies.
Thanks to good retrievable inventory data and modern LCA databases, containing impacts of thousands of processes and materials, we could get detailed results for all product systems for the year 2000 expressed in environmental impacts, such as global warming, acidification, eutrophication, ozone layer depletion etc.[8], and describing the complete product system (e.g. including agriculture for the bread case).
For the year 1800, the product systems are less complicated due to much more manual labour. Nonetheless it was not easy to find inventory data and we needed to make some assumptions on emissions related to the inventory data, as LCA databases do not contain data for the past.
During the search for data for the intervening years it became clear that for 1850, 1900 and 1950 there was no easily available quantitative data on the amounts of materials or energy used in a product system. Also we needed to obtain quantitative data about the production of these materials or energy processes as well. Each production process in fact represents a study on its own. For instance, in order to be able to determine the integral environmental impact of a trip by car, we not only need the exhaust emissions of the car but also the emissions associated with the production of the materials (such as steel, aluminium, rubber, wood) used in the cars. For the bread case we should also know the emissions occurring while producing fertilizers for the year 1950. In practice it was not possible to find all of the required data.

Determining the environmental impact of a product system in a certain year in the past proved to be challenging, but comparing several years is even more complicated. Care needs to be taken that the comparison is made on a fair basis.
In order to make fair comparisons over **all** the years, given the available data, we had to make the following adjustments or simplifications :

- System boundaries: we took a smaller system than initially projected:
  - for bread this meant leaving out the agricultural phase due to lack of data;
  - for water we have focused on the production of drinking water and not on the purification processes for waste water.

[7] This was decided in consultation with the experts of the Dutch Centre for Autohistoric Documentation (NCAD): J. Polman, G. Mom and P. Staal.
[8] Methodology : CML 2 baseline 2000 V2.1 / West Europe, 1995

- For transport we had to focus on train, car and bicycle and leave the bus and tram out of the analysis.
- Simplifying the product systems: we have focused on the processes and materials that contribute most to the environmental impacts (based on data for the first and last relevant key year) (e.g. a train or car from the beginning of the 20th century is modelled as mainly steel).
- Waste phase: we usually excluded the waste phase due to lack of data; however the credits for recycling of steel are reflected in lower emissions while producing steel.
- Environmental impacts: we focussed on the emissions of CO_2, SO_2, CO and NO_x resulting from the use of different energy carriers as these could be reconstructed in an historical perspective, whereas emissions to water or soil are almost impossible to reconstruct. The chosen emissions contribute significantly to much wider impact categories like global warming, acidification etc. If possible, some more specific relevant emissions will be given within the cases (such as lead (Pb) as a car emission).

In each of the specific case descriptions, it is indicated what exactly is included in the system.

3.4. Choice of relevant social and economic indicators

The environmental indicators will be combined with social and economic indicators. First, some more general indicators provide insight in the development of the Belgian society as a whole and can help to explain the trends retrieved within each case study[9]. The indicators are population figures, number of households, life expectancy at birth, infant mortality and purchasing power[10]. The choice of indicators is based on research in social and economic history. These indicators may be compared over the past two centuries, since they remain indicative for the social and economic development for the whole of the period. Moreover, they are selected because of the possible reciprocity with the retrieved trends within each case study. For example, the expansion of the water supply system contributed to the rise in life expectancy at birth and the decrease in infant mortality at the turn of the century, while the population growth (among others) started off the search for a better water supply system. Other indicators could have been used (e.g. illiteracy, child labour). However, they would not have been as useful in the course of this research project, since they are not readily applicable to the context of product systems.
The same reasoning explains the choice of case specific indicators. Since it is impossible to cover every aspect of a product system, some social and economic indicators were chosen. The indicators had to be comparable over the years and for the four product systems. The proportion of the population with access to the product, the consumption figures and the increase in infrastructure show the evolution in product availability. Was the product a luxury product at a certain moment in time, only affordable for the well-to-do? Did this change (why and when)? The real price of the product[11] (nominal price divided by an average day wage)

[9] Further reading : « Recent work in Belgian historical demography », a special issue of *Belgisch Tijdschrift voor Nieuwste Geschiedenis*, 31/3-4 (2001).
[10] P.Scholliers and V. Zamagni ed. (1995), p. 106-137.
[11] R. Fouquet and P.J.G. Pearson (2003), p.1.
« At the microeconomic level, these prices influence choices, behaviour and well-being, as well as the search for new energy sources and more efficient technologies and practices. At the macroeconomic level, higher energy prices can lead to changes in growth, income and employment (that are harmful, for energy importers, or beneficial, for energy exporters). »

represents the days of labour needed to be able to purchase a good. Real prices make it possible to compare 'prices' over time, since the influence of inflation and other economic variables is ruled out. Fourastié ascribes high value to real prices : « On voit sans peine que ces simples calculs de prix relatifs et de prix réels, sont très instructifs. Le prix réels, inverse du pouvoir d'achat, est, comme le pouvoir d'achat, une donnée fondamentale non seulement de la science économique mais des problèmes sociaux et politiques »[12]. Finally, the share of the total household budget spent on the purchase of the various products gives an indication on the (changing) importance of these products in private expenditure.
One also has to bear in mind the underlying social dimensions. For example, the volume of the heated living space evolved over the past two centuries, which is imperative to know when conducting the environmental analysis, but it also means that people in 2000 can afford to heat a larger part of their houses than their ancestors in 1850 could. The shift from rye bread to wheat bread indicates a comparable evolution.

3.5. Representativeness of the research subject

A major subject for debate at the onset of the research project was the issue of representativeness. After all, the project aims to pose a statement about Belgium[13] and 'the average Belgian citizen'. Who is this 'average Belgian citizen' ? Regarding the case study of the heated living space, we needed to determine the (heated) volume of the average living accommodation, the heating system and energy sources that were used to warm this space. For the case study of bread, it was necessary to define the kind of bread that was eaten and the agricultural labour, the milling process and the baking procedure related to this kind of bread. The most significant means of transport (of people, over land) were to be determined, as well as the fuels used. And finally, it was to be determined which water supply system was used by the larger part of the Belgian population, and how this was constructed. We tried to combine our findings in a 'definition' of the research subject, labelled status description. These definitions do not really 'represent' the way in which the basic needs were fulfilled for all people at that moment in time. We did try to compose an 'average', but we must not forget that this is an artificial construction, necessary to continue our research. It is of vital importance to bear this in mind while examining the results.

3.6. Data sources and their limitations

Extended research of the literature, statistics and archives, museum visits and interviews helped completing the database. It is very important to realize that most of the sources are not useful for the whole period. Moreover, different demographic, social or cultural groups appeared in the sources. Nonetheless, occasionally figures retrieved from different sources are combined in order to compare the evolution over two centuries. We have well documented these data, in order to allow readers to be cautious in interpreting them.

[12] J. Fourastié (1977).
[13] Although Belgium can be regarded as representative for a more expanded geographical region (e.g. western Europe). It has an open economy (the nineteenth century politics of free trade probably were 'exemplary'), the maritime harbor of Antwerp was one of the most important harbors of the nineteenth century, migration made of Belgium a 'multicultural society' and Belgium was the first country to industrialize (after Great Britain).

For each of the four cases we started by reading specific literature in order to retrieve technical information about the product systems, since this information was imperative to conduct the environmental analysis. Furthermore, this study made it possible to describe the evolution of the fulfilment of the four basic needs over the past two centuries. By reading more 'traditional' literature concerning social and economic history, the long term evolution became more clear. For more detailed information on the literature that was used, we refer to the bibliography and footnotes.

Retail prices of the different products (in the twentieth century) were provided by the Belgian Ministry of Economic Affairs[14]. Research from P. Scholliers[15] and Y. Segers[16] complemented these figures with prices for the nineteenth century. These nominal prices were combined with the 'average daily wage', as proposed by C. Vandenbroeke[17]. We calculated the average daily wage for the year 2000 (see Annex 4). These wages are rough estimates and should therefore be treated carefully. However, they are very useful to get an idea about the development of the real price of the four basic needs. Moreover, it was not our intention to (re)write the criticism of the sources. We had to make shift with what we had in order to conduct the 'applied history' as it was outlined in the research proposal.
Fourastié explains the benefit of using real prices (and purchasing power) as follows : « Les prix et les salaires variant sans cesse d'un article à l'autre, d'un travailleur à l'autre, d'un pays à l'autre, et bien sûr, d'une époque à l'autre, il doit être instructif de considérer non pas seulement le prix en monnaie d'un article, ou le salaire en monnaie (unité de crédit et de compte toujours variable) du travail d'un ouvrier, mais de considérer ces prix et ces salaires en la quantité physique d'un article pris pour base ou en heures de travail d'un ouvrier pris pour base. … En rapportant tous les prix courants aux salaires horaires de cette série solide, on obtiendra un système de prix réels cohérents, permettant une comparaison sérieuse des valeurs et des pouvoir d'achat à travers le temps »[18].

When trying to examine the availability of the product, we looked at the percentage of people with access to the product, at consumption figures and at the expansion of the infrastructure. For example : how many families owned a car or how many people had access to drinking water delivered by a water company ? These figures can be combined with more general indicators like population figures or life expectancy at birth. The data were retrieved by combining literature and statistics[19]. Statistics should always be used with caution[20] : what was the intention of these statistics, which information was included and which was not, which methodology was used, who commissioned them… ? The answers to these questions become even more important when comparing statistics over the years, since they might have changed over time. In Belgium, it is only since 1939 that the statistical data retrievement is centralized[21]. Prior to that year, several ministries produced own statistics (although a 'commission centrale de statistique' was founded in 1841, under the leadership of A.

[14] Dienst Indexcijfer (2000).
[15] P. Scholliers and G. Avondts (1981/5).
[16] Y. Segers (2002).
[17] For the argumentation : C. Vandenbroeke (1988).
Vandenbroeke 'calculated' the average daily wages from the sixteenth century onwards, up until 1980.
[18] J. Fourastié (1977), p. 57-61.
[19] We examined the Belgian Statistical Yearbook, the year reports of the National Railway Company, the year reports of several water companies, the year reports of Febiac (Fédération belge de l'Industrie Automobile et du Cycle) and several other statistics covering life expectancy at birth, infant mortality and population figures.
[20] H. Balthazar et.al. ed. (1965), p. 29-31.
[21] P. Van den Eeckhout and G. Vanthemsche (1999), p. 438.

Quetelet[22]). Nonetheless, the Statistisch Jaarboek van België[23] (Belgian Statistical Yearbook) provides a wealth of information on the Belgian population, living accommodation, public welfare, education, transport, …

To estimate the percentage of the household budget spent on different products, two kinds of sources may be examined. Since the mid-nineteenth century, working class budget inquiries are carried out[24]. These inquiries try to point out how much of the budget is spent on bread, clothes, heating/lighting, rent,… by working-class families during a period of time (one week, two weeks, one month, one year). These budget inquiries were not conducted in a uniform way[25]. Methods and concepts differ (and were often based on political and ideological foundations[26]). When looking at one family for a long period or at different families for a shorter period, the results will vary. Moreover, a geographical unbalance influences the results[27]. Nonetheless, interesting findings can be retrieved from these working-class budget inquiries : the importance of bread as a foodstuff declines in favour of expenses on meat in the twentieth century. At the same time, expenses on clothing, medical care and leisure time increased, compared with food. However, these budget inquiries are not useful to examine the consumption of the Belgian population as a whole[28], especially since not all of the four basic needs are taken into account in these inquiries. They will be used to stress social differences.
Another way to retrieve the part of the budget spent on different products is provided by national accounts. The first official Belgian national accounts were published in 1953. Their realization must be seen in light of a growing government policy of intervention in economics[29]. Y. Segers[30] completed them for the second half of the nineteenth century and the beginning of the twentieth century. It was not possible to retrieve the data as early as 1800.
The accounts contain all private spending in Belgium. A major flaw in the definition of 'private expenditure' is the fact that the non-monetary sector and the black market are not taken into account[31]. Two other disadvantages of national accounts are the lack of a qualitative approach (although some theoretic approaches consider prices as an indicator of the product's added value)[32], and the missing of an ecological point of view[33].
Nonetheless, the construction of national accounts has several advantages . Statistical data are centralized, homogenized and possible gaps are bridged by additional research. National accounts are a benchmark for other macroeconomic quantities (e.g. budget deficit). Finally, international comparisons are possible, since the accounts are construed using internationally accepted conventions[34].
In the research at hand, national accounts will be used. By looking at the amounts spent on the four products (bread, water, transport and heating), it is possible to calculate the percentage

[22] N. Bracke (2000), p. 182.
[23] P. Van den Eeckhout and G. Vanthemsche (1999), p. 439.
[24] Extensive inquiries were carried out in 1841, 1853, 1886, 1891, 1908, 1921 and on a more regular basis in the twentieth century.
[25] P. Scholliers and G. Avondts (1981/5), p. 155-156; P. Scholliers (1991), p. 145-181.
[26] Y. Segers (2000), p. 4.
[27] Y. Segers (2000), p. 2-4.
[28] Y. Segers (2000), p. 4.
[29] I. Cassiers (1995), p. 121-122.
Indicators like GNP, GNI, private expenditure and government expenditure were found to be very useful to stimulate economy and employment. Inflation and the economic crisis of the interwar period convinced even more people of the need for national accounts.
[30] Y.Segers (2002).
[31] C. Schroeven (1994).
[32] I. Cassiers (1995), p. 125.
[33] For example : the use of irreplacable resources is not taken into account.
[34] E. Buyst (1995), p. 142-143.

of the total private consumption for these products. These numbers are averages for Belgium, not just households of working-class households or other demographic groups.

We investigated which government policy aimed at influencing the environmental, social and economic aspects of the four product systems over the past two centuries. Several publications deal with past and present Belgian legislative norms. However, one must distinguish between the official texts provided by the legislator, and officious publications (that were published because the official texts often are difficult to handle) and corrections that came forth from private initiatives[35].
For our research we made use of two officious collections : the Pasinomie and the Omnilegie. They contain a chronological selection of law texts of general interest, and references to the Bulletin of Acts, Orders and Decrees.

In order to get an idea about the job opportunities the four product systems did or did not provide, industrial censuses were examined[36]. These censuses contain information about occupations and the number of people who were employed within each industrial sector. One must, however, be aware of the fact that these censuses were not always carried out with similar intentions and methods. The aforementioned remarks concerning using caution in interpreting statistics and numbers, also hold true here. Moreover, not all occupations are mentioned in these censuses, since some of them do not pursue profits (e.g. the educational sector), or since especially the contribution of women was underestimated. Nonetheless, these censuses were carried out after a thorough preparation, and help to understand the trends and trend ruptures in several economic sectors[37].

The yearly pattern of spending of rest homes in Leuven (25km East from Brussels) was explored with the intention of gaining an understanding of the evolution of energy sources in the nineteenth century. Even though this information does not concern single-family dwellings but a public institution in a specific city, it might point at an evolution that occurred also (perhaps later) at the level of single-family dwellings.

Research of the ‘Fonds Fauconnier’ at the Brussels city archives and the ‘Vliegende Blaadjes’ at the archives of the Ghent University has also been research conducted. These archives contain all sorts of advertising leaflets from the end of the nineteenth and the beginning of the twentieth century. Several brochures focus on heating systems, baking ovens and water supply systems, and their new features. These leaflets provide an insight into the points of interest at that moment and were therefore an interesting point of reference to our findings.

Finally, we have to mention the environmental measurements at the Open Air Museum of Bokrijk[38] and at VITO. Proceeding from the findings in literature and combining these with the expertise of historians[39] and an architectural engineer[40] we decided upon a ‘representative’

[35] P. Van den Eeckhout and G. Vanthemsche (1999), p. 292-296.
[36] Industrie. Recensement général (15 octobre 1846). Recensement général des industries et des métiers (31 octobre 1896). Algemene Volks-, Nijverheids- en Handelstelling op 31 december 1947. Handels- en nijverheidstelling. 31 december 1961 en 31 december 1970. Sociale statistieken. Enquête naar de arbeidskrachten. Jaar 1999.
[37] N. Bracke (2000), p. 182-197.
[38] The Open Air Museum Bokrijk is an active hands-on museum that aims to take people back in time. Generally speaking, it can be compared to a scale model of Flanders, with 100 historical buildings surrounded by flowers, plants and trees from the authentic landscape. www.bokrijk.be
[39] A. Schoefs, A. Boesmans and R. Nouwen from Bokrijk.
[40] D. Van de Vijver, KU Leuven.

dwelling and heating system for the key years 1800, 1850 and 1900. Based on these descriptions, we heated three houses in Bokrijk, using three different heating systems, to carry out environmental measurements to be able to determine emissions and energy use. It would be very difficult, if not impossible, to retrieve these data from more ‘traditional’ sources. Therefore, this ‘applied history’ is shown to be very useful for our research. Also in Bokrijk, we baked bread in a traditional oven, carrying out the same measurements.
In VITO, a 1925 T-Ford and a 1998 Ford Fiesta were placed on a roller bench, and energy use and emissions were measured and compared.

4 GENERAL SOCIAL AND ECONOMIC INDICATORS

When looking at the population figures[41] over the past two centuries (Figure 1), we can derive the so-called ‘demographic transition’: the transition from a situation with high birth and death rates to a situation with low birth and death rates. Because the death rates diminished faster than the birth rates, the Belgian (as well as the European) population grew dramatically at the end of the nineteenth century and the beginning of the twentieth century. The lower death rates can be explained by a reciprocity between the improvement of the standard of living, agricultural innovations, better transport (which makes the consequences of a bad harvest less catastrophic), the grain import from the United States at the end of the nineteenth century (although initially this created problems for the local farmers[42]), medical innovations and improved personal hygiene and higher wages which e.g. permitted a more varied diet. It is very important not to isolate one of these explanations as the main reason for higher or lower death rates[43].
Deforestation is one of the consequences of this dramatic population growth[44]. Since more people needed to be fed, more land needed to be used for agriculture. Subsequently, woods disappeared. The problem of deforestation will be examined when looking at the case study of the heated living space.

Two world wars temporarily halt the population growth (decreasing birth rates, increasing death rates). Birth rates also slowly start decreasing because of the ideas of birth control and family planning, although after World War II, there is a tendency towards catching up with the level of birth rates at the beginning of the century [45]. Since the 1950s birth rates decline faster then death rates (women have less children; economic crises in the 1970s). Because of this negative equation, the population growth delays dramatically (notwithstanding migration waves in 1948, 1957 and 1964[46]).

[41] M. Goossens (1992). The figure used for the year 1800, was actually registered in 1806. *Statistisch Jaarboek* (1951 and 1975). NIS, *Bevolkingscijfers*, Brussel, 2003 (www.statbel.fgov.be).
[42] After 1880 however, local farmers transformed their businesses. Wheat was substituted by grasslands. Since the urban population was growing, there was an increasing demand for dairy products.
J.A. Van Houtte ed. (1981/10), p. 47-62.
[43] R. Schofield et.al. ed. (1991), p.176.
[44] J.A. Van Houtte ed., (1981/10), p. 47-62.
[45] J.A. Van Houtte ed. (1982/15), p. 116-158.
[46]P. Willems and Ch. Wattelar (1991).

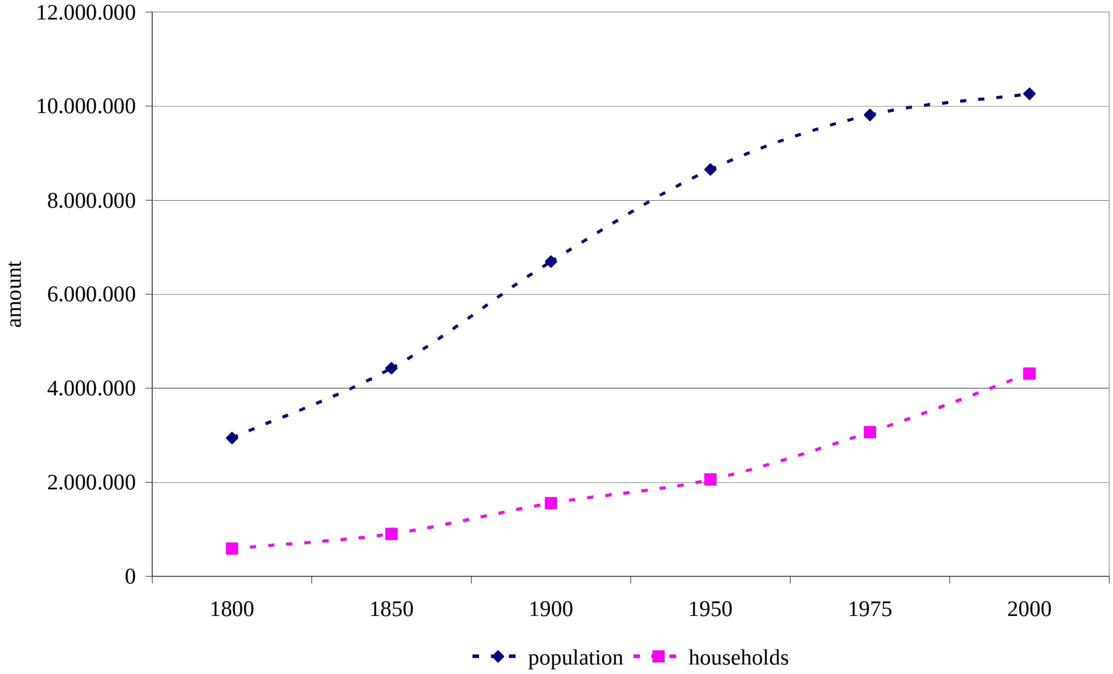

Figure 1 : Belgian population and number of households

The population figures may be combined with the number of households (total population divided by the average number of people in one household. (See Annex 4)[47]. From the 1950s on the average number of people per household decreases: couples have fewer children, more people get divorced, 'extended' families are not common anymore, more people live as a single. "The post-war period witnessed remarkable social and economic changes which influenced demographic behaviour. For instance, the rise in the education of women and their increased participation in the labour force went hand in hand with the delay of the first birth and a smaller number of children per woman.[48]"

[47] NIS, *Bevolkingscijfers*, Brussel, 2003 (www.statbel.fgov.be). V. Duchene (2000). L. Quintens (1976).
[48] E. Lodewijckx (1999), p.5.

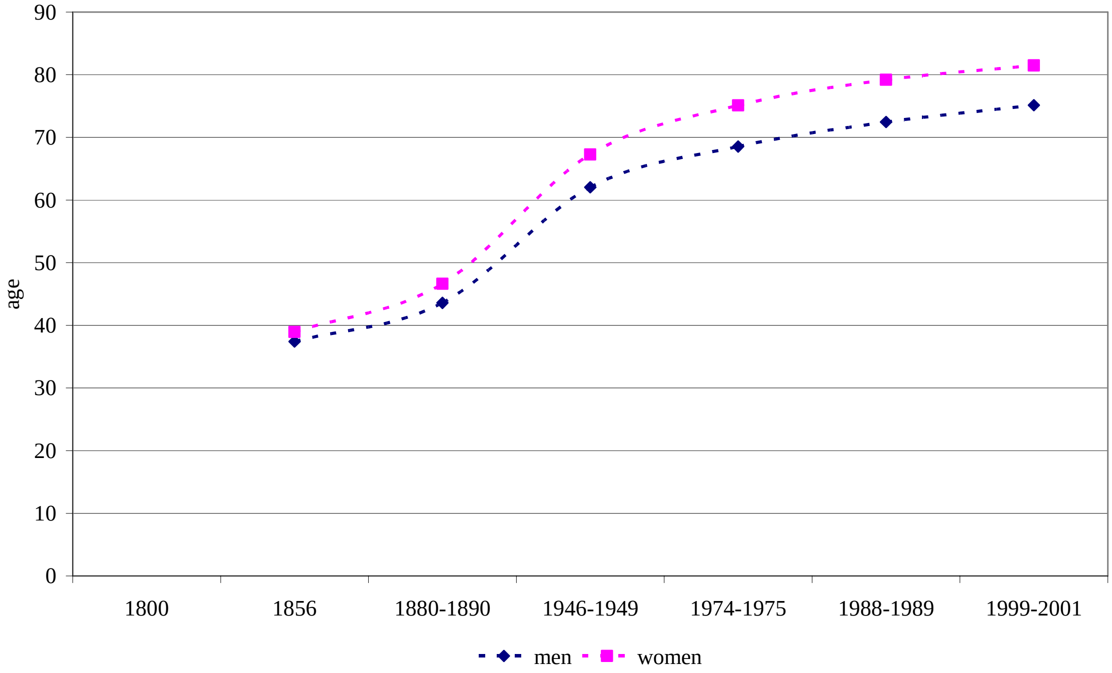

Figure 2 : Life expectancy at birth

Finally, the life expectancy at birth[49] (see Figure 2) increases dramatically at the end of the nineteenth century and the beginning of the twentieth century, due to a decrease in infant mortality[50] (Figure 3). This can be explained by better medical care (for both mother and child) and personal hygiene[51]. A rapidly expanding water supply system contributes to the improvement of the situation since the turn of the century. Increases in life expectancy in the twentieth century are mainly due to the fact that people can grow older. In the first half of the century this can be explained by social factors, such as higher income (the industry needs a skilled workforce), better diet, better living conditions. In the second part of the century, people grow older because of medical-biological factors (diseases can be prevented and cured).

49 P. Willems and Ch. Wattelar (1991). L. Delanghe (1972). NIS, *Bevolkingscijfers*, Brussel, 2003 (www.statbel.fgov.be).

50 E. Lodewijckx (1999). L. Delanghe (1972).

51 Medical science contributed to a decreasing death rate and a higher life expectancy at birth in three ways: 1) people got familiar with medical advice and how to handle it, 2) medication helped to cure several diseases and 3) technological innovations prolonged the life of the incurable.
J.C. Riley (2001), p.119.

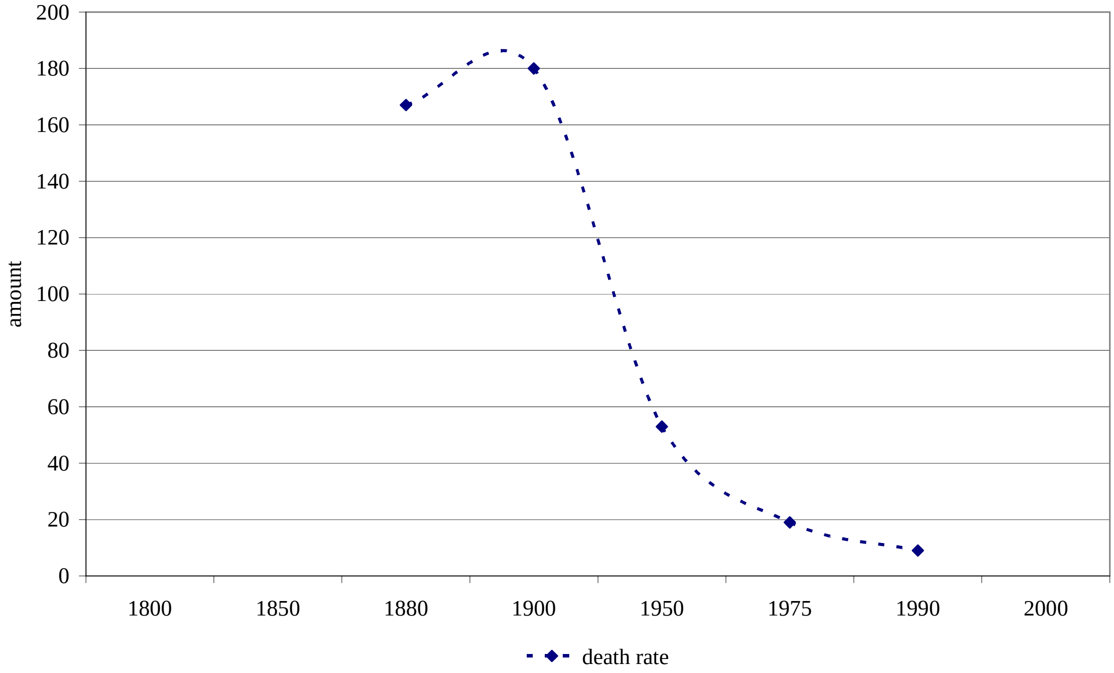

Figure 3: Infant mortality in Belgium

When looking for economic indicators, we see that the purchasing power of people[52] (Figure 4) did not evolve much during the nineteenth century. This might be explained by a comparable evolution of wages and prices (wages did not increase because of a large labour reserve), although some dramatic short-term changes occurred in both directions. In the mid-nineteenth century, Flanders is even labelled ‘Arm Vlaanderen’ (poor Flanders), because of its low wages, poverty, illiteracy and high unemployment rates[53].
Since the beginning of the twentieth century however, purchasing power increased, because of increasing wages on the one hand and declining prices (e.g. grain prices decrease due to the grain import from the United States) on the other.

[52] C. Vandenbroeke (1988).
[53] J.A. Van Houtte ed. (1981/10), p. 183-209.

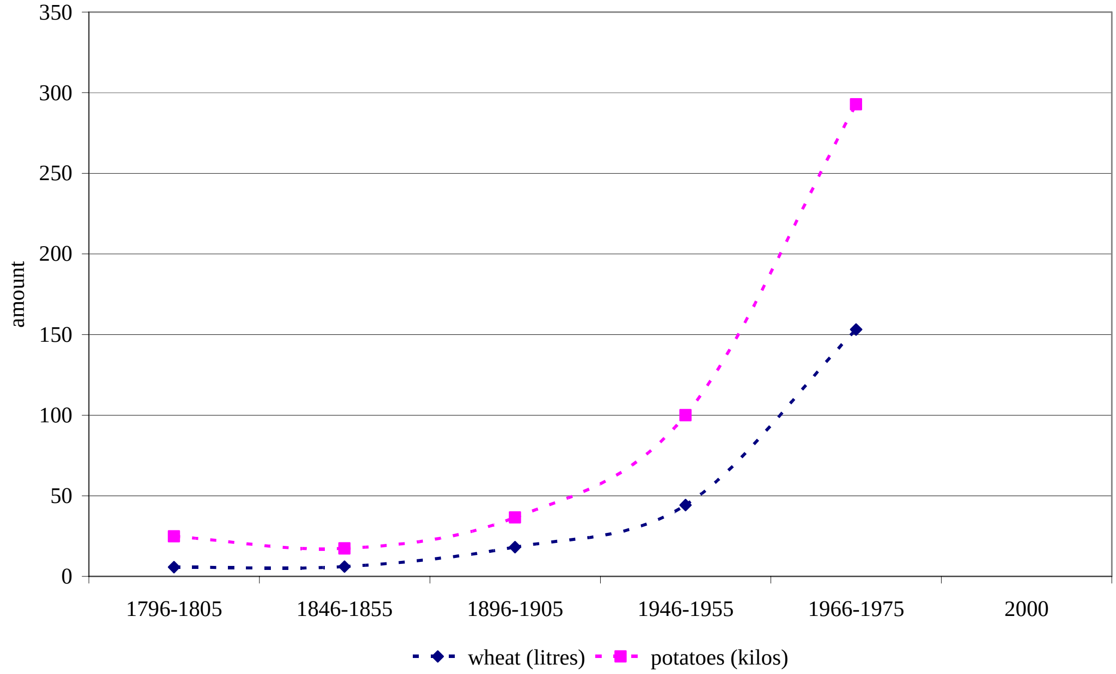

Figure 4 : Purchasing power

In conclusion: over the past two centuries the Belgian population grew dramatically, although not always at the same pace and due to the same ‘causes’, the number of households grew and people nowadays are likely to grow older than previous birth cohorts. The purchasing power increased dramatically since the first half of the twentieth century, after being almost static for a century.

5 ANALYSIS OF THE FOUR CASES

5.1. Case study: Bread

5.1.1. Status description

When examining the production and consumption of 1kg of bread, several aspects should be taken into account: agriculture, milling, baking, distribution (of grain and bread) and consumption. Several factors affect energy consumption and emissions, which are important when analyzing environmental impact. These influences were defined and summarized in the following tables (Table 1 and Table 2).

As shown in Table 1, the most dramatic changes in agriculture and milling occurred since the end of the nineteenth century. It is only after World War I that the mechanization of Belgian agriculture took off[54], and after World War II widely spread[55]. In 1958, the government issued a Royal Decree that granted subsidies to agricultural cooperatives for purchasing agricultural machinery[56].
In the nineteenth century, steam engines were used, but these were too heavy and immobile to be useful on split-up land[57]. "Up to the end of the 1870's there were few qualitative and quantitative changes in the area of the various crops, in the relationship between arable farming and animal husbandry, forage crops, yields, property relationships, the area of farms, mechanization and so on. Up to 1880 agriculture thus appears to be characterized by a certain immobilism."[58]

[54] J.J Van Mol (1998), p. 68-71.
[55] D. Van Nieuwenhuyze (1993), p. 554.
[56] *Omnilegie* (March 13th 1958).
[57] D. Van Nieuwenhuyze (1993), p. 147.
[58] A. Verhulst and G. Bublot ed. (1980), p. 41.

	Origin of the grains	Agricultural phase: use of machinery	Agricultural phase: use of fertilizers	Agricultural phase: use of herbicides and pesticides[59]	Milling process: use of energy
1800	Belgium[60]	Manual labour	Manure Waste from the cities Bonemanure[61].	Cultural measures (e.g. three-course rotation)[62].	Water Wind Animals
1850	Belgium The Ukraine (import: 7,5%)[63]	Manual labour Development of machinery	Manure Bonemanure Guano[64].	Cultural measures Own preparations	Water Wind Animals
1900	USA (import: 74%)[65]	Tractors in the USA Manual labour in Belgium	Development of chemical fertilizers[66].	Cultural measures Own preparations	Water Wind Animals Introduction of steam engines (wood or coals)
1950	France (import: 65%)[67]	Mechanized agriculture	Chemical fertilizers[68]	Chemical products	Electricity
1975	France (import: 55%)[69]	Mechanized agriculture	Chemical fertilizers[70].	Chemical products	Electricity
2000	France (import: 70%)[71]	Mechanized agriculture	Chemical fertilizers. Biological alternatives	Chemical products Biological alternatives	Electricity

Table 1 : Agricultural phase and milling process

The combustion engine that allowed Belgian farmers to mechanize labour. Moreover, the economic situation of Belgian farmers had changed since the turn of the century. In 1846, a bad harvest resulted in increasing grain prices[72]. Import taxes were lowered, the export of grain and potatoes was prohibited and the amount of arable land increased because of expropriation. From 1850 to 1870, grain prices were profitable for Belgian farmers. However, in 1870, a new crisis was imminent. In 1873, grain import became free of charge, and grain was imported from the United States in large quantities (the so-called agricultural invasion)[73]. Grain prices declined, the farmer's wages decreased and this resulted in another agricultural

[59] H.W. Lintsen et.al. ed. (1993/1). J.W. Schot et.al. ed. (2000/3).
[60] D. Van Nieuwenhuyze (1993), p. 175.
[61] J.J. Van Mol (1998).
[62] "On appelle rotation la succession méthodique des cultures sur les terres d'un domaine; la sole étant l'étendue, ou la portion du domaine, qui reçoit des cultures. La rotation des cultures bien combinée a permis de lutter contre les mauvaises herbes et les insectes nuisibles, elle a aussi restitué au sol les réserves nutritives indispensables pour de nouvelles récoltes." J.J. Van Mol (1998), p. 8.
[63] J. Gadisseur (1979).
[64] J. Van Der Vaeren (1930).
[65] J. Gadisseur (1979).
[66] J. Blomme (1992).
[67] NIS, De landbouwstatistiek (1953). NIS, Landbouwstatistieken 1900-1961.
[68] J. Blomme (1992).
[69] Landbouw-Economisch Instituut (1975). NIS, Landbouwstatistieken (1976).
[70] J. Blomme (1992).
[71] Ministerie van Middenstand en Landbouw (2001). Centrum voor Landbouweconomie, Landbouwstatistisch jaarboek 2000.
[72] C. Macherel and R. Zeebroek ed. (1994), p. 111-114.
[73] D. Van Nieuwenhuyze (1993), p. 204. In the United States, land was available, but there was a shortage on farmers. Therefore, agriculture was mechanized and productivity raised. Moreover, the development of a railroad network and steam boats made it possible to transport the grains to Europe. B. Belderok (2000), p.11.

crisis[74]. The situation changed at the end of the nineteenth century: "an increasing share of the labour force left the countryside for the rapidly growing cities; real wages of agricultural labourers…doubled[75]" and farmers decided to specialize in other crops than grains[76], using "chemical fertilizers and purchasing feed stuffs that were typically land saving[77]". In 1987, Belgian agriculture still provided in most of the foods that were eaten by Belgian households (except for bread grains)[78].

At the turn of the century, steam engines were introduced in the milling industry. In 1846, 1 529 mills that were used in the grain milling industry were driven by water, 1 701 by wind, while 100 steam engines were counted for as well as 273 horses[79]. In 1896, already 801 steam mills were registered together with 3 121 mills driven by water, wind or animals[80]. Over the course of the twentieth century, industrial milling gained the upper hand and the shift towards the use of electricity was made.

	Preparing the dough	Baking	Bread distribution
1800	Manual labour	Wood	Push-cart Cart drawn by dogs Horse and carriage
1850	Manual labour	Wood Coal	Push-cart Cart drawn by dogs Horse and carriage
1900	Manual labour	Wood Coal	Carrier-tricycle
1950	Introduction of electrical machinery	Oil	On foot By bicycle
1975	Electrical machinery	Gas	On foot By bicycle Introduction of motorized transport
2000	Electrical machinery	Gas	Motorized transport

Table 2 : Production and distribution of bread

The first bakers appeared in the cities in the Middle Ages[81]. Mostly, the customers brought the ingredients and the baker baked their bread in his oven. In the countryside, however, people made bread themselves. Before World War II, they took the grain to a local miller and used this flower to bake bread themselves[82]. When the bread was ready, the baker blew the horn to inform his customers[83].
The manufacturing process of bread has not changed a lot over the centuries[84]. Grains are ground and mixed with water and other ingredients[85]. This dough is baked in an oven and the

[74] A. Verhulst and G. Bublot ed. (1980), p. 41.
[75] J.L. Van Zanden (1991), p. 215.
[76]B. Slicher van Bath (1960), p. 20.
[77] J.L. Van Zanden (1991) p. 216.
[78] J. Blomme (1988), p. VII.
[79]Industrie. Recensement général (15 octobre 1846).
[80]Recensement général des industries et des métiers (31 octobre 1896).
[81] A. Detremmerie (1986), p.10. *Brood* (1983), p. 21.
[82] J. Blomme (1988), p. 52.
[83] *Brood* (1983), p. 32. *Van graan tot brood* (1986), p.19.
[84] A. Detremmerie (1986), p. 18.

final product is bread. However, techniques and machinery were refined, especially since the end of the nineteenth century, when bread played an important part in the working men's diet (a rapidly increasing part of the Belgian population). The demand was high and productivity was to be increased. Nonetheless, traditional bakers were hesitant about modernization. The price of the machinery was high, in most bakeries there was not enough room for it and bakers did not believe the dough would have the same quality when prepared mechanically. When they did decide to modernize, it was not because they were convinced of the advantages (higher productivity and healthier working conditions), but because they were engaged in some tough competition with the growing industrial bakeries and wholesale societies (e.g. 'Vooruit' in Ghent)[86]. This competition, together with the fact that people went to live outside the city walls, also meant the start of home deliveries. Bakers started doing home deliveries with push carts, carts drawn by dogs, tricycles and even horse and carriage[87]. After World War I, motorized vehicles were used. In the course of the twentieth century, home delivery disappeared.

The modernization of the bakery was based on three pillars: 1) mechanized kneading, 2) directly heated ovens were replaced by indirectly heated ovens, and 3) sourdough was replaced by yeast[88]. Traditionally, baking ovens were heated using wood (that was often free, since it was brush wood)[89]. These ovens were very inefficient and the temperature was incontrollable. Moreover, they were considered unhealthy, since sometimes painted woods (from demolition sites) were used for baking bread. Therefore, bakers started using coal for heating their ovens and mid-twentieth century, the transition to oil and gas was made[90].

5.1.2. Environmental perspective

To quantify the environmental developments of the production and consumption of 1 kg bread a Life Cycle Assessment (LCA) approach is applied. The **goal** of this environmental analysis is to compare the environmental effects of producing and consuming bread in Belgium in 1800, 1850, 1900, 1950, 1975 and 2000. The **functional unit** is "the production and consumption of 1 kg representative bread". The life cycle of bread consists of different phases, as shown in Figure 5.

[85] However, in the 19th century, fraud was the order of the day. Bread often contained 'strange' ingredients, e.g.: a mixture of sulfates, lime, alum. Also, the weight was not always wat is was supposed to be. Several laws were issued to regulate these phenomena. *Pasinomie* (1826, 1829, 1891).

[86] A. Detremmerie (1986), p. 5 and p. 18. J. Buse (1905), p. 92-95. *De Belgische Bakkersgazet*, 1/1 (1897).

[87] W. Plaetinck et.al. (1980), p. 59. *Van graan tot brood* (1986), p.19.

[88] A. Detremmerie (1986), p. 18.

[89] W. Plaetinck et.al. (1980), p. 7.

[90] A. Detremmerie (1986), p. 28 e.v.

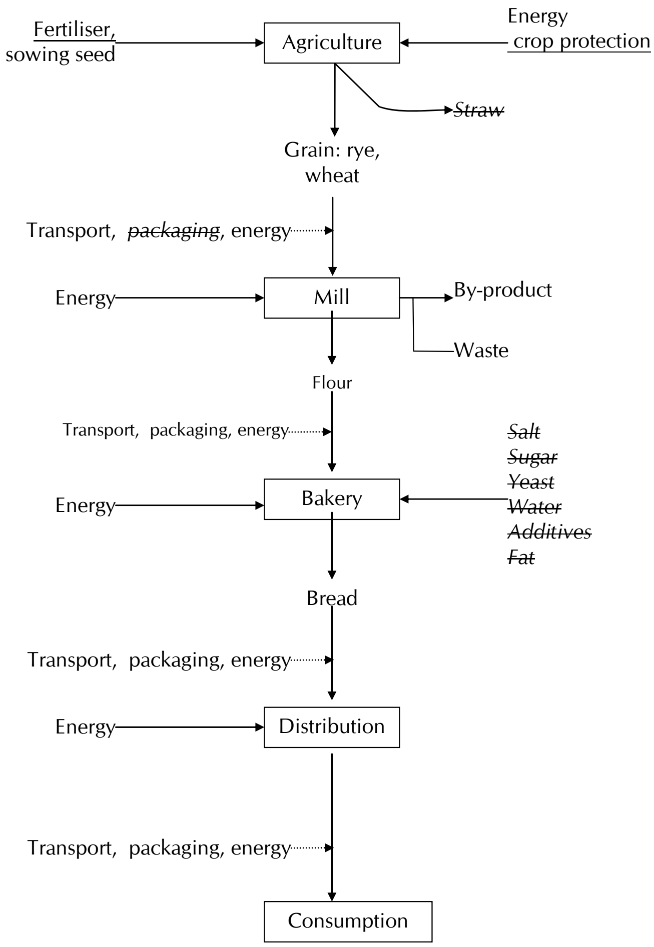

Figure 5 : Process tree for the production and consumption of 1 kg representative.bread[91]

A rough semi-quantitative analysis showed that agriculture, transport of wheat to the mill, milling wheat, baking bread and distribution of bread are important for one or more years. However, it was only possible to quantify all the life cycle steps for the years 1800, 1850, 1900 and 2000.

Inventarisation

2000

Nowadays, wheat bread is the most consumed bread in Belgium. The wheat is mainly locally produced or from European origin. Agricultural processes are mechanised and chemical fertilisers and plant protection products are used to improve the yields. Transport of wheat to Belgian mills is generally done by trains, trucks and ships. Mills operate on electricity and flour is distributed by trucks. Baking processes usually use electricity and heating gas. Transport of bread to households is done by car, bicycle or by foot. For the life cycle inventory, all life cycle steps, from agricultural production to distribution of bread, were considered.
The wheat used originated in Belgium (30 %), France (43.4%), Germany (19,6 %) and The Netherlands (7%)[92]. The yields of wheat crops in these countries have been taken from

[91] strikethrough = not taken into account

FAOstat[93]. Data about fuel consumption involved with growing and harvesting of wheat were obtained from Nielsen and Luoma[94]. Sowing rates were taken from Moerschener and Gerowit[95] and L'Institut du Genech[96]. The amount and type of fertilizers applied to wheat in France, Germany and the Netherlands are based on Ekboir, ITCF and Moerschner and Gerowitt[97]. Concerning the fertilizers production, data are taken from the SimaPro data base or from Davis and Haglund[98]. Nutrient balances were founded on L'Institut de Genech, Lopez Bellido, Audsley et al., Bentrup et al., Castillon and Hansen[99]. The use of plant protection products was taken from Eurostat[100]. Regarding the energy requirements for pesticide production, different sources have been consulted[101].

Data about the milling yield, energy and water consumption of flour and by-products were obtained from CERES, the most important mill in Belgium. An allocation on the basis of the weight was made between flour and by-products. Data about water and energy use for baking have been obtained from PRESTI[102]. The amount of flour/kg bread was based on Andersson[103]. Transport of wheat to the mill was founded on own assumptions, statistical data and information from CERES. Trucks transport the flour to bakeries (CERES), the average distance taken into account is on the basis of own assumptions. Distribution of the bread was established on own assumptions and on statistical data[104]. A sensitivity analysis was done for the distribution phase because data are very uncertain.

1975 and 1950

In 1950 and 1975, wheat bread was the most consumed in Belgium. 55% (1975), respectively 65% (1950) of the wheat was imported from France by trains, trucks and ships. Agriculture was mechanised and the use of chemicals and fertilisers was important. Mills operated on electricity and electrical machinery was massively introduced in bakeries after world war II. Ovens used heating gas (1975) or heating oil (1950).

The distribution of bread was mainly done by foot, bicycle (1950) and sometimes motorized transport (1975). Not all the necessary data were available, only the baking process[105] for both years was well-documented.

1900

White bread made of wheat was habitually eaten in Belgium. About 70% of the wheat was imported from the USA by steam trains and steamships, the remaining 30% was produced in Belgium. The use of chemical fertilizers and pesticides became only important after World War II. Until then, producers depended on the native fertility of the soil to provide the nutrients needed for growth of wheat and on cultural practices and resistant varieties to

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92 CLEA—CEA, 2000
93 FAO, 2003
94 Nielsen and Luoma, 1999
95 Moerschener and Gerowitt, 2000
96 L'Institut du Genech, 2002
97 Ekboir (2002), ITCF (2002) and Moerschner and Gerowitt (2000)
98 Davis and Haglund, 1999
99 L'Institut de Genech (2002), Lopez Bellido (1991), Audsley et al. (1997), Bentrup et al. (2000), Castillon (2003) and Hansen (2000)
100 Eurostat, 2002
101 Audsley et al., 1997; Weidema et al., 1995; Ceuterick and Spirinckx, 1997; Van den Broek et al., 2002
102 PRESTI-project, 1996
103 Andersson, 1999
104 MOBEL, 2000
105 Singh 1976, Chapman 1975, Leach 1973, technical information sheets 1950-2000 and information from the bakery museum in Veurne

control weeds, diseases and insects[106]. Related to machinery, no fuel was consumed because all equipment was propelled by farmers or animals. Regarding the energy used in the mills[107], 41% of the flour was produced by water and wind energy and 59% by steam engines using coal. However, these mills worked very probably only on steam power under windless circumstances. We assumed therefore that these mills used fossil fuels during only 30% of their working time. Transport of flour to bakeries was done by horse carts. At the beginning of the 20th century, dough was prepared manually and the ovens operated mainly on coal or wood, only a few ovens used gas. The distribution of bread was done by carrier-tricycle. Resulting, only data concerning the fuel consumption and subsequent emissions to transport wheat, milling in steam mills and baking have to be taken into account .The yields of wheat crops in Belgium and the USA were founded on NIS and USDA[108]. The flour yield resulting from and the power needed during the milling process are on the basis of figures from Ammann[109]. The coal consumption in the steam mills was founded on Vierendeel[110]. Emissions (SO_2, CO and CO_2) due to coal combustion were obtained from own measurements in Bokrijk and compared with emission factors for burning processes[111]. We assume an equal division between coal and wood ovens. The fuel consumption was founded on Ammann[109]. The coal consumption to cross the Atlantic by steamship per kg cargo was calculated using data from SEWSS[112]. Regarding the steam trains, coal consumption was estimated using data from Sinclair[113]. Emissions (SO_2, CO and CO_2) due to coal combustion were on the basis of measurements in Bokrijk and known sulphur content for Belgian coal.

1850 and 1800

Rye bread was commonly consumed in Belgium. The grain was locally produced and only human or animal energy were used in agriculture. Manure and other organic wastes were applied in low rates to improve the soils. Plant protection was on the basis of cultural measures, e.g. three-course rotation. Transport to the mill, bakery and consumer was done by push-carts and carts drawn by dogs or horses. Mills operated on natural energies (wind and water). In 1800, people baked at home in ovens using brushwood. We assumed that in 1850 20% of the ovens were heated with coal and 80% with brushwood. Summarising, only data about the emissions for baking have to be taken into account. Data about the rye yield/ha are extrapolated from figures for other years. The consumption of brushwood and coal and subsequent emissions were determined by emission measurements in a 19th century baker's oven at open air Museum Bokrijk. The assimilation of CO_2 in wood and grain was not taken into account. The amount of flour/kg bread was founded on Eiselen[114].

Impact assessment

Figure 6 shows the relative contribution of the life cycle phases in **2000**. The agriculture subsystem is a hot spot for most of the impact categories studied. The potential contributions to global warming are associated with the use of fossil fuels for baking and the fertiliser production for the agricultural phase.

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[106] Paulsen, 2002
[107] Bauters, 1998 and own calculations
[108] NIS (1962) and USDA (2002)
[109] Ammann, 1914
[110] Vierendeel, 1921
[111] Bakkum, 1987
[112] SEWSS, 2003
[113] Sinclair, 1898
[114] Eiselen, 1995

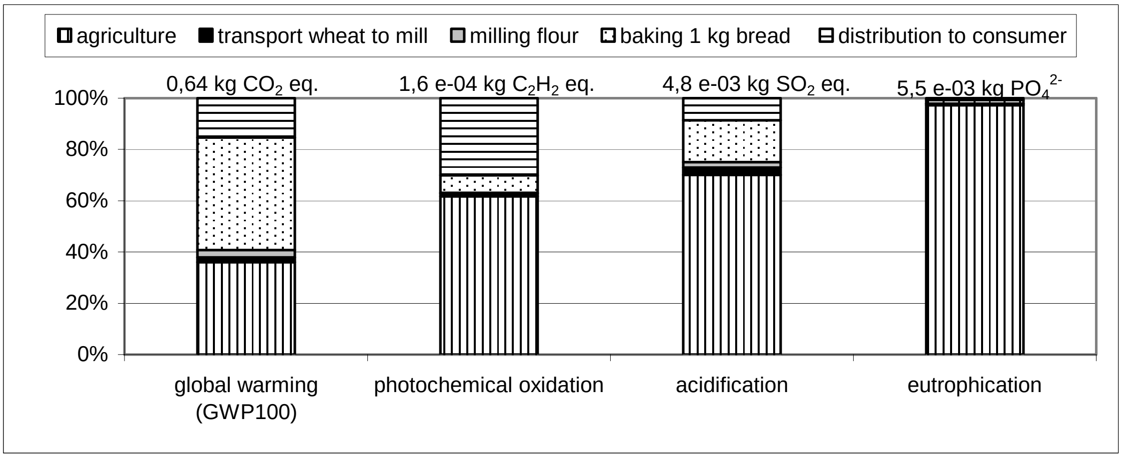

Figure 6 : The environmental profile of Belgian bread in the year 2000

The sensitivity analysis on the transport of 1 kg bread by the consumer showed that depending on the distance assumed, this step can easily dominate the overall ecological effect. We assumed a distance of 0.35 km (taking into account allocation for weekly shopping) in Figure 6. The extreme case of a 3.5 km car transport, with the sole purpose to acquire 1 kg of bread, will entail an emission of 1.37 kg CO_2 eq., 5,7e^{-04} kg C_2H_2 eq., 7,48e^{-03} kg SO_2 eq. and 5,8 e^{-03} kg PO_4^{2-}.

Figure 7 shows the **environmental profiles** for the years **1800, 1850, 1900 and 2000**. The impact categories global warming and photochemical oxidation are higher for the 19th century due to the emissions resulting from the brushwood and coal combustion in the baker's oven and the coal combustion by steam engines (during the transport of grain by steamships and steam trains from the USA in 1900 and to a lesser extent to the combustion processes in the milling phase). Eutrophication is much higher in 2000, mainly caused by the production and use of fertilisers. Acidification is most important in 1900 and 2000 caused by the combustion of coals (1900) and the production and use of fertilizers (2000).

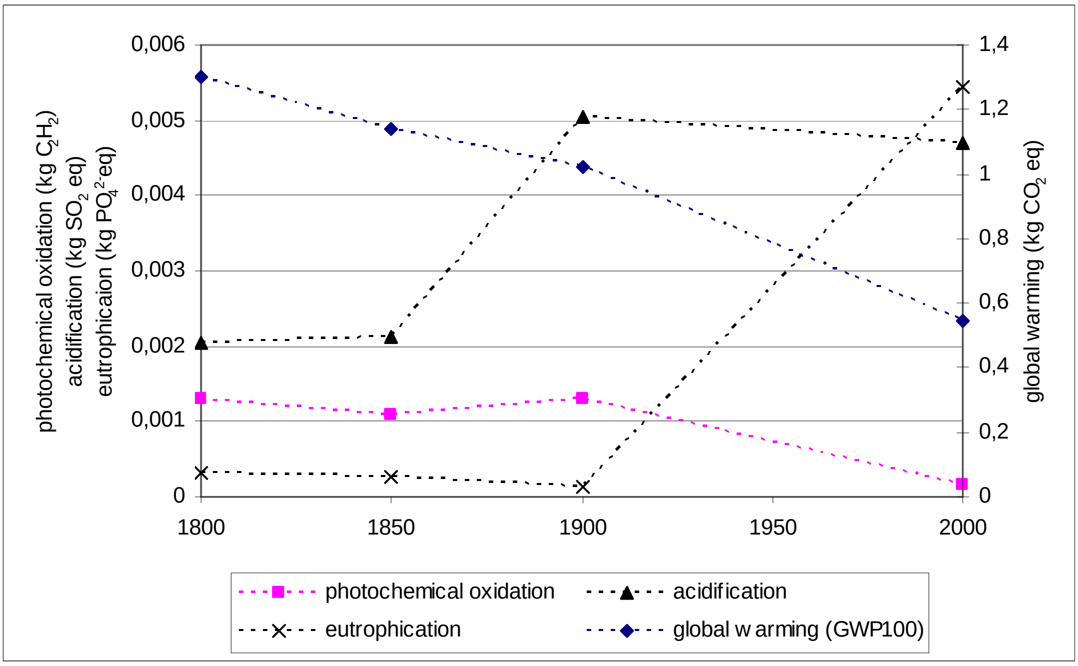

Figure 7 : Comparison of environmental profiles of 1 kg bread in the years 1800, 1850, 1900 and 2000

It was not possible to quantify all the life cycle steps for the intervening years (1950-1975) due to lack of data. Milling of wheat and baking of bread are the only life cycle steps that could be quantified completely for the two centuries.
The energy consumption of the baking and milling processes during the two centuries were quantitatively compared. During the 19th century, no fossil fuels were used during the milling process, and therefore no environmental harmful emissions were released. Around 1900 steam power was used under windless circumstances and emissions were released during the milling process. In the second half of the 20th century, wheat mills started to use electricity. Since then, the energy use has remained more or less stable. The transition from steam power to electricity involved an efficiency improvement with factor 6 (from 5.8 MJ/kg bread to 0.4-0.8 MJ/kg bread). During the last 50 years, emissions that were caused by the milling process decreased (see Figure 9) due to the switch to nuclear power in electricity generation (Annex 5).

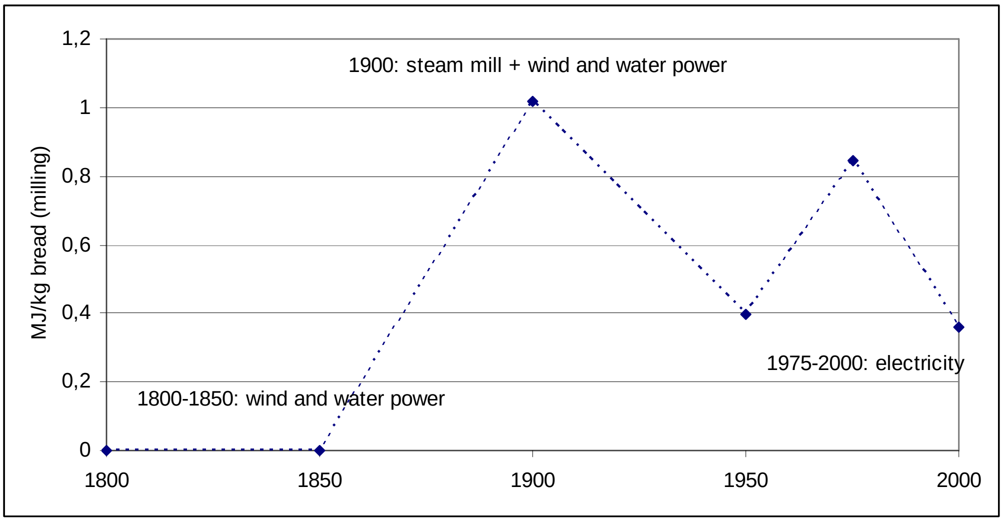

Figure 8 : Energy consumption by the milling industry

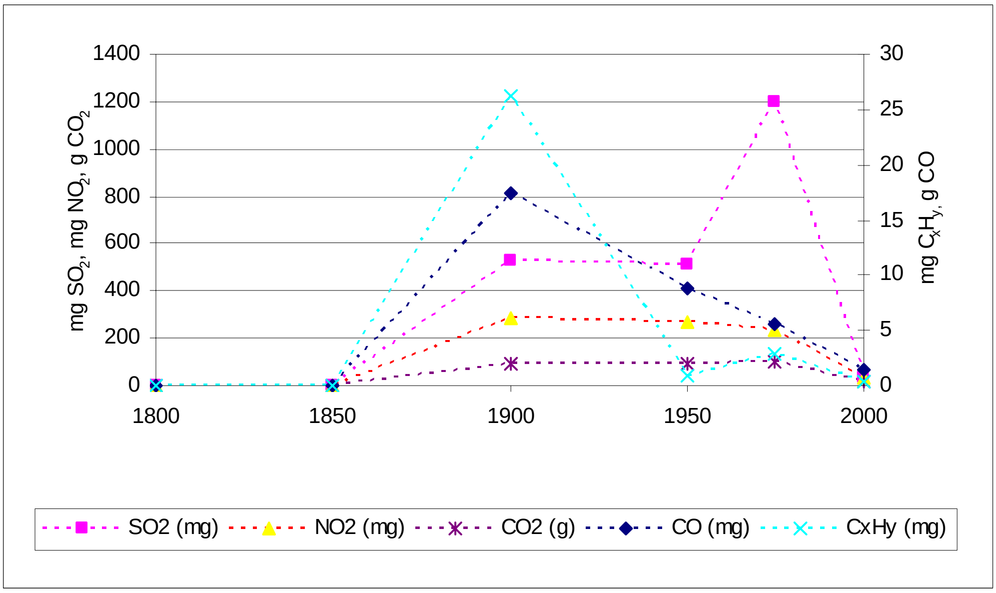

Figure 9 : Emissions caused by the milling industry

The energy efficiency of the baking process has improved 7,6 times during the last two centuries (Figure 10). This improvement, and the transition of oven fuel from wood to coal and later oil and gas, caused the emissions by the baking process to decline drastically (13 - 3 000 times!, Figure 11). When comparing the energy use and emissions for both processes, the baking process is dominant for all years (see Annex 3).

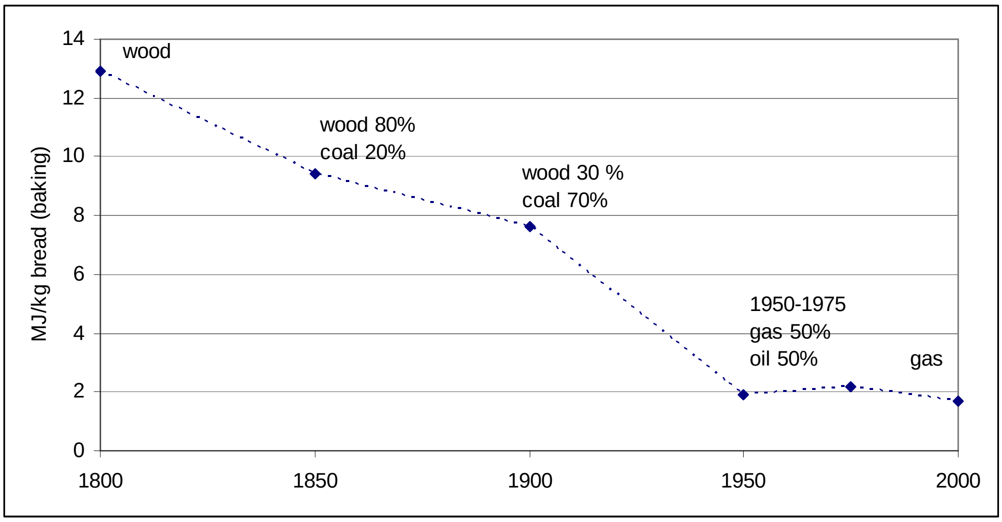

Figure 10 : Energy consumption by the baking process

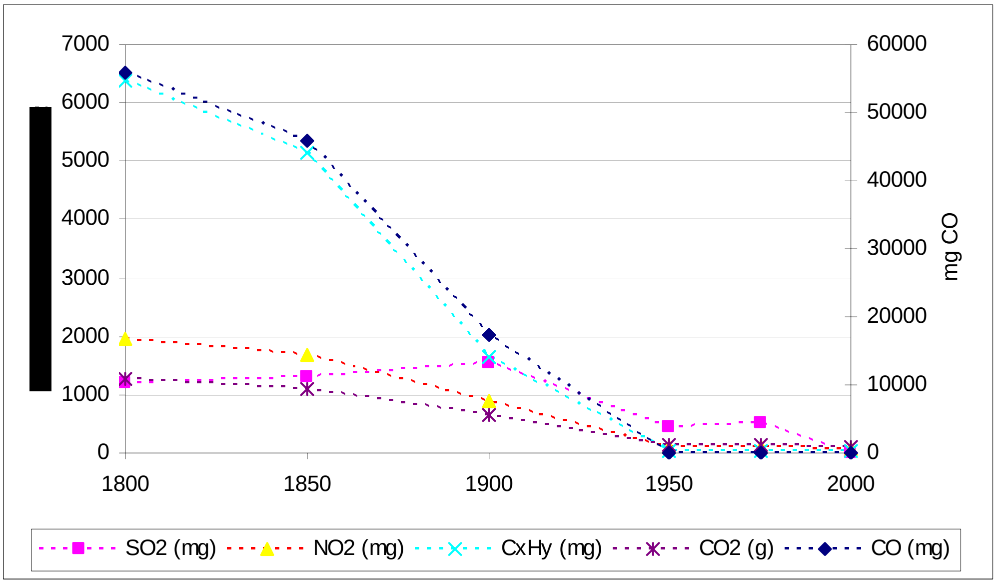

Figure 11 : Emissions caused by the baking process

The combination of the environmental data with consumption figures (kg bread consumed per year in Belgium, see figures in Annex 3) allows to gain insight into the development of the energy use and environmental emissions of baking bread.

The overall trend resulting from the industrialisation of the milling (wind and water → steam power, electricity) and baking (wood → coal, oil, gas) processes is a reduction in energy use. Due to the switch to other fossil fuels, the emissions decrease even more than the energy use.

5.1.3. Social and economic perspective

The real price[115] of bread (Figure 12) shows a decline over the two centuries. In the nineteenth century this can be explained by the decreasing price of grains, since the nominal wages did not evolve much during this century. These lower prices are the consequence of the use of better production techniques, the development of transport (which makes a bad harvest less catastrophically) and the start of the grain import from the United States in 1873. In the twentieth century bread becomes ‘cheaper’ because of the better production techniques and because of higher nominal wages.

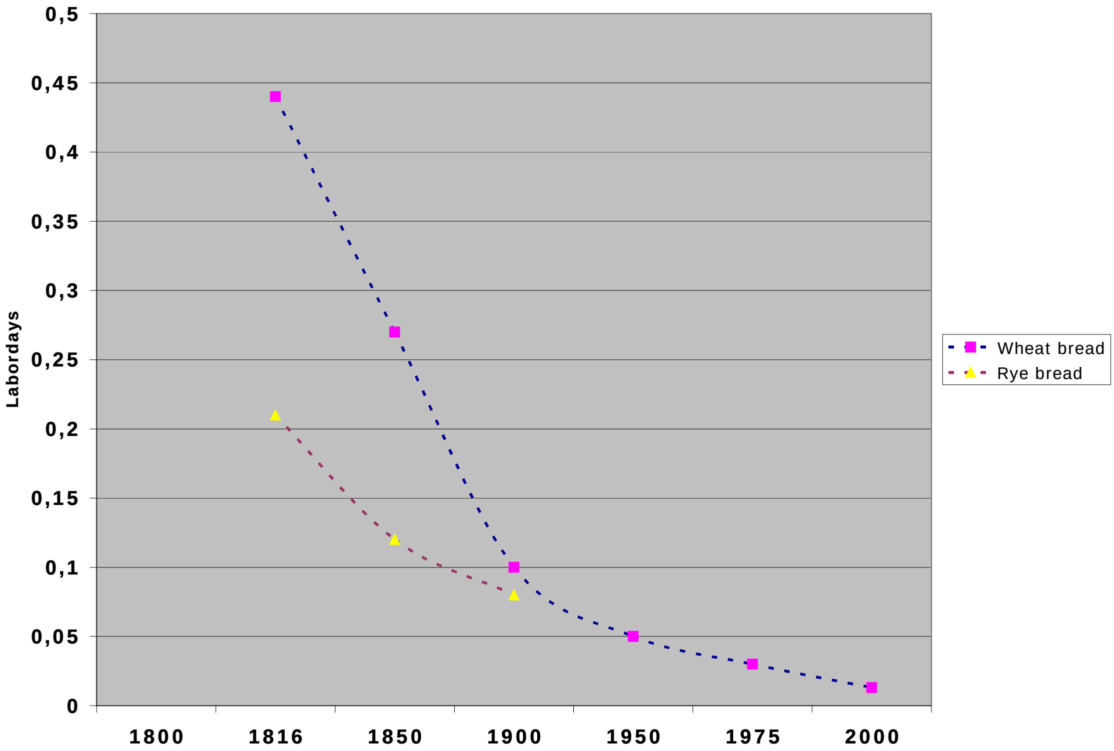

Figure 12 : Real price of bread

When looking at the evolution of the bread consumption in Belgium (Figure 13) [116], the decrease since the end of the nineteenth century is eye-catching, since the real bread price also shows a decline.

[115] C. Vandenbroeke (1988). NIS, *Brutolonen 2000* (www.statbel.fgov.be) (calculation: see Annex 4) G. Avondts and P. Scholliers (1981/5). Y. Segers (2002). Dienst Indexcijfer (2000). F. Michotte (1936-1937).
[116] S. Lenders (1992). C. Macherel and R. Zeebroek ed. (1994). E. Nicolas (s.d.). B. De Lepeleere and J. Viaene (1986).

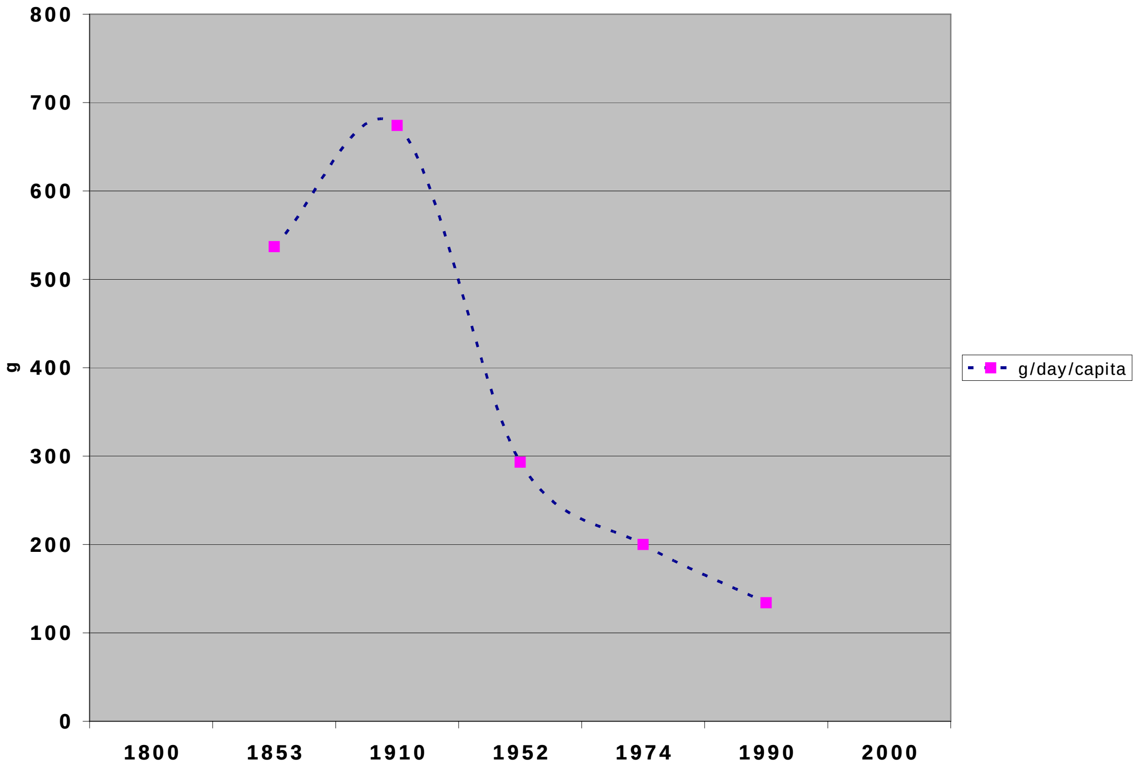

Figure 13 : Bread consumption in Belgium

Until the end of the eighteenth century, people's diet consisted largely of bread. This dependency declined because of the cultivation of potatoes and improved farming techniques. In the middle of the nineteenth century, the diet was again dominated by bread, due to the potato disease and the low grain prices[117]. Until the interbellum period, the eating pattern was dominated by bread and potatoes, however complemented by other products (e.g. dairy products). Since then, the diet of the majority of the population changed completely due to a higher standard of living and the interest in nutritional values (cfr. the health issues that raised the question of clean potable water) and variety. The consumption of bread decreased dramatically[118]. For example, between 1960 and 1978, the yearly consumption of wheat flour declined from 91,9 kg/capita to 69,2 kg/capita, while the consumption of fresh vegetables rose from 78,7kg to 101,6kg.

The same information (decreasing real prices and consumption) can be gathered from the percentage of the total private expenses that is spent to purchase bread[119].

[117] A. Detremmerie (1986), p. 12-13.
[118] In 1927 a committee that had to encourage the consumption of bread, was founded.
De Bakkersbaas. Officieel orgaan van het Huis der Bakkersbazen van België, 9/1 (1927), p. 11.
[119] Y. Segers (2002). NIS, Nationale rekeningen 1953-1962 (1963). NIS, Statistische studiën, 45(1976), blz. 1 e.v . NIS, Statistische studiën, 101 (1994), blz. 1 e.v.
The percentage was retrieved by using the private consumption figures. For 1850 and 1900, the amount spent on rye and wheat was used, in combination with retail prices and the total private consumption figures. For the years 1950 (1953), 1975 and 2000 (1993), the amount spent on bread and bakery products was divided by the total expenditure by Belgian households.

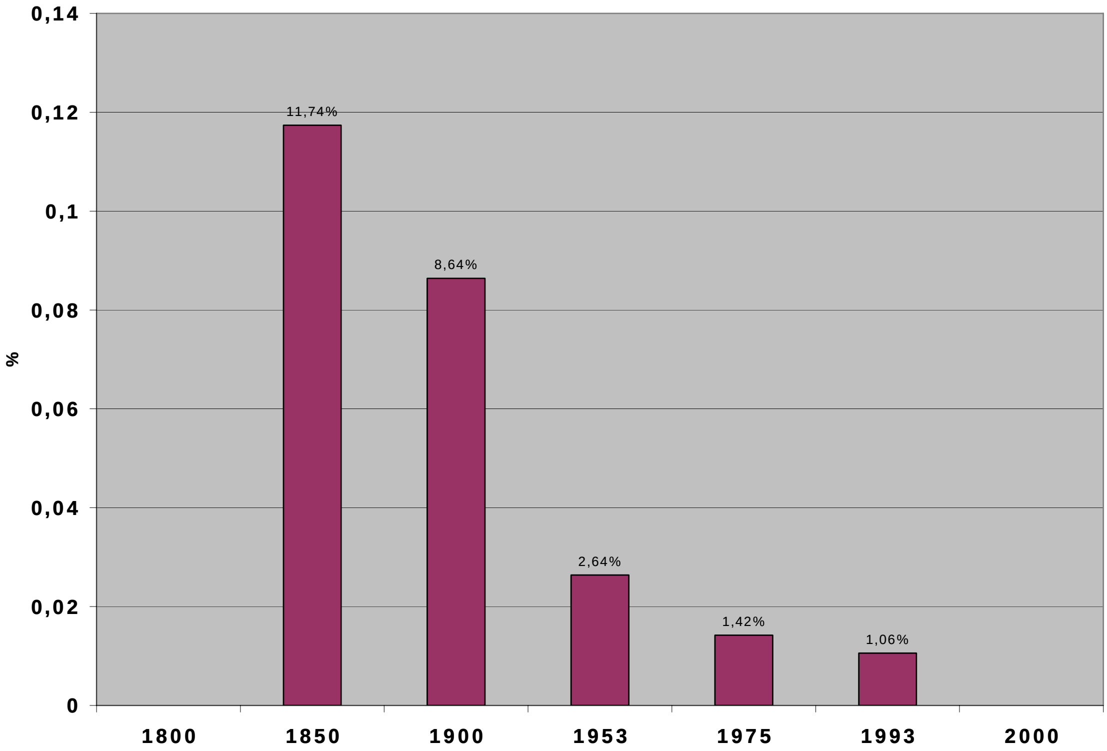

Figure 14 : Private expenditure on bread

The shift from rye bread to wheat bread[120] is an underlying social indicator. A large minority of the population could not afford wheat bread before the start of the grain import from the United States. To illustrate this: the Dutch word for 'honeymoon' is 'wittebroodsweken' (*wit brood* means wheaten bread). This expression refers to that period in people's lives when they could and wanted to afford wheat bread. (White)Wheat bread became more and more important in bread consumption in the first half of the twentieth century (Figure 15). Since the 1970s, other kinds of bread (e.g. wholemeal bread) show an increase in consumption, because they are considered to be healthier[121].

[120] Y. Segers (2002).
Segers calculated the proportion in consumed bread grains for the whole of the Belgian population in 1850 and 1900. The same proportions were used to indicate the proportion in consumed breads. E. Nicolas (s.d.), p. 71. S. Lenders (1992), p.33.
[121] A. Detremmerie (1986), p. 14. For the same reason, the salt content is restricted by law since 1976. *Omnilegie* (March 8th 1976).

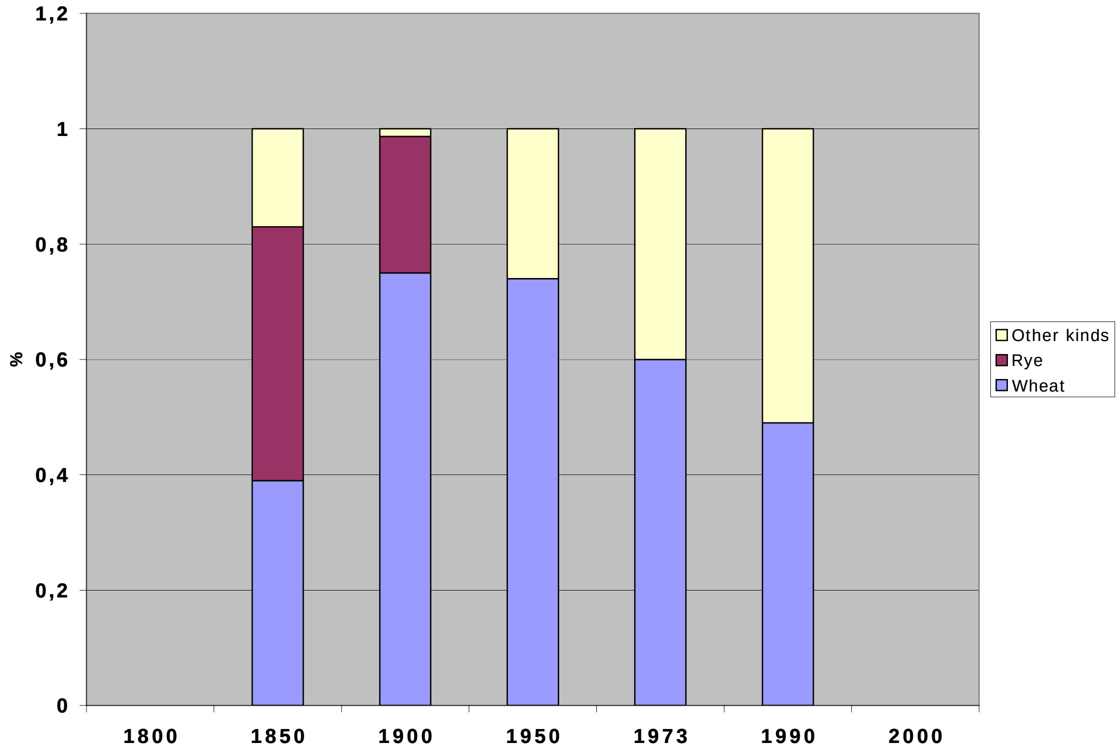

Figure 15 : Consumed kinds of bread

5.1.4. Sustainability trends

The life cycle of the production and consumption of 1 kg bread consists of 6 more or less important life cycle steps: wheat or rye cultivation, transport of corn to mill, milling, transport of flour to the bakery, baking, and distribution to the consumer.
Because we were able to quantify only two life cycle steps for all the years, the **qualitative** sustainability discussion of the other life cycle steps is in brief given below. The sustainability trend for the agriculture is not univocal: environmental emissions increase due to the production and use of artificial fertilisers and mechanisation of the field work. Corn prices and labour hours decrease because of the mechanisation. The transport of corn to mills becomes environmentally important at the beginning of the 20th century when steam ships were used to import wheat from the US. The environmental emissions decreased again when Belgium started importing mainly wheat from European countries. The transport of flour to bakeries was never an important cause of environmental emissions.
The distribution of bread, which is estimated on the basis of very uncertain data, seems to be the most environmental harmful phase in the life cycle of bread in 2000. Until 1950, emission free vehicles (bicycles, on foot,…) were used for this purpose.

The **quantitative** figures representing the trend of the **environmental** parameters energy consumption and corresponding emissions of the baking and milling processes are given above and in Annex 3. The overall trend resulting from the industrialisation of the milling and baking processes is a reduction in energy use. Due to the switch to other fossil fuels, the emissions decrease even more than the energy use. However, the sustainability trend of one dimension (environment in this case) is often linked to the other dimensions. In the third quarter of the twentieth century, oil and gas were used to bake bread as part of a general transition in energy sources.

In the bread production and consumption the subsequent processes developed quite differently during the past two centuries. In the early days several processes in the bread chain (agriculture, the milling process and distribution process of bread) were mainly based on manual, or animal forces and using renewable wind or water power causing no emissions. At their replacement by processes based on fossil fuel the emissions have first gone up and got reduced at a later stage through efficiency improvements thanks to economies of scale some emissions (carbon dioxide, …) were reduced. The emissions from the intense agriculture related to acidification and eutrophication have gone up.

The baking itself has always been based on burning fuels leading to emissions. The emissions of burning wood in the early days have been taken into account (no credits for Carbon sequestration, because of the non sustainable use of wood at that time). The shift towards lower carbon content fuels and the efficiency improvements itself have reduced the emissions considerably. It is also remarkable to see that these environmental improvements have been impressive also for the period before the year 1975 when the consciousness about environmental issues became more widespread in society. Economic driving forces (costs of fuels) probably were the basis for this improvement.

On **socio-economic** level, the consumption of bread peaks in 1900. Since then people started eating more varied which causes a drastically decrease of the bread consumption during the last century. The total bread consumption in Belgium for the years 1800 and 2000 is however of similar size due the combination of a decreased bread consumption and the rise in population.
The real price of bread declined during the last two centuries with factor 15. Wheat bread, an originally luxury product is nowadays affordable for everyone. In contrast to rye, initial the most common used bread corn, wheat has to be imported on a wide scale. In the beginning of the 20th century wheat was imported especially from the US, nowadays Germany and France are main importers.

All three dimensions of sustainability (environmental, social and economic) show relative stability over the nineteenth century (although some short-term changes occurred in both directions), when regarding the society as a whole.
In general there have been major social improvements over the past century. The population, and therefore the number of consumers, has increased, mainly due to a higher life expectancy. The fact that people's diet has become more varied (partial replacement of bread by alternatives) has played an important role in the increase in life expectancy.
The last quarter of the twentieth century shows beneficial trends in all three dimensions. Apparently, 'environmental improvements' occur only after the 'fulfilment' of the socio-economic needs.

It can also be concluded that bread has been a vital and for survival fundamental food component for Belgium society until the beginning of the twentieth century. Although bread is still important in our food consumption, the amount of bread consumption per person is declining, when people eat more meat and vegetables nowadays. This raises a generic question about the concept of sustainability for product systems : Does a product system, that reduces its environmental emissions due to less consumption, contribute to more environmental sustainability ?

The policy angle during the two centuries has been the assurance of an affordable supply of basic food to the population by allowing the import of grain, fixing a maximum price for bread, subsidizing,… This raises again the question about the concept of sustainability for product systems: Does a product system that is subsidized contribute to more economic sustainability ?

5.2. Case study: Transport

5.2.1. Status description

This case study started out by considering five means of transport: on foot, by (horse) tram (bus), by bicycle[122], by train[123] and by car[124]. Due to encountered difficulties in the search for necessary data and budget restrictions, it was not possible to study all five transport modes equally thorough. Therefore, it was decided that (horse) tram and bus would not be included in the analysis[125].
For each key year, characteristic features of the different means of transport were determined. A vehicle is only taken into account when it is used by a large part of the population. An exception is made for the T-Ford, because of its popularity and its representativeness for new production techniques. The consumption figures will be discussed in the social and economic analysis. The main characteristics are summarized in the following matrix (Table 3).

	On foot	By bicycle	By train	By car
1800	To walk 3 miles an hour, a non-athletic person needs 1/10 HP	Not relevant	Not relevant	Not relevant
1850	Idem 1800	Not relevant	Not relevant	Not relevant
1925	Idem 1800	Metal	Wooden carriages Steam locomotives Coal	T-Ford
1960	Idem 1800	Metal	Metal carriages Steam trains (diesel and electrical trains to a lesser extent)	Top 5 of the Belgian car fleet[126]

[122] A. Ritchie (1975). J. Woodforde (1970).
[123] U. Lamalle (1943). B. Van Der Herten et.al. ed. (2001). B. Van Der Herten (2004).
[124] G.N. Georgano (1990). T.P. Newcomb et.al. (1989).
Regarding the car, we joined forces with NCAD, the Dutch Centre for Automotive History. Mr. Polman, mr. Mom and mr. Staal provided us with a lot of useful information, considering the technical aspects of the car and considering the evolution of cars during the twentieth century.
B. Van Der Herten (2004).
[125] We do know that this decision creates a gap in the analysis, since "commercial vehicles, however, are of much more significance than private ones, and the motor omnibus has been one of the most potent factors in shaping the modern social structure, particularly in rural areas. Its predecessor, the horse bus, was of equal significance in the nineteenth century, although its influence was necessarily restricted to towns and suburbs."
The reader must keep this in mind, especially when examining the combined results of the analyses.
A. Bird (1969), p. 127.
[126] NIS, *Statistiek van de motorvoertuigen* (1960). Volkswagen (14,02%), Opel Olympia Rekord (9,63%), Renault 4HP (4,68), Renault Dauphine (3,47%), Chevrolet (3,33%).

1975	Idem 1800	Steel alloy (lighter)	Metal carriages Diesel train Electrical trains	Top 10 of the Belgian car fleet [127]
2000	Idem 1800	Aluminium	Metal carriages Electrical trains (diesel trains to a lesser extent)	Top 5 of the Belgian car fleet [128]

Table 3: Different means of transport

For transport, slightly different key years are used compared to the other cases. This is mainly due to the evolution of car transport. In 1900 the car was not a representative means of transport, while in 1950 it was on its way to get widely accepted. A milestone in the history of the car is situated in 1925, with the introduction of the T-Ford. This was the first car that was made using mass-production. That is why the year 1925 is taken into consideration with regard to transport. 1925 is also interesting as a reference year for train transport with the foundation of the NMBS (National Railroad company) in 1926.
Another difference is the substitution of the year 1950 by 1960. The reason for this is that in the post-war years the situation regarding the car fleet was not yet clear.

In the course of the nineteenth century, transport has undergone many changes. Prior to 1815, road tolls had to be paid. The central government received the revenues, not the local governments that maintained the road network. Consequently, between 1797 and 1806, no investments in the road network were done. Since 1807, the central governments (the French and later the Dutch) decided to invest in roads. When Belgium became an independent state in 1830, it had a well organized road network[129]. In the second quarter of the nineteenth century[130], the roads were of imperative meaning for transport, since the maritime sector was in a poor shape[131]. However, the road network also had some negative features: there were too few roads, maintenance was bad and the connection with neighbouring countries did not suffice. More and more, the outline of a national railroad network[132] became an objective for the government. Because of this concept, state intervention was a must. At the end of the nineteenth century, the railroad network (the most important sector in transport in the second half of the nineteenth century) became a state-owned company[133].
In the second half of the nineteenth century, road transport became subsidiary to railroads. This form of transport was fast, reliable and relatively cheap and it was not regionally

[127] NIS, *Motorvoertuigenpark* (1975). Opel Kadett (2,88%), Volkswagen 1300 (2,62%), Ford Taunus TC (2,61%), Renault R4 (2,48%), Opel Rekord 1700 (2,20%), Toyota Corolla (2,02%), Ford Escort (1,98%), Peugeot 504 (1,94%), Volkswagen 1200 (1,89%), Citroën Dyanf (1,74%).
Because of substantial differences in weight and energy use, for 1975, the top 10 of the Belgian car fleet was considered. In 2000 and 1960, no more than the top 5 was taken into account, since the cars are very much alike regarding weight and energy use.
[128] NIS, *Vervoersstatistieken* (2000). Volkswagen Golf (5,94%), Opel Astra (3,03%), Ford Fiesta (2,79%), Opel Corsa (2,64%), Volkswagen Polo (2,61%).
[129] B. Van Der Herten (2004), p. 165.
[130] In the 1860's, several laws were issued considering the construction and maintenance of the road network. *Pasinomie* (1860-1870).
[131] B. Van Der Herten (2004), p. 232-244.
[132] In 1834, a law was issued for the establishment of a *national* railroad network. *Pasinomie* (May 1st 1834).
[133] B. Van Der Herten (2004), p. 312 e.v. In 1926, the National Railroad Company (NMBS) is established. "Le but essentiel auquel tendent les efforts du Gouvernement est de contribuer à vendre à notre devise nationale sa vertu primordiale: la stabilité." *Pasinomie* (July 23rd 1926).

limited[134]. Railroads were developed to fulfil the needs of the trading business, the national industries[135] and for domestic transport[136]. There was a reciprocity between the railroad sector and other industries[137]: new markets came within reach, cheap materials could be imported, the decreasing prices for transport created a higher demand for industrial products and it became easier to transport the work force (which meant a rising number of passengers)[138]. However, one cannot ignore other developments in society to explain the success of the railway system: the rise of the financial capital, the development of modern corporate policies and the change in people's view on the world[139]. In the third and fourth quarter of the nineteenth century, tramways and district railroads[140] complemented the traffic network. Tramways replaced the horse tram and connected the train stations to the city centres (e.g. to take the work force to the train station). The district railroads were constructed to integrate the economically deprived and sparsely populated regions in the transport network. The infrastructure of these railroads was limited and lighter (and therefore cheaper) materials were used. By integrating these areas in the transport network, the government wanted to counter the exodus from the countryside[141]. In the second half of the twentieth century, district railroads were replaced by bus services[142]. Tramways still exist in city centres and in the coastal region[143].

At the turn of the century, the road network is gaining weight: trucks make road transport possible, the economy is growing and conglomerates are expanding.

After World War II, the industrial sector (especially in Flanders) changes (e.g.: the volume of goods on order decreases, export figures increase). The railroad's response to these changes is very slow. Simultaneously, the conveyance of passengers is expanding. Because of these developments, road transport gains significance rapidly: it is a fast, reliable and flexible means of transport, that can be used for specific tasks. These are the same arguments that accompanied the transition from maritime transport to railroad transport[144]!

Before World War II, the car was only affordable by a small part of the population[145]. Moreover, people thought it was a dangerous artefact, that smelled and made strange noises[146]. In the eighteenth century already, experiments with steam engines and carriages were carried out. Because of the weight of these engines and because of the bad roads, the development of the train was more successful. Nonetheless, several constructors developed 'cars' at the end of the nineteenth century. The development of these first cars is very much obliged to the development and the success of the bicycle. Already at the beginning of the nineteenth century, bikes were made by several producers. The first bicycles were difficult to ride and very heavy. Only young, rich people owned a bicycle and they mostly used it for racing. In the 1890s, this changed: the bicycle became a means of transport for everyone.

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[134] B. Van Der Herten (2004), p. 13.

[135] U. Lamalle (1943), p. 7-15. Ph.S. Bagwell (1974), p. 88. The railway system was needed for the transportation of coals from the mines and to other industries.

[136] B. Van Der Herten (1995).

[137] At the end of the nineteenth century, there were special rates for the transportation of coals by train. *Pasinomie* (June 26th 1890).

[138] B. Van Der Herten et.al. ed. (2001), p. 302-318. Since 1931, bus services could be established to complement the services provided by the district railroads and the tramways. *Pasinomie* (1931).

[139] B. Van Der Herten et.al. ed. (2001), p. 14-19.

[140] In 1884, the National Company for the District Railroads was established. *Pasinomie* (May 28th 1884).

[141] B. Van Der Herten (2004), p. 377-429.

[142] E. Keutgens (1985), p. 79.

[143] R. Van Craeynest (1985).

[144] B. Van Der Herten et.al. ed. (2001), p.315.

[145] G.N. Georgano (1990), p. 61.

[146] T.P. Newcomb (1989), p. 39.

In the 1880s Benz placed a combustion engine on a tricycle: it ran successfully on public roads and cars became more popular[147]. Interestingly enough, the first bikers also became the first car owners. They used the car to distinguish themselves from other people, as they did use the bicycle before it became a means of transport for the masses[148].
At the turn of the century, several car models were on the market and constructors kept searching for improvements. However, it was the T-Ford that provided a major breakthrough in the automobile sector[149]. This model was conceived as practical, affordable transport for the common man[150]. Assembly-line production allowed declining prices and realizing Ford's goal to 'democratize the automobile'[151]. European constructors did not immediately follow this production concept. Therefore, the American fleet of cars expanded more dramatically before World War II[152]. In the 1950s, the car really becomes a vehicle for the masses, due to several causes: e.g. the expansion of the road network (this will be explored in the social and economic analysis) [153], the development of gas stations and a change in people's behaviour and needs (suburbanization, tourism, leisure,…). Together with the expansion of the number of cars, more and more laws are issued concerning safety, car registration, car insurance…[154]
The transition between the different means of transport (although only available for freight transport) becomes clear when looking at Figure 16.

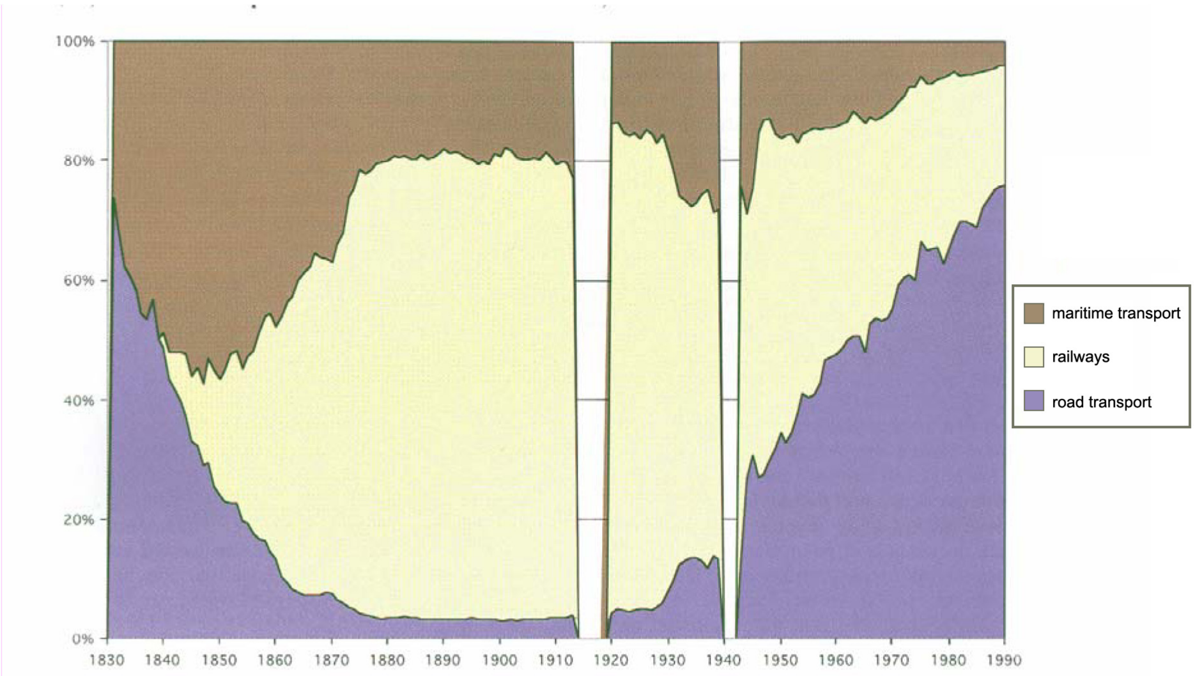

Figure 16: The proportion of the different means of transport in freight transport (Van der Herten, 1997).

[147] T.P. Newcomb (1989), p.16.
[148] P. E. Staal (2003), p. 58.
[149] Built from 1908 until 1927.
[150] Model T, *www.britannica.com*
[151] Model T, *www.britannica.com*
[152] T.P. Newcomb (1989), p.51.
[153] Already in 1913, taxes on motorized vehicles have to be paid for maintaining the roads. *Pasinomie* (1913).
[154] *Pasinomie* (December 1st 1940). Implementation of the driver's license.
Omnilegie (1965). Implementation of a theoretical examination for future drivers.

What is remarkable about these different means of transport, is that there is not really a substitution. The different vehicles co-exist and even supplement each other since the end of the nineteenth century: horse and carriage were needed to supply the first trains and carriage (horse tram) services often complemented train services[155], bicycles are used to get to the train station, as are cars nowadays and tramways connect the train station to the city centre[156]. Moreover, different vehicles benefited from each other in several ways. “The revival of interest in mechanical means of road transport came with a surprising reversion to human power in the form of the bicycle. …seeking to meet the rising consumer demand for a simple and convenient mode of personal transport. There can be little doubt that it helped people, and especially young people and women, to travel more widely than ever before… Nor can there be any doubt that the automobile benefited substantially from the precedent of the bicycle, not only in the creation of a market of potential customers, but also in terms of engineering expertise.[157]” Nonetheless, since the 1960s, cars become more and more dominant (which will be illustrated in the social and economic perspective).

5.2.2. Environmental perspective

To quantify the environmental developments of passenger transport in Belgium a Life Cycle Assessment approach is followed. The **goal** of this environmental analysis is to compare the environmental effects of passenger transport in Belgium in 1925, 1960, 1975 and 2000. The **functional unit** is “human movement over land of one person over 1 kilometre (which amounts to 1 passenger kilometre)”.
The life cycle of transport systems consists of different phases, as shown in Figure 17.

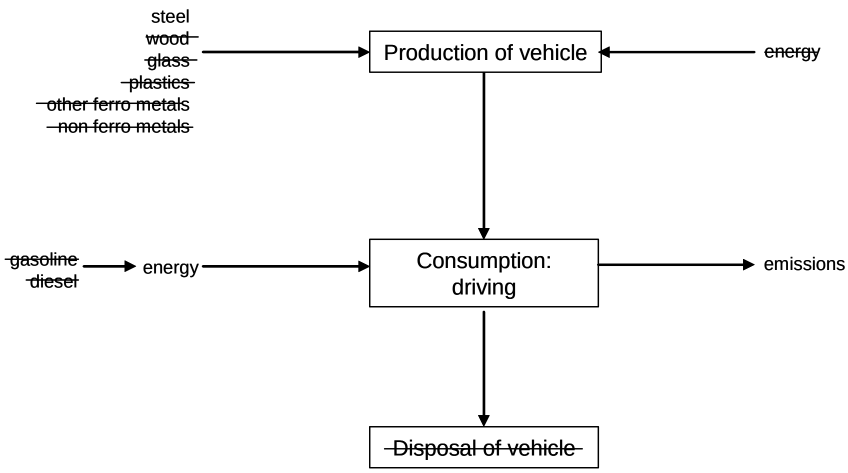

Figure 17 : Process tree for transport by car, train and bicycle[158]

Due to lack of data for the years 1925, 1960 and 1975 we had to simplify the product system and focus our search on the main contributing materials and processes.

[155] Ph. S., Bagwell (1974), p. 138.
[156] J.W. Schot, et.al. ed. (2002/5), p. 19-25. B. Van Der Herten et.al. ed. (2001), p. 40.
[157] R. A. Buchanan (1992), p. 147-148.
[158] strikethrough = not taken into account

Inventarisation

Car transport

2000

An average car in 2000 is heavier than the average car in 1960 because of the introduction of control and coupling technologies, extra safety, comfort and emission provisions and larger and heavier engines. The weight of a car is based on data for the top 10 cars of the Belgian car fleet in 2000[159], which represents about 28% of the total car fleet. In this analysis the weight of a car is considered independent of the fuel. A car consists for about 70% of steel, 12% plastics, 6% aluminium and Al-alloys, 5% rubber, 3% copper, lead and zinc, 3% glass and a negligible amount of other materials[160]. Steel is by far the most important material of a car, therefore we focused on the technology for steel production in the key years. In 2000, 65% of the steel is produced via a Basic Oxygen Furnace (BOF), 35% via an Electric Arc Furnace (EAF)[161]). We assume that this is representative for the automobile as well, knowing that the body is made of primary steel, the chassis of secondary steel. For a summary of the data used for steel production is referred to Annex 6. The other materials are not considered in this study because of lack of environmental data on the production of these materials in the other key years.
The emissions that occur while driving a car are directly related to the composition of the fuel and the fuel consumption (efficiency) of a car. 60% of the cars in Belgium run on petrol, 40% use diesel as fuel. Two important substances of fuels are lead (petrol) and sulphur (diesel). In 2000 the maximum lead content in petrol is 0.005 g lead/litre petrol, the maximum sulphur content in diesel is 0.35 g S/kg diesel (0.035wt%). The enforced decrease of the lead content in petrol was not only due to the effects on public health but also because of the correct functioning of the 3-way catalytic converter. The decrease of the sulphur content fits within the optimal operation of new engine technologies and emission control provisions and of course within the direct decrease of SO_2-emissions and particles.
The emissions during driving are taken from the TEMAT-model for petrol resp. diesel cars[162]. The calculation of the fuel consumption of petrol and diesel cars is based on the fuel consumption data as given by the car producers. These data are usually underestimated because they are based on fixed conditions. Since we dispose for the other key years only of data given by the car producers, we use also this type of data for 2000.
With regard to consumption data three important factors exist: average seat occupancy rate, annual amount of passenger kilometres (pkm) in Belgium and average life span of a car (expressed in vehicle kilometres (vkm)). In 2000 the average seat occupancy was 1.42[163], people drove 99 862 million passenger kilometres (based on car fleet, average number of vehicle km per car and seat occupancy[163]) and the average life span of a petrol car is 200 000 vkm, of a diesel car 300 000 vkm[164].

1975

A car in 1975 was heavier than in 1960 but lighter than in 2000. The main reasons for the increasing weight compared to 1960 are the extra comfort and safety provisions. The average weight of a car is based on data for the top-20 cars of the Belgian car fleet in 1975[165], which

[159] NIS Vervoersstatistieken, 2000
[160] De Vlieger ed., 2001
[161] BREF Iron and steel, 2001 ; T. Considine ed., 2000
[162] TEMAT-model is developed by VITO (centre : IMS) to calculate and model specific emissions for car transport
[163] NIS Vervoersstatistieken, 2000
[164] Maclean ed., 1998 ; Febiac, 2002 ; Tensen, 1996
[165] NCAD and technical data sheet from producers

represents 35% of the total fleet. On average 62% of a car was made of steel. Steel production technologies are (as in 2000) BOF (80%) and EAF (20%)[166].
The major part of the Belgian car fleet used petrol as fuel. Data for fuel consumption are based on producer data for the top-20 cars of the Belgian car fleet in 1975. The emissions related to the driving are taken from literature[167], and are checked with data for Euro 0 cars (MEET-model[168]). The emission of lead is based on the lead content of petrol in 1975 (0.4 g/litre)[169].
In 1975 the seat occupancy was 1.8 persons per car[170], car transport amounts to 53 090 million passenger km (based on total car fleet[171]), average vehicle km per car[171] and the seat occupancy), the average life span is estimated at 150 000 vkm[172].

1960
The average weight of a car is taken from the top-5 cars in the Belgian car fleet in 1960[173], which represents 35% of the total fleet. Compared to 1925 a car in 1960 is lighter because of more experienced car producers and the development of a self-supporting body. A car exists for 80% of iron and steel. The most frequently used steel production technology is the Open Hearth process[174].
In 1960 petrol was by far the most used fuel in car transport. Data for fuel consumption are based on producer data for the top-5 cars and checked with global figures in literature[170]. No emissions regulations existed in 1960, so it was difficult to obtain data on emissions for this period. For NO_x-, CO- and VOC-emissions data are obtained via NCAD (measurements TNO). The emissions of lead and sulphur are calculated based on the lead- resp. sulphur content of petrol in 1960 (0.6 g Pb/l; 0.7 g S/l). No data are found on the S-content of petrol in 1960[175]. The S-content is derived from the fact that in 1975 the S-content in petrol was on average 0.5 g/kg, which matches the SO_2-emission in 1975, and the decrease in S-content of petrol between 1960 and 1975[176].
In 1960 the seat occupancy was 2 persons per car[170], 26 360 million passenger km are driven in Belgium (based on total car fleet[171], average vehicle km per car[177] and seat occupancy), the average life span is estimated equal to 1975.

1925
Data for 1925 are all based on the T-Ford model. This is justifiable since the T-Ford is the most widely used car in this period. It is the first car that was mass-produced. The weight of the T-Ford is taken from literature and is specific for this car. In this period cars are mainly composed of steel (90%, assumption based on own evaluation), the other materials being used are wood and rubber.

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166 Graedel, 1995 ; Grubler, 1998
167 Van Laer
168 MEET-model is developed by VITO and calculates emissions based on a.o. the type of car (Euro-classification) and the type of road
169 Hagner, 1999
170 Van den Brink, 2000
171 NIS Vervoersstatistieken, 2000
172 Tuininga, 1976
173 Source : NCAD
174 Grubler, 1998
175 Blumber K. ed ; Grubler, 1998
176 (http://www.faqs.org/faqs/autos/gasoline-faq/part1/)
177 Staal P., 2003

Figure 18 : T-Ford arrives at VITO for emission measurements

The fuel consumption (petrol) of the T-Ford is taken from literature (NCAD) and measurements by VITO on a still-running T-Ford. Also the emissions of NO_x, VOC, CO_2 and CO are measured on a test installation at VITO. The only emission that is very probably not representative for real practises in 1925 is the CO-emission, since this depends on the proportion oxygen-fuel. This proportion is manually optimised during the measurements, which was not possible in practice in 1925 (drivers could adjust but had no idea about emissions). Experts (NCAD) estimate that the CO-emission measurement could be up to factor 10 underestimated. We take this uncertainty range into account. The emission of SO_2 is based on the sulphur content of petrol (which is assumed identical to 1960: 0.7 g S/l). The emissions of lead are zero since lead was not yet added to petrol in this period.
816 million passenger km were driven in 1925, while the average seat occupancy was 3 persons per car. The annual number of passenger km is calculated using the number of cars in 1925[178], the average number of km covered by car and the seat occupancy[179]. The seat occupancy rate is based on a mixed use of cars in this period: professional use (by doctors etc.) with only 1 person per car and daily use by the rich with up to 8 persons per car. The average life span of a T-Ford is not found in literature, based on data we have (expert opinion, literature) we assume this to be in the range of 50 000-100 000 km.

Train transport

2000

The weight of a train is based on the average length of a train (number of carriages)[180], the weighed average of the weight of carriages resp. motor vehicles[181] and the weight of the representative locomotive[182]. Per fuel type the weight of a train is calculated and combined on the basis of the share of the type of traction in total train transport[183]. In 2000 an average train

[178] Staal P., 2003
[179] both assumptions based on expert opinion of NCAD
[180] Expert opinion from people from Museum NMBS
[181] NMBS, 2000 ; conversation with W. Bontinck
[182] NMBS, 2000 , Technical sheets
[183] NMBS, 2000

weighs 401 ton, of which 327 ton is steel. A locomotive consists for approximately 90wt% of steel, motor vehicles and carriages for app. 80wt%. As for car transport steel is by far the most important material of a train, therefore we focused on the technology for steel production in the key years. We refer to the inventory of car transport in 2000 for more details on the steel production technologies. The other materials are not considered in this study because of a lack of environmental data on the production of these materials in the other key years. The energy consumption for train transport is deduced from the total fuel consumption[183], the total gross ton-km for the different traction types[183] and a correction factor for the energy consumption for passenger transport in relation to goods transport[184]. The two traction types for train transport are electricity and diesel. The share of electrical traction is much higher (96%) than the share of diesel traction (4%) in passenger traffic. The emissions due to driving with an electrical train are based on the emissions for electricity production, taking into account transformation losses. Emissions due to diesel traction are based on emission factors for diesel trains[185].
Consumption figures for Belgium (seat occupancy, annual number of passenger km) are taken from the Annual Statistics 2000 of the NMBS. 7 755 million passenger km are driven by train, the average seat occupancy is 95. The life span of a train is estimated to be 6 million trainkm[186].

1975
The weight of an average train is 384 ton, of which 323 ton is steel. This weight is calculated with the same method as in 2000[187]. The share of steel in locomotives resp. carriages and motor vehicles is almost identical to 2000 (95wt% for locomotive, 80wt% for motor vehicles and carriages). For the production of steel we refer to the inventory discussion of car transport in 1975. The calculation of energy consumption for train transport is performed in the same way as for the year 2000[187]. Both electricity and diesel are the common traction types, the share of diesel for passenger traffic increased compared to 2000 (by 35%). The emissions due to electrical train transport are based on the emissions for electricity production in 1975 (taking into account transformation losses). The emissions of diesel trains are based on measurements from Deutsche Bahn, except the SO_2-emissions that are based on the S-content of diesel in 1975 (5 g/kg diesel).
Consumption figures are taken from the Annual Statistical Report 1975 NMBS. In 1975 train transport is responsible for 8 258 million passenger km, the average seat occupancy is 117 passengers per train. As in 2000 we estimate the life span of a train at 6 million train km[188].

1960
An average train in 1960 weighed 348 ton, of which 291 ton is steel. This calculation is identical to the other years and is based on data of the Annual Statistical Report 1960 and the technical sheets of the NMBS. For the production of steel we refer to the inventory discussion of car transport in 1960. The share of steel in locomotives resp. carriages and motor vehicles is identical to 1975 (95wt% for locomotive, 80wt% for carriages and motor vehicles). The calculation of energy consumption for train transport is performed in the same manner as for 2000[189]. The most important traction type is electricity (50%), steam traction accounts for 32% and diesel for 18%. Despite the high share of electrical traction, this was far less than in the

[184] expert opinion W. Bontinck
[185] De Vlieger I., 2005
[186] Tensen D., 1996 ; expert opinion W. Bontinck and museum NMBS
[187] NMBS, 1975
[188] NMBS, 1975 ; expert opinion W. Bontinck
[189] NMBS, 1960

surrounding countries because the electrification of the rail network appeared very late (approx. 40 years later than surrounding countries). Only the largest lines were already electrificated in 1960, the other lines followed in the 1980s. This is the reason for the relatively large share of diesel traction since 1960. Diesel offered some important advantages compared to steam: the engine could start without delay and less personnel was needed. The majority of steam locomotives that were in service in 1960 date from the first decades of the century. However due to two World Wars too little steam locomotives were available, therefore 300 type 29 locomotives were ordered in Canada. In 1966 the NMBS stopped using steam traction. The emissions due to electrical train transport are based on the emissions for electricity production in 1960 (taking into account transformation losses). The emissions of diesel trains are based on measurements from Deutsche Bahn, except the SO_2-emissions that are based on the S-content of diesel in 1960 (on average 5 g/kg diesel). The emissions of steam trains are based on emission factors for industrial combustion appliances on coal[190]. The SO_2-emission is calculated with the S-content of coal in 1960 (0.9wt%).
Consumption figures are taken from the Annual Statistical Report 1960 NMBS. In 1960 8 577 million passenger km used train transport in Belgium, the average seat occupancy is 138 passengers per train. The average life span of a train in 1960 is estimated to be identical to 1975 and 2000, being 6 million train km[191].

Figure 19 : The steam locomotive type 29 (copyright NMBS-Holding)

1925
In 1925 an average train weighed 310 ton of which 215 ton is steel. This calculation is identical to the other years and is based on data of the Annual Statistical Report 1926 and the technical sheets of the NMBS. For the production of steel we refer to the inventory discussion of car transport in 1925.The share of steel is lower than in the later years because of the lower share of steel in the carriages. In 1925 the carriage was mainly made of wood, the chassis was made of steel (60% steel in carriage). The wooden carriages caused a lot of casualties in case of an accident. For safety wood was replaced by steel in later years. The locomotives existed for 95% of steel, the tender (vehicle for carrying coal) was completely made of steel. The only

190 Bakkum A., 1986
191 expert opinion W. Bontinck and museum NMBS

fuel used in this period is coal for the steam locomotives. The calculation of energy (coal) consumption for train transport is performed in the same manner as for 2000[192]. The emissions of steam trains are based on emission factors for industrial combustion appliances on coal[193]. The SO_2-emission is calculated with the S-content of coal in 1925 (0.9wt%).
Consumption figures are taken from the Annual Statistical Report 1926 NMBS. In 1925 train transport was responsible for 6 256 million passenger km, the average seat occupancy is 152 passengers per train. In consultation with experts we estimated the average life span of a train at 3 million train km.

Bicycle transport

2000

We focused on bicycles for recreational use, not on sports bikes. The weight of a utility bicycle is estimated by VITO and is based on literature[194], expert opinion (O. Beaujon) and producer data (Batavus, Gazelle). We decided to work with the average of all data we gathered, which is 15 kg. Although some new materials are used in bicycles, the average weight of a bicycle has not significantly changed between 1960 and 2000. A common bicycle exists for 77% of steel (alloys), 5% aluminium, 3% plastics and 16% other[195]. Due to lack of environmental data for the production of the other materials in other key years we only consider the steel production for the production phase of a bicycle. For the description and data on steel production we refer to the inventory of car transport in 2000. Unlike the other transport modes a bicycle does not need fuel to drive.
In 2000 3 000 million passenger km are driven by bicycle[196], the average life span of a bicycle is 10 000 km, which is based on a life span of 10 years and 1 000 km that are annually driven with a bike[197]. Logically the seat occupancy of a bicycle is close to 1 person.

1975

The model of an average 1975 bicycle is more or less the same as in 2000 and is called “the safety bike”. The average weight of a bicycle remains the same: 15 kg[197]. The amount of steel is also unchanged compared to 2000: on average 77% of a bicycle is composed of steel[197]. For the steel production technology in 1975 we refer to the inventory of car transport in 1975.
In 1975 2 948 million passenger km are driven by bicycle, which is based on the number of bicycles in 1975[198] and an annual amount of 1 000 km driven per bike in Belgium[197]. The average life span of a bicycle is identical to 2000: 10 000 km (based on the same data).

1960

A new era for the bicycle starts in 1960, with the development of the modern sports bike. Characteristic for this bicycle are the gears and the lighter construction compared to 1925, because of the use of new materials like plastics and aluminium. New materials, new resources and new construction technologies refined the bicycles in this period. The average weight of the bicycle is 15 kg, which is identical to the later period. Bicycles did not change significantly anymore. Because in 1960 the new developments of bicycles just started, the basic materials for bicycles were iron and steel (95%)[197]. For a discussion on steel production technologies we refer to the inventory of car transport in 1960.

[192] NMBS, 1926
[193] Bakkum A., 1986
[194] Bouwman M., 2000
[195] Bouwman M., 2000
[196] Estimation VITO based on historical data
[197] Bouwman M., 2000 ; expert opinion of O. Beaujon
[198] Febiac, 1976

In 1960 2 959 million passenger km are driven by bicycle in Belgium. This is calculated using data concerning the total number of bicycles in Belgium in 1960 (interpolation of data 1950-1975[199], and the average number of km driven per bike[200]. The average life span of a bicycle is identical to the later years: 10 000 km (based on the same data).

1925

The development of a bicycle starts with the hobbyhorse in the beginning of the 19th century. In 1840 this hobbyhorse is provided with a lever system and as such it is transformed into a pedal bicycle. Later in the century this bicycle is further developed (with one big and one small wheel) and in the beginning of the 20th century the safety bicycle is developed, with 2 equally sized wheels and a triangular frame. The same principle is still used nowadays. This type of bicycle swept the market in the beginning of the 20th century. The average weight of a bicycle in 1925 is 18 kg[201], of which 95% iron and steel. For a discussion on the steel production technologies is referred to the inventory of car transport in 1925.
In 1925 many people owned a bicycle[202]. In total 2 810 million passenger km are driven by bicycles in Belgium (based on number of bicycles and average annual mileage per bike). Since the other transport modes (especially car transport) were not yet available for all Belgians, the bicycle was a very important transport mode. We estimate that on average 2000 km are driven by one bike in 1925. The average life span of a bicycle is approximately 24 000 km[203].

Impact assessment

Car transport

Figure 20 to Figure 25 show the results of the environmental analysis of car transport.
The first two figures present the energy consumption respectively emissions that occur during the production of the car and more specific during **steel production**, related to 1 passenger km (functional unit). As discussed above, due to lack of data we only studied the steel production phase regarding the production of a car. Figure 20 shows that the energy consumption for producing steel used for a car (related to 1 passenger km) decreases between 1925 and 1975, and afterwards decreases at a slower rate. Three factors contribute to this decrease:

- decreasing share and amount of steel per car between 1925 and 1960;
- decreasing energy consumption per ton steel production between 1925 and 2000 because of more efficient steel production technologies;
- longer life span of a car (by factor 3) from 1925 to 2000.

On the other hand the decrease in seat occupancy (factor 2) causes a rise in energy consumption.

We took into account an uncertainty range for the life span of a car in 1925, but this does not effect the overall conclusion. The decreasing NO_x, CO_2-, CO- and SO_2-emissions for the production of steel per passenger km are due to the decrease of these emissions during electricity production. The overall reduction of CO- and CO_2-emissions is enhanced by the reduction during steel production (more controlled and efficient steel production technologies). The steady situation of CO_2-emissions between 1925 and 1960 is due to the

[199] Statistical Yearbook of Belgium 1952
[200] Expert opinion: O. Beaujon
[201] Kroonblaadje 1995, expert opinion O. Beaujon
[202] Segers, 2000
[203] Ritchie, 1975 and Woodforde, 1970

rising share of electricity for steel production, which compensates the reduction of CO_2-emissions from coal during the steel production process. Since energy use and emissions are expressed per passenger km, we may not forget the impact of the rising life span and the decreasing seat occupancy. Both effects do not compensate each other completely, since the life span expands with factor 3 and the seat occupancy decreases with a factor 2. The overall effect of both enables thus a reduction of energy use and emissions per passenger km.

The fuel consumption expressed in MJ per vehicle km (not on graph) is reduced between 1925 and 1960 (by 40%) but from then on it remains more or less stable. This is a remarkable fact, which can be explained by the increasing weight of cars between 1960 and 2000. Engine technologies became more efficient, but this was countered by other developments that had a negative impact on the efficiency: emissions reduction technologies, safety and comfort provisions and also the wish of the consumer (more power, larger cars). Figure 22and Figure 23 present the energy (fuel) consumption and emissions during the consumption phase, the **driving** of a car, expressed per passenger km. Taking into account the decreasing seat occupancy, the energy (fuel) consumption per passenger km shows a slight increase between 1925 and 2000.
Before 1960 no emission control systems were present in cars. The fume of crankcase were even sent into the atmosphere while driving. It is a known source of non-tailpipe emissions but we could not compute the amount. Engine technology was not optimised which led to the forming of many CO-emissions while the relative low combustion temperature limited the emissions of NO_x. Per vehicle km CO-emissions of cars continuously decreased between 1925 and 2000. In the 70’s the first regulations were set up with regard to CO-emissions which led to the improvement of inlet systems and a richer mixture. Decreasing CO-emissions contribute to higher CO_2-emissions per vehicle km between 1960 and 2000. Lead was not yet a problem in 1925 since no lead was added to petrol in that time. In 1960 the lead emissions were high because of the high lead content of petrol which was necessary to prevent the knocking tendencies of gasoline and thus permit the use of higher engine compression ratios. In the 70’s the negative health effects of lead became clear and in 1981 the first regulation came into force. This is the reason for the enormous decrease of Pb-emissions by cars between 1960 and 2000. Another reason for the banning of lead out of fuels is the introduction of the catalytic converter. SO_2-emissions show a decreasing trend between 1925 and 2000, which is due to the lowering of the S-content in the fuel. Restrictions for S-content in fuels were introduced in 1980, however in the 90’s the regulations became very strict. The reduction of the S-content in petrol and diesel fits in with the strive for an optimal functioning of new engine technologies and emission control systems. The NO_x-emissions are mostly related to the engine technologies (the combustion temperature etc.) and therefore show a varying trend until 1975. In 1977 a first NO_x-regulation was introduced and from then on the NO_x-emissions decrease. In the late 20^{th} century car constructors developed engine management systems that enabled a controlled ignition moment which, combined with the catalytic converter, led to much lower emissions of CO and NO_x. If we look at the emissions per passenger km, the decreasing seat occupancy rate must be taken into account, which reduces the effect of the decreasing emissions per vehicle km.

It is clear that the development of the engine is influenced by the need to comply with emission regulations for specific pollutants (CO, NO_x, SO_2) leading to lower emissions per vehicle km. However higher consumption levels because of the booming of car ownership and use cause an increasing contribution to total emissions. If we take into account the **Belgian consumption** of car transport (total amount of passenger km driven) in the key years, we notice a booming trend between 1925 and 1960 (factor 15 more cars). Between 1975 and

2000 the car fleet doubles again. Since the fuel consumption per passenger km is almost stable in the entire period 1925-2000, the total energy consumption for car transport in Belgium increases heavily, especially from 1960 onwards (see Figure 24). The same trend is visible for the total CO_2-emissions due to car transport in Belgium (see Figure 25). However the NOx-, SO2- and CO- emissions show a slight decrease between 1975 and 2000, despite of the rising consumption. We can assume a small "decoupling" of these types of emissions and consumption from 1975 onwards, caused by the introduction of emission regulations.

Train transport
Figure 26 to Figure 31 show the results of the environmental analysis of train transport.
The first two figures present the energy consumption respectively emissions that occur during the production of the train and more specific during **steel production**, related to 1 passenger km (functional unit). As discussed above, due to lack of data we only studied the steel production phase regarding the production of a train. When we look at Figure 26 we see a decline of the energy consumption per passenger km between 1925 and 1975. After 1975 the energy consumption per passenger km increases. The decline between 1925 and 1975 is due to:

- decreasing energy consumption per tonne steel production between 1925 and 2000 because of more efficient steel production technologies;
- longer life span of a train from 1960 onwards compared to 1925 (factor 2).

Both energy decreasing factors are opposed by the following:

- the declining seat occupancy of trains during the entire period (30% decrease between 1925 and 2000);
- the rising amount of steel per train due to the rising weight of trains and the higher share of steel. Trains become heavier because of higher demands on safety and comfort, especially between 1975-2000. Out of scope of this study we know that the recently introduced double deck trains need much less weight per passenger seat.

Between 1975 and 2000 the last two factors are not compensated anymore by the more efficient steel production which explains the rising energy consumption per passenger km.

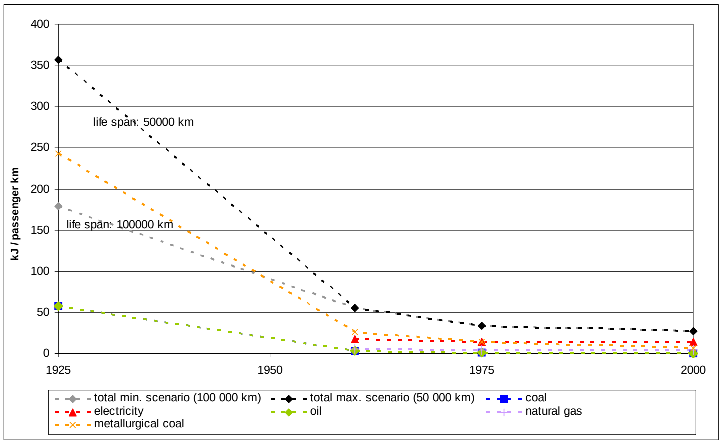

Figure 20 : Energy consumption for steel production (per passenger km)

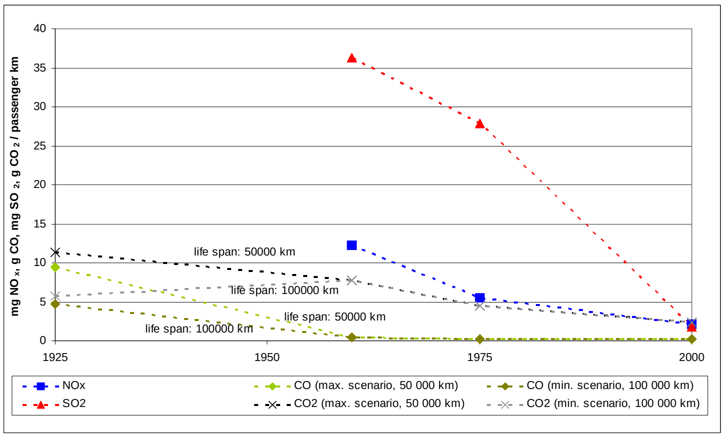

Figure 21 : Emissions caused by steel production (per passenger km)

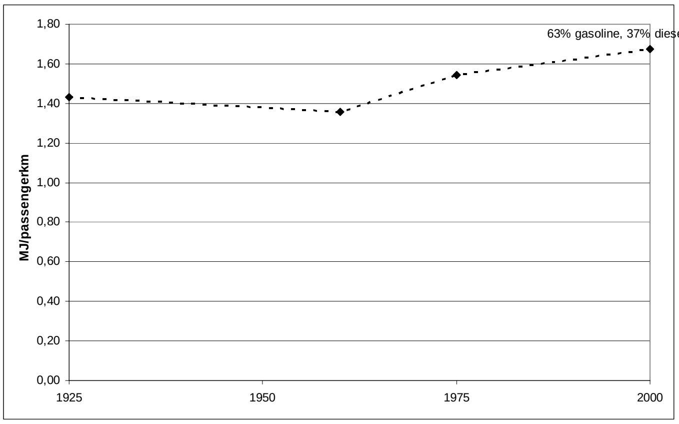

Figure 22 : Energy consumption for driving a car (per passenger km)

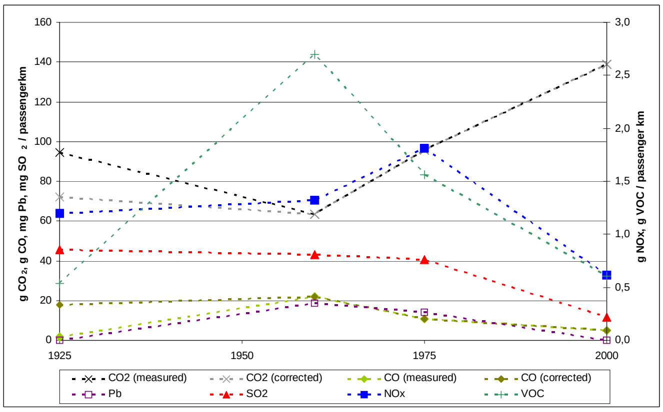

Figure 23 : Emissions caused by driving a car (per passenger km)

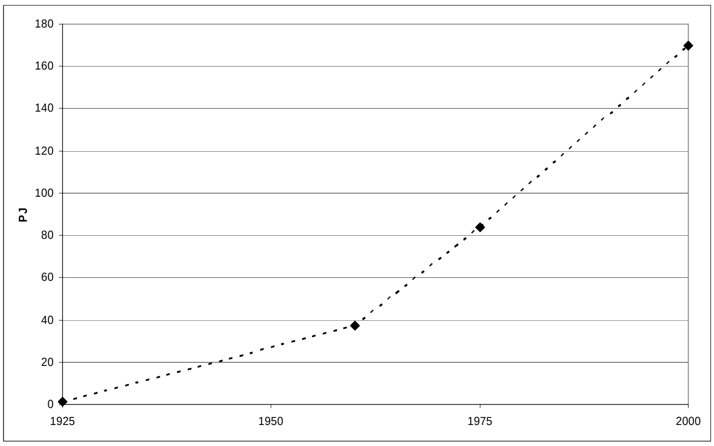

Figure 24 : Total energy use for car transport in Belgium

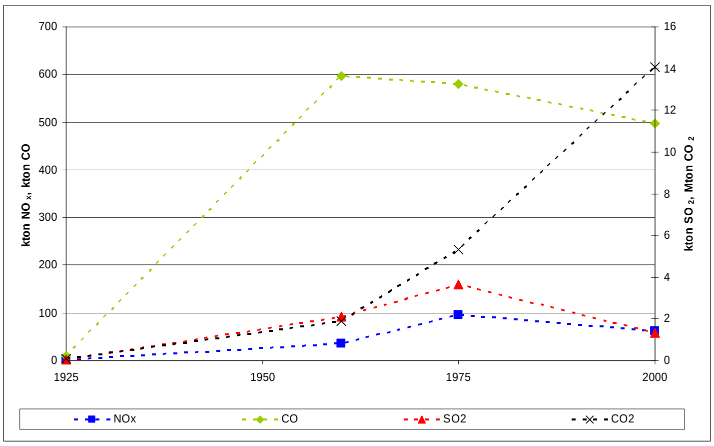

Figure 25 : Total emissions caused by car transport in Belgium

NO_x- and SO_2-emissions in Figure 27 are due to the production of electricity, which became an energy source for steel production in 1960. The power stations reduced both type of emissions between 1960 and 2000. The reduction of SO_2-emissions between 1960 and 1975 was only small and not enough to compensate for the larger input of steel per train and the decreasing seat occupancy. Taking into account the larger steel input per train we notice that the amount of electricity for steel production is more or less stable between 1960 and 1975. The previous reasoning explains the temporary rise of SO_2-emissions between 1960 and 1975. After 1975 both emissions were largely reduced for what concerns electricity production which explains the overall decrease of SO_2- and NO_x-emissions. The CO- and CO_2-emissions are an addition of process-related and energy-related emissions during steel production and process-related emissions during electricity production. Both emissions were largely reduced during steel production as well as during electricity production. However the increasing share of electricity instead of coal for steel production counteracts this effect. The increasing CO_2-emissions between 1925 and 1960 are due to the rising share of electricity for steel production, which is higher than the reduction of CO_2-emissions from coal during the steel production process. This effect is enlarged by the rising amount of steel per train. Since energy use and emissions are expressed per passenger km, we may not forget the impact of the rising life span between 1925 and 1960 and the decreasing seat occupancy over the entire period.

Figure 28 shows that the energy needed for **driving** a train (expressed per passenger km) decreased over the entire period. The large reduction before 1975 is caused by the transition from the energy-intensive steam traction into the more energy-efficient electrical traction (and to a lesser extent diesel traction). In practice steam traction is stopped in 1966, so the large reduction in energy consumption stops in 1966. The small reduction between 1975 and 2000 is due to the higher weight of trains (because of better comfort and safety regulations) which almost compensates the rising share of more efficient electrical traction. All studied emissions (CO, CO_2, NO_x, SO_2) are reduced over the entire period 1925-2000 due to the transition from coal to electricity and the emission reduction efforts on trains. The small increase of CO-emissions between 1975 and 2000 is caused by the fact that the CO-emission/MJ diesel increased a little in this period which is enlarged by the declining seat occupancy of trains.

Unlike car transport, the evolution of train transport is particularly characterized by a change in traction technology, and related to this by a change in fuel type. This contributes most to the energy and emission reduction of train transport. If we look at Figure 30 and Figure 31 we notice a continuous reduction in energy use and emissions for train transport in Belgium. Only the CO-emissions between 1975 and 2000 did not follow this reduction because of reasons explained before. The **consumption** of train transport (number of passenger km) rose between 1925 and 1960, since 1975 passenger km stabilised. For train transport we thus may conclude that a decoupling has occurred between consumption and environmental effects.

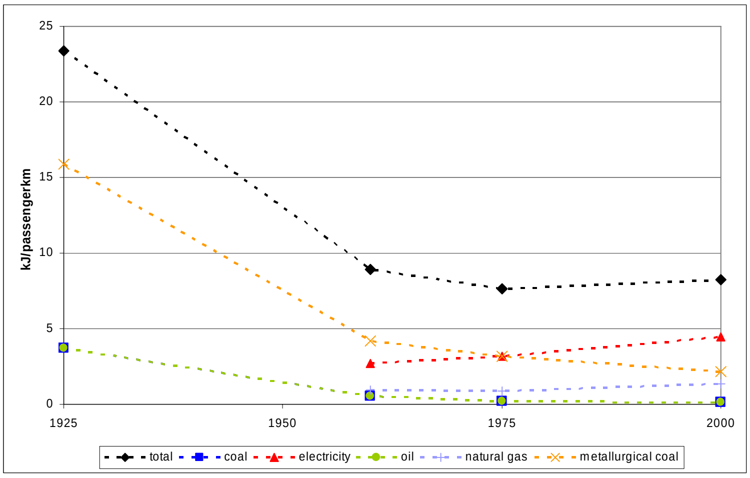

Figure 26. Energy consumption by steel production (per passenger km)

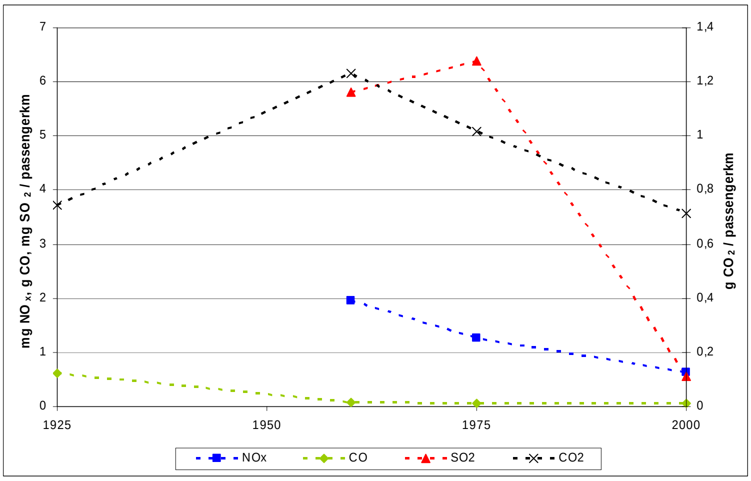

Figure 27. Emissions caused by steel production (per passenger km)

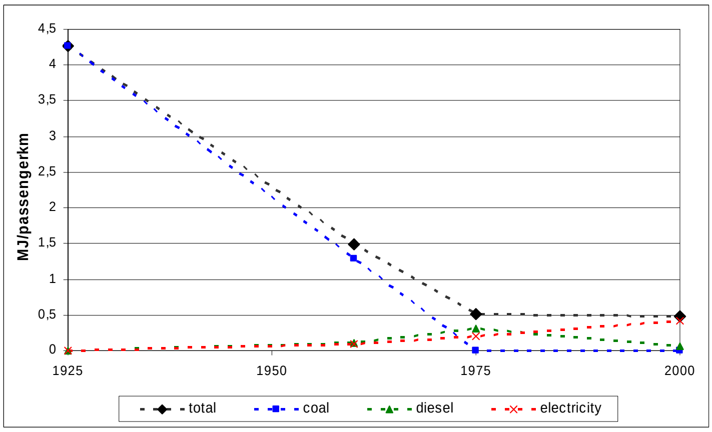

Figure 28. Energy consumption by driving a train (per passenger km)

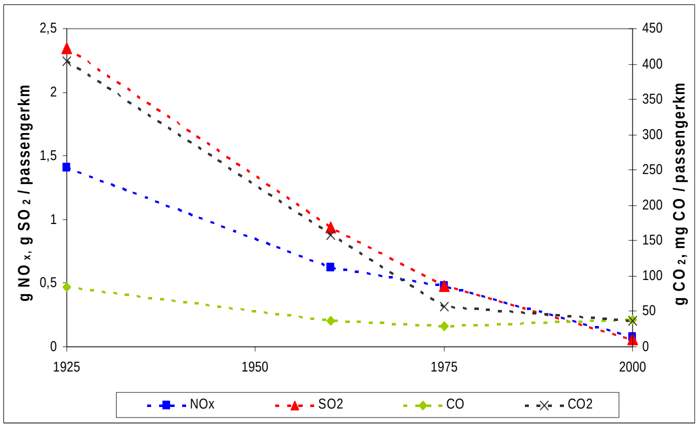

Figure 29. Emissions caused by driving a train (per passenger km)

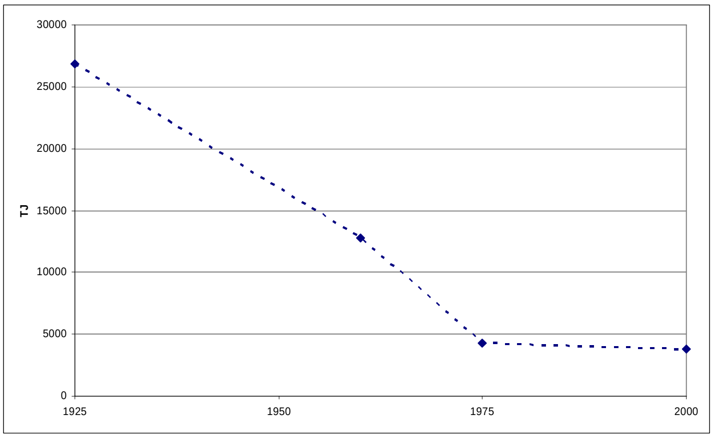

Figure 30. Total energy use for train transport in Belgium

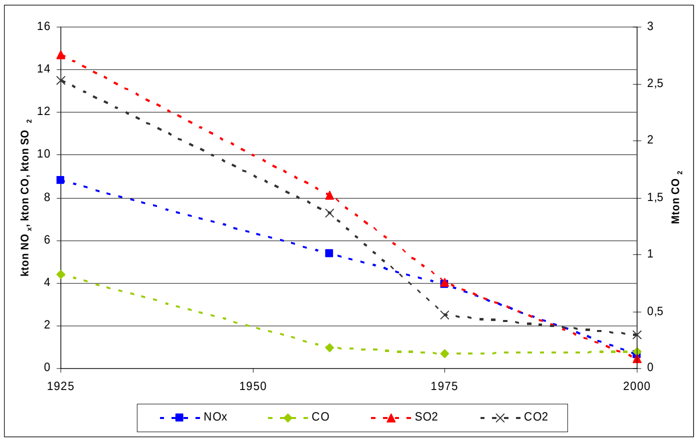

Figure 31. Total emissions caused by train transport in Belgium

Bicycle transport

The environmental analysis of transport by bicycle is limited to the steel production for the bicycle, since no energy use and emissions occur while driving.

Figure 32 shows the energy use per passenger km for producing the steel for the bicycle. The decrease between 1925 and 2000 is logical because steel production technologies become more efficient and because the amount of steel per bicycle decreases. The small increase between 1925 and 1960 is completely due to the lower life span of a bicycle in 1960 compared to 1925 (factor 2.5 lower), which compensates the lower absolute energy consumption per bicycle. The emissions shown in Figure 33 are directly related to the steel production technologies. The increase in CO_2-emissions between 1925 and 1960 is again due to the lower life span and the fact that the CO_2-emissions due to electricity production are higher than the avoided CO_2-emissions for the switch from coal to electricity.

Since the total number of passenger km remain more or less stable during the entire period Figure 34 and Figure 35 follow the same trend as the previously discussed figures (expressed per passenger km).

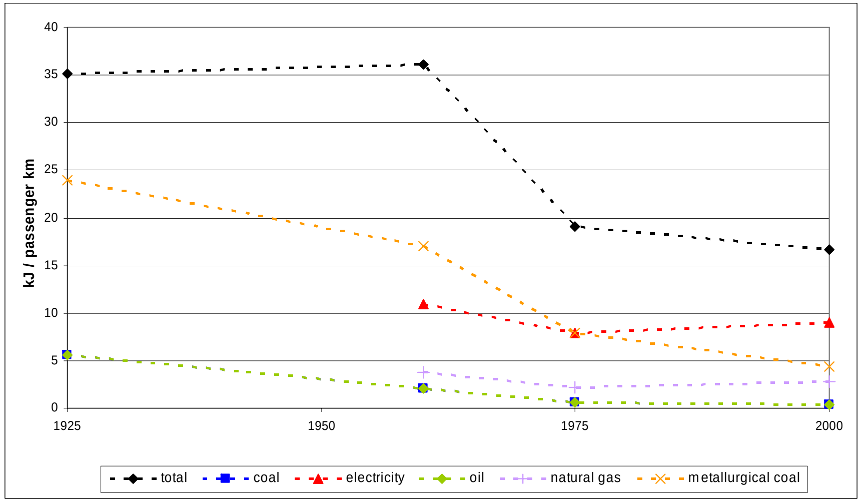

Figure 32. Energy consumption by steel production (per passenger km)

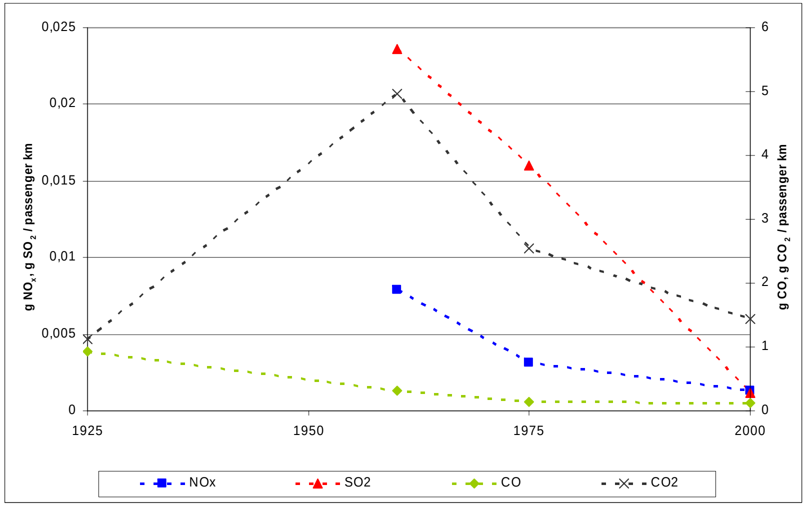

Figure 33. Emissions caused by steel production (per passenger km)

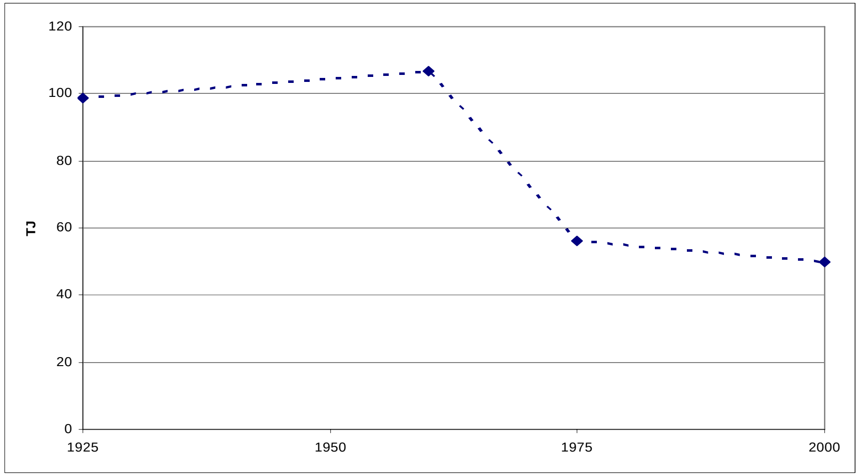

Figure 34. Total energy use for bicycle transport in Belgium

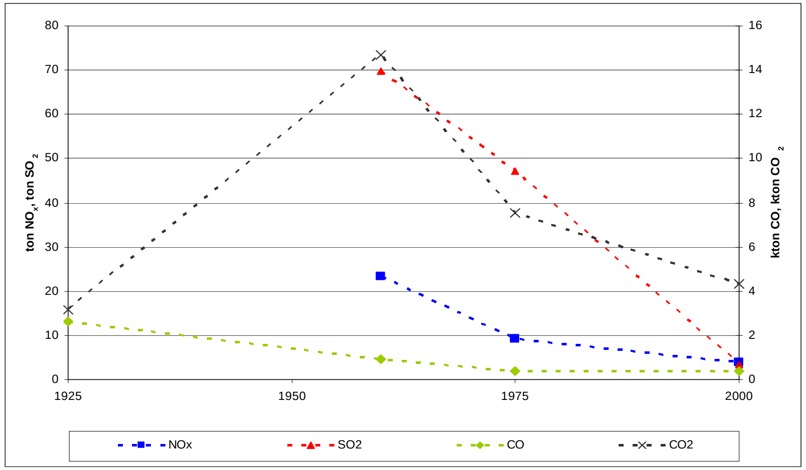

Figure 35. Total emissions for bicycle transport in Belgium

5.2.3. Social and economic perspective

As mentioned in the status description of this case study, the different means of transport do not really substitute each other at a particular moment in time. Nonetheless, when examining the consumption figures (Table 4), it is possible to retrieve a shift in 'popularity'. Moreover, these figures show an increasing 'availability' for each of the modes of transport, which is an underlying social dimension (e.g. the car only becomes available for the major part of the population after World War II).

	Number of train passengers[204]	Number of bicycles[205]	Number of cars[206]	Number of passengers on a district railway system[207]
1850	4 903 000			
1900	139 138 000	116 223	1 484	6 840 456
1925	225 175 760	1 405 154	54 401	
1950		2 980 201		266 890 224
1960	261 366 000		753 136	
1975	232 099 000	2 947 926	2 613 835	240 114 000
2000	153 299 000		4 678 376	

Table 4 : Consumption figures of different means of transport[208]

In the second half of the nineteenth century, the number of train passengers grows enormously. This is mainly due to government's policy. In 1869, the Belgian government decided to issue special working men's subscriptions. This way, the working men were encouraged to keep on living on the countryside (the government wanted to avoid overpopulated cities, epidemics and an agricultural crisis). From 1887 onward the subscriptions can even be used on Sunday[209]. In 1907, 43% of all train passengers had working men's subscriptions[210]. In the same period, the number of people employed by the national railroad company increases tenfold[211].

It is clear that the car is the most important transport mode since the 1960s and especially in the last quarter of the twentieth century. At the end of the 1980s, there are even more cars than households in Belgium (Figure 36).

[204] Annuaire statistique de la Belgique (1901). NIS, Statistisch jaarboek van België (1976). NIS, Statistisch jaarboek voor België (1952). NIS, Regionaal statistisch jaarboek 1999 (2000). Y. Segers (2002).

[205] Y. Segers (2002). NIS, Statistisch jaarboek van België (1976). NIS, Statistisch jaarboek voor België (1952).

[206] Y. Segers (2002). NIS, Statistisch jaarboek van België (1976). NIS, Statistisch jaarboek voor België (1952). NIS, *Regionaal statistisch jaarboek 1999* (2000).

[207] Annuaire statistique de la Belgique (1901). NIS, Statistisch jaarboek van België (1976). NIS, Statistisch jaarboek voor België (1952). Y. Segers (2002). B. Van Der Herten (2004).

[208] These figures could not be retrieved for each of the key years, that is why some spaces are left blank.

[209] *Pasinomie* (January 18th 1887).

[210] B. Van Der Herten et.al. ed. (2001), p. 322-335. *Pasinomie* (1868-1888).

[211] These figures were retrieved from the Yearbook of the National Railroad Company (NMBS).

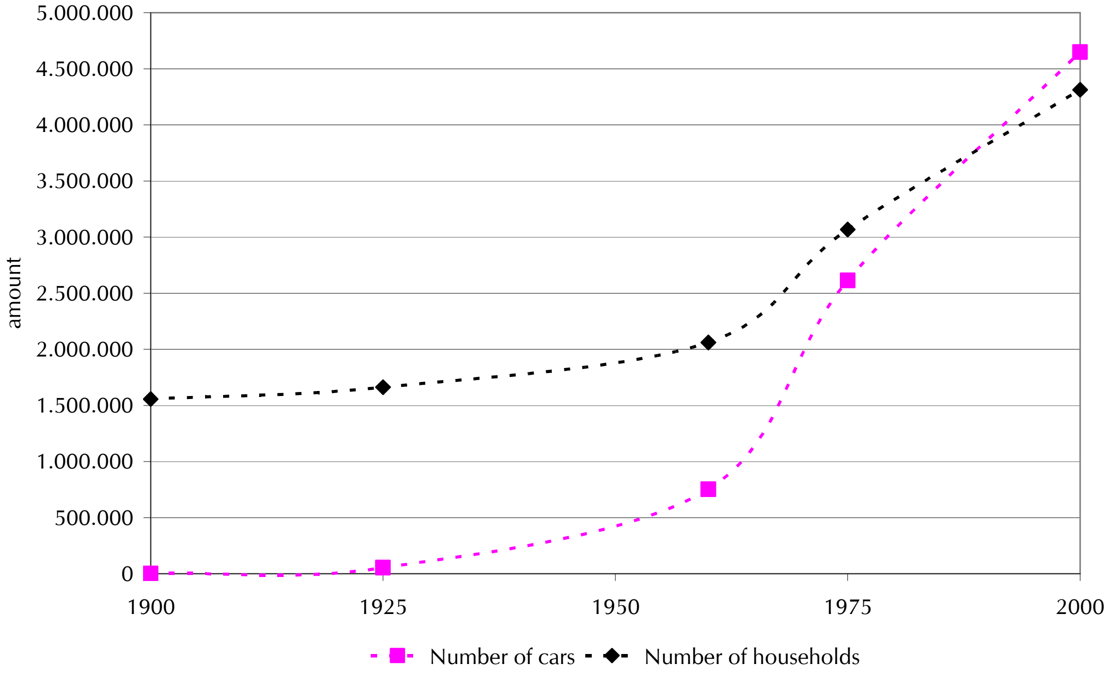

Figure 36: Belgian cars and households

The same evolution can be retrieved from Figure 37[212].

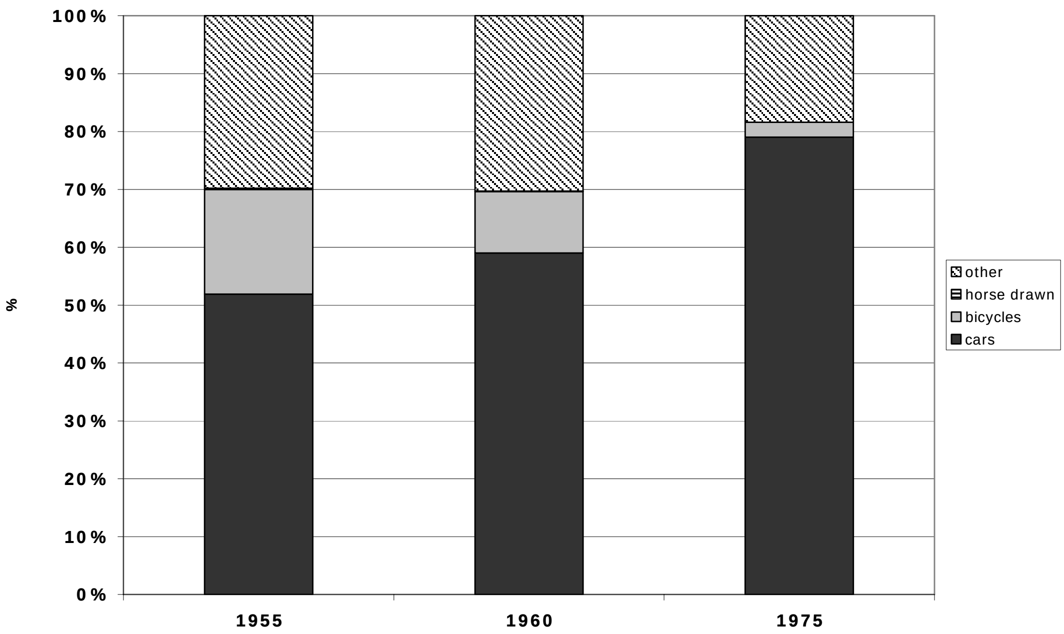

Figure 37: Proportion of road vehicles

In order to achieve an increase in consumption, the necessary infrastructure was to be provided for. In Belgium, local and central governments played a large part in developing a national transport network[213].

[212] NIS, *Recensement* (1975).

	Road network (km)[214]	Railroad network (km)[215]	District railway system network (km)[216]	Number of train stops[217]
1830	3 241.4			
1850	6 236	902		111
1900	9 364.39	4 562.33	1 819.97	1 472
1950	10 868.22		4 823.97 (in 1951)	1 565
1960	11 600	4 632		1 366
1975	12 301	3 992	14 094[218]	1 070
2000	144 914 (in 1997)	3 471		

Table 5: Evolution of the infrastructure[219]

Together with this expansion in infrastructure, transport becomes affordable for a major part of the population. Table 6 shows a dramatic decline in real prices[220].

	Real car price (labour days/car)	Real gas price (labourdays/30l)[221]	Real bicycle price (labour days/bike)
1900	2 716.15		80
1925	1 533.82	2.37	25.5
1960	322.47 (in 1962)	0.6 (in 1967)	7.82 (1961)
1975	168.68	0.55	
2000	125.41	0.28	2.90

Table 6: Real prices[222]

Higher wages only partly explain this trend in real prices. When looking at the real price of gas, an important decrease between 1925 and 1967 may be retrieved. This might be explained by better production techniques and an increase in oil rigs, as a consequence of an increasing demand for fuel. Between 1967 and 1975 gas prices do not further diminish at the same rate,

213 B. Van Der Herten (2004).
214 B. Van Der Herten (2004). Annuaire statistique de la Belgique (1901). NIS, Statistisch jaarboek van België (1976). NIS, *Statistisch jaarboek voor België* (1952). NIS, *Regionaal statistisch jaarboek 1999* (2000).
215 B. Van Der Herten (2004). Annuaire statistique de la Belgique (1901). NIS, Statistisch jaarboek van België (1976). NIS, *Statistisch jaarboek voor België* (1952). NIS, *Regionaal statistisch jaarboek 1999* (2000).
216 B. Van Der Herten (2004). Annuaire statistique de la Belgique (1901). NIS, Statistisch jaarboek voor België (1952). NIS, *Statistisch jaarboek van België* (1976).
217 B. Van Der Herten (2004). NIS, *Statistisch Jaarboek* (1901-1952-1976).
218 13 878 km of this network was used by bus services.
219 These figures could not be retrieved for each of the key years, that is why some spaces are left blank.
220 C. Schroeven (1994). Dienst Indexcijfer (2000). C. Vandenbroeke (1988). NIS, *Brutolonen 2000* (www.statbel.fgov.be)
Email from Patrick Vranken, head of the Department for Consumption figures (POD Economics).
We did not include prices for traintickets, since it is very difficult to compare these prices over the years because of different conditions and price policies.
221 Except for the year 2000 (unleaded gas), these are the prices for 'gas'.
222 These figures could not be retrieved for each of the key years, that is why some spaces are left blank. (calculation: see Annex 4)

probably as a result of the oil crisis. The decline between 1975 and 2000 is again more substantial. However, different sources were used for these key years. This might be the cause of this 'trend rupture'[223].

The real price of cars also shows a dramatic decrease over the twentieth century. Before World War I, European constructors thought of the car as a luxury product and prices were high. Ford, however, wanted to produce a car that was affordable for the masses. The assembly-line in his factories permit to produce more and cheaper cars. After World War I, American cars are imported in Europe and prices decline. Moreover, European constructors also start to conceive of the car as a utility. However, it is only since the 1950s that cars are available for a major part of the population[224].

The decline in the real price of the bicycle might also be explained by the use of better production techniques.

Although the real prices decline and the availability of transport modes grows, the percentage of the total private expenses spent on purchasing 'transport', increases (Figure 38) [225].

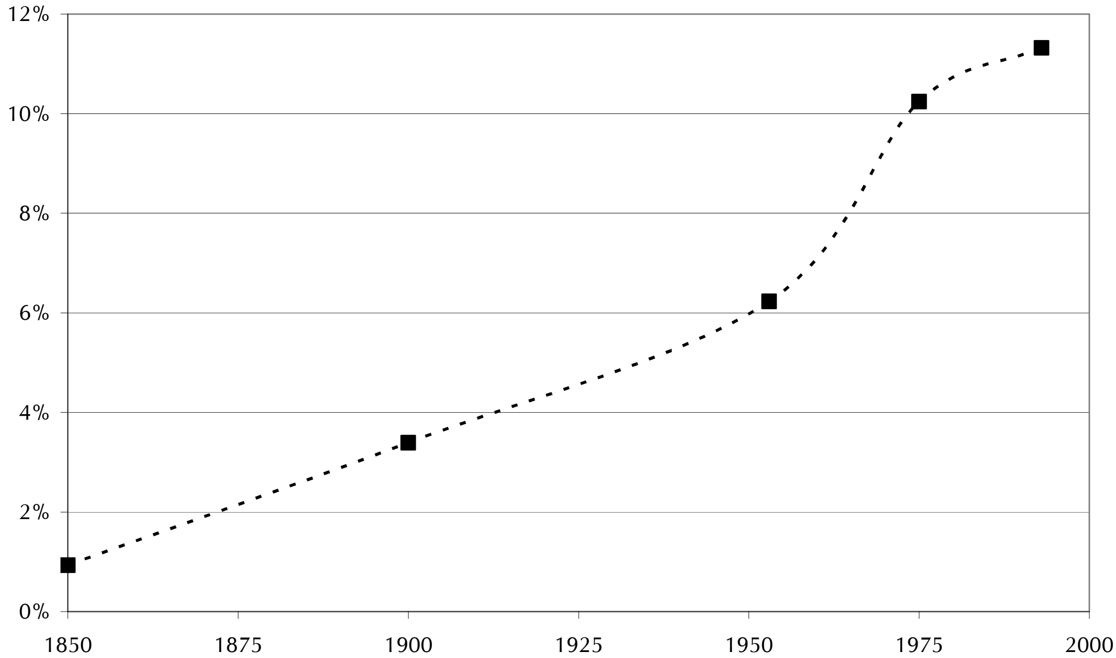

Figure 38: Private expenditure on transport

At the turn of the century, expenditure on transport increases, because of the growing popularity of trains (working men's subscriptions), trams and bicycles. In the first half of the

[223] These difficulties were mentioned before (the search for relevant data sources).

[224] P.E. Staal (2003), p. 11.

[225] Y. Segers (2002).

The percentage was retrieved by using the private consumption figures (the amount spent on transportation divided by the total amount of the private expenses). The following elements were taken into account. In 1850: horses and trains In 1900: horse, bicycle, car, tramways, district railway systems, train. In 1960 (1953) and 1975 other elements were considered: the purchase and use of a vehicle, urban transportation modes, district railway system, busses, train. In 2000 (1993) the following elements were taken into account: the purchase and use of a vehicle, urban and regional transportation modes, train.

NIS, Nationale rekeningen 1953-1962 (1963). NIS, Statistische studiën, 45(1976), blz. 1 e.v. , NIS, Statistische studiën, 101 (1994), blz. 1 e.v.

twentieth century the increasing trend slows down. No new means of transport are introduced and the two World Wars slow everything further down. Since the 1960s, the growth is almost entirely due to the growing popularity and availability of the car. Moreover, people become more ‘mobile’: they need transport to work (due to suburbanisation), to get to the supermarket, during leisure time,… .

5.2.4. Sustainability trends

Introduction

Car

Car technology experienced an enormous development between 1925 and 2000. The development of a self-supporting body caused a huge decrease of the weight of a car and, thus, the share of steel in cars. In the second half of the 20^{th} century the requirements with regard to safety, comfort and emissions (in a later stage) on the one hand and the new developments like control and coupling technologies and heavier engines on the other hand resulted in a slightly increasing weight. Engine technology also improved substantially, however combined with the extra emission reducing measures this did not result in a significant reduction of fuel consumption. Since 1980 diesel cars were, especially in Belgium, more frequently used. In the beginning of the 20^{th} century the developments are especially focussed toward more safety and comfort for the occupants, but later on the automobile sector focussed more on the reduction of specific emissions and fuel consumption, while safety is still an important issue.

Train

When we look at the production of locomotives and carriages both became a lot safer for the train driver as well as for the passengers. One evolved from wooden carriages where the passengers and the conductor needed to walk on the outsides to pass to another compartment over a passage through the interior of the carriage to metal carriages. The comfort of the passengers increased over the years which is e.g. visible in the increasing share of steel per passenger (in carriages).
The technological aspect of train transport (type of fuel and combustion technology) also shows a significant evolution. In the beginning of the 20^{th} century only steam traction existed. Later on the diesel trains were introduced (until now diesel locomotives are still running in Belgium, especially for freight transport) followed by the electrical trains. Heavy investments were needed to electrify the network of railway lines.

Bicycle

Bicycles show a significant evolution before 1900, but since the development of the so-called “safety bike” in the beginning of the 20^{th} century very few major technological developments occur. One important improvement is the development of the gear. From 1960 onwards bicycles did not change very much: they became a little lighter and more comfortable because of the use of other materials and refinements of the frame structure.

Sustainability assessment

Car

Car transport in Belgium shows a booming trend in ownership between1925 and 1960 (by factor 15). Afterwards this slightly slowed down, but the car fleet still doubles between 1975 and 2000. Since fuel consumption per vkm of cars did not decrease that much in this period and cars are driven at a continuously rising yearly kilometrage, it is obvious that the total

energy consumption for car transport in Belgium increases heavily. The CO_2-emissions, that are directly related to the energy consumption, also increase during the 20th century. The NO_x-, SO_2- and CO- emissions show a slight decrease between 1975 and 2000, despite of the still strongly rising consumption. This is due to the fact that these pollutants are subject to emission regulations which incited the automobile sector to develop and introduce specific emission reduction provisions. We may detect a “decoupling” for these types of emissions and consumption from 1975 onwards, caused by the introduction of emission regulations and the availability of technological solutions.
With regard to social aspects of transport by car we may conclude that much attention is paid to the safety of cars and the comfort of the occupants. The extra safety provisions resulted in less casualties, but they also increased the average weight of a car. A policy measure that also reduced the number of casualties with a negligible additional weight for the car was the obligation to place and use the safety belt in cars (see Annex 4). So, apparently in this case the social advantage of less casualties is considered more important than the additional environmental impacts.
The availability of car transport also increased, especially since 1950, thanks to the decreasing “real prices” of a car.

Train
The evolution of train transport is characterized by an increasing comfort and safety level and by a change in traction technology and, related to this, by a change in fuel type. Thanks to the improvements in traction technology and fuel, the energy consumption and emissions of train transport in Belgium continuously decreased nonetheless train transport became more popular between 1925 and 1960. One has to keep in mind that between 1975 and 2000 the number of passenger kilometres for train transport decreased. For train transport we can conclude that a decoupling has occurred between consumption and environmental effects as environmental emissions have decreased more than proportional to the decrease.

Bicycle
The number of bicycles remained more or less stable since 1960. Environmental impacts related to bicycle transport are mainly caused by steel production. The weight of the bicycles also stabilises in the 20th century, while steel production technologies became more efficient. This causes a reduction of energy consumption and emissions due to bicycle transport in Belgium.

(Un)-sustainability conclusions

By combining the outcome of the environmental assessment (based on the total Belgian consumption for transport) and socio-economic historical trends, we reached a number of conclusions regarding (un)sustainability:

- The rise of a transport means (bicycle, train, car) is mostly due to the same arguments: flexible, reliable, affordable and an enlarging view of the society. Both the bicycle and the car were first only available for the rich people and were considered to be a “status symbol” that distinguished them from the others. Only when these means of transport become cheaper, a booming trend occurs. The train on the contrary was, partly due to governments’ efforts, directly available for all people, however the three classes of carriages distinguished the rich class from the others.
- The declining price of cars and bicycles was due to the improved production technology. Train transport became affordable due to governments’ efforts (investments in infrastructure and attractive working men’s subscriptions).

- Regulations with regard to safety and environment came only into being after the rising use of the transport mode. In the early stages of a vehicle's existence the safety and comfort of the vehicles was limited and no attention was paid to environmental impacts. Only when the transport means became widely used, more attention was paid to the safety of the passengers. In a later stage the focus was more towards the improvement of the comfort of the passengers. And it was only when regulations appeared (since 1970s) that producers focussed on reducing the environmental impacts.
- The relation between the expansion of the infrastructure and the success of a transport mode is different for car and train transport. The success of the train is partly due to a government push (expansion of network, workers subscriptions), while for car transport it seems to be the other way around: the booming of the car fleet pushed the government to expand the road network.
- During the 20th century we see a shift in popularity between the three transport types. One chooses commonly for the most fast, flexible and affordable (available) transport mode. In the beginning of the 20th century bicycles were most popular because trains were at that time rather expensive, this evolved into the train being most popular when it became cheaper. Cars then were not yet affordable for the wide public. Since the time cars became cheaper, they became most popular because of their flexibility.
- Related to the previous aspect it is clear that the three transport modes do not substitute each other, but co-exist (for example one uses the type of vehicle that is most suited for the type of transport step that is needed) and supplement each other (for example one drives with a bicycle or car to the train station).
- With regard to the environment, regulations existed since 1970. Since then emission reduction provisions are implemented on cars, the composition of petrol and diesel changed etc. This causes two opposite effects: the specific emissions decline, but the weight of a car increases due to the emission reduction provisions which causes an increase of fuel consumption and thus CO_2-emissions. It is remarkable that the technological improvements in car transport were much less radical than in train transport. During the 20th century train traction evolved from steam traction over diesel to electrical traction, which is much more energy-efficient. Due to these radical changes the same movement by train became more sustainable in the course of the 20th century.
- With regard to car transport it can also be concluded that the car producing industry makes efforts to reduce emissions, but consumers tend to buy larger and heavier cars even though the small, more energy-efficient cars are available on the market. This tendency increases the emissions per vehicle.

5.3. Case study : Drinking water

5.3.1. Status description

Roman aqueducts are a well-known example of a water supply system in ancient times. These aqueducts distributed water from the rivers East of the city of Rome, to the town centre, where it was delivered to privileged users, thermae and public fountains. "Le service des eaux était, chez les Romains, destiné avant tout à satisfaire les besoins publics (fontaines, thermes) et à concourir à l'ornementation monumentale de la ville"[226]. Although they often were a

[226] L. Vire (1973), p. 4.

symbol of power, they were constructed in proportion to the demographic evolution of the population[227].
In the Middle Ages, a system based on wells and public fountains was established. However, these wells and fountains were primarily installed for security reasons in case of a fire. After all, water consumption before the 19th century is not to be compared with water consumption nowadays. People barely drank water. It was used for the preparation of meals, but this was a very limited use[228].
Mid-nineteenth century, there was a growing need for a water supply system, especially in the larger Belgian cities. Typhoid and cholera caused substantial damage among the Belgian population (Table 7) [229], and there was a growing belief in the connection between these diseases and polluted water (although it could only be proved at the end of the nineteenth century, when bacterial research was developed)[230].

	Men	Women	Average total death rate
1832-1833	3 901	4 083	104 200
1848-1849	11 566	11 461	104 050
1866	22 435	20 965	114 497

Table 7 : Deaths by cholera in Belgium

This conception of public hygiene (related to population growth and urbanization) coincided with an evolution in the concept of water distribution[231]. New characteristics of a water supply system were the importance of a theoretical foundation for the supply system, the search for new technical possibilities, the availability of financial resources and the growing awareness of the importance of clean water for the entire population[232]. Nonetheless, at first all political attention was fixed on improving the quality of drinking water for the city elites (since they realized they could also be affected by diseases like cholera). Existing water supply systems were fixed, but these could not see to the needs of the growing population. In Brussels, several hygienic committees were founded in 1849[233]. These committees were to organize a new water supply system. However, in 1852, a new local government was formed and the hygienic committees were pushed into the background[234]. Success of operation was subject to the power relations between actors (hygienists, inhabitants, government,…)[235]. In Antwerp too, the necessity of a new water supply system was doubted by the ruling classes. In 1868, the mayor states: “Men zegt dat het water slecht is; maar als ons drinkwater zoo ongezond is, weet ik niet hoe het komt, dat de heeren leden van den Raad er zo gezond uitzien”[236].

[227] W. Van Craenenbroeck ed. (1991), p. 17.
[228] W. Van Craenenbroeck ed. (1991), p. 19.
[229] Annuaire statistique de la Belgique (1901). Statistisch jaarboek (1870).
[230] B. Decruyenaere (1994), p. 20-22.
[231] This conception was still a very important issue at the beginning of the twentieth century. In 1937 for example, the Royal Committee for Public Welfare was established.
Pasinomie (1937).
[232] L. Vire (1973), p. 6.
[233] *Pasinomie* (January 26th 1849). “Commissions sanitaires locales. Institutions dans les communes où cette mesure sera reconnue nécessaire.” *Pasinomie* (May 15th 1849). Establishment of the “Conseil Supérieur d’Hygiène”.
[234] L. Vire (1973), p. 93.
[235] H.W. Lintsen e.a. ed. (1993/2), p. 17.
[236] W. Van Craenenbroeck (1998), p. 33.

Notwithstanding these constraints, a new water supply system was put into use in Brussels in 1858. Other cities followed the example of the capital: Liège in 1863, Mons in 1871, Antwerp in 1881 and Leuven in 1890. The industrial and trade expansion, the population growth and the development of residential districts (with modern sanitary equipment) at the city boundaries, were decisive for the municipal governments to, eventually, start the development of a new water supply system[237].

At first, only the well-to-do class had access to potable water from within their houses. Other inhabitants had to use the public fountains to fulfil their needs[238]. However, in a time period of a century, the water supply system in Belgium expanded dramatically (see Figure 39).

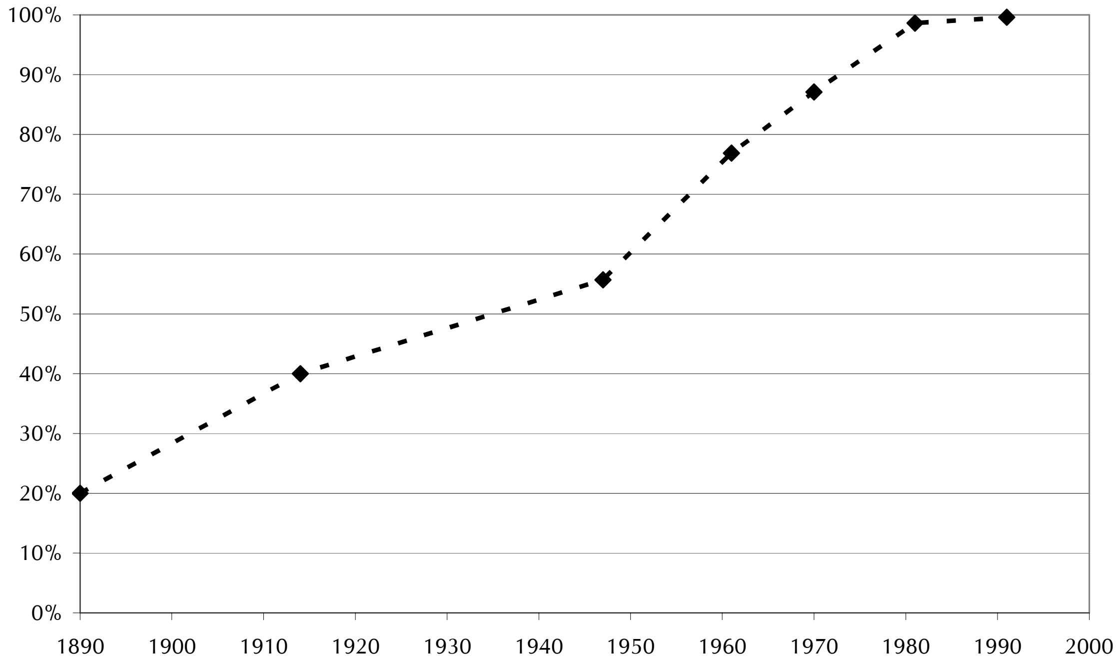

Figure 39 : Population with access to water supply system

From a luxury product for the wealthy town-dwellers, clean drinking water became a basic element for (almost) every household in Belgium (even though the number of households also increased in the twentieth century). The Belgian government played an important part in this evolution. In 1907, the first law regarding intermunicipal companies was ratified[239]. From that moment, municipalities could join forces to produce and distribute potable water. This way, the central government provided a legal basis for this cooperation and it stimulated local governments to continue their way of working. An important aspect of this law is that it safeguards the sector against private investments, since it is an essential element in providing public welfare. Notwithstanding the creation of several other intermunicipal companies, the needs of the Belgian population could not be fulfilled. Therefore, in 1913, the *Nationale*

(*They say we have poor drinking water; but if our drinking water is unhealthy, how is it possible that the members of the Board all seem so healthy*) (translation by the author).

[237] W. Van Craenenbroeck (1998), p. 20-22.

[238] Although the different cities applied different rules. In Antwerp, the price of potable water was the same for every one. People who could not afford to pay for it, had to use the public fountains. While in Brussels, prices were adjusted considering the income, to stimulate the supply of water in working-class houses. W. Van Craenenbroeck (1998), p. 98.

[239] *Pasinomie* (August 18th 1907).

Maatschappij der Waterleidingen (NMDW, National Company of Water Supply Systems) was founded[240]. The main objective of this company, was to distribute drinking water to that part of the population that did not yet have access to a water supply system. After World War I, the range of the NMDW grew rapidly. However, it is only after World War II, that it expands dramatically. In 1965, the *Koninklijke Commissie voor het Waterbeleid* (Royal Committee of Watercontrol) was established. The main task of this committee was “de mobilisatie van voldoende watervoorraden om in de stijgende behoeften te voorzien onder zo voordelig mogelijke voorwaarden, zonder de eerbied voor het natuurschoon uit het oog te verliezen”[241]. This growth may also be illustrated by looking at the industrial censuses. The different kinds of occupation within the product system of drinking water have to do with water collection, water distribution and waste water purification. The 1846 and 1896 censuses make no mention of occupations in this sector. Water supply systems did not yet take root and this sector of industry was of no importance yet. In the twentieth century water collection and water distribution seem to provide the largest part of employment within the sector. The 1970 census also mentions waste water purification[242]. It is also noticeable that the part of ‘water professions’ increased proportionally to the part of the population with access to a water supply system.
At the end of the twentieth century, (almost) the entire Belgian population had access to clean drinking water via a water supply system[243]. In the environmental analysis, the characteristics of the water supply system will be examined more thoroughly.

	Production and distribution of potable water
1800-1850	(public and private) Wells or Water from ponds, ditches, canals
1900	(public and private) Wells or Water from ponds, ditches, canals or Start of public water supply systems
1950-1975-2000	Public water supply systems

Table 8 : Production and distribution of water in Belgium

5.3.2. Environmental perspective

The **goal** of this environmental analysis is to compare the environmental effects of producing and distributing drinking water in Belgium in 1800, 1850, 1900, 1950, 1975 and 2000. The **functional unit** is “the production and distribution of 1 m³ drinking water to households”. The **system boundaries** are shown in Figure 40. Note that the treatment of waste water in sewage works is not part of this study.

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[240] *Pasinomie* (August 26th 1913).
[241] *Omnilegie* (February 16th 1965). (*mobilizing a sufficient amount of water reserves to fulfill the growing needs as beneficially as possible, without compromising nature’s beauty*) (translation by the author).
[242] However, already in 1950, the Hoge Raad voor de Zuivering van Afvalwater was established. *Pasinomie* (1951).
[243] P. Cornut (2003), p. 42 e.v.

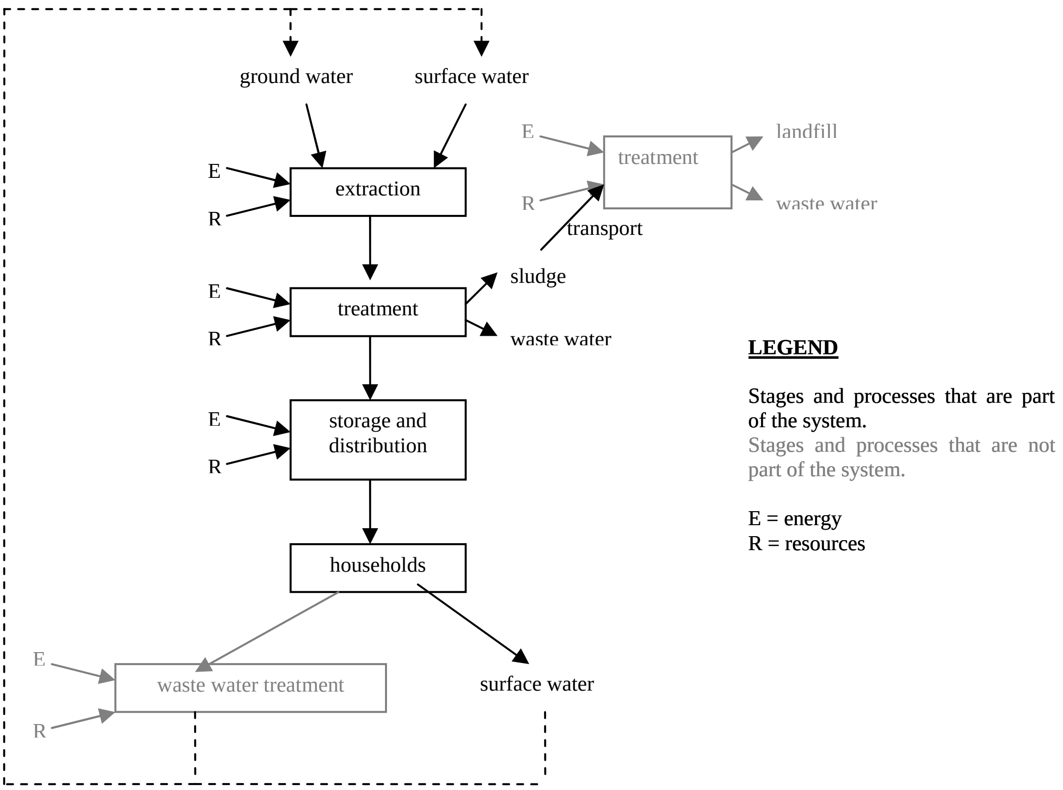

Figure 40 : Process tree and system boundaries for the production of drinking water

For the more recent years, many techniques exist for the production of drinking water and no two water producing facilities are the same[244]. In general, groundwater or surface water is first extracted and then treated and stored before it is distributed to the households. The treatment depends very much on the source of water. Oxygen-rich groundwater is generally only disinfected. Oxygen-poor groundwater is aerated, filtrated and disinfected. For surface water the possible treatment steps are: grids/sieves, flocculation/sedimentation, filtration, adsorption (active carbon), ion exchange, disinfection, removal of nutrients, membrane filtration, …. Of course, not all processes are used in all treatment facilities. Annex 7 illustrates the drinking water treatment processes for the more recent years (1975-2000) as well as for the 19th century.

Inventarisation

2000

The production process of drinking water differs not only from company to company, but also from site to site. It is not possible to choose one way of producing drinking water (from extraction over treatment until distribution to the client) that is representative for Belgium. Therefore it was decided to contact the four largest water companies and collect data on their production processes. Three companies chose to participate: AWW, BIWM and VMW[245], covering 58 % of the total drinking water production in 2000 (see Annex 3). The results obtained are considered to be representative for the whole of Belgium, even though the

[244] *Belgaqua, Blauwboek, 2003.* VMW, Mensen maken drinkwater, 2001

[245] Antwerpse Waterwerken, Brusselse Intercommunale Watermaatschappij, Vlaamse Maatschappij voor Watervoorziening

Walloon region is not as well represented as Flanders and Brussels. The drinking water companies have provided data about the amounts of energy and chemicals required to extract, treat and distribute drinking water, about the way the sludge from the production process is treated and about the kind and amount of materials used for their water mains and distribution and production infrastructure.
These data were combined with LCI-data about e.g. electricity production, transport and production of chemicals and building materials taken from well known LCI-databases[246].
Based on the information provided by the drinking water companies and the LCI-data, an environmental profile for drinking water production in Belgium was constructed for the year 2000. The following life cycle stages and processes are included[247]:

- Extraction and treatment of groundwater and surface water
    - Energy for extraction and treatment
    - Chemicals for treatment
    - Transport of chemicals to the company
    - Transport of sludge to the sludge treatment facility
- Storage and distribution to households
    - Energy for distribution
    - Water mains
    - Infrastructure for distribution (hydrants, pumping equipment)
    - Infrastructure for storage (water towers, reservoirs)
- Production infrastructure (drinking water production facilities and reservoirs)

1950 - 1975

There have been no major changes in water purification processes in the last century: almost all of the techniques in use today were already known at least a century ago. Processes have been fine-tuned but the basic principles remain the same. In recent years some new technologies were developed (e.g. membrane technology) or were re-introduced (e.g. ozone technology), but only as pilot projects or on very small scale. Therefore it can be said that broadly speaking the same processes are applied to purify water for the period 1900-2000.
During the inventarisation phase it became clear that it is not possible to obtain as much and as detailed data for the key years 1950 and 1975 as for 2000. Therefore the efforts were focussed on finding data for the processes which contribute most to the environmental impact of drinking water production in 2000[248]. The drinking water companies were contacted again and were asked to provide data on the energy and chemicals required to extract, treat and distribute drinking water in 1950 and 1975. Part of the data was found in company specific literature, but a substantial part of the information is based on expert opinions from company employees. The information about the amount of energy for extraction, treatment and distribution was combined with data on the production of electricity in the years concerned, which were found relatively easily[249]. Data on the production of the concerned chemicals in 1950 and 1975 however were not found. As an alternative, we have deduced data for the production of aluminium sulphate based on the evolution of energy improvements for the

[246] Preferably EcoInvent 1.1, EcoInvent Centre, Swiss Centre for Life Cycle Inventories, Dübendorf, 2004.
[247] Note on infrastructure: It is common practice not to include infrastructure in LCA's, since in practice it is shown that this has a negligible contribution to the total environmental impact (it is in use for many years and for the production of very large amounts of drinking water). However, we chose to include the infrastructure for the *distribution, storage and production* of drinking water in order to find out if the impact is indeed negligible or not, as was done in several other LCA studies on this particular subject.
[248] These processes are discussed on the following pages.
[249] See Annex 3 and 5.

production of aluminium as a metal[250]. For other chemicals, no data were found and therefore we have assumed that the amount of energy required to produce the substance in 1950 and 1975 was the same as in 2000. Again, this information was coupled to the data for production of energy in 1950 and 1975. As for the production of the materials (mostly concrete, brick and steel) for infrastructure in these years, we encountered the same problems regarding data availability.

The following life cycle stages and processes are the only ones for which information was available for 1950 and 1975:

- Extraction and treatment of groundwater and surface water
    - Energy for extraction and treatment
    - Chemicals for treatment
- Storage and distribution to households
    - Energy for distribution

In general, we found that for the drinking water study little or no quantitative data exist for the key years 1975 and 1950. Qualitative descriptions of the production processes, water mains and infrastructure were fairly easily found, but figures on energy use and type and amount of chemicals were not available, neither from literature nor from primary sources. In comparison to the three other studies, the results are thus based on fewer data.

1800 – 1850 – 1900

In 1800 and 1850 drinking water was not ‘produced’ but solely taken from ponds, ditches or canals or pumped up from wells. Thus no chemicals or energy were used, apart from human labour. The only utilized equipment were buckets, pumps and the occasional water mains made from wood or lead. However, the use of materials for water mains is not part of the comparative analysis, as was explained above.

In 1900 approximately 28 % of the population had access to the public water supply system (see Figure 39). Only a very limited amount of energy and chemicals was required in order to purify the water, because only easily accessible water sources were exploited and because treatment was not as thorough as it is nowadays. Energy for distributing 1 m^3 water was also lower because transport distances were much shorter (access to the supply system was limited to city-dwellers). However, no quantitative data on the amounts of energy and chemicals were found.

[250] We have estimated that the amount of energy required in 1950 and 1975 was respectively 1,6 and 1,3 times the amount required in 2000, based on the following sources:
IAI (International Aluminium Institute), 2002: Industry as a partner for sustainable development – Aluminium (London). W. LEWIS, 1949: The production of Aluminium in about 1945, From “The Light Metals Industry”, London, 1949, pp 3-19.
http://www.energymanagertraining.com/new_industryprocessmain.htm

Impact assessment

2000 in detail

A detailed environmental profile was constructed for the year 2000. The impact assessment was performed using the CML-methodology[251]. As a sensitivity analysis, the Eco-indicator 99 methodology was used[252]. The outcome was very similar, meaning that the processes which were most important were the same according to both impact assessment methods.
The environmental profile for the production and distribution of drinking water in Belgium for the year 2000 is shown in Figure 41.

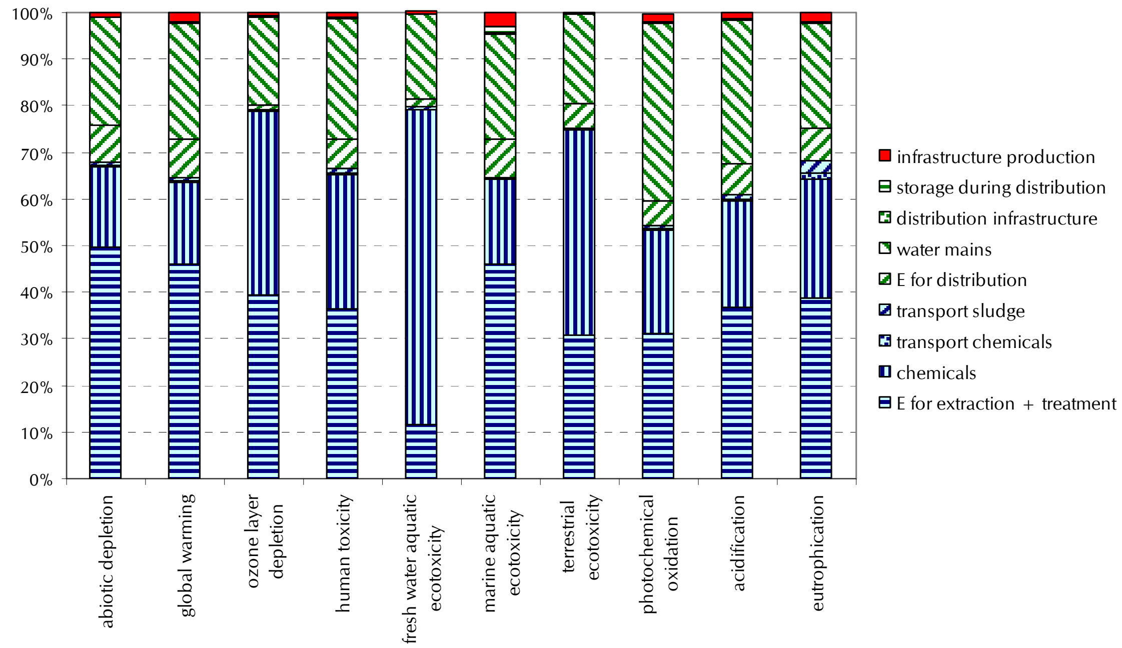

Figure 41 : Environmental profile – drinking water 2000

The environmental profile shows that:

- The energy and chemicals needed to *extract and treat* the water are the most important contributors to all environmental impact categories, where the use of energy contributes more to almost all environmental impact categories than the use of chemicals. Neither the transport of sludge[253] nor the transport of chemicals contributes significantly.
- Energy and water mains for the *distribution* to households also have an important contribution. Contrary to our initial expectations the materials used for the water
- mains contribute relatively more than distribution energy. Storage and distribution infrastructure such as reservoirs, water towers, etcetera is negligible.
- *Production infrastructure* (such as the water treatment plant and reservoirs for unpurified water) is negligible.

[251] CML 2 baseline 2000 V2.1 / West Europe, 1995
[252] Eco-indicator 99 (H) V2.1 / Europe EI 99 H/A
[253] As was shown in Figure 41, only transport to further treatment sites or its final destination was accounted for. The treatment of sludge represents a study on its own due to the many different treatment possibilities.

Comparison 1800-2000

In order to make a fair comparison of the environmental impact of drinking water production between several years, the level of detail and the system boundaries need to be the same for every year under study. Therefore the detailed life cycle that was constructed for the year 2000 was not used as such for the comparative analysis. Firstly, the processes for which no data were found for 1950 and 1975 were left out of the system, so that only the life cycle stages and processes as indicated in the inventarisation of 1950-1975 were included. Secondly, the detailed LCI-data from current LCA-databases for 2000 were replaced by data similar to the data found for 1950 and 1975.

As a consequence, the environmental impacts considered are limited to the impacts for which data for 1950 and 1975 were found. For the drinking water study, these are emissions of CO_2, NO_x, SO_2 ,CO and hydrocarbons to air. The amount of used energy is also discussed.

The results are first discussed for the production and distribution of 1 m³ drinking water and then for the total Belgian drinking water consumption[254].

Based on the circumstances in the 19th century (described in Inventarisation 1800-1850-1900), we conclude that the environmental impact of the production and distribution of 1 m³ drinking water to households is zero for 1800 and 1850.

For 1900, the impact is negligible compared to the second half of the 20th century. Due to lack of quantitative data, however, an exact figure could not be calculated.

Figure 42 shows the **energy** needed to produce and distribute **1 m³ drinking water** in 1800 - 2000, per life cycle stage.

The figure shows that the energy use per m³ is higher in 1975 than in 1950. The energy use in 2000 is almost the same as in 1975.

For 1950 – 1975, the increase is likely the result of more treatment processes necessary to obtain a good water quality. For 1975 - 2000, the small change in energy use for extraction and treatment is likely a result of conflicting trends: more energy is required (more process steps are necessary before water is suitable for consumption) versus a more efficient energy use. Some water companies mention an increased use of energy, others mention a decrease. The combined effect is almost a status-quo.

For 1950 - 2000, the combination of the energy efficiency improvement in the production process of some of the chemicals and the increased usage of chemicals to treat 1 m³ drinking water, results in an increase in energy use for the production of chemicals for the treatment of 1 m³ drinking water. However, the effect on the total amount of energy needed per m³ drinking water is small.

We have assumed that the energy use per m³ for distribution has remained the same for the whole period. The figure for 2000 has been checked with our own calculation based on the average height of water towers[255].

The comparison of the **environmental impacts** for the production of **1 m³ drinking water** in 1800 - 2000 is shown in Figure 42 up to Figure 48.

The figure shows that emissions of CO_2, NO_x and CO increase for 1950 – 1975 – 2000. Emissions of SO_2 and hydrocarbons, on the other hand, increase in the period 1950 – 1975 and decrease in the period 1975 – 2000.

[254] In the social and economic perspective it will be shown that the total consumption of drinking water almost doubles in the period 1950-1975 and remains fairly constant in the period 1975-2000.

[255] Considering the average height of water towers (40 m) and assuming an efficiency of 80 % for an electrical water pump, it was calculated that approx. 0,13 kwh/m^3 is needed to pump water to the top of the water towers.

Based on the data and the assumptions made in this case study, we conclude that the evolution of the environmental impact of the production of 1 m³ drinking water is largely determined by the evolution in the environmental impact of electricity production. The emissions due to electricity production are shown in Annex 5. For 1950-1975, emissions of CO_2, NO_x and CO due to electricity production decline and emissions of SO_2 and hydrocarbons increase. For this period, the amount of electricity needed to produce and distribute 1 m³ drinking water increases, as was shown in Figure 43[256]. For 1975-2000, all emissions due to electricity production decline. Also, the amount of electricity needed to produce and distribute 1 m³ drinking water has not changed much. By combining the trends for the emissions due to electricity production and the amount of electricity needed to produce and distribute 1 m³ drinking water, we observe the shown effect.

Figure 43 shows the **energy** needed for the **total consumption** of drinking water in Belgium in 1800 - 2000.
It is clear that the energy use is much higher for 1975 than for 1950 (a combination of an increased use of energy per m³ and an increased consumption of drinking water). The energy use in 2000 is almost equal to that of 1975 (energy use per m³ as well as total consumption are almost equal).

The comparison of the environmental impacts for the **total consumption** of drinking water in Belgium in 1800 - 2000 is shown in Figure 49up to Figure 53.
The figure shows that **emissions** of CO_2, NO_x, SO_2 ,CO and hydrocarbons increase in the period 1950 – 1975 and decrease in the period 1975 – 2000.
For the period 1950-1975 the improvement in emissions of CO_2, NO_x and CO for the production and distribution of 1 m³ is outweighed by the large increase in water consumption. Because water consumption remains fairly constant in the period 1975-2000, we observe the same improvement in environmental impact for the total Belgian drinking water consumption as in the production and distribution of 1 m³ drinking water.

All evolutions of the environmental impact of the total Belgian drinking water consumption are thus largely due to the evolution in the environmental impact of electricity production.

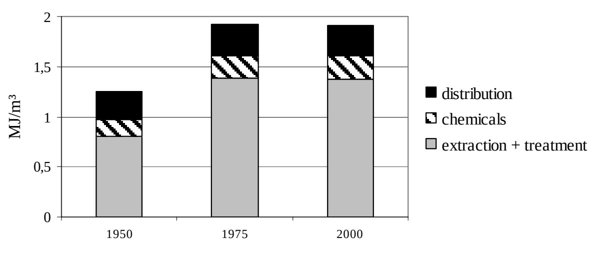

Figure 42 : Energy use per m³ drinking water

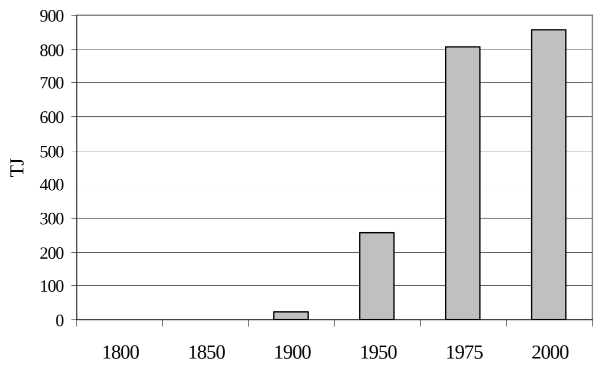

Figure 43 : Total energy use for Belgian consumption drinking water

256 In fact, Figure 42 and Figure 43 show the amount of energy, not solely electricity. However, in this case study the use of fuel oil is negligible in comparison to the use of electricity.

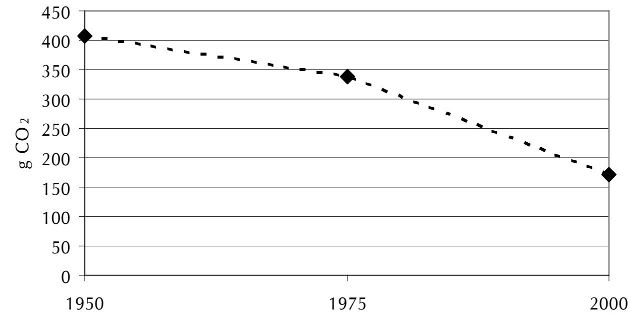

Figure 44 : CO_2- emissions per m³ drinking water

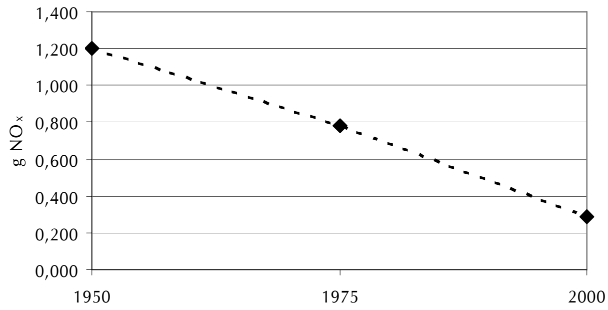

Figure 45 : NO_x- emissions per m³ drinking water

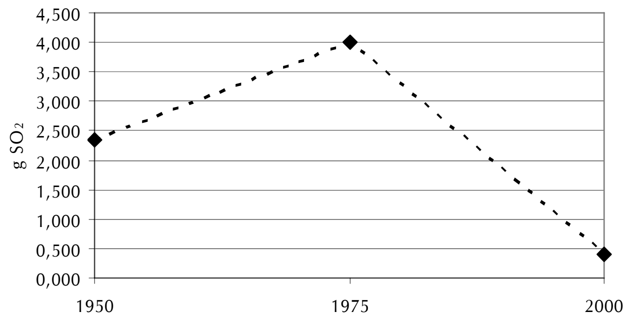

Figure 46 : SO_2- emissions per m³ drinking water

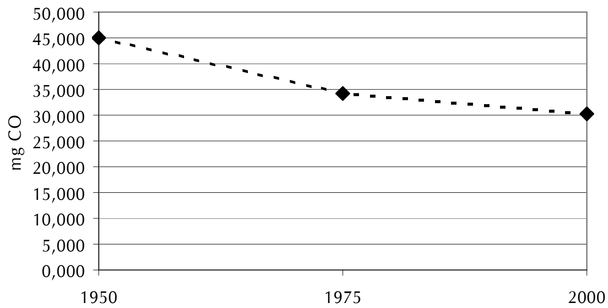

Figure 47 : CO- emissions per m³ drinking water

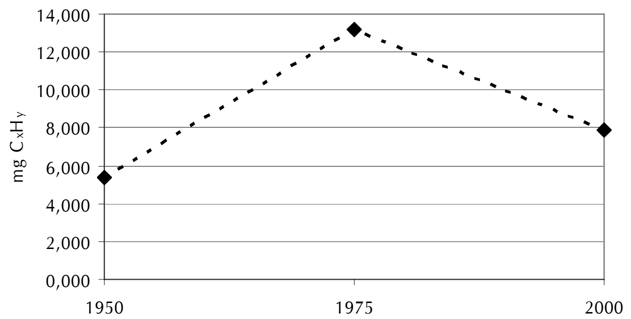

Figure 48 : C_xH_y- emissions per m³ drinking water

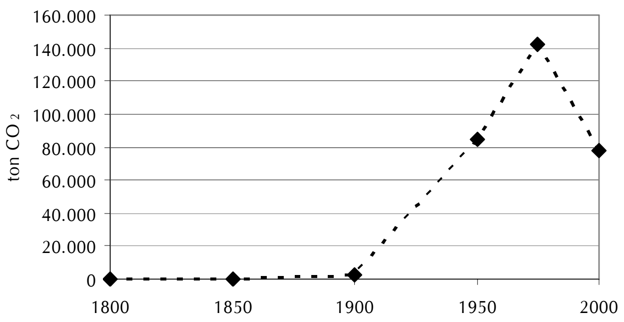

Figure 49 : CO_2- emissions for Belgian consumption drinking water

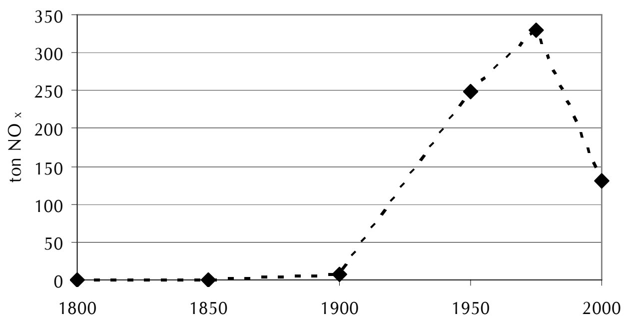

Figure 50 : NO_x- emissions for Belgian consumption drinking water

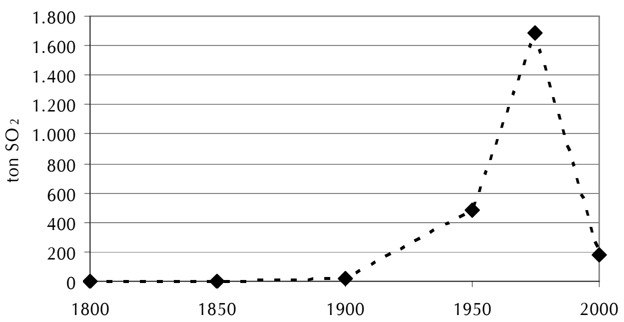

Figure 51 : SO_2- emissions for Belgian consumption drinking water

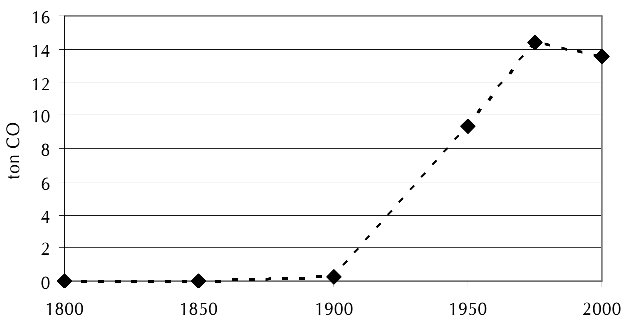

Figure 52 : CO- emissions for Belgian consumption drinking water

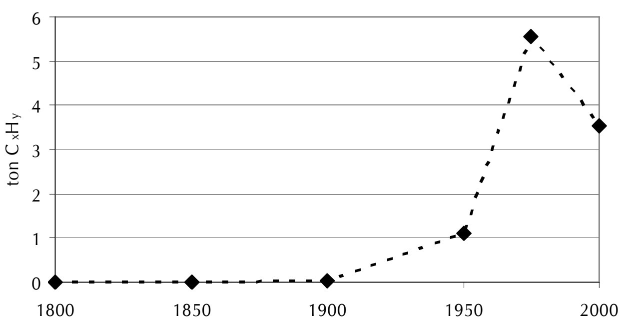

Figure 53 : C_xH_y- emissions for Belgian consumption drinking water

5.3.3. Social and economic perspective

As already mentioned in the status description, the Belgian water supply system expanded enormously since the end of the 19th century. Clean drinking water became available for (almost) the entire Belgian population. This may be considered as a first social indicator. At the same time, life expectancy at birth increases. A better organized supply system of clean drinking water contributed to this increase, although it cannot be isolated from other changes that improved living conditions (installation of sewers, covering up of rivers and canals, increase in living space,…)[257].
Simultaneously with the expansion of the network, water consumption increases (Figure 54) [258].

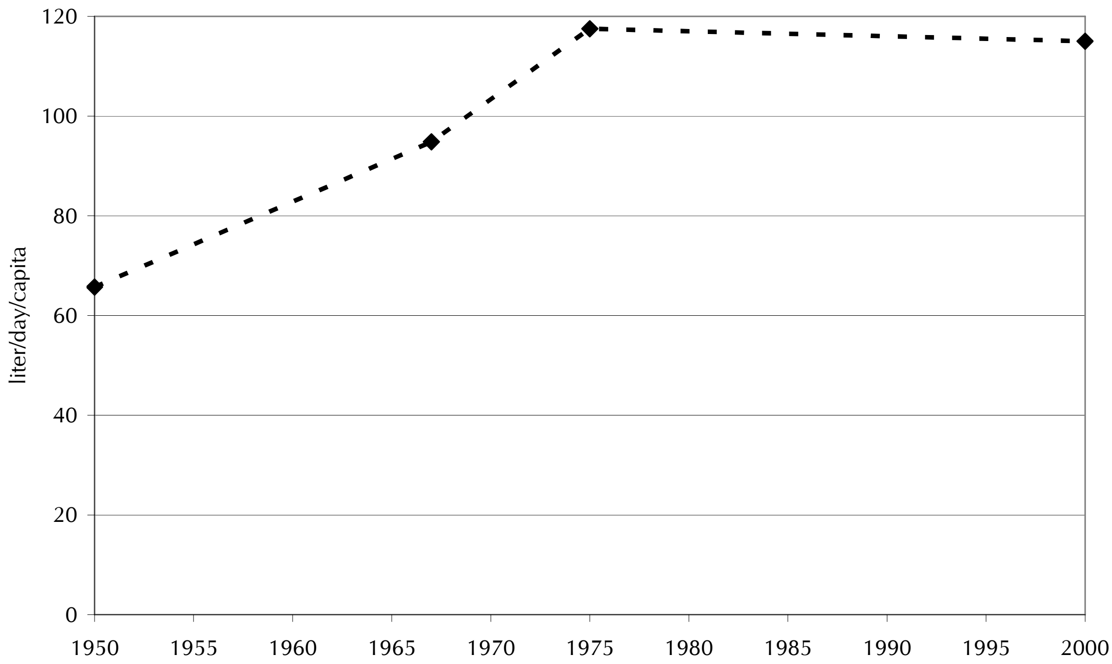

Figure 54 : Water consumption in Belgium (per day, per head)

This increase is related to the rise in durable consumer goods such as washing machines and dishwashers, as well as to the growing awareness of the importance of personal hygiene[259]. Since the 1980s, the increase in consumption slows down. This might be the result of an upcoming environmental consciousness, although the (real) price of drinking water could also have caused this effect. Changing habits, such as showering instead of taking a bath, or technical developments, such as low flush toilets or water appliances with increased efficiency, have contributed to this effect.[260] Moreover, the use of rainwater is stimulated since

[257] W. Van Craenenbroeck (1998), p. 423.
[258] NMDW, *Verslagen* (1951-1959 and 1970-1974). VMW, *Jaarverslag 1995* (1996). W. Van Craenenbroeck (1998), p. 423. P. Cornut (2003).
[259] P. Kristensen (2004), p. 3
[260] P. Kristensen (2004), p. 3 and 7

the last decade of the twentieth century[261]. Or maybe, the consumption of water reached its saturation point[262].
When the data on the daily water consumption per capita[263] is combined with the total Belgian population, we observe a steep rise in total domestic drinking water consumption in the period 1950-1975, while the increase for the period 1975-2000 is very small (Table 9). The activities for which drinking water is used are shown in Annex 3.

	Daily water consumption	Population	Total domestic consumption
	litre/capita/day	*inhabitants*	*m³/year*
1950	65.7	8 653 653	207 518 926
1975	117.5	9 813 152	420 861 556
2000	120.0	10 263 414	449 537 533

Table 9 : Water consumption in Belgium (the indicated numbers are withdrawn from different sources, but are the best available for calculations)

Only the real price of drinking water in the twentieth century will be examined, since tap water became a commodity at the end of the nineteenth century (and, for the larger part of the Belgian population, after World War I). It is difficult to compare the price of water over the past decennia, as water only got included in the cost-of-living index from 1975 onwards. When the previous years are considered, no 'average' price of drinking water is available. Therefore, the comparison is based on the prices provided by several water companies. These prices are not univocal, because they are founded on different policies that depend on staff expenses, investments,… [264]. The Antwerpse Water Werken (AWW) was the only company that could provide prices for several of the key years[265]. Therefore, these prices, as well as the 'average' prices of the Dienst voor het Indexcijfer[266], were used to calculate the real price of drinking water.
Figure 55 shows a dramatic decrease of the real price[267] in the first half of the twentieth century. The expansion of the water supply system might explain this, since this makes it easier to fulfil the demand. Moreover, improving production techniques held production costs (and consumption prices) low. The third quarter of the twentieth century shows a less pronounced decrease, and in 2000, the real price of water is even higher than it was in 1975. Ever-growing difficulties in producing clean drinking water might be the cause of this increase. This was already pointed out in the environmental analysis. Furthermore, in 1997, a Flemish decree stated that 15m^3 of water (per day, per capita) should be provided for free. Consequently, the price of drinking water might have been raised to compensate for this consumption[268].

[261] S. Woestenborghs (2003), p. 21.
[262] Tap water could have been replaced by bottled mineral water. However, the percentage of the private expenses used for purchasing mineral water only rose from 1,05% in 1975 to 1,14% in 1993. This probably does not explain the slowing down of the consumption figures.
[263] Aminal (2002), Watergebruik in Vlaanderen, een blik op de toekomst. Aminal (2002), Watergebruik in Vlaanderen, huidige situatie
[264] B. De Raeymaecker (1998), p. 79.
[265] Interview with mr. Wim Van Craenenbroeck (Antwerp Water Works), on April 20th 2004.
[266] Dienst Indexcijfer (2000).
[267] Calculation: see Annex 4
[268] B. De Raeymaecker (1998), p. 79. *Omnilegie* (December 20th 1997).

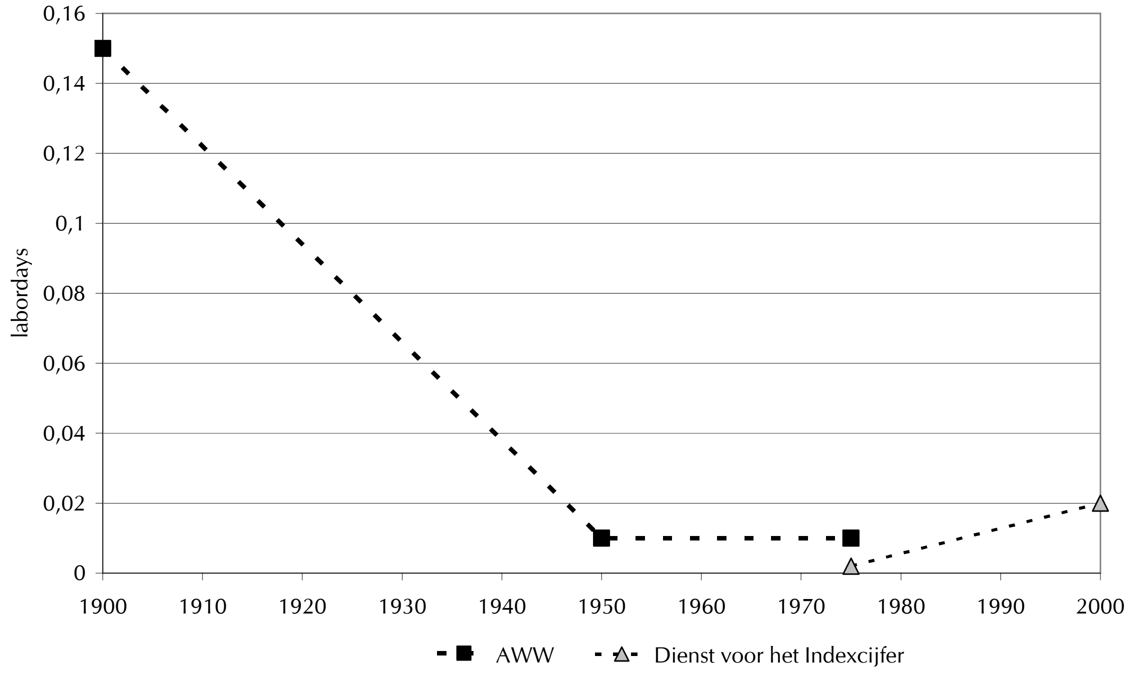

Figure 55 : Real price of water

In the first half of the twentieth century, the percentage of water in the total private consumption in Belgium rises (Figure 56)[269].

"De bedoeling van het decreet is om de principiële basisvoorziening aan water, gas en elektriciteit te waarborgen, zodat een gezin, volgens de huidige levensstandaard, op een menswaardige manier lan leven." (*This law's objective is to ensure the fundamental fulfillment of the need for water, gas and electricity, in a way that every household can live a decent life according to the current standard of living*) (translation by the author).

[269] Y. Segers (2002). NIS, Nationale rekeningen 1953-1962 (1963). NIS, *Statistische studiën*, 45(1976), blz. 1 e.v., NIS, *Statistische studiën*, 101 (1994), blz. 1 e.v.

We retrieved these percentages by using private consumption figures (the amount spent on water/rent/taxes divided by the total amount of private expenses). In 1953, water provided for 1/38 part of 'water, rent and taxes' in the national accounts. In 1975 and 1993 the proportions were not mentioned. We assumed the same proportion as in 1953. Therefore it is possible that we underestimate or overestimate the part of drinking water in the total private expenses in these years.

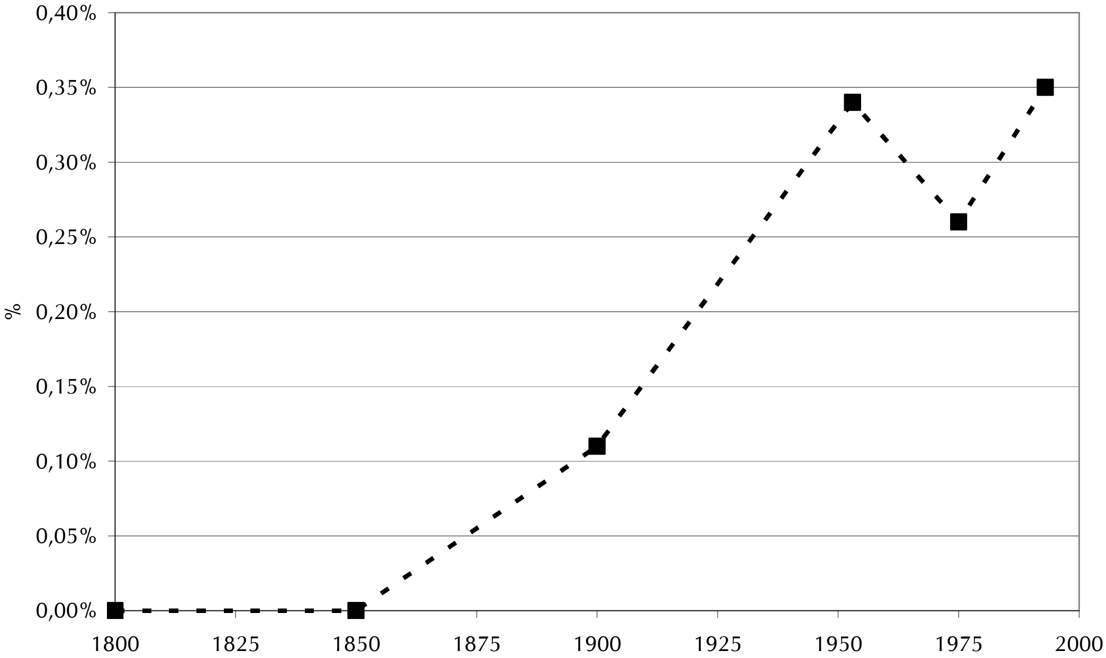

Figure 56 : Private expenditure on water

Again, this indicates an increase in the part of the population with access to a public water supply system.
Although real prices decrease less pronounced since the mid-twentieth century, the share of water in total private expenses shows a decline of 30% between 1950 and 1975. Rapidly increasing incomes might explain this trend. During the last quarter of the twentieth century, the share of water increases again, which might be explained by higher real prices.

5.3.4. Sustainability trends

Environmental aspects
Compared to the other case studies, there has been no spectacular environmental improvement. There are several causes for this observation. One of them is that energy efficiency improvements and the need for more purification steps (due to more polluted surface water or groundwater) compensate each other. Also, the techniques used to produce drinking water have not changed much in the course of the century, because water production is still based on traditional processes. In recent years, some new technologies have been developed (e.g. membrane technology) or technologies have been re-introduced (e.g. ozone technology) but only as pilot projects or on very small scale.

Social aspects
There has been a continuous improvement during the period 1800 – 2000: there are more subscribers, less mortality, more comfort. In 1900 only the happy few had access to tap water in their houses, in 2000 almost everyone has access to tap water.
In the 19th century living in the country was healthier than in the cities, which were troubled by diseases and epidemics. In the beginning of the 20th century life expectancy was higher in the cities and in larger communities, thanks to the introduction of waterworks. Remote communities had to wait until as late as 1975 to be connected to the drinking water mains.

Economic aspects
The real price has decreased continuously from 1900 onwards (19th century: free of charge but possibly unhealthy), therefore drinking water becomes more and more affordable. The percentage of drinking water in the household budget increases from 0,1 % in 1900 to 0,3 % in 2000, because the consumption has increased relatively more than the real price has decreased. For 1975 and 2000 drinking water is fairly cheap.

Further reflections
For the other case studies, we may state that an improvement for the environment results also in an improvement for human health. For drinking water this is not necessarily true: because drinking water is essential for human health, one must be careful not to adapt the purification processes in such a way that the quality cannot be guaranteed.

5.4. Case study : Heated living space

5.4.1. Status description

When examining the 'sustainability development' of heating a living space, one has to bear in mind two components: the volume of the living space that is heated and the heating system (including fuel type). In addition, building materials and constructions are important, since insulation of walls and windows has an influence on the amount of energy used to heat the building. However, given that the research subject is the *heating* of a single-family dwelling, the production of building materials itself will not be taken into consideration.
After reading specific literature about building and heating[270], as well as looking at several statistics[271] concerning 'housing' in Belgium and after several discussions with experts[272], we were able to define the research subject. The following matrices (Table 10 and Table 11) show our 'definitions'. Again, these do not represent the housing and heating conditions of all people at that moment in time. We did try to compose an 'average', but we must not forget that this is an artificial construction. These definitions were especially useful to perform the environmental measurements in Bokrijk (which were discussed earlier), since we needed to decide which houses and heating systems to use. The results of these measurements were very important to retrieve the emissions related to the heating of the living space. They were combined with figures covering the total heating consumption of Belgian households. This will be examined more thoroughly in the environmental analysis.

[270] M. Stokroos (2001). P. Van Overbeeke (2001). Y. De Bont (1995). L. Busseniers (1978). A. De Clippel (1992). G. Avondts and P. Scholliers (1981/6).
De Clippel and Avondts and Scholliers described several houses at different moments in time. They also mentioned the volume of these houses. Of these figures, the median was used as the 'representative' volume of the living space.
J.J. Vriend (1960).
[271] Centrale Dienst voor Statistiek (1930). NIS, *Statistieken over bouwnijverheid* (1947-1961). NIS, *Statistieken over gebouwen* (1947-1991).
[272] Dirk Van de Vijver, Ph.D. in architectural engineering at the KU Leuven. Robert Nouwen, Ph.D. in history, Open Air museum Bokrijk. An Schoefs, scientific co-worker, Open Air museum Bokrijk. Annick Boesmans, curator, Open Air museum Bokrijk.

	Countryside walls	City walls	Windows	Use of insulating materials	Volume of (heated) living space[273]
1800	Clay	Brick (1 stone)	Single glazing, wooden frames	No	54 m^3
1850	Clay	Brick (1 stone)	Single glazing, wooden frames	No	55.84 m^3
1900	Brick (1 stone)	Brick (1 stone)	Single glazing, wooden frames	No	45.29 m^3
1950	Brick (1 stone)	Brick (1 stone)	Single glazing, wooden frames	no	147 m^3
1975	Hollow wall	Hollow wall	Introduction of double glazing, steel or aluminium frames	Limited use	205 m^3
2000	Hollow wall	Hollow wall	Double glazing, aluminium frames	Yes	260 m^3

Table 10 : The heated living space

Insulating materials were used since the 1970s, although its use is not yet widespread. The same may be said about double glazing[274].
As shown in Table 10, the volume of the heated living space increases dramatically in the twentieth century. Houses get bigger and more rooms are heated. Further on, we will show the impact of this increase when the sustainability development of heating is concerned.
Obviously, the distinction between city-dwellings and countryside dwellings, or better (when assessing energy use), between open-space development and closed development, also has to be kept in mind, as enclosed houses will require less energy for heating. The period of time a house or room is heated, the average outside temperature and the average comfort temperature might all have an influence on the environmental impact of the heating of the living space. These factors were all taken into consideration.

Different fuels and different heating systems can be considered when looking at the case study of the heated living space (Table 11). The transition between different kinds of fuel, and its possible causes, will be examined later (the social and economic perspective).

[273] The figures about the volume in 1950, 1975 and 2000 are figures about the *actual* living space, not the heated living space. Since in 1950, centralized heating is not yet common, the heated volume is probably much lower than the figure shown in the matrix. In 1975, centralized heating has become more popular. It is possible that in some rooms, other than the living room, electrical and petrol stoves were used for secondary heating.
[274] K.J. Noorman and T. Schoot Uiterkamp ed. (1998), p. 44.

	Heating system	Central/decentral	Proportion of fuels based on expenses[275]	Proportion of fuels based on MJ[276]
1800	Open fire Stove	Decentral		
1850	Stove	Decentral	Coals (60.77%) Wood (14.62%)	Coals (88.39%) Wood (11.61%)
1900	Stove	Decentral	Coals (58.55%) Wood (5.17%)	Coals (96.79%) Wood (3.21%)
1950 (1953)	Stove Radiators	Decentral Central	Coals (64.12%) Petrol (8.94%)	Coals (93.21%) Oil (6.79%)
1975	Radiators Stove	Central (51,2%) Decentral	Coals (13.67%) Oil (41.68%) Gas (12.23%)	Coals (16.82%) Oil (77.86%) Gas (5.32%)
2000 (1993)	Radiators	Central (64%)	Coals (3.42%) Oil (18.59%) Gas (24.36%) Electricity (53.62%)	Coals (5.95%) Oil (42.20%) Gas (51.85%)

Table 11 : Heating systems - fuels

5.4.2. Environmental perspective

The **goal** of the environmental assessment over the two centuries is to compare the environmental impacts related to the heating of the living space in Belgium over the different key-years. To assess these environmental developments we use the LCA approach. The **functional unit** is defined as "the heating of 1 m³ of an average single-family dwelling in Belgium, which may be considered as representative for that key year, to a comfort temperature of 18°C, averaged over the seasons (per degree-day). The **system boundaries** are shown in Figure 57. Note that the production of the dwelling (building materials, etc.), the production of the heating system and the fuel production are not part of this study.

275 The proportion of the fuels is based on the private expenses for heating and lighting. We divided the amount spent on coals and wood by the total amout spent on heating/lighting. The same calculation happened for petrol and gas, although we ascribed the amount spent on petrol/wood/bottled gas as a whole to petrol (in 1953 and 1975). Consequently, we overestimated the use of petrol.

276 Based on the private expenses on heating/lighting and the unit prices of the different kinds of fuels, the total amount of the different kinds of fuel could be calculated. Using the conversion figures to MJ, the total production of MJ through heating/lighting in Belgium could be calculated. The amount of MJ produced by the most important kinds of fuel in that period, was considered as 100% of the produced MJ. Then, the proportion of the different kinds of fuels was calculated. This way, the differences between the kinds of fuel is (partly) taken into account (contrary to the proportion based on expenses).

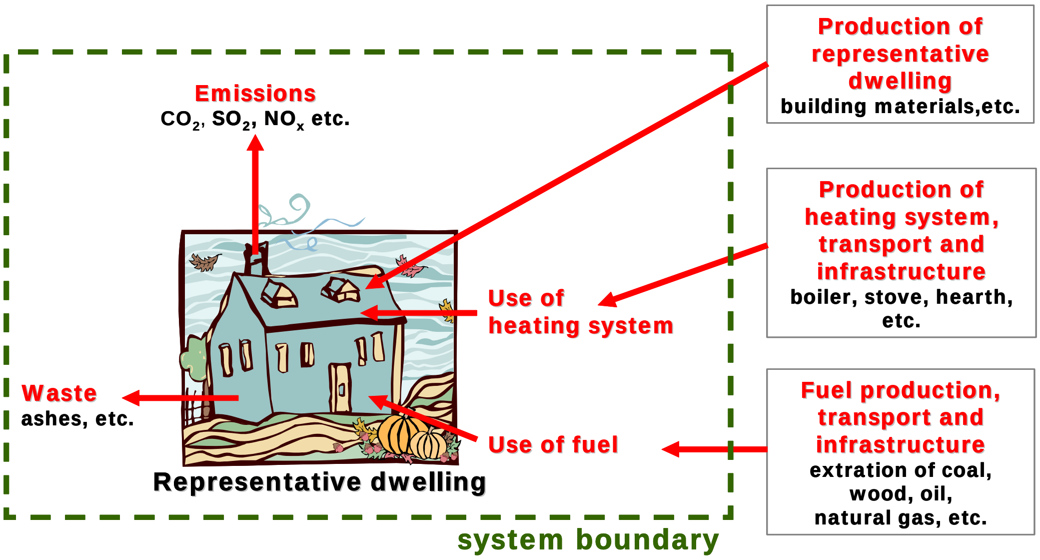

Figure 57 : System boundaries of the heated living space case

Inventarisation

Different factors determine the total energy consumption when private living space is heated: age of house, ratio open-space/closed space, energy carriers, energy systems, etc. For a general description of the way private houses were heated in the different years, we refer to the status description. In the next paragraphs we are focusing on the collection of the data that are needed to calculate the environmental burdens of heating private living space over the years studied.
For the former years 1800 till 1975, it was difficult to find reliable data on the exploitation of energy carriers. Only for the year 2000 relevant exploitation data were available. Therefore the environmental burdens associated to the extraction (mining) of the energy carriers is not taken into account in the total comparison between the years that were studied. The amount of degree-days is assumed as a constant over the years, being 2 488 on an average[277].

2000

For the calculation of the total energy consumption for heating private living space, we used various sources of literature. Different factors determine the total energy consumption: the age of the private dwellings (54% of the single-family dwellings in 2000 was built before 1970, 18% between 1971 and 1980, 15% between 1981 and 1990 and 13% later than 1990)[278],[279]; the ratio open-space, closed space and half-open space development[280],[281]; the heated volume (based on the average actual living space, see status description), fuel sources[280] and the heating systems and their efficiency[281],[282]. The emissions related to the use

[277] FIGAS (http://www.gasinfo.be)
[278] VIREG, 2001.
[279] Nationaal Instituut voor de Statistiek, NIS, Ministerie van Economische Zaken, Kerncijfers 2002 – Statistisch overzicht van België, 2002
[280] Peeters E., 1999
[281] Simulatiemodel ter evaluatie van combinaties van CO2-emissie reductiemaatregelen, DWTC project N° CG/DD/211, 2001
[282] Vekemans G., 1997.

of the energy carriers in 2000 are based on emission factors for residential combustion appliances for oil, gas, electricity and solid fuels[283].

1950 and 1975

The calculation of the total energy consumption for heating private living space in 1975 and 1950 is based on a former SPSD study[282] en NIS statistics[284].

For oil and gas emission factors from TNO[283] are taken into account. To map the emission factors of coal for 1950 and 1975, we used own emissions measurements carried out in the open-air museum of Bokrijk, more specifically in a house that was heated by using coal in a "Leuvense stoof" (see Figure 59)[285]. The measured SO_2 emissions were corrected, because in these former years coal with a higher sulphur content was used, compared to the measured composition of the used coal during the emission measurements.

1800-1850-1900

Together with the expertise of historians and an architectural engineer[286], we decided upon a 'most common' dwelling and heating system for the years 1800, 1850 and 1900. Based on these descriptions, a hypothetical average single-family dwelling has been defined for these years. We heated three different houses in the open-air museum of Bokrijk[285], using three different heating systems, to carry out environmental measurements (see Figure 58 and Figure 59) to be able to determine emission factors and energy use, both necessary to map some of the environmental parameters based on the LCA approach.

[283]Bakkum A., 1986

[284]NIS, Statistieken voor gebouwen en woningen, Algemene socio-economische enquête 2001, Woonindicatoren (1981 en 1991).

[285] The Open Air Museum Bokrijk is an active hands-on museum that aims to take people back in time. Generally speaking, it can be compared to a scale model of Flanders, with 100 historical buildings surrounded by flowers, plants and trees from the authentic landscape. www.bokrijk.be.

[286] An Schoefs, Robert Nouwen and Annick Boesmans, Museum of Bokrijk and Dirk Van de Vijver, Katholieke Universiteit Leuven.

Figure 58 : Emission measurements at the chimney of one of the houses in the Bokrijk museum

Figure 59 : Picture of a "Leuvense stoof" used for emission measurements in Bokrijk

In order to make a comparison of the functional unit (the energy consumption in MJ per m³ and per degree-day) over the different years the measurements in Bokrijk have been extrapolated to a comfort temperature of 18°C and to an average heating behaviour of 12 hours per day. When coal was used as energy carrier, for the former years 1850 and 1900 some modifications of the measurements are implemented in the life cycle inventarisation:

- Because in these former years coal with a higher sulphur-content was used (compared to the sulphur-content of the coal used in Bokrijk), the measured SO_2 emissions have been adapted accordingly.
- For the years 1850 and 1900 reliable data of private expenses for coal were available[287], so that consumption figures have been calculated from these data. Data on private expenses for wood were also available[287], however these were not considered for further calculations. The reason for this is that these data do not fully represent the actual amount of wood that is consumed for heating private livings space in the years 1850 and 1900. The major part of the wood that is used for heating in these years was cut down by the dwellers themselves in their back garden or in a nearby forest, for example. Therefore the Bokrijk measurements were used to calculate the consumption figures for wood. Regarding the emission factors for both coal as wood (emissions per kg of fuel) we used the measurements in Bokrijk. We considered this approach more reliable than the one that would use the measured emissions of the representative heating systems and dwellings directly. In this way, the aforementioned extrapolations did not have an influence on the outcome for these years. For 1800 there was no reliable data on private expenses. Therefore we used the measured data from Bokrijk as a good indication. During the measurements we could only reach a comfort level of about 15 degrees in the farmers house with open fire, so we assumed that this was representative for that period. The results of this 'applied history' are incorporated in the analysis further on.

The measurements in Bokrijk gave vital information about the emission factors (expressed as emissions per kg of fuel type) when using representative heating systems in dwellings typical for the key years. When wood is used as a fuel (mainly in the nineteenth century), the full

[287] Segers Y., 2002.

emissions of burning are included. No credits for afforestation are given because the production of wood was not a sustainable practice. The emissions of the different fuel extraction processes (like wood, coal, oil, gas) are excluded in the study due to lack of data for these processes for the years before 2000. Only the direct emissions from the burning of the fuels are considered in the analysis.

Evolution of the energy consumption (functional unit)

Figure 60 shows the evolution of the functional unit and more specifically the energy use (in MJ) that is needed to heat one cubic metre (m³) of an average Belgian single-family dwelling to a comfort temperature of 18°C, per degree-day, for the different key years. This graph contains dashed lines to connect the results for each of the key years. These dashed lines do not necessarily indicate the actual development. With this assumption in mind, we can conclude from Figure 60 that over the years much less energy is required for heating one cubic metre (of a single-family dwelling to a comfort temperature of 18°C, averaged over the seasons). This implies that the energy efficiency has improved substantially (more than factor 20). Note again that for the years 1800, 1850 and 1900 we have extrapolated the measured energy use (valid for 15 degrees) in the Bokrijk museum to a comfort level of 18 degrees.

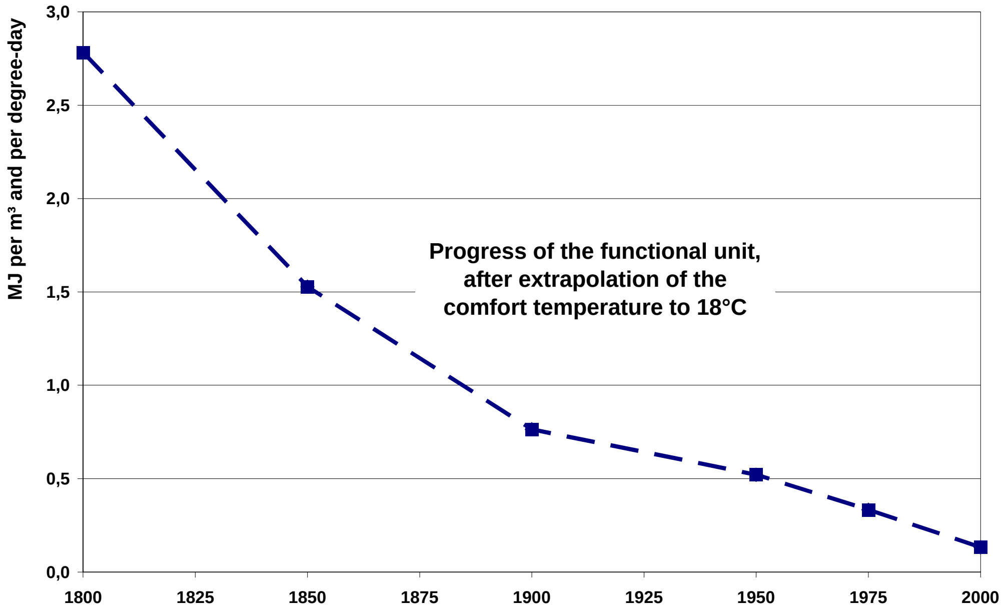

Figure 60: Tendency in energy consumption per m³ and per degree-day

Efficiency improvements can be ascribed to a combination of various factors. The conversion from open hearth (efficiency approx. 15 %) to modern boilers with continuously improving boiler performances (more efficient incineration processes: around 100 %) is one of these factors. Since 1988, heating systems should comply with several demands concerning energy efficiency[288]. More stringent insulation measures (e.g. introduction of cavity wall and double glazing) also contribute to the improvement in efficiency. In 1975, the Belgian government grants an incentive bonus to people who improve the insulation of their houses. It wants to encourage energy efficiency among the population. Urbanization implies a higher ratio of

[288] Pasinomie ou collection complète des lois, décrets, arrêtés et règlements généraux qui peuvent être invoqués en Belgique (1788-1952). Bruxelles.

closed-space dwellings and the introduction of high-rise buildings. These types of construction suffer less heat losses. Finally, the increase in double-income couples (working outside the house) and the introduction of the thermostat result in a decrease in energy use. These various factors add up to an impressive efficiency improvement in 200 years, mainly due to the use of more efficient heating systems, dense city building and better insulation measures.

Impact assessment

To calculate the emissions associated with the aforementioned energy needs (**functional unit**), for each key year the amount of energy was multiplied with the corresponding emissions factors of the different fuel types that were used. The results are presented in the figures below.
Figure 61 presents the comparison of the total amount of CO_2 emissions caused by the functional unit over the years. Similarly to the evolution of the efficiency, the CO_2 emissions follow a descending trend. The less energy is consumed, the less CO_2 is emitted. The explanation of the marked regression is the same as explained for the efficiency improvements. The trend of the other emissions studied over the past two centuries, follow a similar trend as the CO_2 emissions (see Figure 62, Figure 63 and Figure 64). For all emissions the trend shows a relatively small kink in 1950: the slope of the descending line is more steeper from 1950 on. The reason is twofold: 1) heating of private living space is done in a more energy-efficient way; and 2) from 1950 on there is a shift towards less coal and more oil and gas (coal emits for example relatively more CO, in comparison to oil and gas, so that the kink is more explicit in Figure 64).

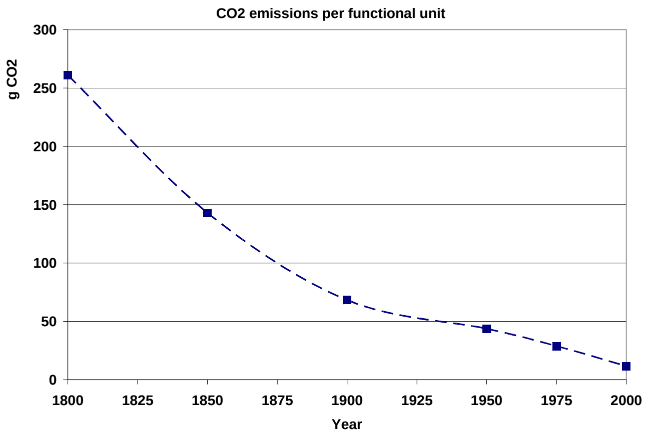

Figure 61: Comparison of the CO_2 emissions related to the functional unit

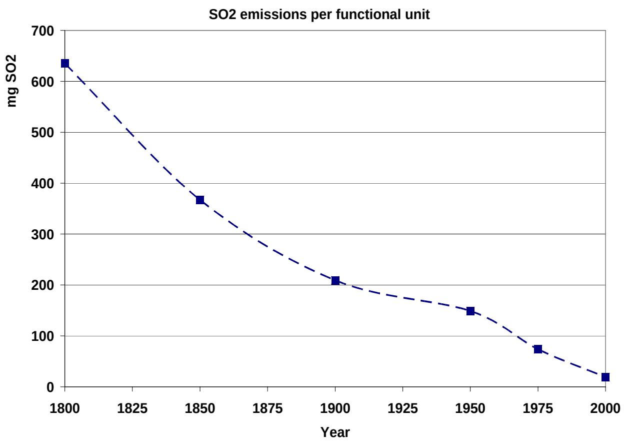

Figure 62: Comparison of the SO_2 emissions related to the functional unit

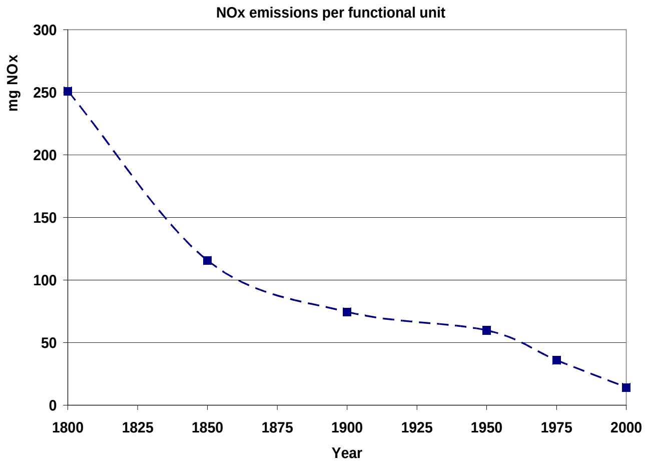

Figure 63: Comparison of the NO_x emissions related to the functional unit

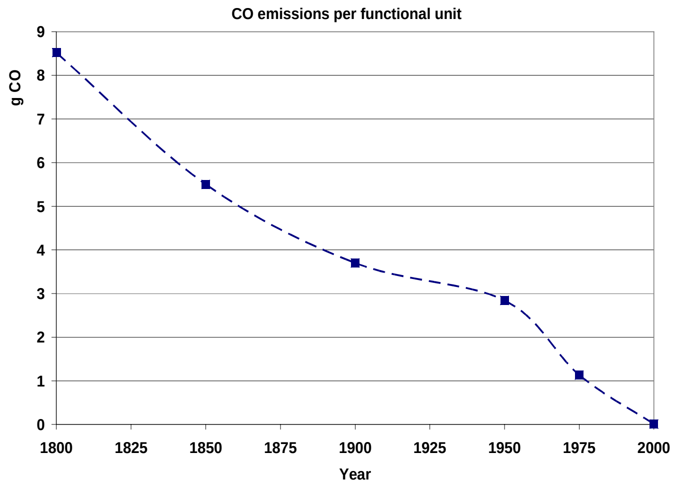

Figure 64: Comparison of the CO emissions related to the functional unit

To calculate the environmental emissions associated with the **total Belgian population** we used a step-by-step approach, starting from the "actual" amount of energy (without extrapolations to a comport temperature of 18°C) that is needed to heat one cubic metre (m^3) of an average Belgian single-family dwelling, per degree-day, for the different key years. For each year this amount was multiplied with the corresponding emissions factors of the different fuel types that were used. In order to relate these emissions to the total Belgian society, the figures were then multiplied with the respective volumes (m^3) of the heated living space for the different key years (see Table 12). These results are then divided by the average number of people living in the representative dwellings and further multiplied by the total number of the Belgian population in the different key years (see Table 12). And finally, these results are multiplied with the average number of degree-days, which has been considered as being a constant over the years (see Table 12).

	1800	1850	1900	1950	1975	2000
heated volume of living space (m^3)	54	55,8	45,3	147	205	260
amount of persons living in the dwelling	5	4,9	4,3	4,2	3,2	2,4
Belgian population	2942803	4426202	6693548	8653653	9813152	10263414
yearly amount of degree-days	2488	2488	2488	2488	2488	2488

Table 12 : Data used to calculate the emissions related to the total Belgian consumption

Figure 65, Figure 66, Figure 67 and Figure 68 present the contribution of heating private living space caused by the total Belgian society to the exhaust of respectively CO_2, SO_2, NO_x and CO emissions. It can be clearly seen that when multiplying the aforementioned energy needs with total consumption figures of the Belgian population as a whole, it appears that the efficiency improvement (see Figure 60) is counterbalanced by the population growth (increased evolution) and the increased consumption (more m^3 of the houses are heated over the years). The energy efficiency improvement almost totally neutralizes the dramatic increase of population and consumption, when considering the key years 1800 and 2000.

Looking at Figure 65 we see that between 1800 and 1850 the impressive efficiency improvements are neutralised by an enormous population growth in Belgium (almost 4,5 million people in 1850 as opposed to almost 3 million people in 1800). Consequently, the total contribution to CO_2 emissions for example during that time period remains stable. Between 1850 and 1900 efficiency improvements have the upper hand, which means that the total contribution to the exhaust of CO_2 emissions decreases slightly. From 1900 until 1975, the efficiency improvement is counterbalanced by a more luxurious life (more cubic metres of the living space are heated) and by the decline of the average number of people per household and the population growth. Consequently, the total CO_2 emissions increased rather spectacularly in that time period. Since 1975 there is a turn towards less CO_2 emissions. This is caused by a synergy of different factors. More stringent insulation measures resulted in the introduction of hollow walls and the advent of the thermostat. The energy use during working days decreased because of the increase in two-income families. Households consume more electricity, due to an increase in the use of electrical appliances that emit heat. Consequently, less fuel energy is needed for heating. Finally, there has been a substantial improvement in boiler efficiency (more than 100%). However, the rise in two-income families and use of electricity are no real savings for society as a whole, as the working place is also heated and electricity use increased over the past decades.

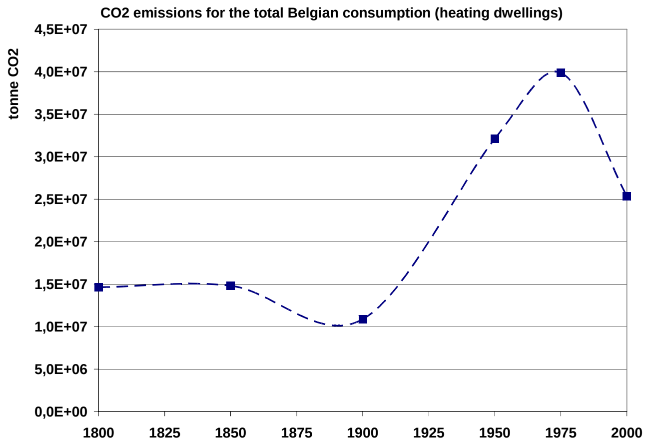

Figure 65: Trend in CO_2 emissions related to the total Belgian consumption for heating houses

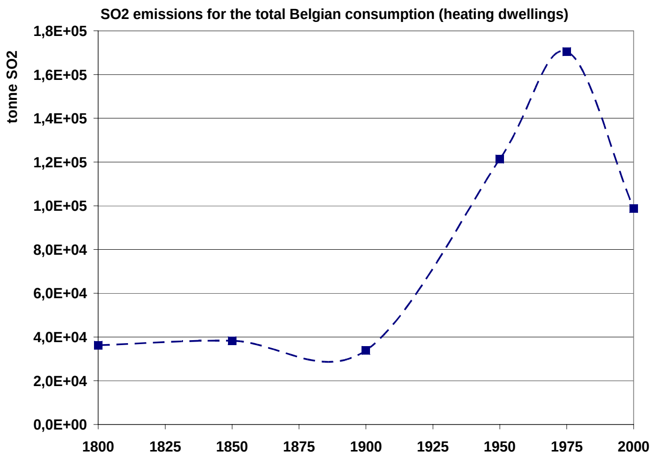

Figure 66: Trend in SO_2 emissions related to the total Belgian consumption for heating houses

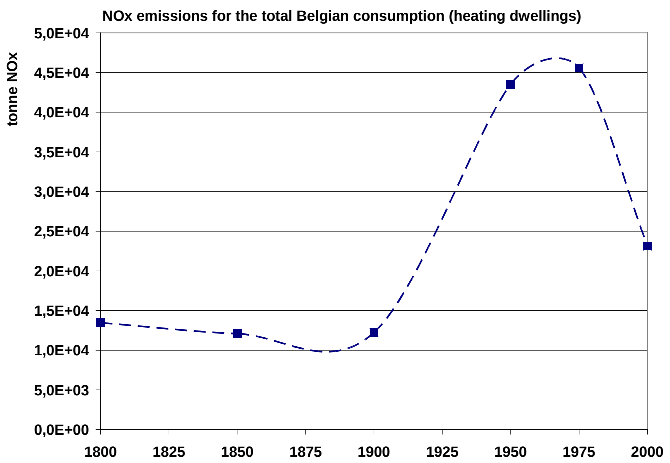

Figure 67: Trend in NO_x emissions related to the total Belgian consumption for heating houses

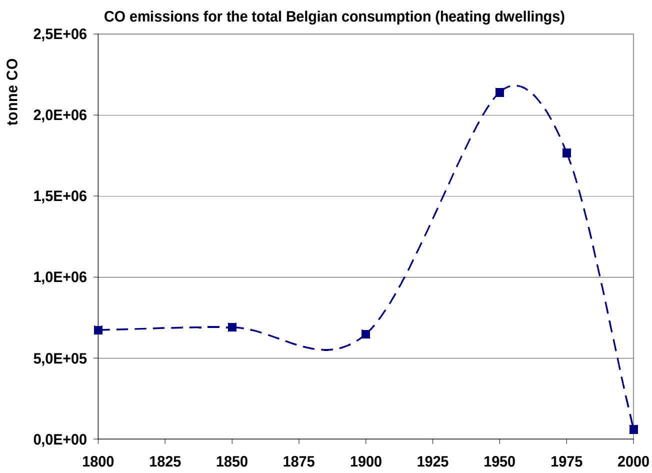

Figure 68: Trend in CO emissions related to the total Belgian consumption for heating houses

The trend of the other emissions studied over the past two centuries, follow a similar trend as the CO_2 emissions. The difference between 1800 and 2000 lies, for all emissions, in the order of factor 2. We consider this as a surprisingly small difference looking at the much higher individual consumption level, the growth in population and the more 'individual' way of life. Figure 66 shows the trend in released SO_2 emissions related to the total consumption for heating of the living space over the past two centuries in Belgium. From around 1975 the gradual shift from oil to natural gas results in a reduced exhaust of SO_2 emissions. On the contrary the reduction in NO_x emissions is less sharp in the same time period (see Figure 67) since natural gas contains relatively more N, which results in more NO_x emissions. The overall decrease of NO_x from around 1975 may be explained by a combination of various factors. The use of more efficient boilers (e.g. atmospheric, condensing boilers, with low NO_x exhaust) is one of them. In the same time period (from around 1975) more stringent regulations have resulted in the use of a more refined oil (lower S content), so that less SO_2 emissions are released during burning in the boiler. The evolution of the total CO emissions is very much similar to the evolution of the other emissions, except between 1950 and 2000, where the decreasing trend is relatively more pronounced. This more pronounced decrease is mainly to be allocated to the transition from the use of mainly coal towards mainly oil and gas. Coal emits relatively more CO, so that the transition to oil and gas led to a relatively higher decrease of the total CO emissions. The impact of this transition for the other emissions is less explicit.

5.4.3. Social and economic perspective

When looking at the status description of the heated living space, some underlying social and economic dimensions may already be retrieved. The volume of the living space that is heated, increased over the past two centuries. This is necessary knowledge when performing an LCA, but it also means that people in 2000 can afford to heat a larger part of their houses than their ancestors in 1850 did[289]. In 1950, more then half of the Belgian population used a stove and coals for heating the house. This means that only one room (the 'living' room) of the house was heated regularly. Electric and oil stoves might have been used for secondary heating. Centralized heating became more common in the 1970s[290].

Different fuels and different heating systems can be considered when looking at the case study of the heated living space. This transition becomes clear when regarding the energy use of households[291](Table 13).

[289] Y. Segers (1999), p. 218.
[290] H.W. Lintsen et.al. ed. (1993/3), p. 223. M. Stokroos (2001), p.30.
[291] Some data were not at our disposal and were therefore not entered in the table.
To calculate the energy use per household we combined the private expenses per fuel kind, the nominal fuel prices and the number of households. When the private expenses are divided by the nominal price, you know the amount of fuel used by the total population. When you divide this number by the number of households, you get the amount of fuel used per household per year.
The figures for petrol are actually the figures for petrol/bottled gas/wood. Since these could not be separated, we ascribed the total amount of the expenses to petrol. This means we have overestimated the use of petrol.
The figures for 1950 were actually registered in 1953, those for 2000 in 1993.
NIS, Nationale rekeningen 1953-1962 (1963). NIS, Statistische studiën, 45(1976), blz. 1 e.v., NIS, Statistische studiën, 101 (1994), blz. 1 e.v., G. Avondts and P. Scholliers (1981/5). NIS, Het gezinsbudgetonderzoek 1961 (1963). NIS, Gezinsbudgetonderzoek 1973-1974 (1978). NIS, Huishoudbudgetonderzoek 2000 (2003) (www. statbel.fgov.be). Y. Segers (2002). F. Govaerts (1961). L. Quintens (1976).

	Coals (kg)	Wood (m^3)	Oil (l)	Gas (MJ)
1800				
1850	550	0.429		
1900	1 675	0.328		
1950	3 641		173.77	
1975	732		2 216.75	6 348
2000	124.39		579.36	29 831.92

Table 13 : Energy use per household per year in Belgium

The shift between different kinds of fuel can also be (implicitly) examined using real prices. "Prices provide an indication of a fuel's relative scarcity and value"[292].

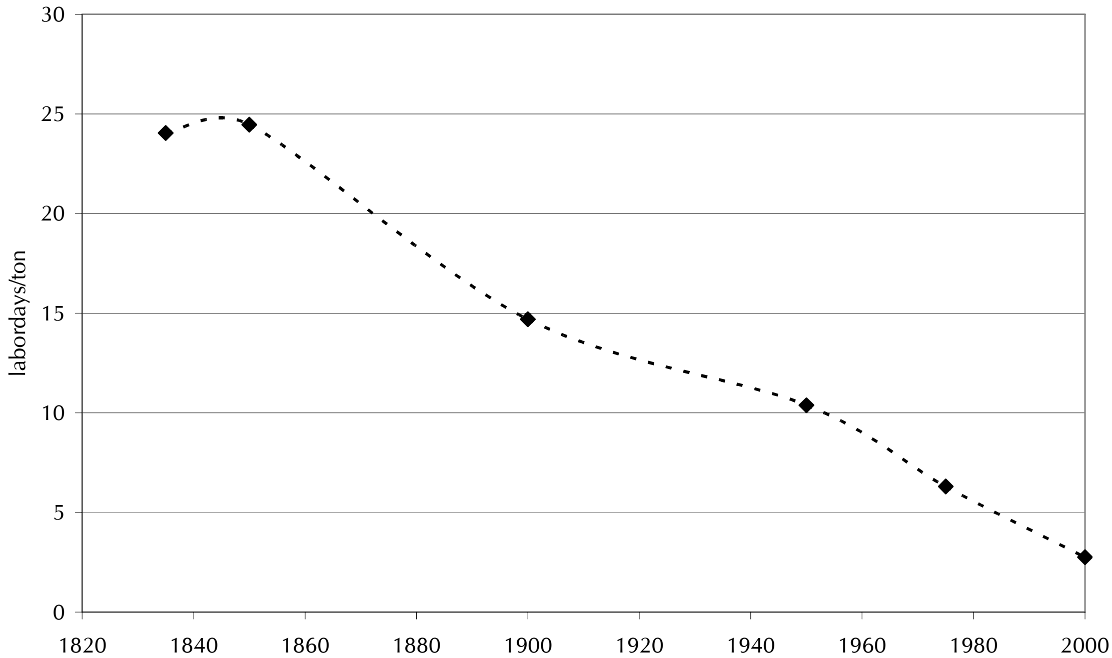

Figure 69 : Real price of coal

At the end of the nineteenth century, the real price of coal[293] (Figure 69) starts declining.
This might be the result of better production techniques and better transport systems, but also of the wood scarcity. Wood was probably the most important base material in the past. It was used for heating, in construction works, in shipbuilding and it was a fuel in industrial processes[294]. It was easy to find, immediately available and sometimes free (brushwood)[295]. Trees were cut down as if they were inexhaustible. Already in the seventeenth century[296], Great Britain is confronted with severe wood scarcity and it has to import wood for

[292] R. Fouquet and P.J.G. Pearson (2003), p. 3.
[293] Y. Segers (2002). C. Vandenbroeke (1988). NIS, *Brutolonen 2000* (www. statbel.fgov.be) (see Annex 4). F. Michotte (1936-1937). Dienst Indexcijfer (2000).
[294] H. Van Zon (2002), p. 55.
[295] C. Ponting (1991), p. 306.
[296] Although the problem already existed centuries earlier. H. Van Zon (2002), p. 56.

shipbuilding[297]. This scarcity results in a transition to the use of coals (an irreplaceable energy source). The world production of coals increased dramatically in the nineteenth century: from 15 million tons in the beginning of the century to more than 700 million tons at the turn of the century[298]. In Belgium too, the government encourages coal production by granting mine concessions[299]. Coal became the only important source of energy and a pillar of the economy until the 1950s[300]. In 1850, 5.8 million tons of coal were produced in Belgium. Production increased to reach 23.9 million tons in 1910. That year, approximately 146 000 people were employed by mine corporations[301]. Nonetheless, the domestic transition from an open fire to a stove and from wood to coal was not self-evident. People were convinced that the smoke of coal was poisonous and that a closed stove only made this worse[302].

The decline of the real coal price carries on during the first half of the twentieth century, due to an increasing supply. In the third quarter of the twentieth century oil replaces coal, mostly due to the ease of use (less storage space was needed, it was easier to turn the heat on and off, less dust was produced and the filling up of the stove was physically less demanding)[303], although there also was a fear of coal scarcity. As with coal in the nineteenth century, the availability of cheap oil was the mainspring for the continuity of the economic expansion in the twentieth century, especially in the United States (e.g. combustion engine)[304]. Since the 1970s, gas became more popular as a fuel for heating (in 1946, it was still prohibited to use gas for centralized heating!)[305]. It has the same (or even a higher) ease of use as oil and is less subordinate to world politics[306]. As shown in Figure 70, the real fuel prices are converging towards the end of the twentieth century[307].

[297] C. Ponting (1991), p. 308.
[298] C. Ponting (1991), p. 312.
[299] e.g. *Pasinomie* (1831 and 1860).
[300] In the 1950's and 1960's, the mining industry collapsed. The government issued several laws to rehabilitate the sector and to support the workforce that got fired.
*Omnilegie (*July 12th 1955). Encouragement of investing in coal mines.
*Omnilegie (*July 28th 1960). A fund is raised to stimulate the sale of the surplus on coal.
*Omnilegie (*October 15th 1963). Establishment of a National Committee to encourage coal consumption.
*Omnilegie (*July 22nd 1966). Former mineworkers can get a reinstatement bonus.
[301] J.A. Van Houtte et.al. ed. (1981/10), p. 47-62.
[302] C.E.P.M. Raedts (1974), p. 44.
[303] P. Van Overbeeke (2001), p. 54 and 170.
[304] C. Ponting (1991), p. 317.
[305] *Pasinomie (*December 13th 1946).
[306] In 1984, the National Oil Bureau was established. Its task was to follow up the supply and distribution of petrol. This was a consequence of the oil crisis in 1973, when oil products were claimed by the government, to make sure important sectors (e.g. fire fighters) had the necessary amount of fuel.
*Omnilegie (*1973 and 1984).
[307] We combined the real prices of the different kinds of fuel with figures about the amount of MJ per fuel quantity. This way, the real price per MJ was calculated, which made it possible to compare the real price of the different kinds of fuel (as shown in Figure 70)

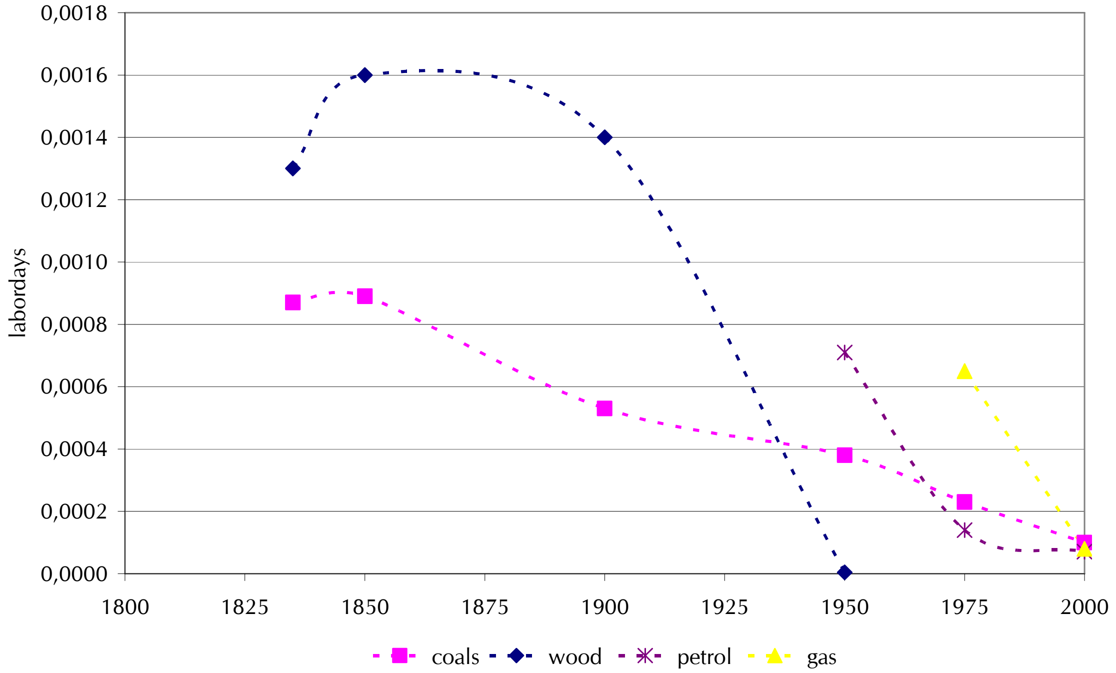

Figure 70 : Real price per MJ

However, to put the importance of the real fuel price in a present-day perspective: because of the current high oil prices, the federal government has decided to financially support less fortunate families to make sure they can heat their houses[308](even though, since 1997, a minimum amount of water, gas and electricity is free of charge for every Flemish family).

As mentioned when discussing the different data sources, two approaches are possible when examining the household budget: the national accounts[309] and the budget inquiries of the working class[310]. Both of these were used to gain insight in the part of the budget spent on heating (Figure 71).

[308] *De Standaard* (April 6th 2005). *De Standaard* (December 31st 2004).
[309] Y. Segers (2002). NIS, Nationale rekeningen 1953-1962 (1963). NIS, *Statistische studiën*, 45(1976), blz. 1 e.v. NIS, *Statistische studiën*, 101 (1994), blz. 1 e.v.
The percentage was retrieved by using the private consumption figures (the amount spent on heating/lighting divided by the total amount of the private expenses). In 1850 and 1900 coals, wood and peat were taken into account. In 1953: coals, bottled gas, petrol and wood. In 1975 and 1993: coals, natural gas, electricity, bottled gas, petrol, wood.
[310] G. Avondts and P. Scholliers (1981/5). NIS, Het gezinsbudgetonderzoek 1961 (1963).
NIS, Gezinsbudgetonderzoek 1973-1974 (1978). NIS, *Huishoudbudgetonderzoek 2000* (2003) (www. statbel.fgov.be). G. Jacquemyns (1951).

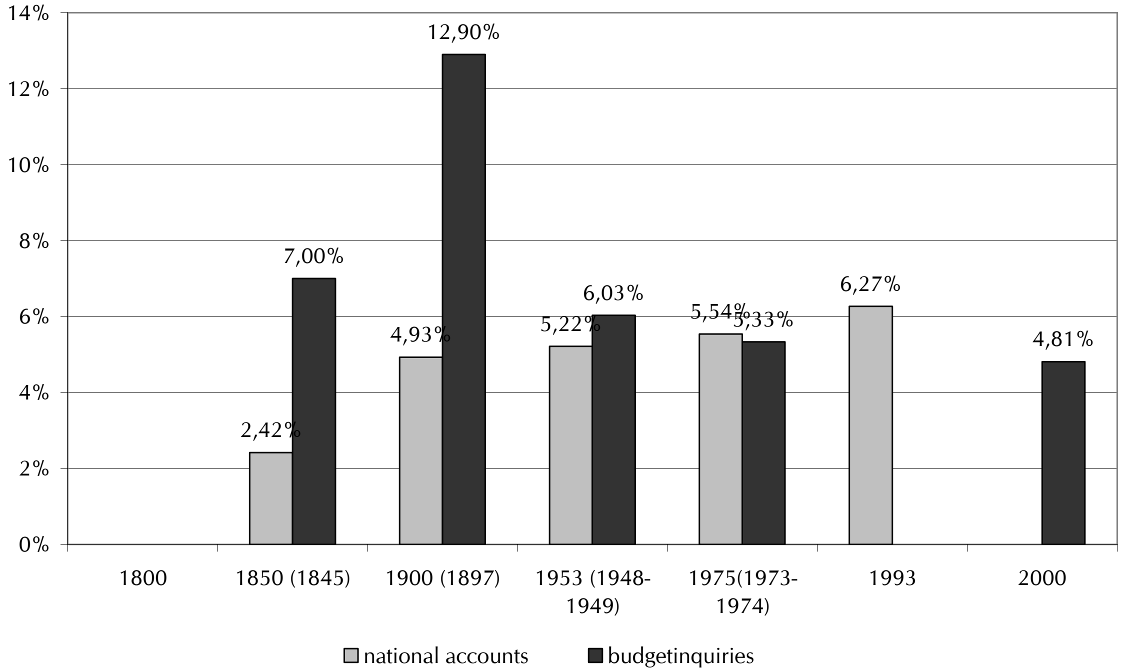

Figure 71 : Private expenditure on heating/lighting

According to the national accounts, the percentage of the private consumption spent on heating/lighting[311] doubles in the second half of the nineteenth century. This might be explained by the increasing use of coal instead of wood, which was often free. The slight increase during the twentieth century was probably linked to the increasing consumption figures (mostly due to an increasing heated volume). However, the results of the budget inquiries show the opposite trend: the percentage of the budget spent on heating/lighting by working men's families decreased over the past hundred years. It almost triples in the second half of the nineteenth century. This can be compared with the trend shown by the national accounts. After 1900, it declines dramatically. Apparently, the improvement of the standard of living is more noticeable when examining working men's families. The differences (between the two approaches) that occur in the second half of the twentieth century are not really significant. They might be an outcome of the characteristics of the different approaches.

5.4.4. Sustainability trends

Introduction

When assessing the heating of single-family houses over the past two centuries several changes could be determined: houses got bigger, although ceilings got lower; central heating systems replaced stoves that had already outnumbered open fires; wood scarcity made people look for other energy sources like coal, oil and gas; isolation became an issue since the 1970s and the average number of people per household has been declining since the beginning of the twentieth century. The assessment of the energy efficiency of heating in 200 years per functional unit (the heating of 1 m³ of a single-family dwelling, that is a good representative

[311] It was not possible to retrieve the proportion heating/lighting for every key years. Therefore, the figures for heating and lighting were used. However, where the proportion could be retrieved, it became clear that this was always the same. This way, conclusions can be based on the figures for heating and lighting.

for the year studied, to a comfort temperature of 18°C, averaged over the seasons) resulted in impressive improvements (decrease with approximately a factor 20). This progress is mainly caused by the use of more efficient heating systems, dense city building and better isolation measures.

Sustainability assessment

By combining the outcomes of the environmental analyses (regarding CO_2, SO_2, NO_X en CO emissions), with the social and economic trends, we come to a number of conclusions about (un)sustainability developments for heating private living space over the years studied. When calculating the contribution of the total Belgian consumption for heating private single-family houses it may be concluded that the efficiency advancements have compensated to a large extent the Belgian population growth and the increased consumption for heating. Actually we can determine four time periods, with three points of inflection (1850, 1900 and 1975). Between 1800 and 1850 the impressive efficiency improvements are neutralized by the enormous population growth in Belgium, so that the release of emissions for that time period stays approximately the same. Between 1850 and 1900 efficiency improvements have the upper hand, so that emissions decrease. From 1900 till 1975 the efficiency improvements could not compensate a more luxury life (more cubic metres of the dwellings are heated, less people live in the houses, considerable population growth in Belgium). Consequently emissions increased in that time period. Around 1975 there is a turn towards less emissions. This is caused by a synergy of different factors, such as:

- more stringent insulation measures, the introduction of hollow walls and the advent of the thermostat;
- more double income couples working outside the house, allowing lower temperatures during absence;
- the raise of the electricity consumption in the household (electrical apparatus emit heat at the use phase so that less fuel energy is needed for heating);
- substantial improvement of the boiler efficiency.

Of course, the second and third factors are no real savings for society as a whole, as the working place also has to be heated and the electricity use has been rising. From 1975-2000 we see the specific emissions like SO_2, NO_x and CO reducing more strongly due to fuel mix changes and policies on heating systems. The overall difference between 1800 and 2000 is for the total society and for most environmental emissions approximately higher by factor 2. Only for CO emissions the contribution is lower. All emissions that have been studied in the heating case expressed per person have decreased in 200 years. For CO_2, NO_x and SO_2 approximately by factor 2; for CO by more than factor 20. Table 14 gives an overview of the different underlying parameters that collectively have set the trend for the total CO_2 emissions.

Overall ratio CO2 emissions from total Belgian consumption (1800 vs. 2000)	factor 1,7 higher
Overall ratio CO2 emissions per person (1800 vs. 2000)	factor 2 lower
Factors that have increased the emissions	
the growth in population	factor 3,4
more comfort (more m3 heated per person)	factor 10
Factors that have decreased the emissions	
efficiency improvements (heating system)	factor 6
better isolation and more closed-space development	factor 5,3 (calculated)

Table 14: Parameters that influenced that trend for the total CO_2 emissions

(Un)-sustainability conclusions

By combining the outcome of the environmental assessment (based on the total Belgian consumption for heating houses) with socio-economic historical trends we came to a number of conclusions regarding (un)sustainability.

- All three dimensions of sustainability (environmental, social and economic) show relative stability over the nineteenth century (although some short-term changes occurred in both directions), when regarding the society as a whole. Living conditions were far from equally distributed over the society. The working class had to work hard to afford a small room to be heated.
- Unsustainable environmental trend from 1900 till 1975. Due to strong increase in consumption and population the environmental emissions increase much faster than the efficiency improvements of the heating system, isolation measures and more closed building constructions, resulting in an increase of about factor 4 in CO_2 emissions. Nonetheless there is a strong socio-economic progress for consumers that allows also the working class to heat their homes properly and live with comfort for an affordable price. Since the efficiency improvement of heating systems and insulation measures do not improve at the same pace, the total amount of emissions increases too. Nonetheless, there is a strong social and economic progress for consumers. More people can heat a considerable part of their houses at an affordable price. Real ‘environmental improvements’ have occurred only after the ‘fulfilment’ of some basic social and economic needs. Heating became more economically and socially sustainable from the second quarter of the twentieth century. However, these developments provoked an unsustainable development in environmental emissions.
- After 1975 there is a beneficial trend in all three dimensions (social, economic and environmental). We could state that the product system is developing in a more sustainable way, as all considered aspects develop positively: total environmental emissions are reduced, while the growing needs of society are fulfilled at an affordable price, without putting producers at a disadvantage. This observation shows what a more sustainable development could mean at a product level : reducing total environmental emissions while satisfying the (growing) needs of society at a more affordable price level for the consumer and still a sufficient profit margin for the producer to invest in further improvements.

6 CONCLUSIONS

6.1. Differences across and similarities between the cases

6.1.1. General observations during the 200 years

The population has increased by factor 3.4 over the last 200 years. This was due to a higher life expectancy (with an increase from about 40 to 78 years), as well as to various immigration waves. The increasing life expectancy not only shows social progress, but it also has led to a large increase in number of consumers.
Most socio-economic and environmental indicators show relatively little change in the 19th century compared to the changes in the 20th century. This is not a surprising result as the industrialization spread at the end of 19th century.
All four product systems have changed considerably over the past 200 years in terms of type and numbers of employees needed, production circumstances, applied technologies, applied fuel mix, and consumption levels. There is a constant need for the production part of the product system to adapt to new circumstances or to create changes in order to survive. Sustainability may not be interpreted as “stability” or “low level of changes”.
Although we could not completely assess and quantify the environmental emissions in all cases, we can still see that the number of transport processes and the related emissions have increased considerably in the whole production and distribution chain, as the chains have become more and more complex and longer during the change from a local oriented economy to a global economy.
The transition from wood to coal for heating purposes was influenced by scarcity and user benefits of coal. The transition from coal to oil and gas was influenced by user benefits (much longer “unattended use”), but the influence of scarcity at that time is not so clear. At the time there were worries about the available resources in coal, but today we know that coal still is available in abundant quantities.

6.1.2. Consumption and availability

All four basic needs have started as a kind of luxury product with a relatively low consumption level. Luxury is defined as very expensive or hardly available. For bread this statement is especially true for white wheat bread, whereas rye bread was much more easily available and affordable. Could this transformation of new products starting as a luxury, followed by a commercialization phase be a universal standard pattern in our consumption patterns ?
There has been an enormous social progress in 200 years regarding the fulfilment of the four basic needs of increasingly more consumers. Belgian society as a whole has achieved good progress in the quality of life for consumers. In all four cases the authorities have played a role in creating progress by e.g.:

- investments in infrastructure (water production and distribution system, railway network, road network).
  The choice to not increase the railway network furthermore around 1900 but to invest alternatively in (horse) tram systems, is understandable and logical, as cars were still very expensive at that time.
- influencing price levels (maximum price for bread, ownership of water supply systems)

- establishing minimum standards for healthy living (water quality, minimum space per person, bread quality control))
- ensuring security of supply (promoting shifts in energy carriers and allowing for cheap grain imports from USA).

Do our consumption levels of products always rise?

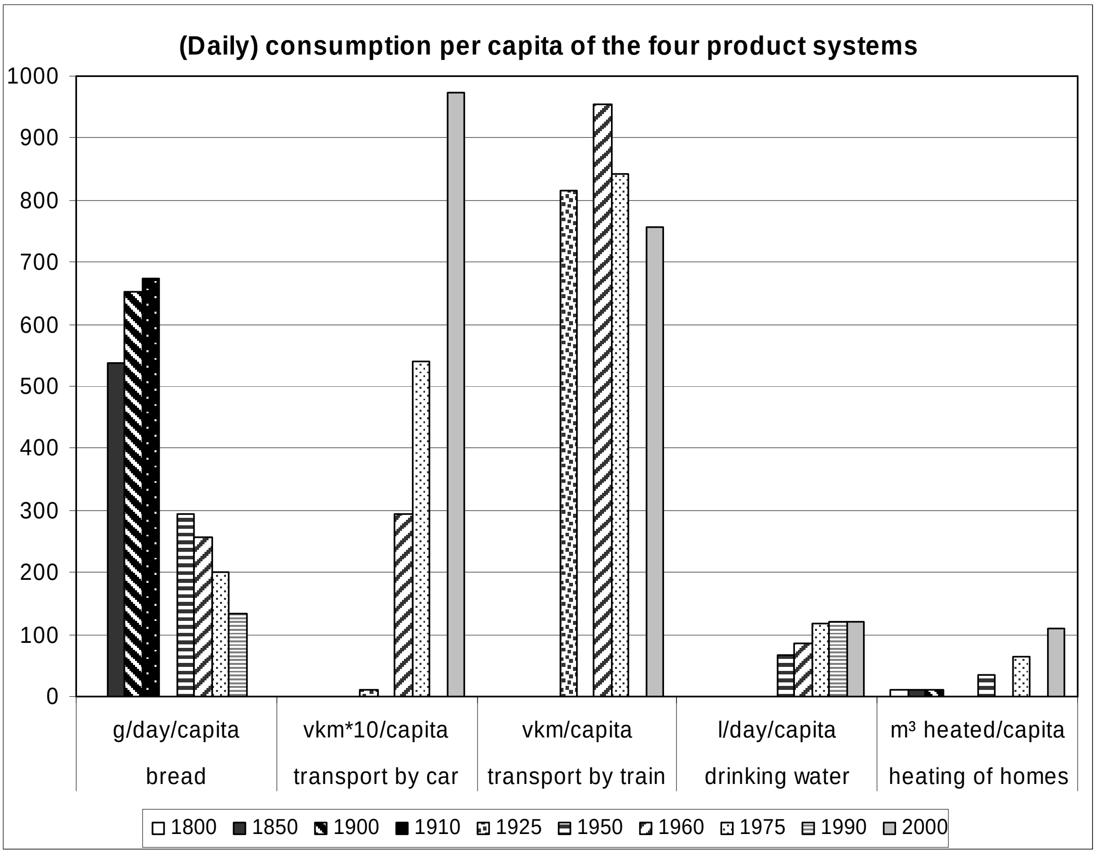

Figure 72 : (Daily) consumption per capita

One of the four needs shows a decreasing consumption level: bread consumption is increasing until approx. 1900, but is decreasing afterwards. Since then there has been a shift from consuming bread to a more varied diet (as well toward ‘substitute’ products of bread, such as breakfast cereals).
Heating (in terms of cubic meter/capita) and transport (in terms of km/capita) show an ever-increasing consumption level: our needs are growing all the time.
Water consumption was rising until approximately 1975, while the infrastructure improved and people developed other hygienic standards. After 1975 the water consumption starts stabilizing.
For water the change in availability is most spectacular (from about 0 % to 100 % in 100 years, i.e., “water” in our definition).
For personal transport by car and train the question raises whether there was a clear existing need for more transport, or did the availability of infrastructure and vehicles create the need. A theory exists that humans are territorial animals, who increase their distances to travel (for

commuting, holidays) whenever the speed of the transport means get higher[312]. There seems to be a kind of universal average constant of travelling about an hour per day.

6.1.3. Prices

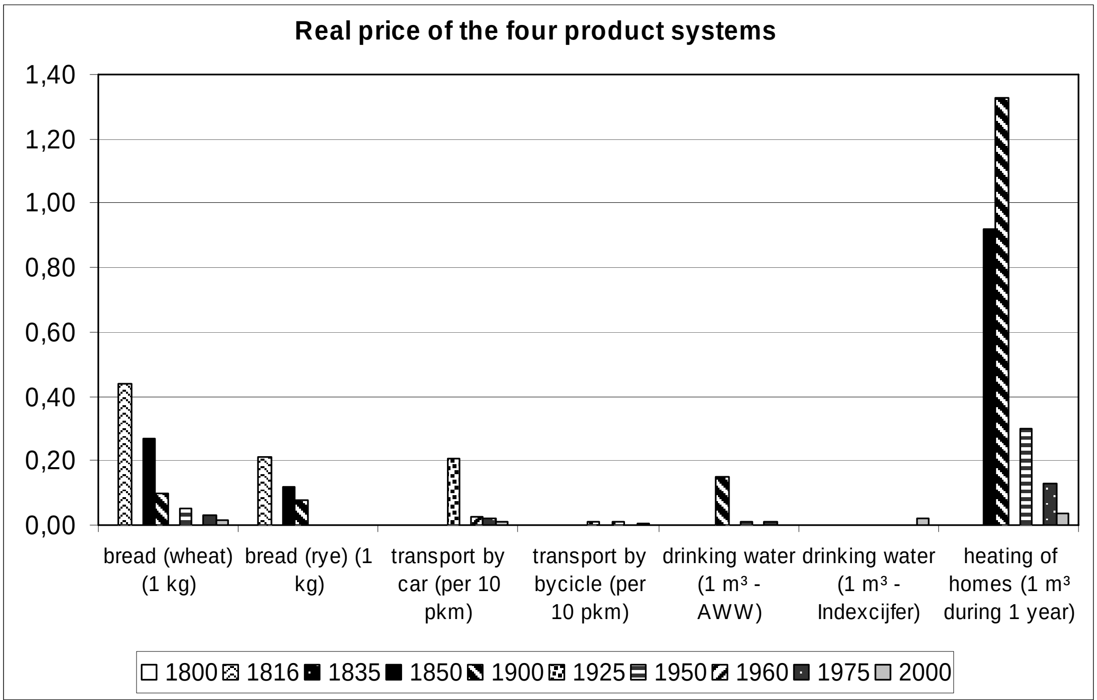

Figure 73 : Real price per functional unit for the 4 cases

The real prices (expressed in number of working days to buy one functional unit) of all four needs show a continuous decrease (sign of socio-economic progress). The exception for heating homes in 1850 is probably caused by poor national statistics on wood consumption for heating.
There are always two reasons for the decrease of the real price: general increase in purchasing power due to higher productivity (i.e. rising wages per worker), and reducing price levels due to product system improvements. Some examples :

- bread : factor 22 (1816-2000) ;
- water : factor 15 (1900-1975)
- petrol : factor 4 (1925-1975)
- car : factor 9 (1925-1975). In 1925 a car had a price of about 4 yearly wages, in 1975 about half a yearly wage;
- coal : factor 3.4 (1850-1975) ;
- heated living space : factor 38 (1900-2000).

Lower real prices have resulted in a better affordability for all social classes.

[312] Filarski, R; 1997

6.1.4. Private expenditure

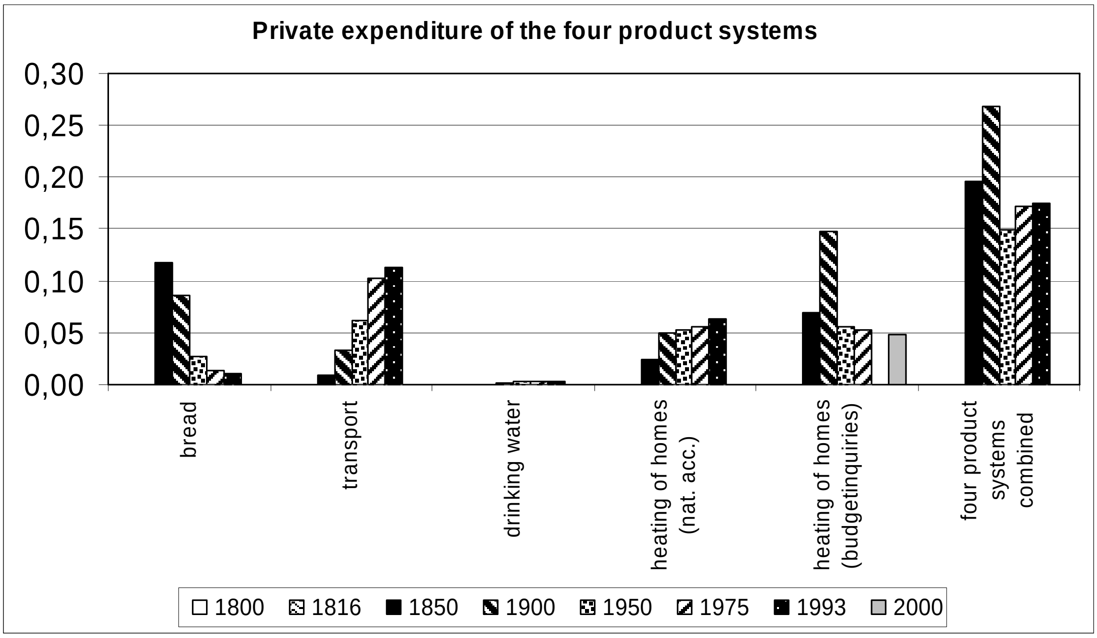

Figure 74 : Private expenditure for the 4 cases

Private expenditure (based on national accounts, i.e. an average for the total Belgian population) on bread decreased, while the expenditure on water, heating and transport rose.

- Bread budget decreased from15 % to 1 % (1850-2000);
- Water increased from 0.1 % to 0.3 % (1900-2000);
- Heating decreased for working class from 7 % to 5 % (1850-2000) and rose from 2 % to 6 % for the total population;
- Transport rose from 1 % to 11 % (this relates to the costs of purchasing and using the vehicle).

It is a sign of socio-economic progress that in 1850 we spent such a significant percentage of the budget on bread, and a similar percentage today on transport (confirming Engel's law, which sustains that the higher is the income, the lower the share of basic needs –i.c. food- on total family spending).

6.1.5. Environmental aspects

Energy efficiency improvements differ widely over the four basic needs :

- Heating : approx. factor 20
- Transport : approx. factor. 1.6 from 1925 to 1960, factor 1.8 from 1925 to 2000 (valid for petrol car use only).
- Bread : a factor 2-4 (strongly dependent on the last trip from shop to consumer).
- Water shows no significant energy efficiency improvements.

It is quite remarkable that heating systems for home have been able to improve their performance much more than the internal combustion engine for cars. There have been some improvements in energy efficiency of the engine but they do not necessarily lead to more energy efficiency per km because the cars are much heavier due to more safety and comfort demands and higher possible speed levels to reduce travel time.

Emissions per functional unit

Substitution of human and animal labour processes by mechanical processes based on fossil fuels first makes the emissions rise. At a later stage the emissions start decreasing thanks to efficiency improvements. It is remarkable to see that the emissions per functional unit decreased even long before 1975 when society started to show an interest in environmental issues.

- Changes in fuel mix (wood, coal, oil, gas, nuclear) are of great importance for e.g. CO_2- and SO_2-emissions. The increase in nuclear electricity has reduced the CO_2-emissions.
- During the last 25 years emissions like CO, NO_x and VOS decrease stronger compared to CO_2 for transport and heating.
- Most emissions decrease over time but there are exceptions: for bread the CO_2 has decreased thanks to baking efficiency but acidifying and eutrophying emissions have been rising because of intensive agriculture.

Total emissions related to Belgian consumption

Based on the figures below, the following conclusions can be drawn:

- Specific emissions (CO, NO_x, SO_2, Pb, VOS) are decreasing for transport and heating since 1975. These are the results of the combination of policy and technological innovations that have proven to be possible.
- Water shows the least significant changes.
- Bread emissions are decreasing but this is partially caused by decreasing consumption.
- For home heating it is quite remarkable that the total emissions over the years vary only within a bandwidth of approx. factor 4, and that the emissions in 2000 have only doubled compared to 1800/1850. The very big changes in efficiency have compensated to a large extent for the growing population and increasing comfort level demands.

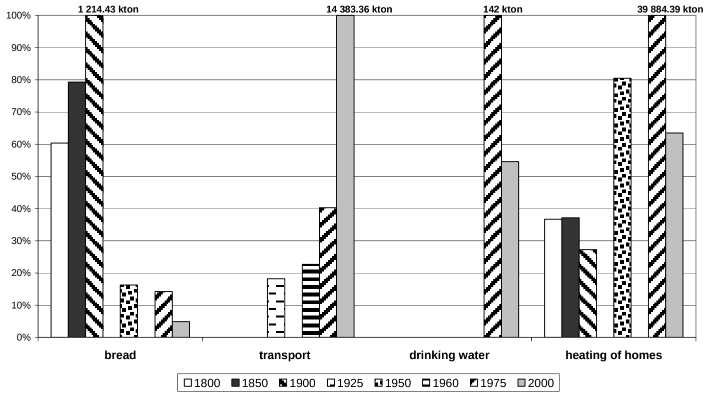

Figure 75 : Total CO_2-emissions of the 4 cases

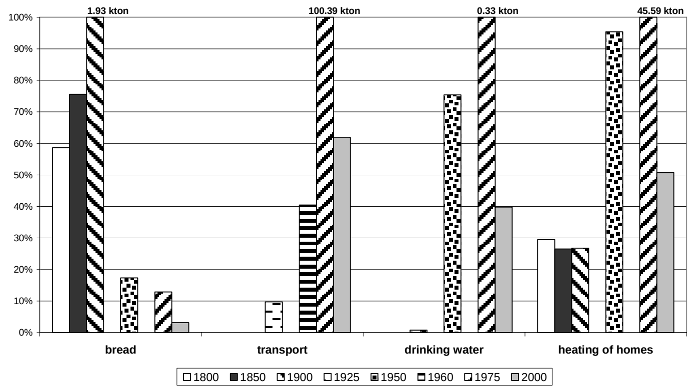

Figure 76 : Total NO_x-emissions of the 4 cases

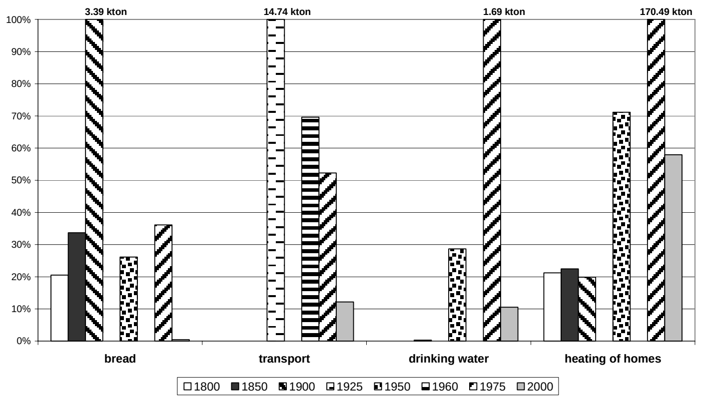

Figure 77 : Total SO_2-emissions of the 4 cases

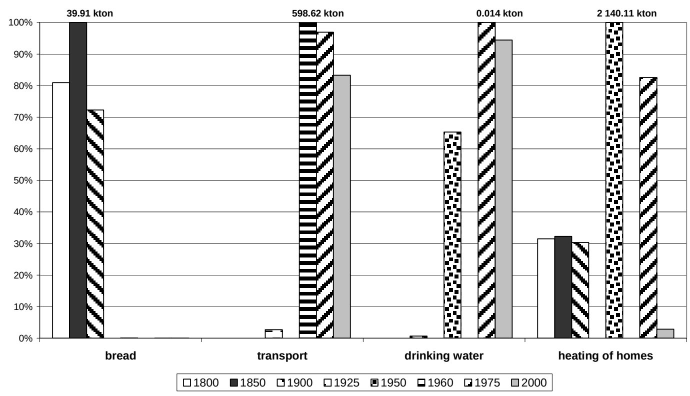

Figure 78 : Total CO-emissions of the 4 cases

Relation between environmental emissions and real prices per functional unit

What can be said about the hypothesis "environment and economy go hand in hand", as we see a general tendency that both environmental emissions and real prices are declining per functional unit ? There are three main reasons for decreasing real prices and their influence on the environmental emissions differs :

- decreasing real prices thanks to application of less material and fossil fuels through higher energy efficiency, result also in decreasing emissions. We have seen this effect in most cases.
- decreasing real prices thanks to less needed labour hours through more mechanization using more fossil fuels result in increasing emissions. We have seen this happening between 1850 and 1900 in the bread case where quite a lot of processes changed from animal/wind/man power to mechanized fuel consuming processes.
- decreasing real prices thanks to mainly higher purchasing power. This does not decrease the emissions per functional unit as such, it only creates power to buy more or other products and indirectly leads to higher emissions through higher consumption levels.

So the hypothesis is sometimes true, but this is definitely not always the fact. We should also realize that the relation between prices for labour and resources like oil, coal, ores is not constant over time. In the nineteenth century labour rates were relatively low due to a largely available workforce.

6.2. Discussion about the three dimensional concept of sustainability for product systems

In this project we did not use definitions of sustainability from the onset, because there is no universal scientific agreement . We wanted to first experience the concept of (un-)sustainability by studying the four specific case studies in the three dimensions.
Today the Brundtland definition for sustainable development is still widely accepted as a good description at the highest level possible. The three-pillar approach is also a widely accepted concept. Yet making the definition more concrete for application at the level of countries and making the progress measurable, is still an ongoing process without final outcomes[313].
One of the reasons to start this project was to get a better understanding of the (un-)sustainability trends of the four product systems from the past, as described above. Another reason was to get more clarity on the three dimensional concept of sustainability for product systems that basically only form a part of total society.

Questions:
Is it possible to determine whether a product system is sustainable as an absolute statement or is this only possible in a relative sense ?
A product system that shows a higher efficiency improvement in resulting emissions than the growth in consumption level, does contribute to more environmental sustainability (in a relative sense). In that way, it creates more space for other possible and justified needs to be fulfilled. But what can we say about a product system that is reducing its overall emissions partially due to lower consumption levels (like e.g. the bread case) ?

Our observations through the experience of this project on product systems to create a good definition for sustainability are :

- The considered **scale** is very important (world, country or region, product system). This project aimed at the product system scale, whereas the sustainability challenge can only be achieved at world level when the sum of all our consumption patterns is sustainable in all three dimensions at the same time.
- It is important to address **production and consumption separately**, the issues are very different in these phases, whereas production and consumption of course are tightly linked.
- It is needed to address the **three dimensions separately** to create an overview. It is not possible yet to integrate all indicators into one single sustainability indicator. At macro level the complexity of the concept is illustrated by the Eurostat Task Force that has recently proposed a set of 155 Sustainable Development Indicators (SDI's) to monitor the progress and inform policy makers and the public[314]. Every dimension as such consists of several different aspects or issues. During our project we have realised that for the environmental dimension the used Life Cycle Approach allows for summing up scores

[313] Giovanni E., 2004
[314] Final report of the Sustainable Development Indicators Task-Force, 2005

regarding e.g. greenhouse gas emissions among the production and consumption phase of a product. Nonetheless there still is no scientific consensus on how to balance greenhouse gas emissions with e.g. acidifying emissions etc. For the social dimension the issues are much more specific and separated for the production phase and the consumption phase: working conditions in factories are important in the production phase but are not really an issue in the consumption phase. The percentage of people having access to a basic need is an important issue for the consumption phase only. Again, balancing between very different and probably sometimes conflicting issues, is very complex. For the economic dimension there is a more universal monetary indicator available that applies well to both production phase and consumption phase.

- Will the definition be a **positive** one (sustainable when …) or a **negative** one (unsustainable when …).
- **Sustainability or sustainable development?** Sustainability is probably the expression of a **wished state**, whereas sustainable development is more the expression of a **wished process**. Which concept is better to use ? The state of **sustainability** is evidently not simple to define both on macro and on micro level. But looking at the four product systems we would conclude (looking with our reference framework of today) that there has been no period in the previous 200 years that could be labelled sustainable. Until 1950 the social inequality within Belgium was very large, and many people could not afford needs that we consider basic today. After 1950 the increasing consumption levels created un-sustainable growing environmental emission levels. **Sustainable development** as a process calls for an integrated and balanced view on the process we should follow. If there is an unbalance between the three pillars, we should try to correct this unbalance without of course creating new unsustainable problems in the other pillars. If we project this view on the four product systems we studied for the past 200 years, we would conclude (looking again with our reference framework of today) that in the 19th century we have not improved much on the social inequality by not being able to provide the majority of the population with basic needs, but that from the early twentieth century on we have started to work successfully on improving the living conditions for the majority of people and still not creating too much total environmental emissions (due to relatively population growth, and still low consumption levels). Between 1950 and 1975 this success combined with a still growing population subsequently has led to a strong increase in environmental emissions. Since 1975, for some of the emissions we see a favourable decoupling with lower emissions for still growing consumption levels. These trends from 1950-1975 and 1975 – 2000 have also been seen at world level for the global emissions from Carbon, Sulphur and Nitrogen which have been caused to a large extent (about three quarters) by the industrialized countries[315].

Having reached the end of our project, we now formulate a definition for the three-dimensional concept of sustainability for product systems and see what the consequences would be.

<u>Economic sustainability</u>
A product system is economically sustainable when the production creates enough profit margin to invest in future improvements, and the price level is acceptable to fulfil the needs of the consumers.

[315] Trends in Global Emissions : Carbon, Sulfur, and Nitrogen, Arnulf Grübler, Encyclopedia of Global Environmental Change (ISBN 0-471-97796-9), John Wiley & Sons, 2002)

A product system is **not** economically sustainable when the production is creating losses during an extensive period (e.g. caused by a too high price level) or needs permanent subsidies to survive.
Respecting these definitions a product system can be seen as sustainable in an absolute sense.

Social sustainability
A product system is socially sustainable when the production takes place under decent labour conditions (in terms of working hours, hygiene, remuneration, etc), and the price level is acceptable to fulfil the fundamental needs of the consumers.
A product system is **not** socially sustainable when the production is based on overexploitation of employees (in terms of working hours, hygiene, remuneration etc), or is not able to fulfil the fundamental needs of the society it makes part of.
In this definition it also becomes clear that economic and social sustainability are very much related through the price level (hence, the importance of state intervention and balanced social relations).. A statement on social sustainability is possible in absolute terms but does depend on the applied scale: a product system might be sustainable in a Western country but not on world level because of non-fulfilment of consumption needs. Another discussion point is the item of unemployment. How far does the responsibility of a producer extends for the employment of its personnel ? In all four cases we have seen that there is a continuous change in needed professions sometimes leading to unemployment. Through re-education, the unemployed might stay employable within the product system. If not, the social and economic costs are usually paid by society as a whole.

Environmental sustainability
A product system is environmentally sustainable in absolute terms when in the full chain of production and consumption, sources are used that are not exhaustible and do not cause any emissions that might contribute to exceeding the earth’s capacity to carry them.
A product system **cannot** be called environmentally sustainable in absolute terms as soon as in the full chain of production and consumption, sources are used that are exhaustible or do cause emissions that might contribute to exceeding the earth’s capacity to carry them. In this case one has to assess the total resource use and emission level of all product and service systems in society and have a fair distribution of the shares corresponding to them.
In this definition only very few product systems might be called absolutely environmentally sustainable. In this dimension the assessment can usually be done only in relative terms. This relative statement also connects better to the concept of sustainable development as a process.