(Un-)Sustainability developments of product systems, 1800-2000: Lessons learnt about transport and heating in Belgium

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ABSTRACT

In order to make the concept of sustainable development more concrete and well founded for product systems and to study the relation between sustainable production and consumption, VITO has performed a study in collaboration with the History Department of the University of Brussels, co-financed by the Belgian Federal Public Planning Service Science Policy. The developments for four basic needs (bread, drinking water, transport and heating) regarding production and consumption over the period 1800-2000 are determined and interpreted. The environmental, social and economic aspects of the four products in the 'key-years' 1800-1850-1900-1950-1975 and 2000 are analysed, using quantitative and qualitative analyses.

By studying the production as well as the consumption, the trend in total environmental pressure can be determined over the last two centuries and it becomes clear how and to which extent efficiency improvements in the production have compensated for the growing consumption. We look back in time because of the importance of creating a better understanding of the historical development of (un)sustainability within particular product systems. This helps to determine which factors have an influence on sustainability as a whole.

The paper will focus on the (un-)sustainability developments of the cases "heating houses" and "car transport".

Introduction and project description

To create a view on 'sustainable development' on the long term, important lessons could be learned from the past. 'Sustainability' has little meaning without an understanding of long-term ecosystem trajectories and a knowledge of baseline conditions, if they ever existed. The interdisciplinary research project '(Un)sustainability developments of product systems, 1800-2000' [1] investigates the (un)sustainability development of four basic needs in Belgium over the last two centuries, to gain insight into sustainable development on a micro level. The project want to gain insight into sustainable development on a micro level. The goal of the research project is to make the concept of sustainable development more concrete and well-founded on a micro level (for products) and to study the relationship between sustainable production and consumption. During the project we do not start from today's situation to think of scenarios for future sustainable development, but we wish to gain insight into the process of (un)sustainable development during the past two centuries. We analysed the environmental, social and economic aspects of these four products in the 'key-years' 1800-1850-1900-1950-1975 and 2000, using quantitative and qualitative analysis, in order to be able to interpret and steer recent and future developments. Both the production and consumption phases are studied and related with one another. That way the total 'lifecycle' of a product is analysed, taking into account all the factors that can be of influence. This paper focuses on the cases "heating houses" and "car transport".

Methodology

During the project modern LCA-techniques were used to determine *environmental impacts.* This methodology is useful to make a systems-based understanding of sustainable consumption and production, because of its 'cradle to grave'- approach. Every aspect of the product system is being analyzed. As soon as the environmental parameters have been collected they were combined with total Belgian fuel consumption figures. By doing so

statements could be made about the total societal environmental load related to the different product systems.
To gain insight in the (historical) *social and economic dimensions* more 'general' and case 'specific' data and indicators were collected. Some 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. Some examples are: population figures, number of households, life expectancy at birth, infant mortality and purchasing power. Specific indicators are for example the real price of the product (nominal price divided by an average day wage) representing the days of labour needed to be able to purchase a good.
And finally the *environmental impacts* are *combined with* the outcomes of research on *socio-economic trends* in order to map out changes in consumption patterns and to explain these changes. By combining environmental aspects and socio-economic indicators the 'total cost' of these four product systems will be defined, now and during the past two centuries, in Belgium.

Case "Heating houses"
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 as of the 1970's and the average number of people per household has been declining since the beginning of the twentieth century. While analysing the heating of a single-family dwelling, one should consider a representative mix of housing facilities, heating systems and energy sources, since not every family lives in a dwelling that was built in the year that is studied and not every family immediately acquires a new kind of heating system or energy source. Together with the expertise of historians and architectural engineers, we decided upon a 'most common' dwelling and heating system for the different years studied.
To map the year 1800, 1850 en 1900 for example we heated three different houses in the open-air museum of Bokrijk [2], using three different heating systems, to carry out environmental measurements to be able to determine emission factors and energy use, both necessary to map some of the environmental parameters based on the LCA approach.

Environmental indicators "heating houses"
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. 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 1. 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.

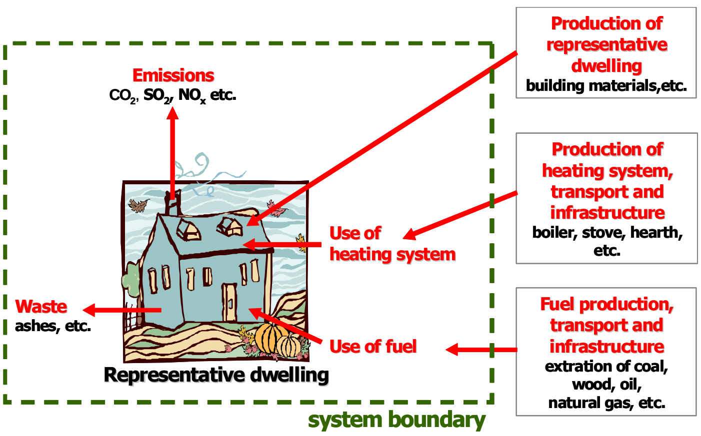

Figure 1: System boundaries case heating houses

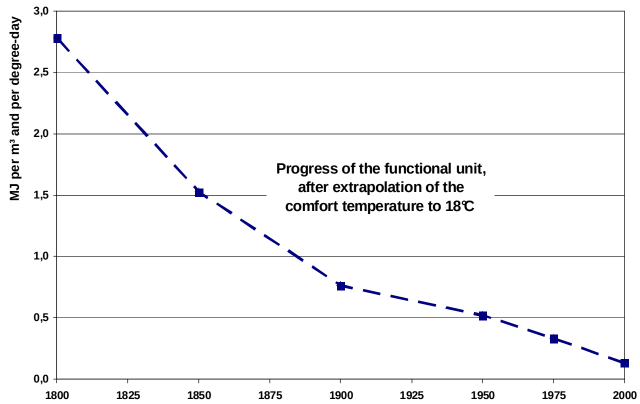

Figure 2: Tendency in energy consumption per m³ and per degree-day (functional unit)

Figure 2 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 2 that over the years much less energy is required for heating one cubic metre. This implies that the energy efficiency has improved substantially (more than factor 20). 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.

Figure 3 presents the comparison of the total amount of CO_2 emissions caused by the functional unit over the dfferent 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 trend of the other emissions studied over the past two centuries, follow a similar trend as the CO_2 emissions.

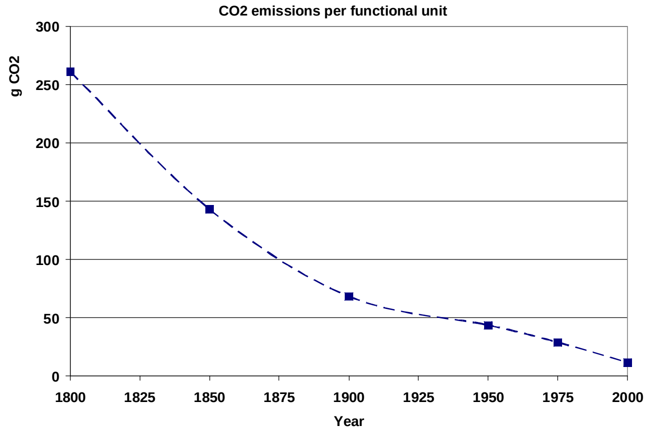

Figure 3: Comparison of the CO_2 emissions related to the functional unit

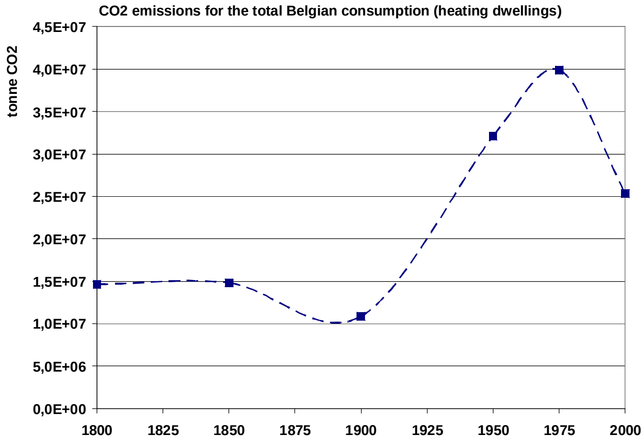

Figure 4: Trend in CO_2 emissions related to the total Belgian consumption for heating houses

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 (m³) of an average Belgian single-family dwelling, per degree-day, for the different key years. Figure 4 present the contribution of heating private living space caused by the total Belgian society to the exhaust of CO_2. 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 2) is counterbalanced by the population growth (increased evolution) and the increased consumption (more m³ 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. 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.

Socio-economic indicators "heating houses"

Both general indicators, like population figures and life expectancy, as well as more case-specific indicators like real prices and the percentage of the budget spent on heating were examined thoroughly for the heating case. The shift between different kinds of fuel for example can be (implicitly) examined using real prices. "Prices provide an indication of a fuel's relative scarcity and value" [3] (see figure 5). Besides this two approaches are possible

when examining the household budget: the national accounts and the budget inquiries of the working class. Both of these were used to gain insight in the part of the budget spent on heating (Figure 6).
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. This is imperative to know when analysing the environmental issues by using the LCA approach. It also means that people in 2000 can afford to heat a larger part of their house than their ancestors in 1850 did. The total amount of m³ heated increased dramatically between 1800 and 2000.

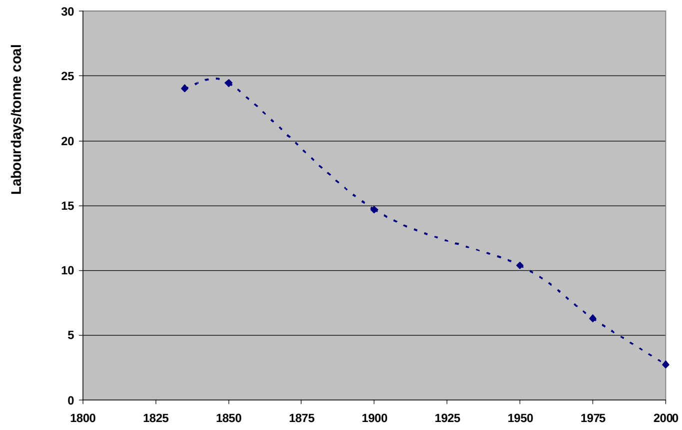

Figure 5: Real price of coal

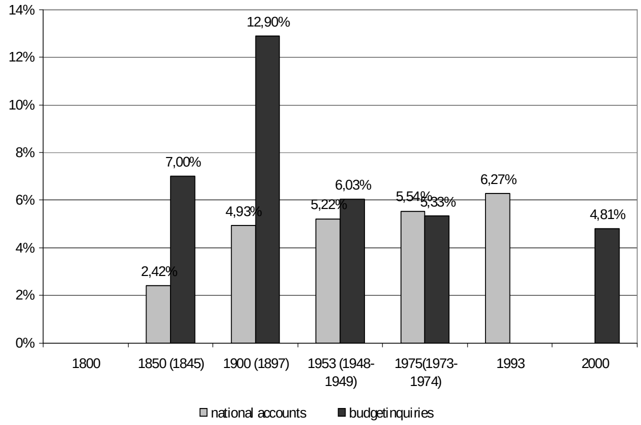

Figure 6: Private expenditure on heating/lighting

Sustainability trends case 'heating houses'

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.

Case "Car transport"

In the overall project five means of transport are considered: on foot, by (horse) tram (bus), by bicycle , by train and by car. For this paper only vehicles used for people transportation by car over land are considered. The environmental aspects related to transportation over the last 2 centuries are combined with socio-economical aspects over these years, like extent of the road network, accidents, real prices, share of transport in total expenditures.

Environmental indictors "car transportation"

The goal of this environmental analysis is to compare the environmental effects of car passenger transport in Belgium in 1925, 1960, 1975 and 2000. The functional unit is "human movement over land of one person over 1 kilometre by car (which amounts to 1 passenger kilometre)". Figure 7 to Figure 12 show the results of the environmental analysis of car transport. 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. Figure 7 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. Futhermore 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 11). The same trend is visible for the total CO_2-emissions due to car transport in Belgium (see Figure 12). However the NO_x-, SO_2- 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.

Socio-economic indicators "car transportation"

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 13). The same evolution can be retrieved from Figure 14.

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 (see Figure 15). Together with this expansion in infrastructure, transport becomes affordable for a major part of the population. The real price of cars (see Figure 16) 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.

Sustainability trends case "car transportation"

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 20th 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 20th 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.

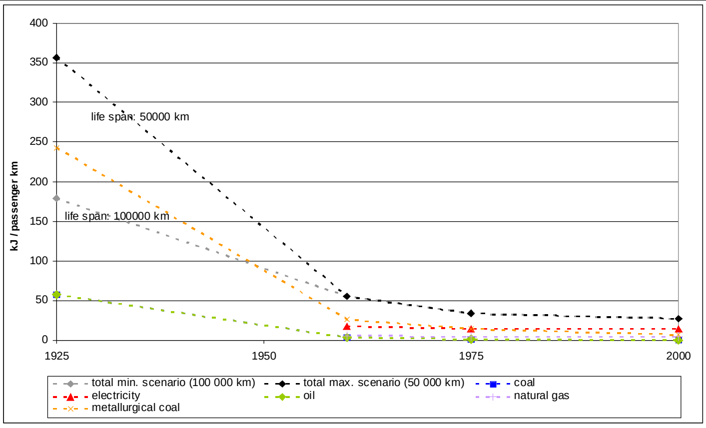

Figure 7: Energy consumption steel production (per passenger km)

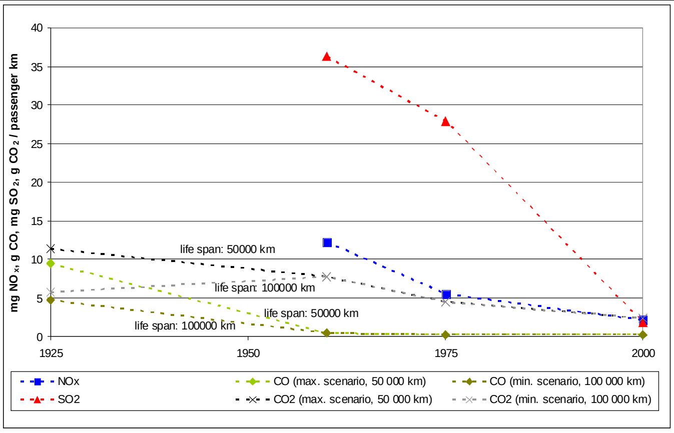

Figure 8: Emissions caused by steel production (per passenger km)

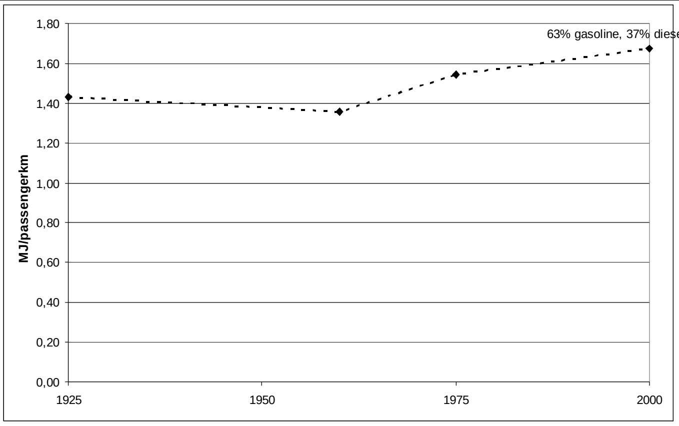

Figure 9: Energy consumption for driving a car (per passenger km)

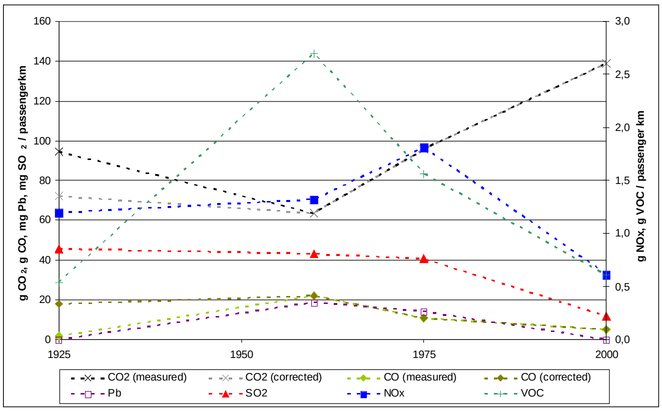

Figure 10: Emissions caused by driving a car (per passenger km)

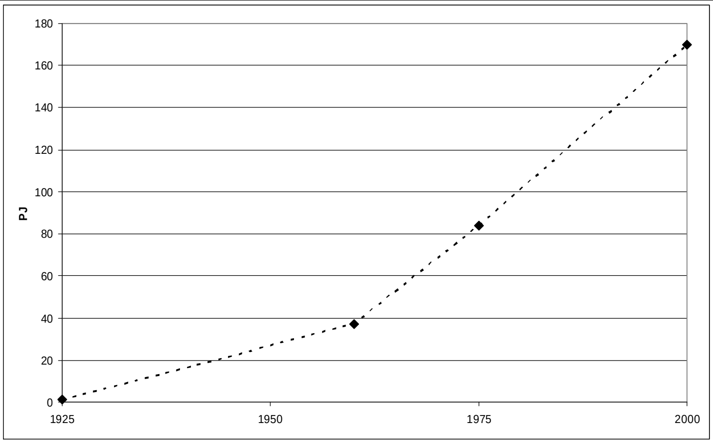

Figure 11 Total energy use for car transport in Belgium

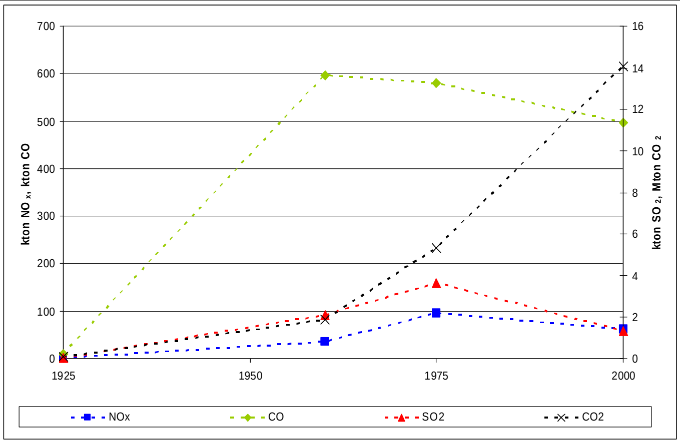

Figure 12: Total emissions caused by car transport in Belgium

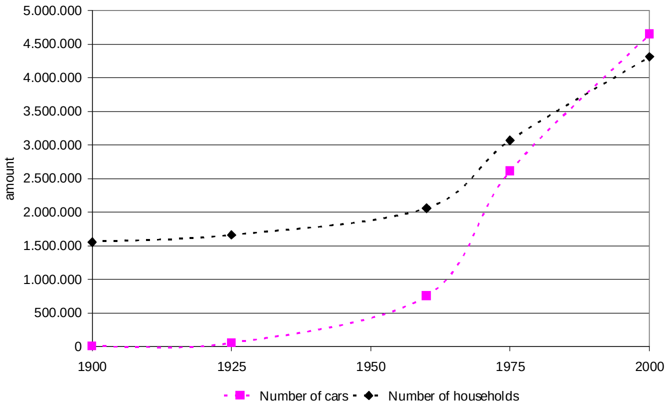

Figure 13: Belgian cars and households

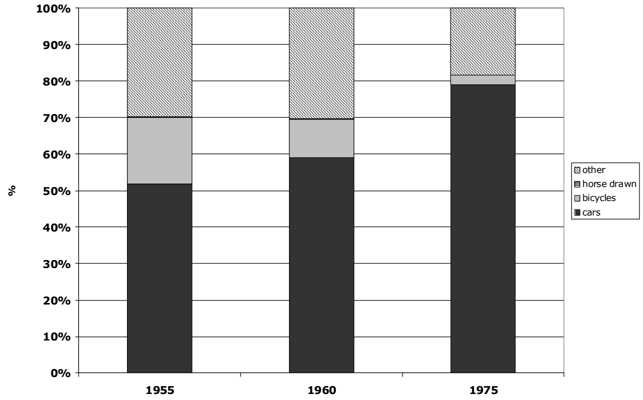

Figure 14: Proportion of road vehicles

	Road network (km)
1830	3 241.4
1850	6 236
1900	9 364.39
1950	10 868.22
1960	11 600
1975	12 301
2000	144 914 (in 1997)

Figure 15: Evolution of the infrastructure

	Real car price (labour days/car)
1900	2 716.15
1925	1 533.82
1960	322.47 (in 1962)
1975	168.68
2000	125.41

Figure 16: Evolution of the real prices

Car transport in Belgium shows a booming trend in ownership between 1925 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. 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.

Conclusions

The two cases 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”.

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.

The real prices (expressed in number of working days to buy one functional unit) show for both cases 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. Lower real prices have resulted in a better affordability for all social classes.

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.
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.
During the project we learnt to address the three dimensions of sustainability 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. 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 Assessment Approach allows for summing up scores 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.

References

[1] Geerken, T.H., De Vooght, D., Scholliers, P., Spirinckx, C., Timmermans, V., Van Holderbeke, M. & Vercalsteren, A. (2006). Sustainability development of product systems, 1800-2000. Final Report (May 2006). Brussel. Commissioned by the Belgian Federal Public Planning Service – Science Policy, Research partners: VUB (Free University of Brussels) History Department and VITO (Flemish Institute of Technological Research) Product and Technology Studies.

[2] Bokrijk museum. 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

[3] R. Fouquet and P.J.G. Pearson (2003), p. 3