SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT POLICY

Intermediary report – December 2002

SUSTAINABILITY DEVELOPMENTS OF PRODUCT SYSTEMS, 1800-2000
CP-10

Vito - VUB

SPSD II

PART 1

SUSTAINABLE PRODUCTION AND CONSUMPTION PATTERNS

- GENERAL ISSUES
- AGRO-FOOD
- ENERGY
- TRANSPORT

This research project is realised within the framework of the Scientific support plan for a sustainable development policy (SPSD II)

Part I "Sustainable production and consumption patterns"

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Sustainability developments of product systems, 1800 – 2000

Report for DWTC

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1 Project Title: “Sustainability developments of product systems, 1800-2000”

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2 Introduction

2.1 Context and summary

The objective of sustainable development on a macro level (global, national, over the generations) has to be converted into objectives on the micro level (companies, products, consumers and their behaviour). Here, we are still at the beginning. This can be illustrated by the fact that hardly any sustainability indicators exist on a micro level for products. That’s why we’ve chosen to study 4 product systems.

For this project we do not want to start from today's situation to think of scenarios for future sustainable development, but we wish to gain an insight (positive and negative factors) into the process of (un)sustainable development during the past two centuries. We think their still is a lack of understanding about the relationships between the environmental, social and economic developments. Through this project we hope to determine a history of the most relevant environmental, social and economic developments for each product system and to learn lessons about sustainability from the shown trends, relations and differences between the case studies.

2.2 Objectives

Objective:

Gaining insight into the factors that influenced the process of sustainable development on a micro level for four basic needs, using a quantitative and qualitative analysis for the period 1800-2000, in order to better interpret and steer recent and future developments.

Sub-objectives are:

1. Mapping the (un)sustainability development of four basic needs in Western Europe during the last 200 year.
2. Identification of dominant factors of influence that were decisive for this development.
3. Deriving of relevant sustainability indicators on micro level for product systems on environmental, economical and social level, individually as well as in their mutual relationship.
4. Following previous points: identify policy elements that can stimulate sustainable development.
5. Distributing and testing the results of the research via publications, colloquia and education

2.3 Expected outcomes

We expect to gain insight in the combinations of factors that influenced the process of sustainable development in the past in a positive and negative way. Among other things, the course of the improvement process will not be identical for each of the selected basic needs and it is of great importance to understand the causes of these differences. On the basis of the eco-efficiency improvement of the functional unit together with the increase of the consumption we hope to give a quantitative indication of the historic development of the environmental component of sustainable development. By complementing these trends with quantitative and qualitative developments we will learn a lot about the mutual relationships between environmental, economical and social developments.

At the end we also expect to make suggestions for relevant economic and social indicators for sustainable products (i.e. on micro level).

3 Detailed description of the scientific methodology

1. The research objects we have selected are those basic needs we wish all persons on earth would have: water, bread, the ability for mobility and heating of living space. We use the modern life cycle analysis (LCA) method to determine the environmental load (ISO 14040). Therefore it's necessary to define the functional unit for each basic need as absolute as possible in order to allow comparisons between time and space. As functional units we have chosen the following: 1 litre drinking water, 1 bread , 1 human trip of 40 km over land (by foot, bicycle, car ,train , tram/bus) and the heating of 1 cubic metre living space during 1 year.

2.We have selected a number of "key data" in the past: 1800, 1850, 1900, 1950, 1975 and 2000

3. Based on historical research and actual available data we will make a quantitative and qualitative status description of the fulfilling of the four basic needs, for each selected date. The research will examine the environmental, social and economic aspects on the production side as well as the consumption side. We will integrate the most important influences that have lead, in the intervening period of 50 or 25 year, to changes in the status description. We focus on Belgian sources for data on production and consumption. If the tracing of these data does not fit in the project planning and we dispose of representative Western European data, we will use these data with a specific acknowledgement of sources. When literature or other sources do not supply enough data for the LCA analysis we will try to measure the inputs (energy, materials) and outputs (emissions, waste) on representative still existing products and processes.

The following aspects are quantitatively founded:

Environmental: integral environmental load (production, consumption, disposal) by means of LCA

Economical : real cost price, consumption per person

Social: distribution of the consumption over the community (degree of equality)

4. On macro level we will give a description of important data on environmental, social and economic level for the "key data". The following elements that come up quantitatively are the total amount of consumers, the average life expectancy, the GNP, the available accommodation, the infant mortality.

Qualitatively, aspects like the abolition of child labour, the rise of the unions, rights of employees, technological breakthroughs in the production system, causes of change in consumption patterns, consumer behaviour, marketing, educational level etc. will also be included for interpretation of the trends.

4 Detailed description of the intermediary results, preliminary conclusions and recommendations

In the first year we focused on the following subtasks :

1. A quick orientative phase followed up by a rapid prototype session to define important aspects to consider within each product system.
2. Defining the typical or representative product systems over the years. The deliverable is a kind of status description of each system over the years. Meanwhile some data on social and economic aspects have been gathered as well.
3. Collecting environmental basic data to perform the LCA. We have decided to start with the last (2000, reference year) and a first relevant year (e.g. car started with T Ford in approx. 1920). Having results for these extremes we can make the search for data for the intermediary years more efficient. For the year 2000 often more accuracy can be obtained by working with average data, because of more data availability. For the first relevant year we are already happy to find realistic data for a kind of representative or frequently seen product system. There are differences in progress for each of the case studies because of availability of basic data. The water case study is a little behind schedule and also more complicated (even for 2000).
4. Some measurements on emissions and energy use for house warming and baking of bread have been performed.

4.1 Status description and sources

4.1.1 Introduction

Before starting an environmental analysis for each case study, we have to define in which way the basic needs were fulfilled in each « key year ». This means we have to try to determine what kind of bread people ate and how this was produced, where they got their drinking water, how they heated their houses and by which means they moved themselves from one place to another in the years 1800, 1850, 1900, 1950, 1975 and 2000.

Different sources can be used to get this kind of information. Because of our limited time we tried to get as much as possible out of already published data. The specific results per research topic will be looked at further on, because the sources are different for each of those case studies.

Finally, something very important must be kept in mind while looking at the 'definitions' : none of them 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 perform the environmental analyses.

4.1.2 Status description and sources

4.1.2.1 1m3 of heated living space

When analyzing the life cycle of the heated living space, several factors have to be considered, being :

- the building materials that were used for walls and windows
- the use of insulating materials
- the volume of living space that was actually heated
- the kind of heating system used (central or decentral heating; open fire, stoves or radiators)
- the kind of fuel that was used (wood, coals, gas, petrol, electricity)

After reading specific literature[i] about building and heating, as well as looking at several statistics concerning 'housing' in Belgium[ii] and after several discussions with Dirk Van de Vijver, Robert

Nouwen, An Schoefs and Annick Boesmans[iii], we have been able to define our subject. The following matrices show our ‘definitions’.

Table 1 Heated living space

Year	Countryside walls	City walls	Windows	Use of insulating materials	Dimensions of heated living space	Windows in heated living space
1800	Clay	Brick (1 stone)	Single glazing; wooden frames	No	$16m^2$ height : 3m?	2 windows, $1m^2$ each?
1850	Clay	Brick (1 stone)	Single glazing; wooden frames	No	$16m^2$ height : 3m?	2 windows, $1m^2$ each?
1900	Brick (1 stone)	Brick (1 stone)	Single glazing; wooden frames	No	$16m^2$ height : 3m?	2 windows, $1m^2$ each
1950	Brick (1 stone)	Brick (1 stone)	Single glazing; wooden frames	No	58,75m^2 *actual* living space height : 3,5m?	
1975	Hollow wall	Hollow wall	Introduction of double glazing; steel or aluminium frames	Limited use	71,39m^2 *actual* living space height : 3,5m?	
2000	Hollow wall	Hollow wall	Introduction of triple glazing; aluminum frames	Yes	86,29m^2 *actual* living space height : 3,5m?	

- Regarding this information, we have to take into account that not all houses are newly built.
- So far we haven’t been able to determine a difference between windows in city and countryside houses.
- Insulating materials were used since the 1970’s, although its use is not widespread yet. We probably only have to take this into account in the analysis for the year 2000.
- We assume that the dimensions of a countryside house are larger than those of a city house. We have to take this difference into account when doing the LCA.

Table 2 Heating system. Fuels.

Year	Heating system	Central/decentral	Fuel
1800	Open fire Stove	Decentral	Wood
1850	Stove	Decentral	Wood or coals
1900	Stove	Decentral	Coals Electrical and petrol heaters for secondary heating
1950	Stove Radiators	Decentral Central	Coals Petrol, gas
1975	Radiators Stove	Central (51,2%) Decentral	Petrol, gas, coals Coals, electricity
2000	Radiators	Central (64%)	Gas (38%) Petrol (56,3%) Electricity (4,3%)

- In order to get additional information about energy consumption and emissions when heating a house, we did three ‘environmental measurements’ in Bokrijk. We chose three houses, representing three ‘key years’ and we used three different heating systems.
  1800 : farmer’s house in clay ; open fire
  1850 : ‘dijkhuisje’ in brick ; wood stove
  1900 : working-class cottage in brick ; coal stove

When these choices are being compared to the relevant definitions in the matrices, a high level of correspondence occurs. These measurements resulted in valuable information with regards to the life-cycle analysis. Moreover we foresee a further refinement of these results by looking at additional literature and archives research.

4.1.2.2 1 kg of bread

Production and consumption of 1 kg of bread consist of several steps[iv] : agriculture, milling, baking, distribution and consumption. Several factors affect energy consumption and emissions. We have tried to define these influences for each 'key year' and summarized them in two matrices.

Table 3 Agricultural phase and milling process

Year	Origin of the grains	The use of machinery during the agricultural phase	The use of fertilizers	The use of herbicides and pesticides	Energy consumption during the milling process
1800	Belgium	Manual labour	Manure, waste from the cities, bone-manure	Cultural measures (e.g. three-course rotation)	Water, wind, animals
1850	Belgium, the Ukraine (import: 7,5%)	Manual labour. Machinery is being developed.	Manure, bone-manure, waste, guano	Cultural measures, own preparations	Water, wind, animals
1900	USA (import: 74%)	Harvesters. Tractors in the USA	(chemical) fertilizers N: 6,33 kg/ha P2O5: 7,84 kg/ha K2O: 1,17kg/ha	Cultural measures, own preparations	Steam engines. (wood or coals)
1950	France (import: 65%)	Mechanized agriculture (machinery: +516%)	(chemical) fertilizers N: 41,9kg/ha P2O5: 43,5 kg/ha K2O: 82,3 kg/ha	Chemical products	Electricity ?
1975	France (71%) (import: 55%)	Mechanized agriculture	(chemical) fertilizers	Chemical products	Electricity
2000	France (56%) (import: 70%)	Mechanized agriculture	(chemical) fertilizers, biological alternatives	Chemical products, biological alternatives	Electricity

- It is important to know the origin of the grains, in case it had to be transported before being milled in Belgium.
- Mechanisation of the agricultural phase implies that fuels are needed.
- Concerning fertilizers and pesticides, energy consumption and emissions during production are important. We haven't been able to determine these yet.
- In order to get more information about the milling process we have planned a visit to Ceres. This company is the oldest industrial milling company in Belgium. It has been founded at the end of the nineteenth century.

Table 4 Fuels needed during the baking process. Distribution. Consumption.

Year	Preparing the dough	Baking	Distribution	Consumption
1800	Manual labour	Wood	Push-cart ; cart drawn by dogs ; horse and carriage	Rye
1850	Manual labour	Wood Coals	Push-cart ; cart drawn by dogs ; horse and carriage	Rye 537g/day/capita
1900	Manual labour	Wood Coals	Carrier-tricycle	Wheat 674g/day/capita
1950	Electrical (?) machinery	Gas ?	Mechanized transportation	Wheat 293g/day/capita
1975	Electrical machinery	Gas ?	Mechanized transportation	60% wheat 200g/day/capita
2000	Electrical machinery	Gas ?	Mechanized transportation	49% wheat 134g/day/capita

- Concerning this aspect we also did environmental measurements in Bokrijk. The objective of these measurements was to determine energy consumption and emissions during the baking process. Again, this information can be tweaked by additional research. We also plan to visit the bakery-museum in Veurne.

- After World War II transportation was mechanized. This is of influence for the environmental impact of 'consuming 1kg of bread', because fuels are required.
- In order to know the environmental impacts of 'consuming 1 kg of bread' we have to know how much bread was consumed (and which kind) per capita in each 'key year'.
- Other elements that are important for this case are the trends in yielding of the crops and the required sowing seed for 1 kg of bread. These have not been determined yet.

4.1.2.3 1 l of potable water

The required information for this case can be summarized in six questions :

- How did the extraction, treatment and distribution of potable water take place ?
- How much energy is required for the production of potable water and what kind of fuel is used ?
- Which reagents are required ?
- Which materials are used, especially for the distribution of water ?
- Which emissions and waste are released into the environment or processed ?
- How much water is used per person ?

As in all 4 cases, priorities are energy consumption during the process as a whole, followed by emissions and which materials were used for the water pipes.
The most important problem in this case is the diversity between different regions. Every region[v] has its own way of producing potable water, related to its environmental capacities.
So far we tried to summarize these differences in one matrix.

Table 5 The producing of drinking water in different regions

Year	Antwerp	Ypres	Tienen
1800	Public wells with hand-pumps Private wells (groundwater ?)	Water from ponds via wooden or leaden water pipes to city canals and then to wells (surface water)	Water from ditches, canals or wells (surface water)
1850	Public and private wells Water from 'Herentalse vaart' via wooden water pipes to the borders of the city ; via 'waterkarren' to the city (surface water)	Idem 1800	Private wells (groundwater)
1900	Idem 1850 Waterworks are being developed ; different filter-beds and active carbon filtration for purification ; chlorine is used as a disinfectant (surface water)	Water from ponds via water pipes to wells (surface water)	Spring water via water supply system to public drinking fountains in the city
1950-2000	Waterworks ; water from Nete en Albertkanaal ; different filter-beds and active carbon filtration for purification	Waterworks ; water from ponds ; different filter-beds and active carbon filtration for purification	Waterworks ; spring water ; since 1962 chlorine was used as a disinfectant

4.1.2.4 40 km personal transportation over land

This case considers six means of transportation : on foot, by horse, by bicycle[vi], by train[vii], by car[viii], by bus/tram. Again priorities lie with energy consumption, emissions and materials, for the steelmaking process as well as for the production of vehicles itself. Regarding the steelmaking process we have not determined these aspects yet.
For each 'key year' we tried to determine the characteristic features of the different means of transportation, as we did for the subjects of the other cases.

Table 6 Different means of transportation

Year	On foot	By bicycle	By train	By car	By horse tram By tram/bus
1800	To walk 3 miles an hour, a non-athletic person needs 1/10 HP	Not relevant	Not relevant	Not relevant	A horse that pulls a carriage uses the equivalent of food for 8 people
1850	Idem 1800	Not relevant	Not relevant	Not relevant	Idem 1800
1900	Idem 1800	Metal frame ; pneumatic tyres	Wooden carriages (type GCI) ; steam locomotives ; coals	FordT (1908)	No information yet
1950	Idem 1800	Idem 1900 ?	Metal carriages (type K2, K3 and M2) ; diesel trains		No information yet
1975	Idem 1800	Steel alloy ; lighter	Metal carriages (type M3 and M4) ; diesel trains, electrical trains		No information yet
2000	Idem 1800	Aluminium bikes	Metal carriages (type M5 and I11) ; electrical trains	Volkswagen. 43,5% petrol cars 56,3% diesel cars (all brands)	No information yet

4.1.3 Conclusion

So far we tried to define our subject as accurately as possible (at this moment in time). This is necessary because the specific characteristics might determine the results of the environmental analysis. At the end of this research we will combine the environmental results with economic, social and political factors. This will provide an overview of the sustainability developments of four product systems during the past two centuries.

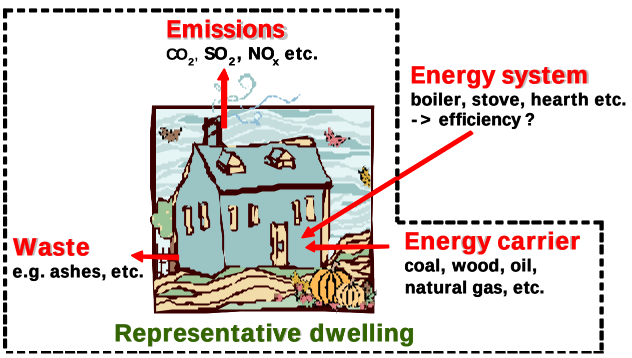
4.2 Case study: heated living space

4.2.1 Goal description, functional unit and process tree

The objective of the LCA-study is to perform a quantitative assessment of the environmental effects related to the heating of single-family dwellings in several fixed years (1800, 1850, 1900, 1950, 1975 and 2000) and to compare the environmental profiles of the different years studied.

The LCA-study makes a comparison of the environmental impacts based on a functional unit. For this case it has been defined as "*the heating of 1 m³ of a single-family dwelling that is representative for the year studied, per degree-day (taken into account the seasons)*". For each of the years studied, it was decided to analyse a countryside dwelling as well as a living house in the city.

Process tree and system boundaries:



The LCA focuses on the heating of the dwelling. Therefore the construction phase of the dwelling is not taken into account in the LCA. However, for each year studied, a representative dwelling has to be defined in order to analyse correctly the operation of the heating system. The insulation values of building materials for example can influence the total energy consumption for heating. Only the use of the heating system (efficiency) is considered in the analysis. The production of the system itself is not included. On the other hand the extraction and the combustion (emissions) of the energy carriers (e.g. natural gas) is taken into account. All emissions and waste related to the heating of the dwelling are counted for.

4.2.2 State of affairs: inventarisation environmental data 1800 and 2000

The energy consumption for domestic heating is determined by two important factors:

- the heating losses of the dwelling, depending on the type of building, the degree of insulation, the proportions of the used building materials and the comfort heating temperature;
- and secondly by the specific fuel consumption of the heating system, in relation with the building and depending on the efficiency of the heating system.

For 1800 and 2000 a brief overview of available, measured and/or estimated inventory data that have been used for the LCA is given below. The results of the LCA are presented in paragraph 4.2.3. For 1850 and 1900 environmental measurements (emissions, use of wood and coal, ashes, temperature in and outside a representative dwelling) have been carried out in Bokrijk. However these data still have to be assimilated into a full LCA.

2000

- In Belgium 64% of the dwellings is heated by using a central heating system – the other 36% is heated decentralised (electrical heater, stove, etc.)[ix]. The fuel partition for both systems and the yearly efficiency of the heating systems is presented in the tables below [ix]. Data on the extraction and emissions related to the use of the different fuels (emissions) are taken from BUWAL[x].
- In the city more natural gas is used (82% in the bigger cities such as Antwerp); more than 50% of the dwellings at the countryside are heated with oil[xii].

Fuel partition	City	Countryside
Oil	13%	67%
Natural gas	82%	28%
Electricity	4%	4%
Other	1%	1%

Energy carrier	Heating system	Yearly efficiency
GAS central	Old atmospheric boiler Modern atmospheric boiler Condensing boiler	50 to 75% 88 to 90% (HR + label) 100 to 107% (HR TOP label)
GAS decentral	Modern gas stove	between 80 and 90%
OIL central	Old oil boiler Modern oil boiler	from 50 to more than 75% 88 to 90% (Optimaz label)
OIL decentral	Modern oil stove	between 70 and 80% (Optimaz label)
Solid mineral fuels, coal (decentral)	Modern coal stove	between 50 and 90%
Elektricity decentral	Modern electrical stove	dependant of the efficiency of the production of elektricity, independant of the stove

- The number of degree-days in 2000 is 2097[xi].
- 54% of the nowadays single-family dwellings was build before 1970, 18% between 1971 and 1980, 15% between 1981 and 1990 and 13% later than 1990[xii].
- Tentatively the Brussels region has been chosen to represent the single-family dwellings in the city[xiii]. In order to reflect on the countryside, the Walloon region has been considered[xiii].

Area / Dwelling type	Open space development	Half-open space development	Closed space buildings	Appartments	Others
City	1,42%	5,97%	18,89%	71,45%	2,27%
Countryside	34,70%	23,46%	24,30%	15,87%	1,67%

- Preliminary it has been calculated that average 344.5m³ of the house is heated (102.5m² x 3.36m). Calculations are based on a combination of data from NIS[xv] and DWTC-report[xiv]. Future efforts need to be focused on the difference between the city and countryside. At this moment it was not feasible (no specific data found) to make a distinction between both areas.
- Average K-value distribution (indicator for global insulation level of the building) that is used to calculate the total yearly energy consumption of the mix of representative dwellings in Belgium[xiv].

K-value of building	< 1970	1971-1980	1981-1990	> 1990
Open space development	140,1	101,2	84,3	72,5
Half-open space development	130	94,4	73,4	64,7
Closed space buildings	132,1	100	86,4	74,8
Appartments	124	81	66,5	57,9

- The next table presents the yearly energy consumption (for the year 2000) per type of dwelling (in kWh), presented by the date of construction(data sources [xiv] and [xv]).

Yearly energy consumption	< 1970	1971-1980	1981-1990	> 1990
Open space development	40287,99003	26537,46551	20843,03546	16825,08762
Half-open space development	31782,03987	20813,56236	15486,76265	12701,745
Closed space buildings	26400,99224	17960,77952	14686,62248	11998,56978
Appartments	21267,98393	12339,20889	9415,581511	7523,78056

And finally the total energy consumption to *heat one cubic metre of a single-family dwelling per degree-day* for the year 2000, has been calculated by using all inventory data listed above. The results are presented in the table below. These figures are divided correctly amongst the mix of energy carriers and the related energy systems used, in order to calculate the environmental impacts.

Area	Total energy consumption (kWh by dwelling a year)	Total energy consumption (kWh by 1 m³ heated dwelling and 1 degree-day)
City	17453,01656	0,024166231
Countryside	24606,87288	0,034071782

1800

Environmental measurements (emissions, use of wood and coal, ashes, temperature in and outside the representative dwelling) have been carried out in Bokrijk. The farmer's house in clay with open fire (Kilbershoeve) has been used as reference house for 1800 (60 m³ heated space). It has been calculated that the 27th of November 2002 (measurements in Bokrijk in the farmer's house) had 7 degree-days. During 4.5 hours 60m³ of the farmer's house was heated by using 43.02 kg of wood (75% oak and 25% birch). According to literature wood from oak and birch has an average net heating value of 15.5 MJ/kg[xvi]. Some pictures of the measurements in Bokrijk can be found in the annex.

4.2.3 Impact assessment – preliminary environmental profiles

Following impact categories were taken into consideration:
- energy resources (MJ Lower Heating Value, according to Eco-Indicator 95 method);
- global warming (kg CO_2 eq, according to CML Baseline 2 method);
- acidification(kg SO_2 eq, according to CML Baseline 2 method);
- eutrophication (kg PO_4^{3-} eq, according to CML Baseline 2 method);
- photochemical oxidation (kg C_2H_2 eq, according to CML Baseline 2 method).

Figure 1 makes the comparison of the environmental profiles of a representative dwelling in the city and at the countryside for the year 2000. The comparison is based on the functional unit (kWh per m³ heated space and per degree-day).

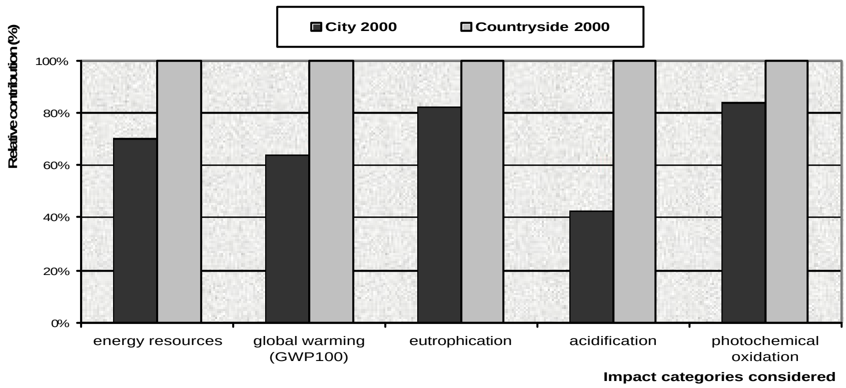


Figure 1: Comparison of the environmental profile of the representative dwellings for 2000 (city versus countryside)

The impact categories can not be compared mutually. Therefore the house with the highest contribution to each impact category is set at 100%; the alternative is presented relatively to the one with the highest contribution. The table below gives an overview of the absolute values behind the Figure 1.

Impact categories considered	City 2000	Countryside 2000	Unit
energy resources	0,118	0,168	MJ (LHV)
global warming (GWP100)	0,00727	0,0114	kg CO2 eq
eutrophication	1,51E-06	0,00000184	kg PO4--- eq
acidification	9,62E-06	0,0000227	kg SO2 eq
photochemical oxidation	8,58E-07	0,00000102	kg C2H2 eq

Figure 1 shows that for all impact categories considered in the study the dwelling at the countryside has a relative higher environmental impact. As it has been calculated the *total energy* resources that are needed at countryside is higher than in the city. The contribution to *global warming* is on the same wavelength of the energy resources (this is mainly caused by CO_2 emissions). *Eutrophication* is mainly determined by energy related emissions of NO_x. Therefore the difference between the city and the countryside is less high, since in the city more natural gas is used (which causes relatively more NO_x emissions). On the other hand at the countryside more oil is used. The combustion of oil causes relatively more SO_2 emissions compared to the use of natural gas. That is why the difference between the city and the countryside is much higher for *acidification*. Conversely the extraction of natural gas releases more emissions that potentially can contribute to the formation of smog. Therefore the difference for the formation of *photochemical oxidation* (smog) again is less high.

For the comparison of 1800 and 2000, Figure 2 first shows a comparison of the energy demand (expressed in kWh) for heating 1 m³ of a single-family dwelling at the countryside per degree-day. The figure shows clearly that domestic heating in 1800 needed twenty times more energy per m³ heated space and degree-day than it is needed nowadays.

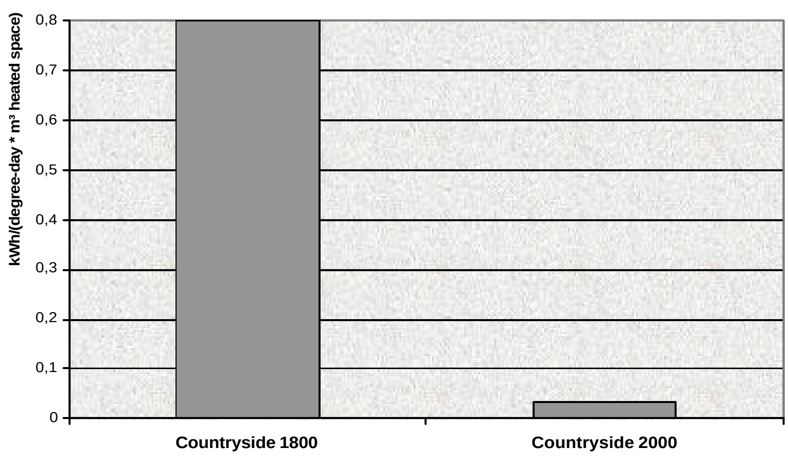


Figure 2: Comparing the energy demand in 1800 en 2000 for heating 1 m³ of a single-family dwelling at the countryside that is representative for the year studied, per degree-day

Processing both figures for energy demand (functional unit, kWh per m³ heated space and per degree-day) results in two environmental profiles, which are presented next to each other in Figure 3.

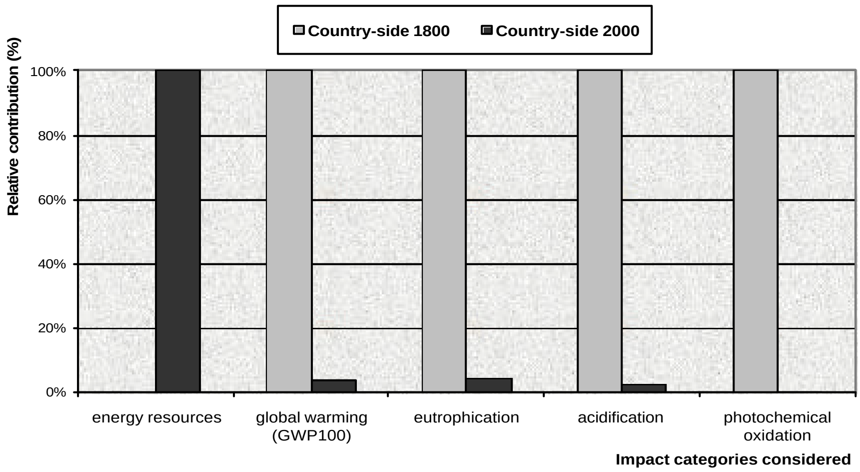


Figure 3: Comparison of the environmental profile of the representative dwellings at the countryside for 1800 and 2000

Figure 3 shows that heating the dwelling in 1800 cause a relative higher environmental impact for most of the impact categories considered in this study. Per m³and degree-day, more CO_2 (global warming), NO_x (eutrophication), SO_2 (acidification) and volatile organic components (formation of smog) are emitted into the air. An exception is made for *energy resources*, since for wood in 1800, no environmental burdens are counted for (manual labour for cutting down trees). On the contrary the use of the energy carriers nowadays lead to the exhaustion of fossil energy resources.

Further efforts towards more representative data collection (especially with regard to the differences between the city and the countryside nowadays, a possible difference in degree-days (1800 versus 2000), etc.) shall refine these preliminary results.

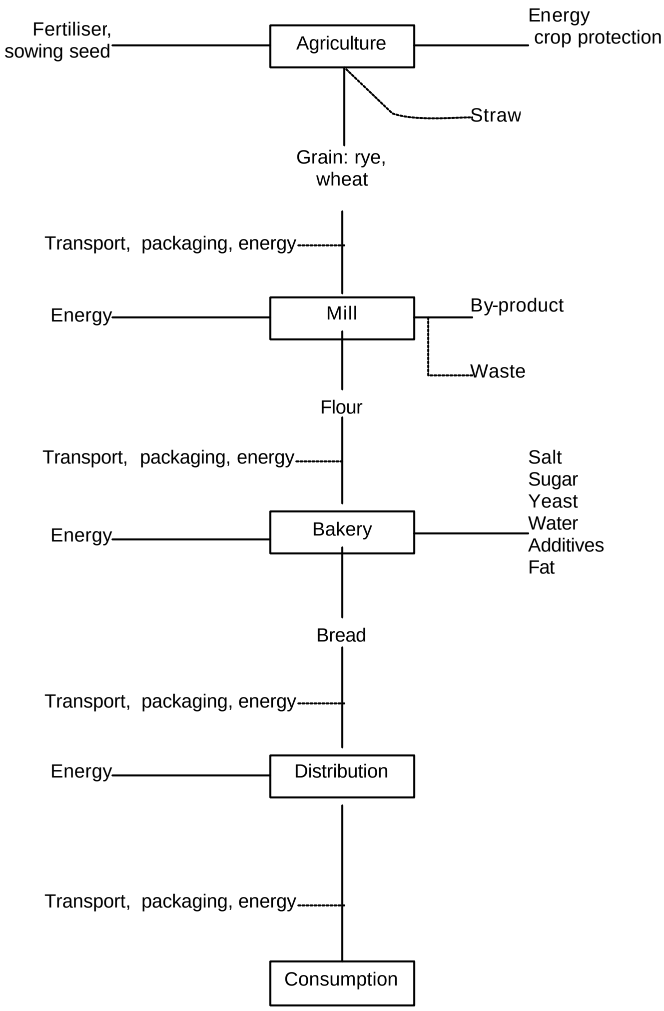
4.3 Case study: bread

4.3.1 Goal description, functional unit and process tree

The goal of the LCA is to compare the environmental effects of producing and consuming bread in several years (1800, 1850, 1900, 1950, 1975 and 2000). The idea is to picture and explain the development in the environmental effects caused by this activity. When combined with social and economical factors (price, quality, …) this will provide an overview in the sustainability development of the production of bread during the past two centuries.

The functional unit is “the production and consumption of 1 kg bread”.

Process tree:



System boundaries:

The cradle of the life cycle is the extraction of resources required for the production of fertilisers used in the cultivation of grain, production of packaging materials and generation of the electricity and thermal energy (human and animal energy was not taken into account). The grave of the life cycle is production of waste and the distribution of bread to the consumer.

The only valid argument for leaving out a part of the life cycle is that it is insignificant, i.e. that its exclusion does not affect the total result of the study. In order to get an idea of what can be left out, international life cycle studies for bread were consulted[xvii,xviii]. The life cycle screening of Weidema[xvii] demonstrated that a substantial part of primary fuel consumption is related to the bakery, while for other environmental parameters the agricultural production was the most important part of the life cycle. Agriculture processes should therefore be included in the study. Weidema also concluded that all other packaging than the retail packaging may be disregarded. From an energy point of view, all non-grain ingredients may be disregarded. According to Andersson[xviii], in the cultivation step, the assimilation of CO_2 by the crop was not taken into consideration. Production of capital goods was also left outside the system boundaries. Use of manure and waste as fertilisers was not taken into account, due to allocation problems and lack of data. However, both will be discussed qualitatively.

4.3.2 State of affairs: inventarisation environmental data 1800 and 2000

A brief overview of available or estimated inventory data for each life cycle phase (agriculture, milling, bakery and distribution) will be shown below.

Agriculture

1800: No fossil *energy* and artificial fertiliser are required for grain production. Data about yield/ha are still missing.

2000: *Fuel consumption* involved with cultivation of winter wheat was taken from Danish data for conventional soil preparation[xix]. *Use of mineral fertiliser* and *crop protection* were based on a German study[xx]. *Production and transportation of fertilisers* were taken from a Belgian study[xxi] and the IVAM LCA-database 3.0. *Production of crop protection*, just as *emissions due to fertiliser use* during crop growing were mainly taken from Ceuterick et al.[xxi]. An *allocation* between straw and wheat was made based on the sales value and the yield/ha (CLE, Centrum voor Landbouweconomie). Data concerning drying of wheat in Belgium are still missing.

Milling

1800: No fossil *energy* is required for grain milling.

2000: *Transportation of wheat* to the mill was based on own assumptions, statistical data and information from the CERES website. *Energy and water consumption* were founded on Weidema[xvii] and Andersson[xviii]. An allocation between flour and by-products was made according to Weidema[xvii]. In order to get more representative data, we plan a visit to CERES.

Baking

1800: The *consumption of brush wood* and following *emissions* were investigated by environmental measurements in Bokrijk. Results of the measurements are not yet available.

2000 : *Transport* of flour to the bakery was based on own assumptions, according to Weidema[xvii], *packaging* of flour was not taken into consideration. *Energy and water consumption* in the bakery were founded on a PRESTI Project report[xxii]. Non-grain ingredients and releases of ethanol during fermentation were disregarded.

Distribution to the consumer

1800 : No fossil *energy* is required for the consumption phase.

2000 : *Energy* required to slice up a loaf was not taken into consideration. The *packaging* type was based on the PRESTI Project report[xxii], and transport was based on own assumptions.

4.3.3 Impact assessment – the environmental profiles

Following impact categories were taken into consideration for the LCA of bread:

- land use - m^2 per kg of bread for cultivation of wheat;
- energy resources -MJ Lower Heating Value (according to Eco-Indicator 95 method);
- global warming - kg CO_2 eq. (according to CML Baseline 2 method);
- acidification - kg SO_2 eq. (according to CML Baseline 2 method);
- eutrophication - kg PO_4^{3-} eq. (according to CML Baseline 2 method);
- photochemical oxidation - kg C_2H_2 eq.: (according to CML Baseline 2 method).

4.3.4 Preliminary LCA Results

Figure 4 shows the relative contribution of the life cycle phases agriculture, milling, baking and distribution of bread to the consumer in 2000 for the environmental impact categories mentioned above. The agriculture subsystem is a hot spot for most of the impact categories studied. The use of energy resources is mostly related to the bakery.

Land use: 1,175 m^2 per kg of bread for cultivation of wheat.

Global warming: the potential contributions to global warming are related to the use of fossil fuels used for baking and fertiliser production in agriculture.

Photochemical oxidation: transportation processes are important, both for emissions of nitrogen oxides and carbon monoxide.

Acidification: the amounts of sulphur dioxide and nitrogen oxides emitted are key parameters. Both of these emissions are related to the use of fossil fuels.
Eutrophication: leakage of nitrogen from the fields and emissions in conjunction with the production of nitrogen fertilisers are key-parameters in the agriculture sub-system.
Energy resources: a substantial part (55 %) is related to the bakery and the distribution to the consumer (21 %).

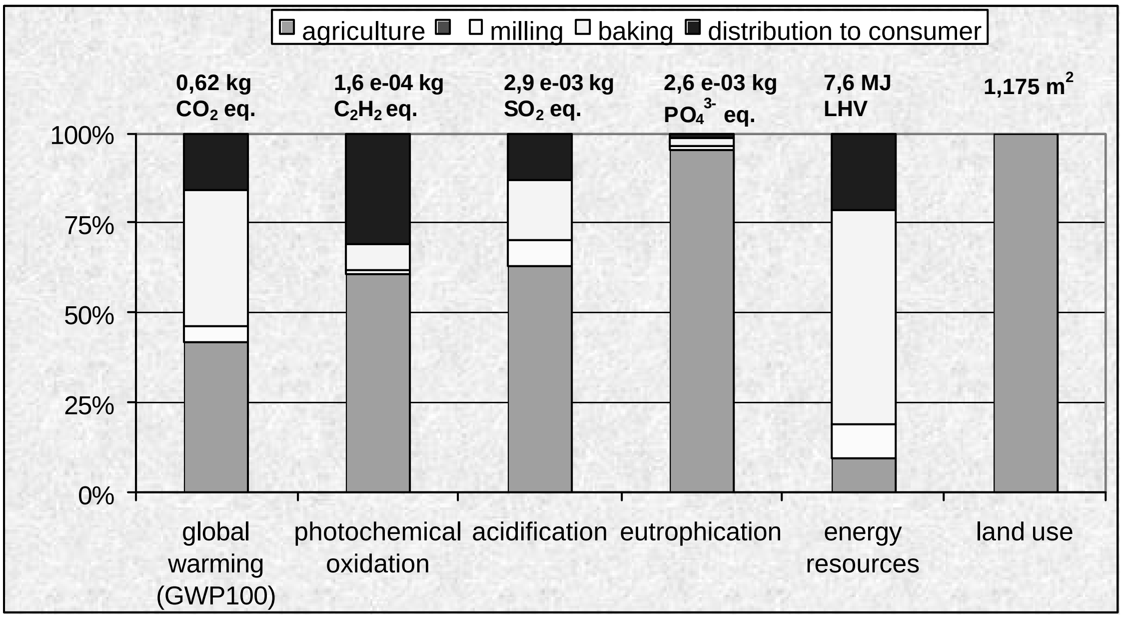


Figure 4: Preliminary results for “the production and consumption of 1 kg bread in 2000”.

When comparing the *energy content of the fuels used during the baking process,* the process in 2000 is 3,8 times more efficient than in 1800: 2000 (heat gas + electricity) = 3,43 MJ/ kg bread and 1800 (wood + straw) = 12,91 MJ/ kg bread

4.4 Case study: water

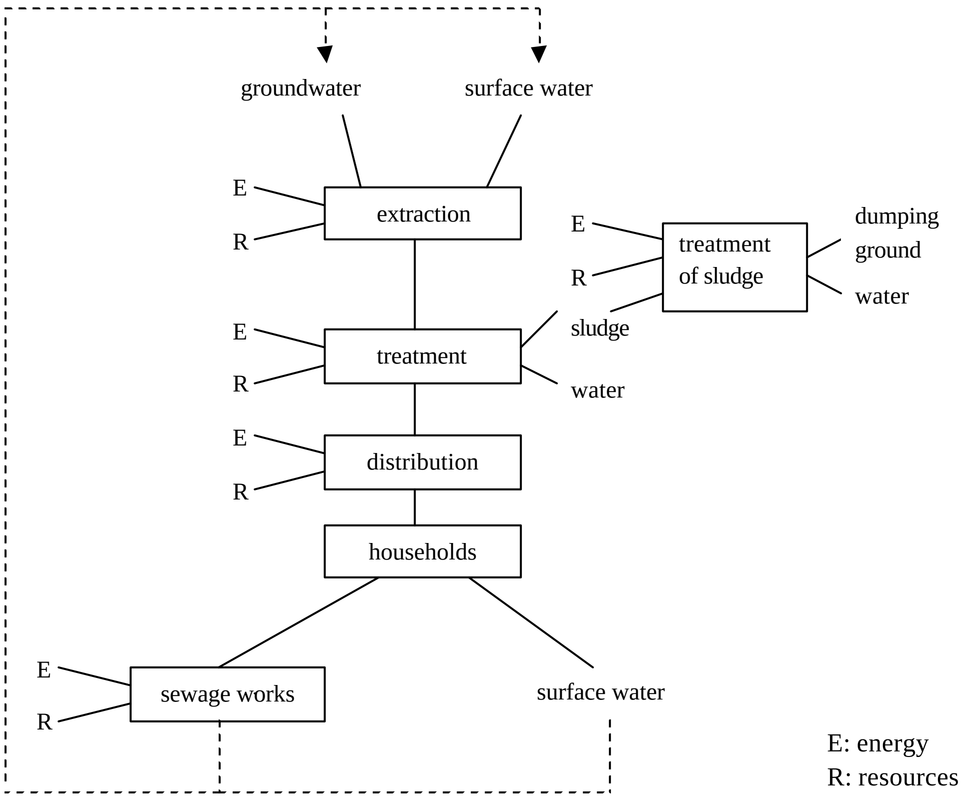
4.4.1 Goal description, functional unit and process tree

The goal of the LCA is to compare the environmental effects of producing potable water in several years (1800, 1850, 1900, 1950, 1975 and 2000). The idea is to picture and explain the development in the environmental effects caused by this activity. When combined with social and economical factors (price, quality, …) this will provide an overview in the sustainability development of the production of potable water during the past two centuries.

The functional unit is “the production and distribution of 1 m³ potable water to households”.

Many techniques exist for the production of potable water and no two facilities are the same. Therefore a selection will be made of the techniques investigated in this study. AWW has agreed to cooperate, but since their production originates from surface water only and is thus not representative of the Belgian situation, other companies will also be contacted (see below).

Process tree:



Until now, all attention has been focussed on the *process steps before the households*, the treatment of waste water in sewage works will be investigated later.

4.4.2 Required information for period 1800 - 2000

The six basis questions that need to be answered are mentioned before in 4.1.2.3.

City versus countryside

The difference between cities and the countryside is relevant, since water mains were introduced later in the countryside.

Infrastructure

The production of potable water also requires infrastructure, such as pumping-stations, mains, laboratories, reservoirs, … 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. The reason is that although the infrastructure may represent a large amount of materials by itself, it represents only a small amount of materials per functional unit (e.g. 1000 l potable water), since it is in use for many years and for the production of very large amounts of potable water.
However, several LCA studies[xxiii] for the production of potable water in other countries do include infrastructure such as mains, reservoirs, pumping stations, … Also, environmental data and data on the length of mains in Belgium were already found for distribution mains for 2000[xxiv].

Therefore we opt to include the infrastructure for the *distribution* of water (such as mains, reservoirs, water towers, …) but not other kinds of infrastructure (such as laboratories, office buildings, …).

4.4.3 State of affairs: inventarisation environmental data 1800 and 2000

A) How did the extraction, treatment and distribution of potable water take place?

- 1800: extraction and distribution: several possibilities, groundwater as well as surface water: local public wells with hand-pumps or private wells (Antwerp); water from ponds via wooden or leaden mains to city canals and then to wells (Ieper); water from ditches, canals or shallow wells (Tienen)
  purification or treatment did not take place
- 2000: extraction and treatment: differs from site to site, especially the origin (groundwater vs. surface water) has an important influence on the kind of treatment (surface water → more extensive treatment)
  distribution: supply mains to water towers and reservoirs, distribution mains to houses, possibly also 'hydroforen'

B) How much energy is required for the production of potable water and which energy sources are used (electricity, oil, wood, …)?

- 1800: no energy is required for extraction, distribution or treatment (manual labour is considered as a social aspect, not an environmental aspect)
- 2000: in order to obtain these data, a questionnaire will be sent to a number of large water production companies

C) Which resources (reagents) are required?

- 1800: no treatment, thus no reagents
- 2000: questionnaire

D) Which materials are used, especially for the distribution of potable water?

- 1800: wooden or leaden mains, materials for wells still unknown, amounts will probably have to be estimated
- 2000: materials can be PVC, 'asbestcement', cast iron, steel, PE
  data on length of mains, sometimes already split up between kinds of material: in annual reports[xxiv]; data on environmental effects: literature + already available from LCA-databases

E) Which emissions (to water, air or soil) and waste are released to the environment or sent to treatment?

- 1800: no treatment, thus no emissions or waste (the fact that water is discharged untreated is a separate issue)
- 2000: questionnaire

F) How much water is used per person?

- 1800: so far no information available
- 2000: several sources available

4.4.4 Questionnaire

The questionnaire will be sent to (if the selected companies wish to cooperate):
- Flanders: VMW, AWW
- Brussels: BIWM
- Walloon: SWDE

For every region, the production companies with the largest annual water production were chosen. If these companies choose to cooperate, 59 % of the total water production in Belgium will be covered. This corresponds to 60 % of the number of connections and 52 % of the network of mains.

4.4.5 Others

- Information is also available on the issue of pipes made from lead and copper.
- A list of contact persons in the field of LCA regarding water issues is being made. These persons will be contacted in the course of January.

4.5 Case study: transport

4.5.1 Goal description, functional unit and process tree

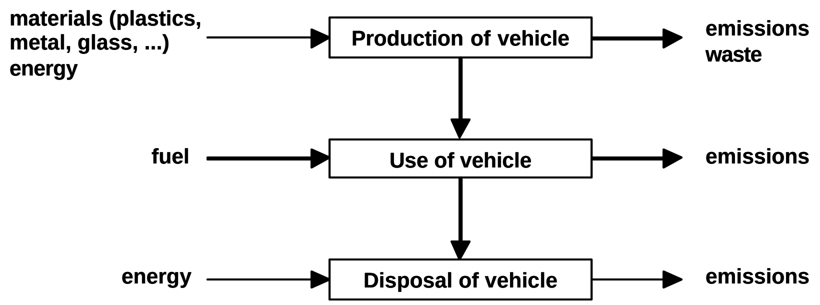
Goal of the LCA is to compare "a human movement by land" in the reference years 1800, 1850, 1900, 1950, 1975 and 2000. The study aims to describe (and explain) the development of the environmental burdens caused by this human movement. Together with an overview of social and economical aspects (e.g. price, comfort) this will give a clear insight in the sustainability development of transportation through the past centuries.

The functional unit is "a human movement by land of one person over 40 kilometres".
It was decided to study the most important modes of transport during the past years: on foot, bicycle, train, car, bus/tram. Since not all of these transport modes occurred during all reference years, for each year a selection of the relevant transport modes is made.

	1800	*1850*	*1900*	*1950*	*1975*	*2000*
on foot	x	x	x	x	x	x
bicycle			x	x	x	x
horsetram-bus/tram	x	x	x	x	x	x
train			x	x	x	x
car			x (1925)	x	x	x

The horse tram is considered to be the predecessor of the present tram and bus. The horse tram will be taken into account for 1800 and 1850, as from 1900 this was replaced by the tram (urban region) and bus (rural region).

Process tree:



The life cycle assessment studies the following life cycle stages:

- the production (extraction, processing) of materials needed for producing the vehicle;
- production of the vehicle in the factory;
- driving the vehicle;
- disposal of the vehicle (dumping, incineration, recycling).

4.5.2 State of affairs: inventory environmental data 1800 and 2000

For every transport mode, a brief overview of available or estimated inventory data for each life cycle phase will be shown below.

On foot

Bicycle

1900: Relevant for this year was the "safety bike", with triangular frame, two equally sized pneumatic tires.

Production: no detailed data found

18 kg[xxv], mostly steel, no manufacturing data

Use: no energy use (only human power), no emissions

Disposal: 50% dumping, 50% reuse for other purposes ("second life" as toys)

2000: Common type is the "utility bike", with more or less the same shape as the safety bike, but light-weight materials

Production: no detailed data found

11 kg, steel/aluminium/plastics/others, 1250 MJ needed for production of 1 bike[xxvi]

Use: no energy use (only human power), no emissions

Disposal: 50% recycling, 50% incineration and dumping (assumption, needs to be refined)

Horse tram – bus/tram

At this moment, no information is gathered on these types of transport modes. This will be subject of the second phase of the inventory.

Train

1900: Most trains consisted of a steam locomotive + tender (for transporting the coal) and a number of carriages (no data on the average number of carriages per train)

Production: no detailed data found

36.9 ton (loc), 13.5 ton (tender)[xxvii], mostly steel, no manufacturing data

Use: use of coal (not yet specified data), no information about emissions

Disposal: dumping, dismantling?

2000: Electrically driven locomotives (locs) or motor vehicles are mostly used for passenger transport, possibly linked with a number of carriages (no data on the average composition of a modern train)

Production: no detailed data found

85 ton (loc), 165 ton (motor vehicle)[xxviii], mostly steel, no manufacturing data

Use: electricity use (not yet specified data), no information about emissions

Disposal: dismantling?

Too little data are inventoried at this moment to perform already an impact analysis on the train. The data inventory and impact assessment will be further investigated later on.

Car

A lot of data on cars are available for 2000 and 1975. The previous years were more difficult to find information on. Therefore, the data inventory was, besides the year 2000, focused on 1975, rather than on 1900.

1975: No information available at this moment on the type of car (brand), only petrol cars (95%) were used.

Production: no detailed data found
850 kg[xxix], steel (62%)/cast iron (17%)/aluminium (4%)/glass (3%)/rubber (7%)/copper (0.5%)/others[xxix], production energy estimated at 46.2 GJ (assumption: same as 2000)

Use: 9.3 litre petrol/100 km[xxx]
emissions per km: 3.3g NOx/0.013g particles/2.8g VOC/0.073g SO2/19.2g CO/0.037g lead (no data on CO2)[xxix]

Disposal: dumping (assumption)

2000: No information available at this moment on the type of car (brand), diesel (40%) as well as petrol (60%) cars are used[xxxi].

Production: no detailed data found
1108 kg for average petrol car, 1351 kg for average diesel car[xxxi]
composition: steel (68%)/aluminium and alloys (6%)/non-ferro (3%)/glass (3%)/plastics (12%)/rubber (5%)/others[xxxii]
production energy estimated at 46.2 GJ[xxxiii]

Use: 8.5 litre petrol/100 km, 6.5 litre diesel/100 km[xxxiv]
Emissions petrol car per km: 1.42g NOx/0.011g particles/0.58g VOC/0.019g SO2/5.01g CO/0.00032g lead/203g CO2[xxxiv]
Emissions diesel car per km: 0.56g NOx/0.095g particles/0.064g VOC/0.22g SO2/0.396g CO/0.0000006g lead/173g CO2[xxxiv]

Disposal: 75% recycling (steel, aluminium), 25% dumping and incineration

It is obvious that the data inventory is not at all complete at this moment. Serious efforts need to be done in order to gather all the data needed to study the environmental impacts of the different means of transport. The impact assessment discussed in the following paragraph only shows preliminary results, calculated with limited data sets.

4.5.3 Impact assessment – the environmental profiles

The following impact categories were taken into consideration for the LCA of transport:

- energy resources (MJ Low Heating Value, according to Eco-Indicator 95 method);
- global warming (according to CML Baseline 2);
- acidification(according to CML Baseline 2);
- eutrophication (according to CML Baseline 2);
- photochemical oxidation (according to CML Baseline 2).

Figure 5 shows the relative contribution of “driving 40 km with a bicycle” in 1900 compared to 2000. The production, use and disposal of the bicycle is related to these 40 km. For the impact categories energy use, global warming and eutrophication the bicycle in 2000 contributes twice as much as in 1900. This is related to the production energy that is needed for manufacturing the bicycle. In 1900 manufacturing was mainly handwork. The greater contribution of the bicycle in 1900 to photochemical oxidation and acidification is only attributed to the larger weight of the bicycle in 1900.

Some remarks related to the limited data inventory – assumptions:

- production of steel in 1900 is assumed to be identical to 2000, although it is well-known that this is an underestimate. In reality, the relative difference between both years will be smaller for the energy-related impact categories.

- the life span of a bicycle (expressed in kilometre) in 2000 is estimated at 20000 km, in 1900 this is assumed to be half of this.

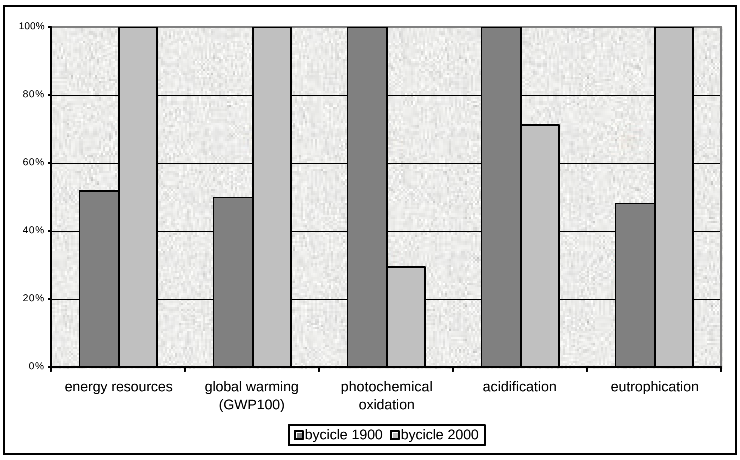


Figure 5: Preliminary results for the life cycle of a bicycle in 1900 versus 2000 (related to 40 km)

Figure 6 gives the preliminary results of the environmental analysis of a car in 1975 compared to a car in 2000. Except for acidification, the contribution of the car in 1975 was slightly higher than the current car. The most important reason for the higher contribution in 1975 is the higher fuel consumption of a car in that time.

Some remarks related to the limited data inventory – assumptions:

- production of steel and other materials in 1975 is assumed to be identical to 2000, although it is well-known that this is an underestimate. In reality, the relative difference between both years will be larger for the energy-related impact categories.
- the composition and production of petrol is assumed to be the same in 1975 as in 2000. No data related to this aspect are found yet, but it can be expected that this is also an underestimate.
- Since no data are available on the energy needed for manufacturing a car in 1975, the same value as for 2000 is assumed. Also this is probably an underestimate, since production processes are presumably more efficient nowadays.
- The seat occupancy and the life span of a car is assumed to be identical for both years.

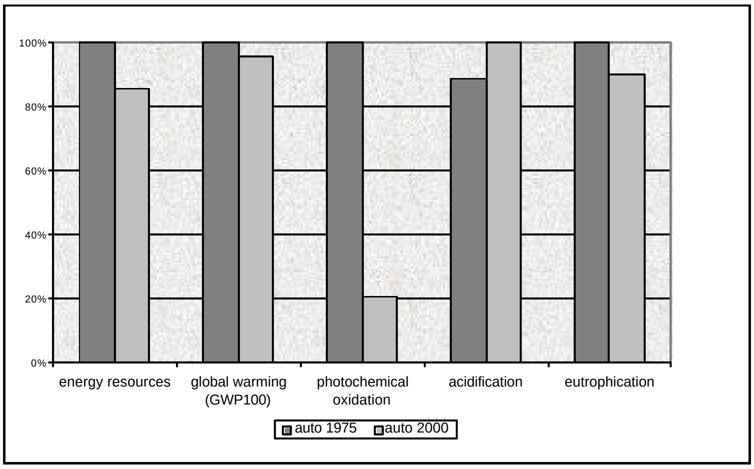


Figure 6: Preliminary results for the life cycle of a car in 1975 versus 2000 (related to 40km)

5 Future prospects and future planning

For the first months of 2003 we want to finish and complement the results of the final and the first relevant year first for each of the case studies (water will stay a little behind). Looking at the results we can then determine how important several process steps in the LCA of the product system are. In that way we may be able to search more efficiently for data about the intermediary years.

Halfway the coming year we will also start with the less time consuming gathering of data about social and economic aspects and consumption figures. Having done that for the first and final year we can already start looking at the first final results and get a first vision on and understanding of (un-) sustainability developments.

6 Annexes

6.0 Measurements Bokrijk

Some pictures of the environmental measurements in Bokrijk (farmer's house in clay with open fire).

Some pictures of the environmental measurements in Bokrijk (bakery house).

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