Part 3. Ecological debt and the case of Energy and Climate Change

3.0. Introduction

Building on the findings of the core research, this modular research attempts to elaborate on the operationalisation of the concept of ecological debt for the case of fossil energy consumption and resulting CO_2 emissions and its application to the Belgian energy system.

In a first introductory part, the characteristics of fossil fuels are briefly illustrated by means of the carbon cycle and due attention is paid to the ecological aspects related to the use, i.e. the combustion of fossil fuels.

A second part gives a quantitative and qualitative overview of fossil energy consumption and resulting CO_2 emissions in Belgium for the period 1830-2000. Detailed data on the amounts of coal, oil and natural gas annually imported, exported and consumed are given, together with the geographical origin of the imported species. These figures together with their historical evolution are analysed and discussed in terms of the social, economical, cultural and technological background.

The third chapter focuses on the issue of ecological debt. Based on the general working definition, elaborated in the core research, the relevant aspects of ecological debt for this module are indicated. Without going into quantitative nor methodological detail the aspects of ecological debt related to the extraction process and to the depletion and excessive use of fossil fuels are briefly discussed here, leaving the carbon debt for a separate chapter.

Much effort has been put in further elaborating on the so-called Carbon Debt: all aspects of ecological debt resulting from CO_2 emissions from fossil fuel combustion. This is reflected in the fourth part which exclusively deals with the carbon debt issue. The carbon debt is defined and it is made clear how it could be split up into two different parts: the Historical Carbon Debt, (an intragenerational interstate part) and the Generational Carbon Debt, (an intergenerational part), which together make up the total carbon debt. A preliminary proposal on how these concepts could be brought into practice is presented including an emission rights system which embodies compensation for the historical carbon debt. Based on the data of fossil fuel combustion in Belgium presented in the second part, relevant figures concerning the carbon debt will be calculated and compared on an international level.

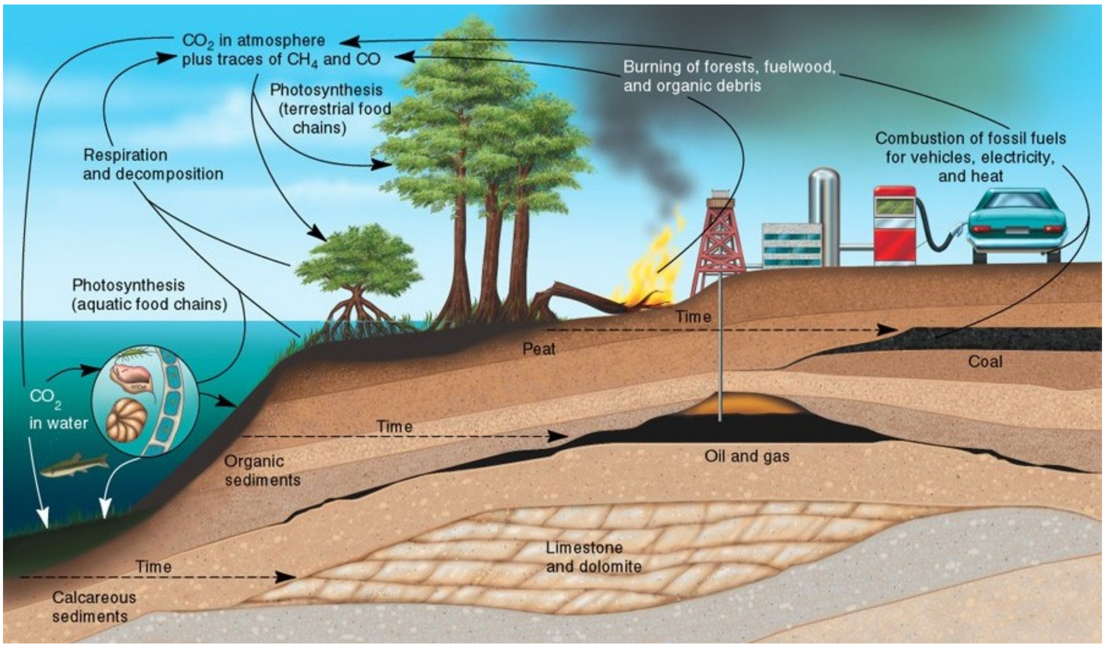
3.1. Fossil fuels

3.1.1. The carbon cycle

The carbon cycle (see Figure 1) is a complex series of processes through which all of the carbon atoms on earth rotate. Carbon dioxide is released into the atmosphere by most living organisms as a result of respiration. The CO_2 is taken up and converted into high-energy chemicals – glucose and other carbohydrates – during photosynthesis by plants; the oxygen component is released back into the atmosphere. Some glucose is used by the plant and some is converted into other carbon compounds, making new tissues. However, some of these compounds can be transferred to other organisms. An animal may eat the plant and that animal may be eaten and so on down the food chain.

But carbon can also be stored as biomass in the roots of trees and other organic matter for many decades. This carbon is released back into the atmosphere by decomposition.

Figure 1 The carbon cycle



Not all organic matter is immediately decomposed. Under certain conditions dead plant matter accumulates faster than it is decomposed within an ecosystem. The remains are locked away in underground deposits. When layers of sediment compress this matter, fossil fuels will be formed. They are fossilized organic remains that over millions of years have been converted into a hard, black rock-like substance called coal, a thick liquid called oil or petroleum, and natural gas; the three major forms of fossil fuels. Fossil fuels are usually found below ground. Coal is either mined or dug out while oil and natural gas are pumped out. Coal is widely distributed and is easier to locate than oil and gas. Because their formation takes so long, these sources are regarded as non-renewable sources of energy.

3.1.2. Ecological aspects of fossil energy use

3.1.2.1. *Depletion of fossil fuels*

Depletion, defined in the core research (see §1.3.4.1.) as “the extraction or use of natural resources at such a speed or rate that exploitation can but continue for a limited time at a certain level of quality”, is certainly at stake here if one talks about the consumption of the natural resources coal, oil and gas. As mentioned in the preceding paragraph (§3.1.1.) these resources are regarded as non-renewable and as such, their exploitation is depleting the existing reserves.

3.1.2.2. *Global Warming*

Among the gases emitted when fossil fuels are burned, one of the most significant is carbon dioxide, a gas that traps heat in the earth's atmosphere. Over the last 150 years, burning fossil fuels has resulted in more than a 25 percent increase in the amount of carbon dioxide in our atmosphere. Fossil fuels are also implicated in increased levels of atmospheric methane and nitrous oxide, although they are not the major source of these gases.

Since reliable records began in the late 1800s, the global average surface temperature has risen 0.6 ± 0.2 degrees Celsius. Scientists from the Intergovernmental Panel on Climate Change concluded in a 1995 report that the observed increase in global average temperature over the last century "is unlikely to be entirely natural in origin" and that "the balance of evidence suggests that there is a discernible human influence on global climate." (IPCC, 1995). Climate scientists predict that if carbon dioxide levels continue to increase, the planet will become warmer in the next century. Projected temperature increases will most likely result in a variety of impacts. In coastal areas, sea-level rise due to the warming of the oceans and the melting of glaciers may lead to the inundation of wetlands, river deltas, and even populated areas. Altered weather patterns may result in more extreme weather events. And inland agricultural zones could suffer an increase in the frequency of droughts.

3.1.2.3. *Air Pollution*

Several important pollutants are produced by fossil fuel combustion: carbon monoxide, nitrogen oxides, sulphur oxides, and hydrocarbons. In addition, total suspended particulates contribute to air pollution, and nitrogen oxides and hydrocarbons can combine in the atmosphere to form tropospheric ozone, the major constituent of smog.

Carbon monoxide is a gas formed as a by-product during the incomplete combustion of all fossil fuels. Exposure to carbon monoxide can cause headaches and place additional stress on people with heart disease. Cars and trucks are the primary source of carbon monoxide emissions.

Two oxides of nitrogen -nitrogen dioxide and nitric oxide- are formed in combustion. Nitrogen oxides appear as yellowish-brown clouds over many city skylines. They can irritate the lungs, cause bronchitis and pneumonia, and decrease resistance to respiratory infections. They also lead to the formation of smog. The transportation sector is responsible for close to half of the US emissions of nitrogen oxides; power plants produce most of the rest.

Sulphur oxides are produced by the oxidization of the available sulphur in a fuel. Nitrogen oxides and sulphur oxides are important constituents of acid rain. These gases combine with water vapour in clouds to form sulphuric and nitric acids, which become part of rain and snow. As the acids accumulate, lakes and rivers become too acidic for plant and animal life. Acid rain also affects crops and buildings.

Hydrocarbons are a broad class of pollutants made up of hundreds of specific compounds containing carbon and hydrogen. The simplest hydrocarbon, methane, does not readily react with nitrogen oxides to form smog, but most other hydrocarbons do. Hydrocarbons are emitted from human-made sources such as car and truck exhaust, evaporation of gasoline and solvents, and petroleum refining.

The white haze that can be seen over many cities is tropospheric ozone, or smog. This gas is not emitted directly into the air; rather, it is formed when ozone precursors mainly non-methane hydrocarbons and nitrogen oxides react in the presence of heat and sunlight. Human exposure to ozone can produce shortness of breath and, over time, permanent lung damage. In addition, it can reduce crop yields.

Finally, fossil fuel use also produces particulates, including dust, soot, smoke, and other suspended matter, which are respiratory irritants. In addition, particulates may contribute to acid rain formation.

3.1.2.4. *Water pollution and land degradation*

Production, transportation, and use of oil can cause water pollution. Oil spills, for example, leave waterways and their surrounding shores uninhabitable for some time. Such spills often result in the loss of plant and animal life. Coal mining also contributes to water pollution. Coal contains pyrite, a sulphur compound; as water washes through mines, this compound forms a dilute acid, which is then washed into nearby rivers and streams.

Coal mining, especially strip mining, affects the area that is being mined. Characteristically, the material closest to the coal is acidic. After the mining is completed, the land will remain barren unless special precautions are taken to ensure that proper topsoil is used when the area is replanted. Materials other than coal are also brought to the surface in the coal mining process, and these are left as solid wastes. As the coal itself is washed, more waste material is left. Finally, as the coal is burned, the remaining ash is left as a waste product.

3.1.2.5. *Thermal pollution*

During the electricity-generation process, burning fossil fuels produces heat energy, some of which is used to generate electricity. Because the process is inefficient, much of the heat is released to the atmosphere or to water that is used as a coolant. Heated air is not a problem, but heated water, once returned to rivers or lakes, can upset the aquatic ecosystem.

3.2. Fossil energy consumption and resulting CO_2 emissions in Belgium

This part presents figures on fossil energy consumption and resulting CO_2 emissions for Belgium for the period 1830-2000. A brief description of methodologies and data sources used will be followed by a presentation and analysis of the main results.

3.2.1. Fossil fuel consumption in Belgium: 1830-2000

The Belgian energy situation is mainly characterised by the fact that, apart form coal, it does barely have any domestic fossil energy resources. Nevertheless, being one of the richest and most industrialised regions in the world, Belgium uses massive amounts of energy for all kinds of purposes, as well in the domestic, as in the industrial and the tertiary sector. Therefore, it yearly imports vast amounts of energy carriers from regions all over the world. In the following paragraphs, figures will be presented on the amounts of fossil energy imported, consumed and exported in the course of the Belgian existence, i.e. from 1830 till 2000.

3.2.1.1. *Data compilation: sources and methodology*

A top-down approach has been adopted in order to obtain relevant numbers on fossil fuel consumption in Belgium, which could afterwards be used as input for the calculation of the resulting CO_2 emissions (see §3.2.2.). For the three relevant energy carriers, coal, oil and gas, data concerning yearly amounts of imports and their geographical origin, export and domestic consumption have been gathered. In order to be of relevance for the calculation of resulting CO_2-emissions, the domestic consumption has been disaggregated to the level of detail necessary for the so-called ‘reference approach’ documented in the IPCC Guidelines for National Greenhouse Gas Inventories Workbook (IPCC, 1996).

Different energy units have been used in data reporting on energy use throughout the years. As long as coal was the dominant energy source, SKE (‘SteenKool Equivalent’, Equivalent Coal Units) was mainly used in statistical energy reports. Later on, as oil took over, TOE (Tons of Oil Equivalent) became the energy unit worldwide used. Apart from physical units, i.e. weight (coal and oil) and volume (gas), mainly Joule[1] (J; the standard SI unit) and TOE will be used in this report. A conversion table including energy values for a few relevant fuels is given in Table 1.

Table 1 Energy conversion table[2]

		TJ (10^{12} J)	10^3 TOE
SKE	10^3 ton	29.3	0.70
Coal	10^3 ton	29.3	0.70
TOE	10^3 ton	41.9	1.00
Crude oil	10^3 ton	42.8	1.02

[1] One joule is the amount of energy it takes to lift an object that weighs one Newton a one meter distance; an energy supply providing one joule per second gives one watt of power
[2] Taken from IPCC, 1996

Natural gas	10^6 m^3	31.7	0.76
LPG	10^3 ton	47.3	1.13
Jet Kerosene	10^3 ton	44.6	1.07
Lignite	10^3 ton	21.6	0.51

Regarding data sources for the different energy carriers :

- Coal: For the period after 1952, yearly detailed coal balances including domestic production, import and export disaggregated to geographic region and consumption are available from the Ministry of Economic affairs (Mineco 1, 2004). The yearly report 'The Belgian economy in 19.." (Mineco 2, 2004) available for the period 1951-1986 includes energy balances which gives numbers concerning coal consumption for selected years (1900, 1910, 1920, 1930 & 1948-1986). Wherever these numbers were not available, consumption is estimated as domestic consumption plus import minus export. The Belgian Statistical Yearbooks (Statistisch Jaarboek, 2004) give global figures on the domestic production, import and export of coal for selected years in the 1830-1951 period.
- Oil: Concerning the import of crude oil and its geographic origin, data have been reported from 1973 on in the Annual Reports of the Belgian Petrol Federation (Petrolfed, 2004). Foreign trade data (Jaarboeken buitenlandse handel van de BLEU, 2004) were used to cover the 1953-1972 period. The yearly report 'The Belgian economy in 19.." (Mineco 2, 2004) reports on oil consumption in Belgium for selected years (1900, 1910, 1920, 1930) and includes energy balances presenting figures on domestic consumption, international bunkering, import and export disaggregated to individual oil products for 1938, 1949 and the 1951-1986 period. Similar data for the most recent period (1987-now) are readily available from the Ministry of Economic affairs (Mineco 1, 2004).
- Gas: Nearly all necessary data from 1950 on, were retrieved from the Annual Reports of the Belgian Gas Industry Federation (FIGAS, 2004). Figures on non-energetic use have been obtained from the Ministry of Economic affairs (Mineco 1, 2004).

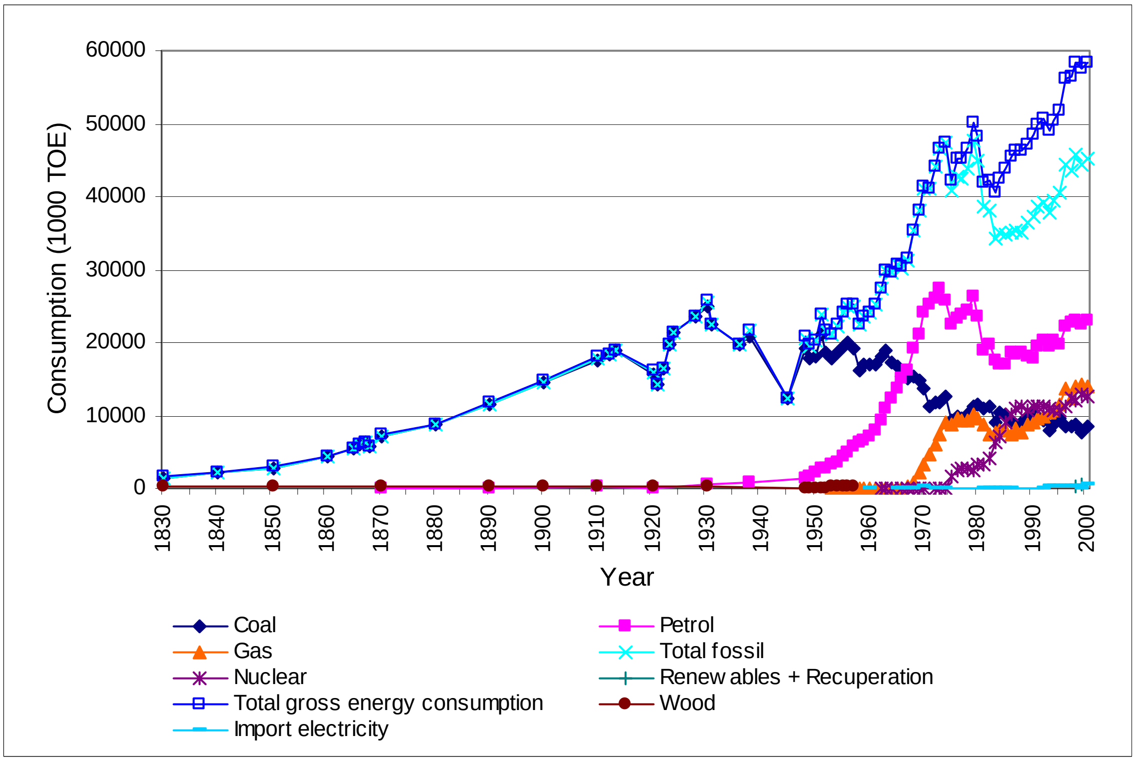
3.2.1.2. *Gross Belgian energy consumption*

Figure 2 shows the gross Belgian energy consumption from 1830, when Belgium became an independent and sovereign state, up till 2000. In 170 years time the gross energy consumption has increased from 1678 10^3 TOE to 58269 10^3 TOE.

Before the 19th century, wood was the main fuel used and transportation relied largely on muscle power supplemented by hydro. At the beginning of the 19th century coal started to take over; wind mills were replaced by factories ('mills') and instead of horses, coal driven machines were used. At that time, only wood and coal were available as energy carriers; oil had been discovered already, but it was never thought of as an energy source. Coal would remain the main energy resource till after the second World War. A temporary decline in the use of coal can be noticed during and immediately after both world wars. Oil and gas start to take over from 1950 on: liquid and gaseous energy carriers were relatively cheap and produce less dust and are less polluting compared to coal. In 1948 petrol was used for the first time in the electricity plants and this for only 0.1% of the total electricity generation, twenty years later this number had increased up to almost 40%. The decline in the use of oil in 1973 and 1979 is due to the respective oil crises in those years. The high oil prices made the world, and

Belgium, turn towards other energy sources and energy conservation. At the same time the demand for electricity, mainly due to an increased availability of electrical appliances, kept increasing. Belgium made the choice for nuclear power to partially foresee in its electricity generation. The presence of gross uranium reserves in its colony Congo have played a major role in this decision.

Figure 2 Gross Belgian energy consumption



The Belgium uranium ore industry (Union Minière, controlled by the Société Generale) delivered the necessary uranium resources to the USA for the construction of the first atomic bomb under the “Manhattan Project”. The uranium mines in Katanga in Congo were then the richest in the whole world. In exchange for uranium ore delivery contracts, Belgium gained a privileged access to nuclear expertise for commercial, non-military applications. From 1975 on nuclear energy has been used in significant amounts and its use increased to 10000 10^3 TOE in 1986. It has since than slightly increased to a rather constant level of about 12000 10^3 TOE. Apart from nuclear power, the use of natural gas, which began in the 1960’s (see §2.1.4. for details) keeps increasing in the 1970’s. Recently a very strong reduction in the consumption of solid fuels, mainly on the part of industry (cokes, iron and steel) can be viewed (see also Figure 5). From solid fuels it has shifted further away towards natural gas as a result of the conversion of electric power stations. The primary consumption of gas keeps increasing, especially because of a stronger demand for electricity generation. A more detailed description of the evolution in the consumption and supply for the different fossil energy carriers is given in separate paragraphs (see §3.2.1.3. – §3.2.1.5.).

Looking at the figures from a per capita viewpoint, as depicted in Figure 2, makes clear that our lives have become increasingly dependant on energy consumption. Whereas in 1830 an average Belgian consumed about 0.5 tons of oil equivalents, this has increased to almost 6 tons. Until 1950 this increase seems to show a linear behaviour, after 1950 it is rather exponential.

Nuclear energy production as such is not included in this research as the main focus is on aspects of ecological debt related to the input of fossil fuels in the Belgian energy system and resulting CO_2 emissions. Because of the increasing attention given to the climate change problem in political as well as other domains, the 'nuclear option' for energy production tends to get back on the agenda. Various people call for intensified use of nuclear energy generation as it does not directly emit greenhouse gasses.

It is true when individual nuclear reactors replace fossil-fuel power stations, they contribute towards reduction of CO_2 emissions. However, it should be avoided to restrict the scope of environmental problems related to energy supply in general to emissions of greenhouse gasses alone. At this moment, climate change is perceived as one of the major environmental problems facing humanity, which it most probably is. But this should not divert the attention from the problems and risks related to nuclear energy. Reducing CO_2 emissions should be viewed as only part of a strategy of minimizing risks. This strategy is embedded in the sustainable development discourse under the term 'precautionary principle'. Narrowing the discussion on the sustainability of Belgians energy system, which involves issues on both demand and supply, to the resulting emissions of greenhouse gasses should be avoided: it 'opens' the path for restricted solutions. Considering nuclear energy means implementing as part of a strategy for minimization of risk to employ a technology linked with high and partly incalculable risks. Without going into detail, the reactors now being developed may promise greater safety but they cannot exclude catastrophic releases of radioactive fissile material. Apart from that the question of decommissioning is still unresolved after four decades of atomic energy. At present, no facilities exist for highly radioactive waste, which could guarantee sufficiently safe storage of fissile products for thousands of years. The risk is also increased by the transportation procedures involved. In addition, the utilization of nuclear energy is always linked with dangers of proliferation. So, if the criterion of minimizing risk is taken seriously, nuclear power generation can hardly be viewed as a valuable alternative to fossil energy.

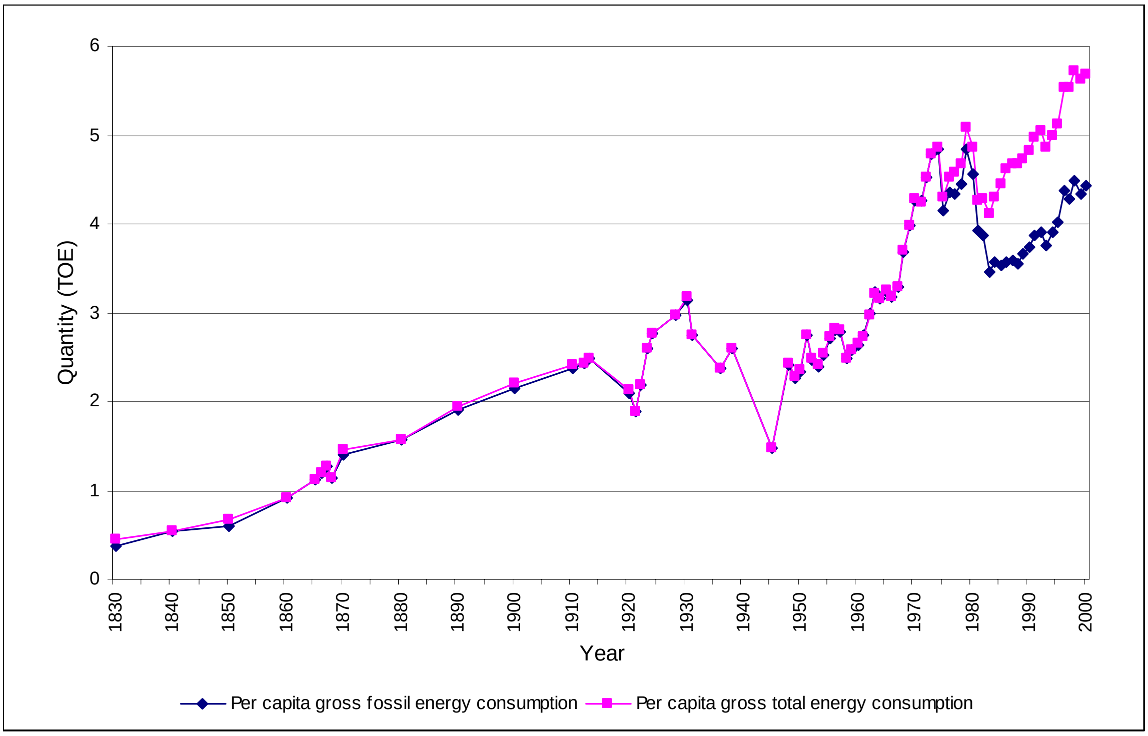
Rather than narrowing the discussion to greenhouse gas emissions, the broad complex issue of the whole energy system should be taken into consideration. Climate change is 'only' one part of the environmental problems related to the energy system.

In Figure 4 per capita energy consumption for different regions and categories of countries are shown. These numbers are taken from B. Podobnik (2002), which adopts a categorisation widely used in world system theory[3].

[3] Core regions roughly correspond to what we call First World countries (high per capita income, advanced industrial technologies, dominating trade and overseas investment); Peripheral regions to Third World countries (underdeveloped economies, low per capita incomes, low levels of technology, with high dependency on external trade). The semi-peripheral regions lie between the core and the periphery. South Korea, Taiwan, Malaysia, Brazil, and India are examples of semi-peripheral countries. In other contexts these are referred to as the newly industrialized countries.

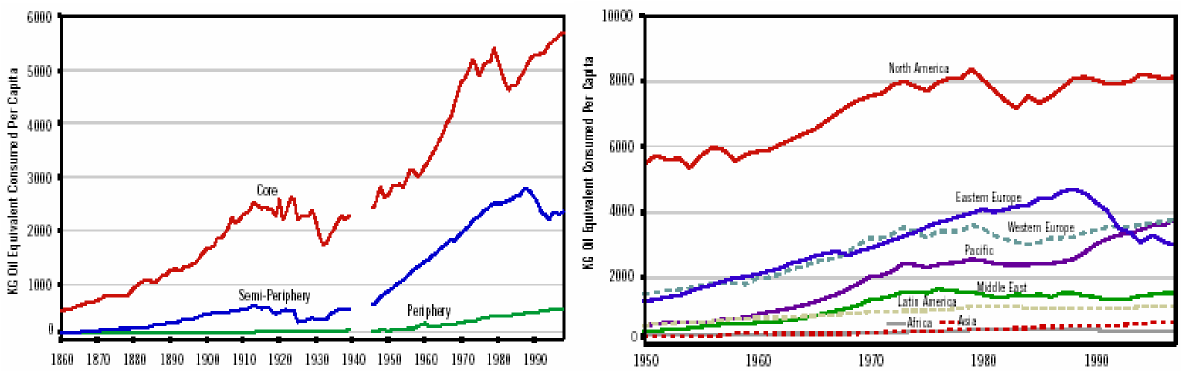
Comparison with Figure 3 learns that Belgium roughly follows the level of core states per capita energy consumption. Throughout the modern period core states have attained much higher levels of per capita energy consumption than their (semi-)peripheral counterparts.

Figure 3 Belgium Per Capita Gross Energy Consumption



If we focus our attention to the post World War 2 period and examine world regions in more detail, we again see enduring patterns of inequality. Moreover, it shows that Belgium's per capita energy consumption level lies significantly higher than that of Western (and Eastern) Europe.

Figure 4 Per Capita Energy Consumption[4]

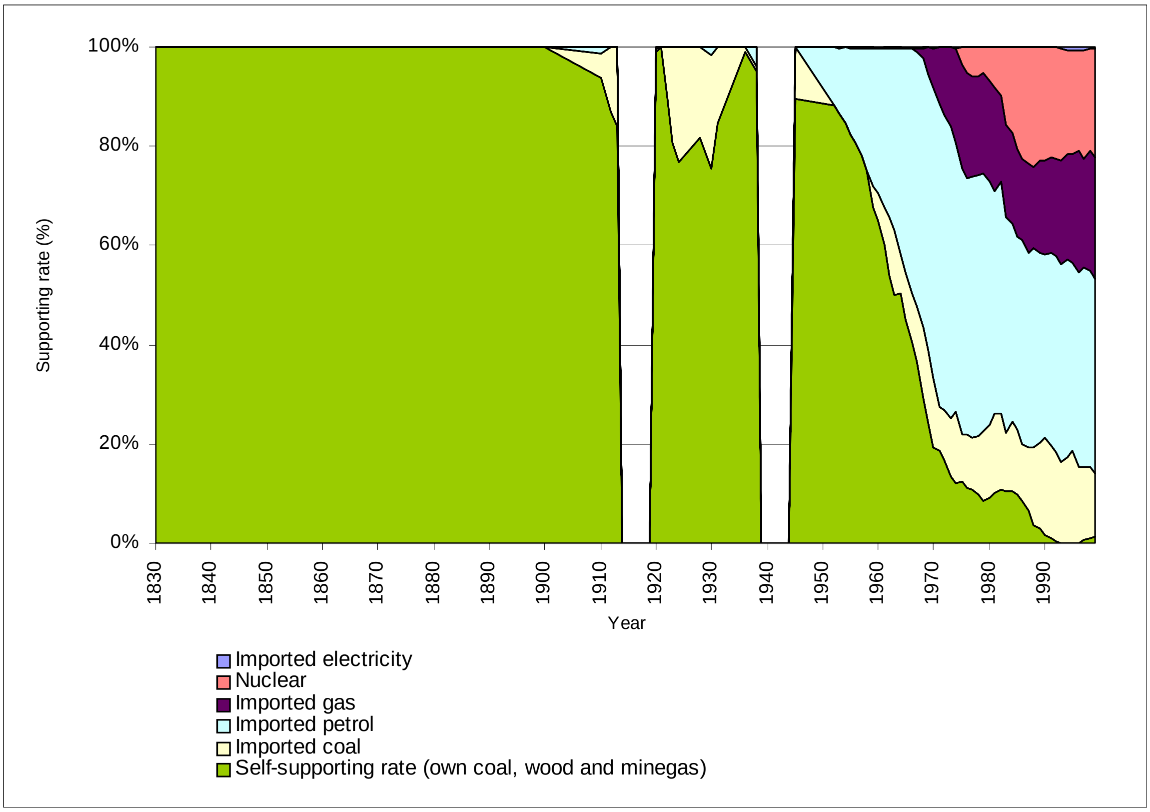


In the early years, Belgium was self-supporting in its energy supply by the extraction of coal in the Walloon basins. From the Second World War on, however, the Belgian energy system became increasingly dependant on imports of coal, oil and gas. In Figure 5 this evolution is shown, representing the self-supporting rate as the proportion of the own primary production

[4] Taken from B. Podobnik, 2002

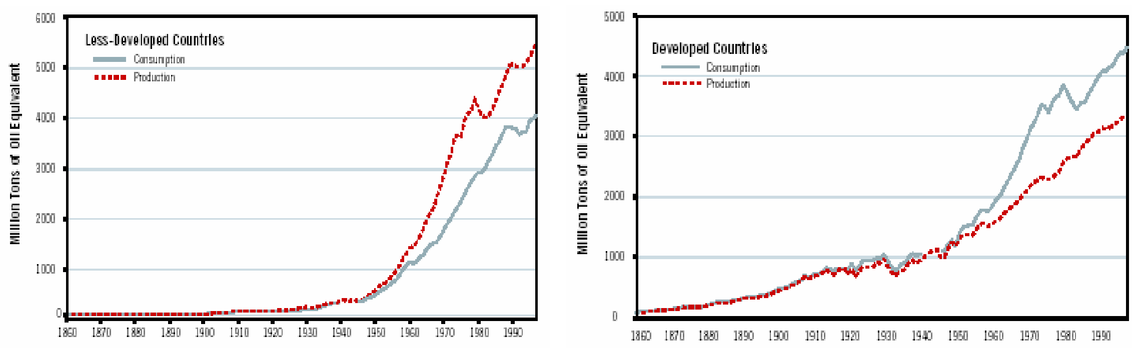
of energy carriers, i.e. wood, coal, mine gas, renewables and recuperation, over the total gross energy consumption. Also, the supporting rate of other energy carriers is depicted.

Figure 5 Supporting rate of the different energy carriers



As Belgium built its wealth, during the industrialisation phase, mainly on coal, it can be said that until the 1950's, it had done so mainly relying on its own resources. The same conclusion can be drawn for developed countries as a whole. As shown in Figure 6, through the end of the Second World War the developed world was almost totally self-sufficient in energy. Since then however, nations of the global south (developing countries) have been transferring energy resources to nations in the global north (developed countries) at a steady state.

Figure 6 Energy Production and Consumption[5]

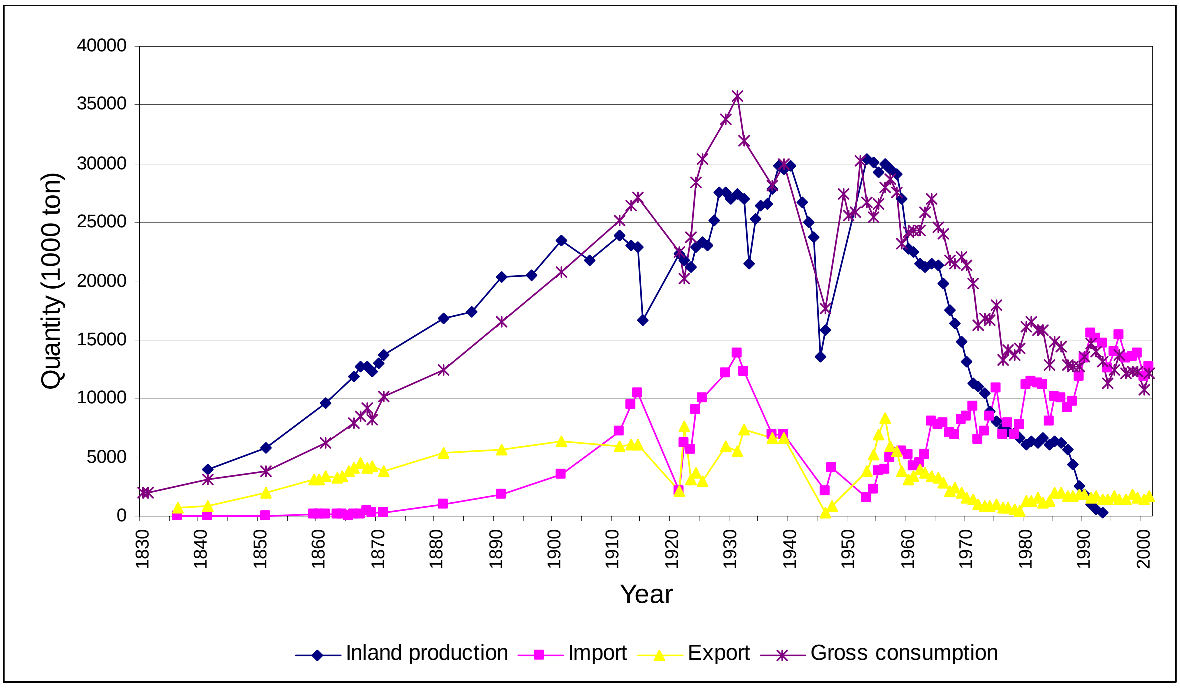


[5] Taken from B. Podobnik (2002)

3.2.1.3. Coal[6]

Figure 7 depicts the gross domestic consumption of coal in Belgium together with the quantities produced, exported and imported. Coal, together with steel, can be considered as the engine of the industrialisation in Europe and England and Belgium in particular. Belgium had cheap coal from the Walloon coal mines (Borinage) at its disposal, which was transported by water to power the growing industries. The steam engine had been known in Belgium from 1720, when a so-called Newcomen engine was installed in a Belgian coal mine to pump water out of the mines. The availability of massive amounts of coal, which could be easily transported, made the steam engine to move to the textile and metal working factories and the iron industry. The coming of the railway in 1830, which emerged as a method of bulk transport, which was cheaper than canal transport opened up national markets and stimulated the coal, iron and steel industries. In 1901 coal is discovered in Flanders (Limbourg).

Figure 7 Gross consumption, inland production, import and export movements of coal 1830-2000

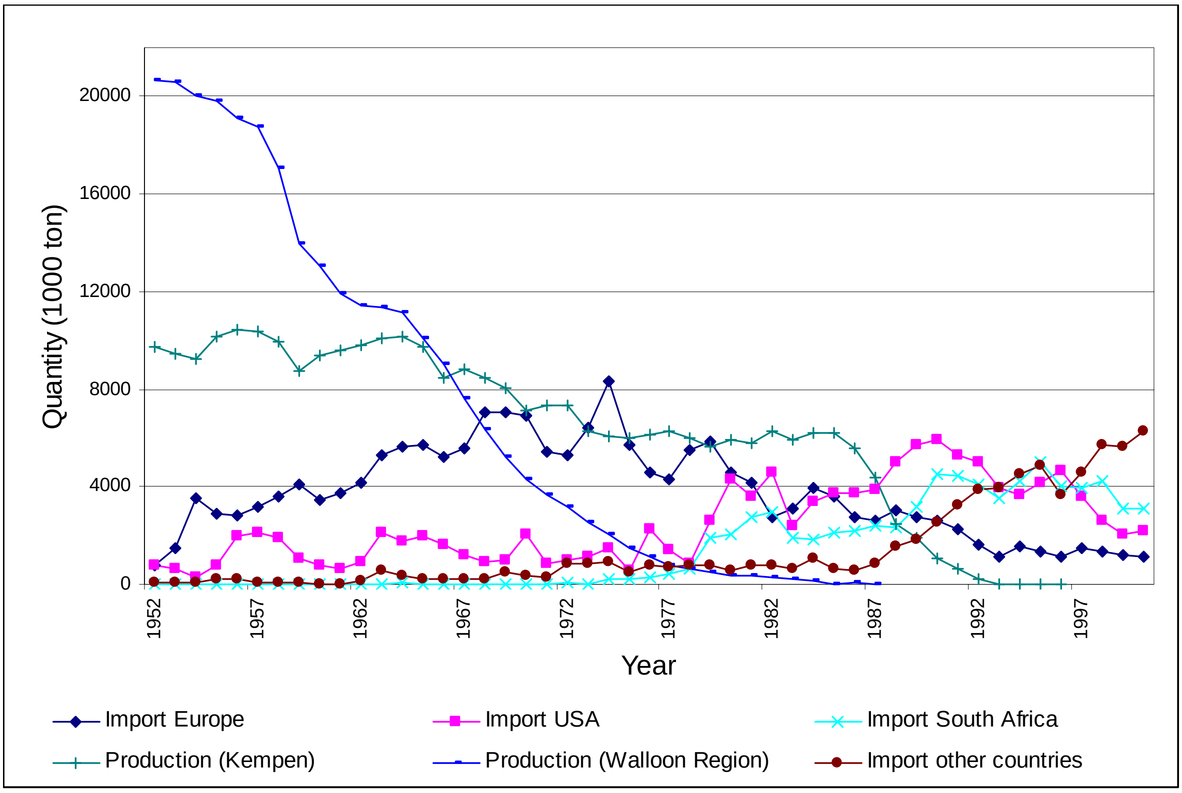


An accelerated exploitation of the Flemish coal mines brought the economy back on track after the first world war. After the First World War, oil began to take over from coal in shipping and motor cars, diesel trucks and tractors were produced in ever growing quantities. But until 1967 coal maintains its position as the main energy source, especially for all stationary end-uses but it is even still in use for inland transport by boat and train. From the 1960's on and despite the still present huge reserves, domestic coal could no longer compete with imported cheap oil. The economics of domestic mining are deteriorating and import coal (from USA, Eastern Europe and South-Africa) is substituted for domestic coal as can be seen in Figure 8. Obsolete pits are given up but also in the most efficient pits private capital sees no opportunities. Figure 7 shows the decline in domestic consumption and the increase in amounts of imported coal. In the 1970's oil and gas are increasingly substituted for coal in most end-uses (e.g. space heating, steam raising, electricity generation). Where coal stands,

[6] Partly based on Fraunhofer, 2003

import coal out competes by far domestic coal. The hope for revival is fed by the oil price hikes (since 1973; first oil crisis); significant subsidies are directed towards the inland mining activities but cannot stop the further decline of the mining sector. In 1984 the last Walloon pit is closed and in 1989 Flanders decides the closure of all Limbourg pits by 1991-1992. Coal consumption is based on a few large consumers such as power plants, blast furnace industries, etc. and maintains a rather constant level. In the latest years the climate change issue has added an extra argument, i.e. the high carbon intensity of coal, to prohibit the promotion of coal as an alternative to nuclear power or to the scarcity of oil and gas.

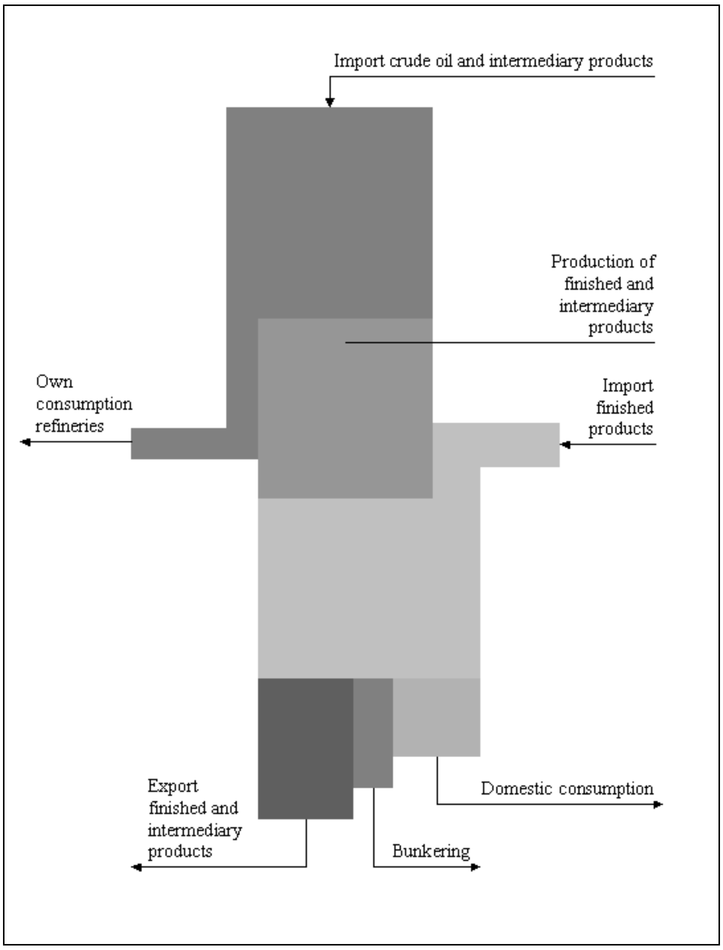
Figure 8 Coal import and production 1952-2000



3.2.1.4. Oil

Belgium has a significant oil-processing industry, which imports massive amounts of crude oil. The 'oil-balance' and the flows of oil and (semi-)finished oil products is illustrated in Figure 9. Crude oil and intermediary products are imported from different world regions. These are transformed by Belgian refineries into finished and intermediary products. During this transformation process some oil is consumed, i.e. combusted, by the refineries, some gets lost in this process. The total amount of intermediary and finished products is made up of the production in Belgian refineries increased by the import of finished products. The total amount of finished and intermediary products available respectively serves the export, the domestic consumption and bunkering, i.e. international aviation and shipping. Domestic consumption mainly consists of energetic use; a minor part is meant for non-energetic use such as lubricants, white-spirit, bitumen and naphta which serves as feedstock for the petrochemical industry (the production of ethylene and propylene, essential elements in synthetics production.).

Figure 9 Oil balance



As mentioned in the previous section, a major part of the supply of finished and intermediary products for domestic consumption, bunkering and export is produced in Belgian refineries.

Table 2 Primary distillation capacity (1000 ton/year)[7]

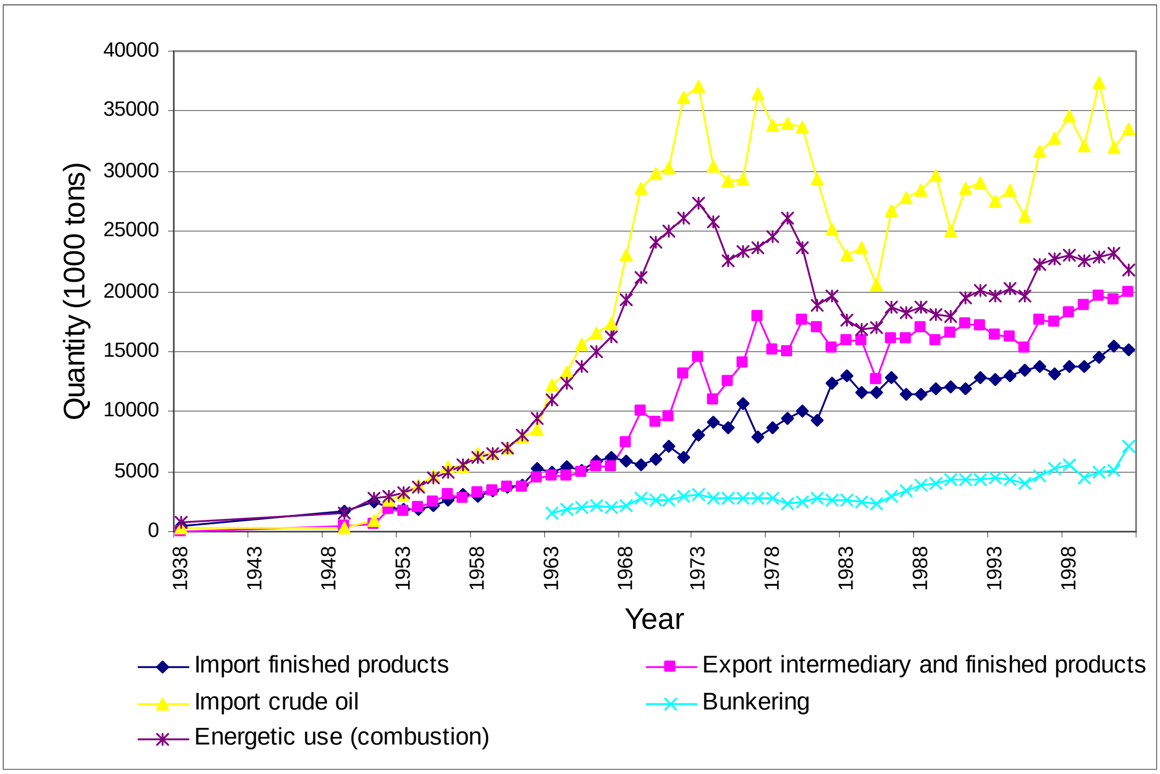
1 January	*1973*	*1979*	*1999*	*2000*
Belgian Refining Corporation	3500	4600	4215	5500
Belgian Shell	544	544	-	-
BP Belgium	40	-	-	-
Chevron	5000	7000	-	-
Esso Belgium	4730	12000	12500	12500
Fina Raffinaderij Antwerpen	17000	17000	16235	16760
Nynas Petroleum	-	-	1200	1200
Raffinerie Belge des Petroles	5000	5000	-	-
Texaco Belgium	7270	9370	-	-
Petroplus Refining Antwerpen	-	-	2500	2500
Total	43084	55514	36650	38460
Usage (%)	85.9	59.5	87.7	88.3

These refineries transform imported crude oil into intermediary and finished products. In the year 2000, Belgian refineries present a total primary distillation capacity of 38460 10^3 tons per year. In 2000, this capacity has been used for 88,3% which means that 33960 10^3 tons of

[7] Source: Belgische Petroleum Federatie, Jaarverslag 2000

crude oil (88,3% of 38460 10^3 tons) were transformed. Table 2 gives an overview of the Belgian refinery capacity.

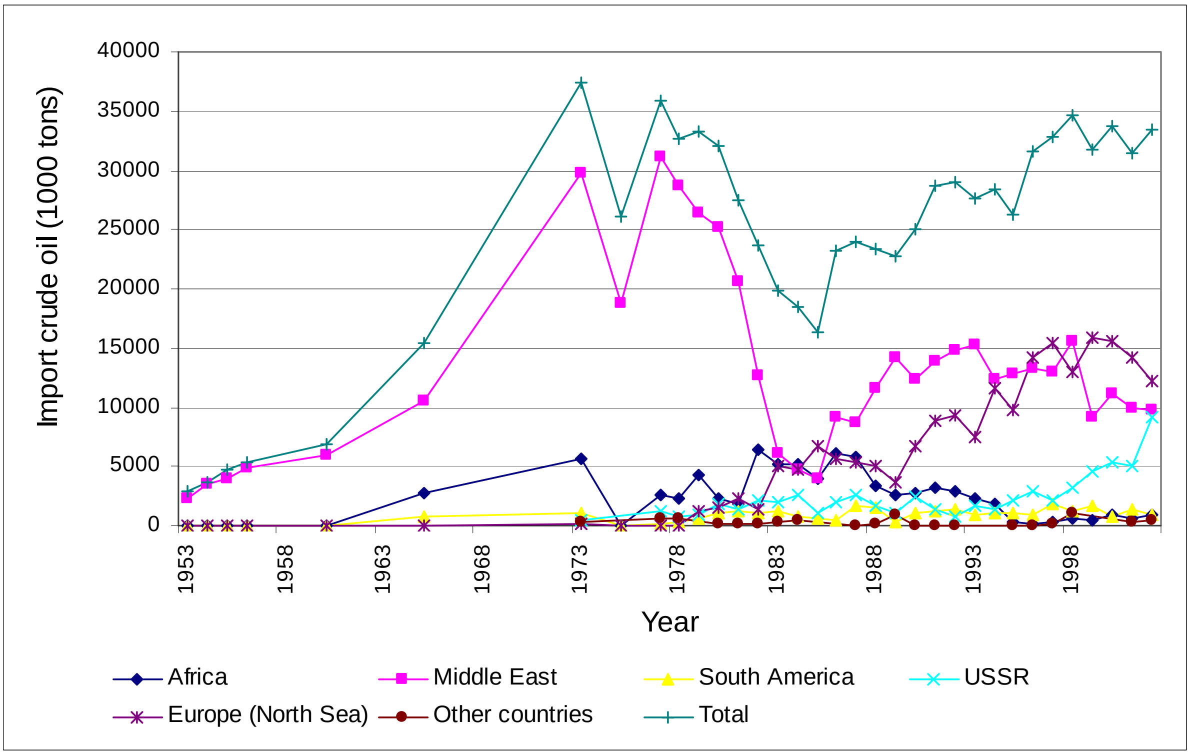
Figure 10 Import, export and energetic consumption of oil products



The evolution in the Belgian oil balance is shown in Figure 10. Here, the energetic consumption of oil products is shown together with the supply of fuels for bunkering and the import and export flows of crude oil, intermediary and finished products. The energetic use is characterised by a continued steep increase until the oil crises of 1973 and 1979-1980. It has since than remained on a roughly stable level of about 20 billion tons.

As already mentioned, Middle East oil was discovered commercially early in the 20th century and was to become a vast, almost limitless supply of very cheap oil until the early 1970's. Great amounts of oil gushed from each cheap shallow oil well. With weak national states (or colonies and protectorates) there was little, if any, tax and also low, if any, royalties. The great investment in large tankers, pipelines, and giant refineries was yet to come. After the First World War, the growth of road transport, driven by liquid fuel driven engines, began. But it was only from 1950 on that oil became a major energy carrier in Belgium. The cheap Middle East crude oil that flooded the world markets, combined with investment in energy technology such as refineries, power stations, electrical appliances and oil based transportation was the basis for this period's high rate of economic rate. This period of 'cheap petroleum' is characterised by the exponential growth in oil and energy consumption between 1950 and 1973.

Figure 11 Import of crude oil



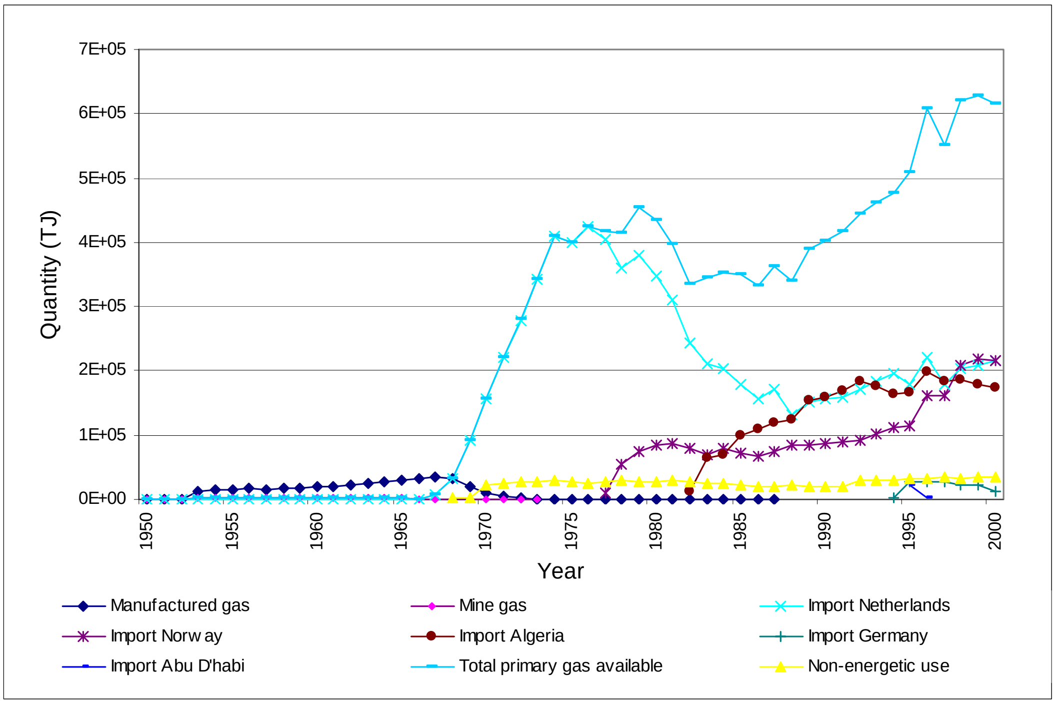
The geographical origin of imported crude oil distributed over the different world regions is depicted in Figure 11. The Middle-East, with mainly Saoudi-Arabia, Iran, Iraq and Kuwait, has been the main supplier until 1998. The impact of the first (1973) and second (1979-1980) oil crisis in the share of import from the Middle East is clearly visible. Whereas the first oil crisis was caused by a restriction on the supply initiated by OPEC (quadrupling of the oil prices as a retaliatory measure for the Western positioning in the Arab-Israelitic conflict), the second crisis had a less political character: it was the unstable war-situation in the Middle-East itself that levelled the oil prices. In order to be sure of a stable supply Western countries looked for diversification. In this context the increase of import of Russian oil and oil from the North Sea has to be interpreted.

Oil exploration and development was stimulated in other areas and a turn towards other (and alternative) energy sources and energy conservation could be noticed. Around 1985 the prices of most oil products crumble down to levels below the pre-1979 prices. Whereas in the first years, the oil crises had been an incentive for interest in the energy question (R&D in frontier energy efficiency technologies, energy efficiency projects in companies), the decline of the oil price results in society losing interest in the energy issue. Anyway, the result of the exploration and development of new oil fields, alternative energy sources and energy conservation has been a higher cost for energy to the consumer. From 1980 on, the consumption of oil in Belgium has stagnated. In the 1990’s, oil remains the single largest energy source of Belgium with a share of about 40%. It is the dominant energy in the automotive sector that has been growing continuously while average efficiency of cars has been topped by the shift to more luxury or special types.

3.2.1.5. *Gas*

In 1819 in Brussels, the first gas plant is founded at the borders of the river Zenne. It produces gas from coal, which in turn provides street-lightning in a few districts. Little by little, every town has its own gas plant and in 1885, 85 gas plants serve 115 towns and villages. In 1900 already 5,706 TJ (136 TOE) is produced. All kinds of household gas-appliances like the gas cooker and bath-heater get introduced. After the First World War, the cokes-factories, which produce (as a by-product) cokes gas that is sold to the gasworks, become the main gas-producers. The gasworks make their distribution network available. Until 1965, however, the gas sector remains limited to manufactured gases such as gases from oil refineries (bottled gas for cooking), blast furnace gases, cokes gases. Figure 12 gives a quantitative overview of the gas supply and consumption in Belgium since 1950.

Figure 12 Gas in Belgium: supply and use



From 1965 on, natural gas becomes available: The Netherlands massively export cheap natural gas from their Slochteren bubble in Groningen. It is introduced in the urban distribution networks (replacing manufactured gas and requiring a retrofit of gas equipment and appliances). From then on natural gas becomes a new competitor in the domestic and industrial market. The arrival of natural gas preludes a rapid expansion of the gas sector as a whole. In the 1970's urban gas networks are all converted to natural gas and firmly extended; import and transport infrastructures are built. Zeebrugge is developed as the landing port for the LNG (Liquid Natural Gas) imports. In 1975 natural gas stands for 20% of the gross Belgian energy consumption. From 1982 on, natural gas from Algeria arrives in Zeebrugge by LNG-tanker. Along the oil exploration in the North Sea, gas is found, and Norwegian gas is piped to Belgium. Natural gas is penetrating the energy market swiftly. More and more end-uses are developed and prove to be the most efficient one in their categpry, e.g. heat supply. The number of households connected to the gas grid is expanding. Many companies and institutions substitute natural gas for oil an for coal.

From the end of the 1960's on, a significant amount has been used for non-energetic purpose: the production of ammonia, which is an important element in fertilizer production.
The gas sector is further developing the networks (adding 15000 km in the 1990s up to about 50000 km of transport and distribution mains). Gas is a favourite energy source in the domestic, the services, the industry and the power sector, because it can be applied in a very efficient way in a wide range of technologies. Additionally it is the cleanest fossil fuel available in nature, and it has a low carbon content, causing the least greenhouse gas emissions per Joule delivered (See Table 3).

3.2.2. CO_2 emissions from fossil fuel combustion in Belgium: 1830-2000

In this paragraph, CO_2 emission data based on the carbon content of the fossil fuels consumed in Belgium are presented for the period 1830-2000.

3.2.2.1. *Data compilation: sources and methodology*

In the Belgian federal context, the major part of environmental responsibilities lies with the regions. Compiling greenhouse gas emissions inventories is one of these responsibilities; each region implements the necessary means to establish their own emission inventory in accordance with the UNFCCC guidelines for the common reporting format. The emission inventories of the three regions are subsequently combined to form the national greenhouse gas emission inventory. There is co-ordination in an official intergovernmental working group, the " working group emission inventories", with representatives of Flanders, Wallonia, Brussels and the Federal Ministry of Environmental affairs. The three regions exchange information on methodology, but each region has its own methods to obtain activity data and emission factors. For CO_2 emissions from the energetic use of fossil fuels, all regions base their calculations on the regional energy balances. At the moment, Vito compiles the regional energy balance of Flanders, while ICEDD (former Institut Wallon) compiles energy balances for Wallonia and Brussels. The calculation of the regional inventories is based on the "Sectoral Approach" (CO_2 emissions by source categories) of the IPCC guidelines with some specific modifications.

As this work aims at presenting CO_2 emissions for a period covering several decades, it is instructive to adopt the reference approach as historical data are in general on a supply level. No sector specific data are available for early years. Still, this top-down approach yields an accurate estimate of the national CO_2 emissions by accounting for the carbon in fuels supplied to the economy. These are corrected for international bunkering and non-energetic use of energy products. Some carbon emission factors are given in Table 3.

Table 3 Selected Carbon Emission Factors

Fuel	Carbon Emission Factor (ton C/TJ)
Lignite	27.6
Crude oil	20.0
Jet Kerosene	19.5
Gasoline	18.9
Natural gas	15.3

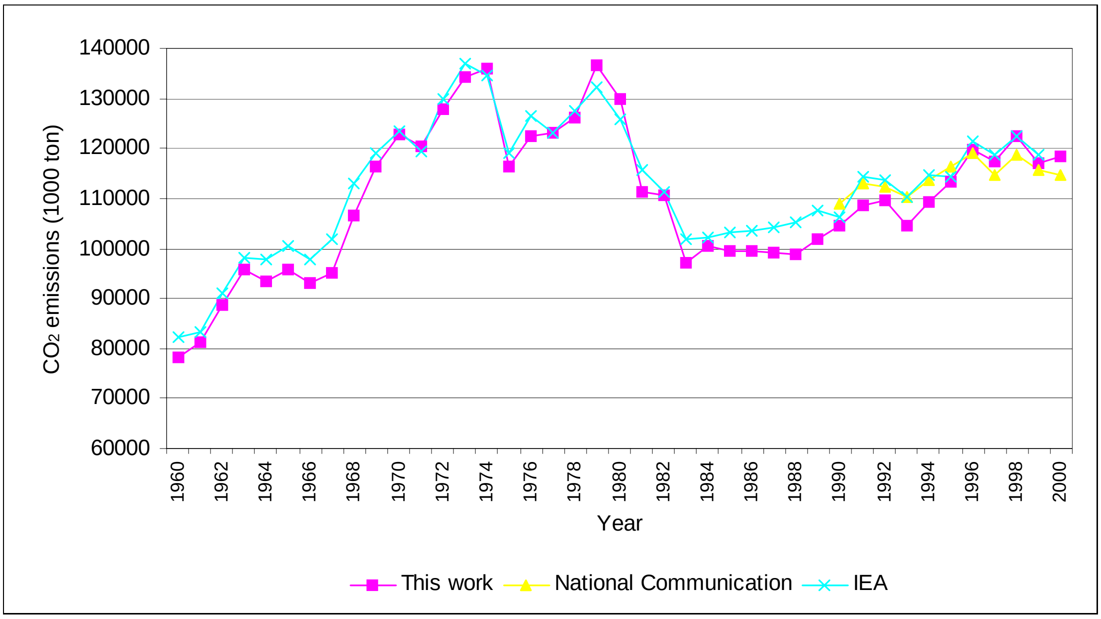
Based on supply data reported in §3.2.1., CO_2 emissions have been calculated following the IPCC Reference Approach. This approach is documented in Module 1 of the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Workbook (IPCC, 1996), which concentrates on the calculation of CO_2 emissions from energy activities.

Regarding methodologies for the different energy carriers:

- Coal
  The case for coal is rather straightforward. As mentioned in §3.2.1., data on domestic consumption of coal and lignite have been compiled. These data are transformed into CO_2 emission data by multiplying by the net-calorific value and the CO_2 emission factor, as reported in the IPCC guidelines.
- Oil
  The case for oil is somewhat more complex. Based on the flow-scheme compiled in §3.2.1., we have calculated CO_2-emissions form the use of oil by calculating the carbon stored in the diversity of oil products contained in 'domestic consumption' and 'own consumption refineries'. Therefore, product specific carbon emission factors and calorific values have been adopted. Non-energetic use and bunkering have not been taken into account.
- Gas
  As only imported natural gas has to be taken into account (as primary energy source), it is straightforward to calculate resulting CO_2 emissions after correcting for non-energetic use.

Figure 13 makes a comparison of the results obtained in respectively this work, by the International Energy Agency IEA and the figures reported to UNFCCC in the annual Belgium's Greenhouse Gas Inventory submitted under the UNFCCC. Differences in results are limited to a few percent range. The figures obtained in this work have the tendency to be systematically lower than these obtained by IEA. Compared to the IEA straightforward approach, this work treats non-energetic use in more detail. In the further course of this research, post-1990 CO_2 emission data will be taken from Belgium's Greenhouse Gas Inventory; the period 1830-1990 will be covered by the results obtained in this work.

Figure 13 Comparison of methodologies



3.2.2.2. Results

Figure 14 CO_2 emissions from fossil fuel combustion

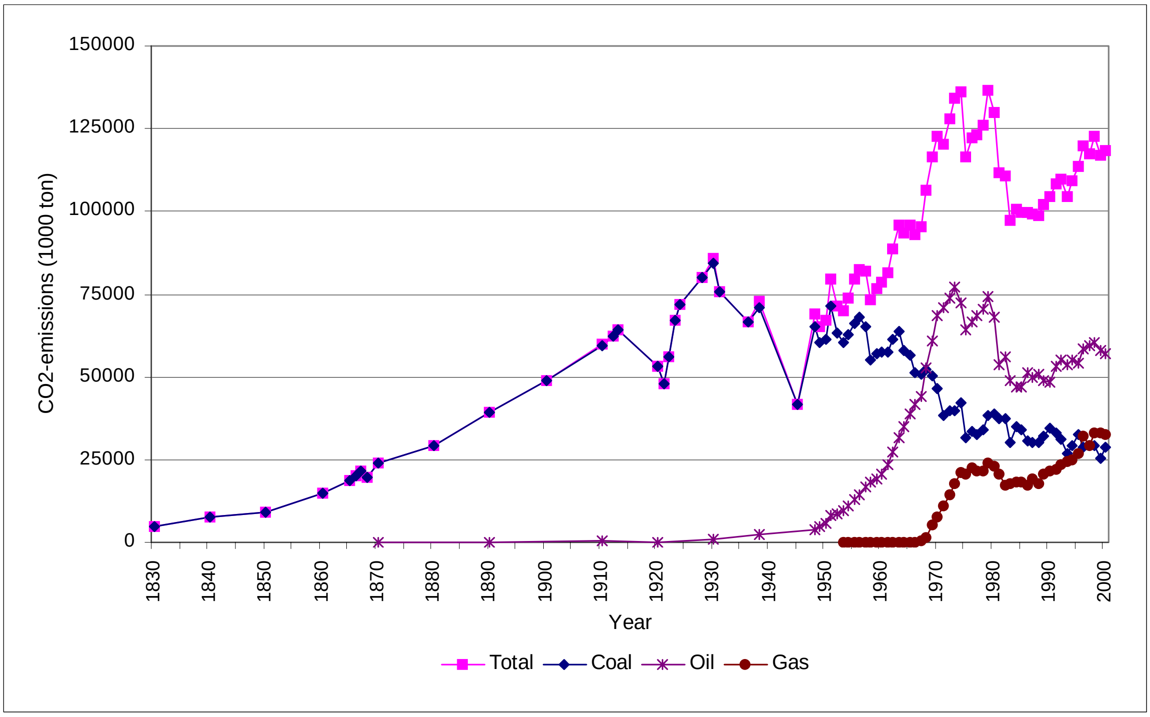
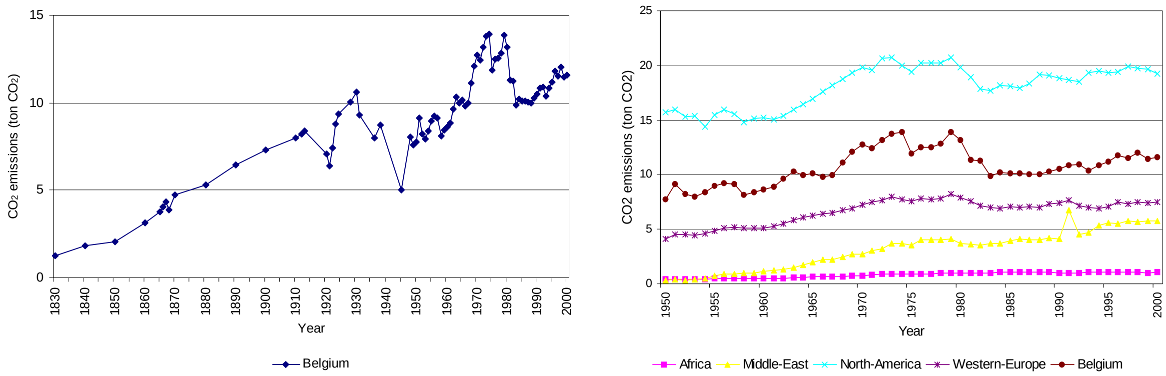


Figure 14 shows total CO_2 emissions from fossil fuel combustion in Belgium, differentiating between the three energy carriers concerned. From almost 5 billion tons of CO_2 in 1830 it increases up to 137 billion tons in 1979. The lowered, yet again increasing, emission rates in the period 1980-2000, are due to the significant amounts of nuclear energy used. Once again, it should be kept in mind that CO_2 emissions only tell part of the Belgian energy issue. It is one important aspect of ecological impact related to the Belgian energy system.

A per capita approach, reflected in Figure 15, shows that in 2000 an average Belgian ‘emitted’ about 11,5 tons of CO_2 in 2000 compared to 1,3 tons in 1830. An international comparison is also given in Figure 15.

Figure 15 Per capita CO2 emissions from fossil fuel combustion



3.3. Ecological debt due to fossil energy consumption: an introductory approach

In order to make clear which specific aspects of ecological debt are relevant for fossil energy consumption, it is advisable to fall back on the general definition:

> “The ecological debt of country A consists of
> (1) the ecological damage caused over time by country A in other countries or in an area under jurisdiction of another country through its production and consumption patterns,
> and/or (2) the ecological damage caused over time by country A to ecosystems beyond national jurisdiction through its consumption and production patterns,
> and/or (3) the exploitation or use of ecosystems and ecosystem goods and services over time by country A at the expense of the equitable rights to these ecosystems and ecosystem goods and services by other countries or individuals.”

As discussed in the core research this definition mainly deals with two processes which cover the core meaning of ecological debt. Firstly, as stipulated in part (1) and (2) of the definition, a country accumulates ecological debt through its process of wealth accumulation by causing ecological damage elsewhere. Secondly, as covered in part (3) of the definition, the use of ecosystems and ecosystem goods and services by one country may add to its ecological debt by limiting the use by other countries and future generations.

Regarding ecological damage caused elsewhere by the Belgian energy system, the following main aspects may be easily identified (see also §3.1.2.) and further refined by classifying the ecological damage by the type of interference with the environment. It mainly concerns ecological debt due to

(a) Extraction activities: ecological damage caused by the extraction process of fossil fuels abroad but meant for consumption in Belgium. As has been made clear in the introductory part (§3.1.2.) this concerns mainly *degradation* and *pollution*
(b) Excessive consumption of fossil fuels: ecological damage caused by the *depletion* of fossil fuel stocks
(c) Fossil fuel combustion: ecological damage in other countries and ecosystems beyond national jurisdiction caused by anthropogenic greenhouse gas emissions (pollution) and resulting climate change

Concerning the exploitation and use of ecosystems and ecosystem goods and services at the expense of the equitable rights to these ecosystems and ecosystem goods and services by other countries or individuals, two aspects may be identified:

(d) Excessive consumption of fossil fuels: Belgium's fossil energy consumption rate may limit the possibilities of other countries to benefit from the use of fossil fuels.
(e) Excessive use of the sink capacities of the atmosphere: Belgium's greenhouse gas emissions are emptying the total available absorptive capacity of the planet earth, limiting other countries' opportunities to benefit from greenhouse gas emissions.

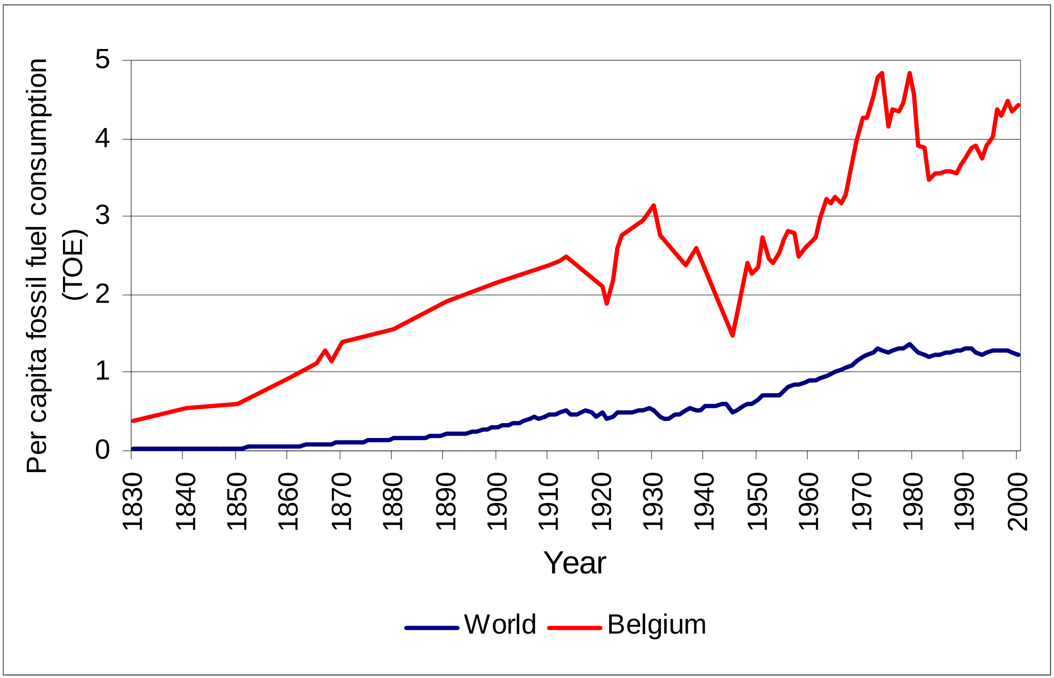
This research project has mainly focussed on the so-called carbon debt, the ecological debt related to CO_2 emissions from fossil fuel combustion, i.e. aspects (c) and (e). Chapter 2.4. is entirely dedicated to this subject

Aspect (a), ecological debt due to ecological damage from fossil fuel extraction activities for Belgian consumption, will not be covered here as it was impossible – within the time frame and the means of the project – to track all ecological damage caused by extraction activities abroad which are intended to provide fossil fuels for Belgium. For more than 50 years Belgium has been importing fossil fuels from many regions all over the world (see §3.2.). The specific ecological damage will not only depend on the specific extraction process used but also on the location. In §1.4.2. of the core research five steps were identified to determine the damage in other countries from fossil fuel exploitation for Belgian consumption:

1. composition of the flow of fossil fuels imported in Belgium
2. tracing of the countries of origin of the different fuels
3. suppose we want to further analysis natural gas: an important part of it comes from Algeria (see module climate/energy)
4. identification of indicators to describe the ecological damage in Algeria due to gas exploitation
5. how much of this damage is attributable to Belgium? e.g. a percentage equal to extraction for Belgium

Steps 1, 2 and 3 have been done and are documented in chapter 3.2. Steps 4 and 5 however require, as made clear by the example of Algeria, a case by case treatment. Because of the limited time no such effort was undertaken.

Figure 16 Per capita fossil fuel consumption



Aspect (b) and (d), ecological debt due to the excessive consumption of fossil fuels, leading to depletion on the one hand and hampering other countries to benefit from these natural resources on the other hand will be briefly illustrated by available numbers on fossil fuel reserves compared to Belgian consumption. Limited time hampered a detailed treatment as much uncertainties and discussion exist on numbers of fossil fuel reserves and also because of the subtleties in the equity aspect as mentioned in §1.3.4.3. of the core research. Following the Friends of the Earth campaign on environmental space, energy and non-renewable materials can be seen as global commodities, with globally accessible resources, global sinks and causing environmental problems on a global scale (Spangenberg 1995, p. 6). As a result, an egalitarian 'equal per capita' view on equity is adopted in their calculations and considerations, although this contrasts with the sovereignty principle, i.e. the *sovereign rights* of states over their natural resources (see §2.2.1. of the modular research on MEA for more details).

Anyway, adopting an egalitarian equal per capita approach and taking numbers on proven fossil fuel reserves, published by British Petroleum (BP, 2002), might give us a first clue of the magnitude of this aspect of ecological debt for Belgium. Figure 16 shows the per capita fossil fuel consumption for Belgium and the world. It makes clear that for the last 100 years an average Belgian citizen has been using roughly 4 times the world average per capita amount of fossil fuels, his consumption level starting at 0.4 TOE in 1900 and increasing to up to 4.4 TOE in 2000. Contrasting this with the figures of British Petroleum on fossil fuel reserves which state that there is a proven reserve of another 850 billion TOE (= 140 TOE/capita), makes at least one point very clear: if every world citizen was to consume as much fossil fuel as an average Belgian in 2000, this would leave the world, supposing that world population remains constant, with just another 32 years of fossil fuels. These figures do not directly make clear how big Belgian's ecological debt is concerning the depletion of fossil fuels or the overuse at the expense of other countries; what it makes clear is that Belgium is a disproportionately high consumer and it does so at least at the expense of future generations.

3.4. The Carbon Debt: operationalisation and application

Within the scope of this module 'Energy/Climate", the term 'Carbon Debt' will be used to indicate all aspects of ecological debt resulting from the emissions of CO_2 from fossil fuel combustion. Based on the findings of the core research an attempt to operationalise the carbon debt concept will be presented: a methodology for quantification together with a few preliminary elements of a framework to deal with this debt in practice.

In a first paragraph the general definition of ecological debt, developed in the core research, will be adopted to identify the relevant aspects of ecological debt resulting from CO_2 emissions from fossil fuel combustion. Based on this, the carbon debt will be defined. A second part makes clear that the carbon debt can be separated in two different parts: an intragenerational debt between nations, the Historical Carbon Debt and an intergenerational debt towards future generations; the Generational Carbon Debt. Two models, introduced in the core research (see §1.3.4.4.), are worked out in detail showing how the Historical and Generational Carbon Debt could be interpreted and quantified. A third paragraph contains a proposal on how these concepts could be brought into practice. First ideas on an emission rights system, which embodies compensation for the Historical Carbon Debt, will be presented. Finally, formulas and rules will be applied to the case of Belgium: based on the data on fossil fuel combustion in Belgium presented in chapter 3.2., relevant figures concerning the carbon debt will be calculated.

3.4.1. Defining the Carbon Debt

In the core research the question of defining the ecological debt concept has been extensively dealt with in view of the relevance and applicability in international policy and negotiations. A general definition has been proposed but the possibility and desirability of formulating operational definitions for specific features of ecological debt was mentioned. Based on the general definition we will elaborate on an operational definition for the carbon debt.

Let us start by referring once more to the general definition of ecological debt presented in the core research, i.e.

> "The ecological debt of country A consists of
> (1) the ecological damage caused over time by country A in other countries or in an area under jurisdiction of another country through its production and consumption patterns,
> and/or (2) the ecological damage caused over time by country A to ecosystems beyond national jurisdiction through its consumption and production patterns,
> and/or (3) the exploitation or use of ecosystems and ecosystem goods and services over time by country A at the expense of the equitable rights to these ecosystems and ecosystem goods and services by other countries or individuals."

Aspects (1) and (2) explicitly refer to ecological damage in other countries and ecosystems beyond national jurisdiction. Do anthropogenic CO_2 emissions, and greenhouse gas emissions in general, cause ecological damage? The UN organised Intergovernmental Panel on Climate Change (IPCC, 2001) says yes: it reports that the global mean temperature has increased by 0.6 ± 0.2ºC over the last century and that most warming over the last 50 years is attributable to human activities, i.e. greenhouse gas emissions. It also reports that, globally the 1990s was very likely the warmest decade, while 1998 and 2001 were the warmest and the second warmest years respectively since the start of the records. The IPCC projects an increase in the globally averaged surface temperature of 1.4 to 5.8°C by 2100. In addition to the increase in average global temperature, a range of wider changes has been observed in our climate system, like the rise of global average sea level and the increase of heavy rainfall events.

Also, and especially, the third aspect of the general definition of ecological debt, i.e. the exploitation or use of ecosystems and ecosystem services at the expense of the equitable rights to these ecosystems and ecosystem services by other countries or individuals, is applicable. The natural absorptive capacity of the atmosphere that allows for the decay of a certain amount of greenhouse gas emissions should indeed be regarded as an ecosystem service. Costanza e.a. classify it under the ecosystem services ‘gas regulation’ and ‘climate regulation’ (Costanza e.a. 1997, 254 – see also the discussion in part 1, 1.3.4.3.). It could further be argued that this capacity belongs to nobody and should therefore be assigned to everybody in an equitable way in order to give everybody the opportunity to benefit from greenhouse gas emissions (Principle of equal opportunity).

It is thus a logical next step to “translate” the general definition of ecological debt in more concrete terms as follows:

> The ***carbon debt*** of a country A consists of
>
> (a) “over-emission of CO_2 by country A over time with respect to a sustainable level; i.e. emission levels which overshoot the absorption capacity of the atmosphere and are thus causing ecological impact in other countries and ecosystems beyond national jurisdiction”
> (b) “over-emission of CO_2 by country A over time at the expense of the equitable rights to the absorption capacity of the atmosphere by other countries or individuals”

It should be stressed that the carbon debt is not merely the sum of both aspects, as both aspects are intertwined. Mostly, over-emitting at the expense of the equitable rights to the absorption capacity of the atmosphere by other countries or individuals includes at the same time over-emitting with respect to a sustainable level. Simply summing up both debts would obviously lead to double-counting in these cases. Further on, it will become clear how this will be dealt with.

Both the aspects of the carbon debt imply the evaluation of emission levels against *normative standards*, i.e. ‘sustainable level’ and ‘equitable rights to the absorption capacity of the atmosphere’. We refer to the core research for a more profound discussion on these topics; here, we will briefly discuss both issues and propose tentative estimates.

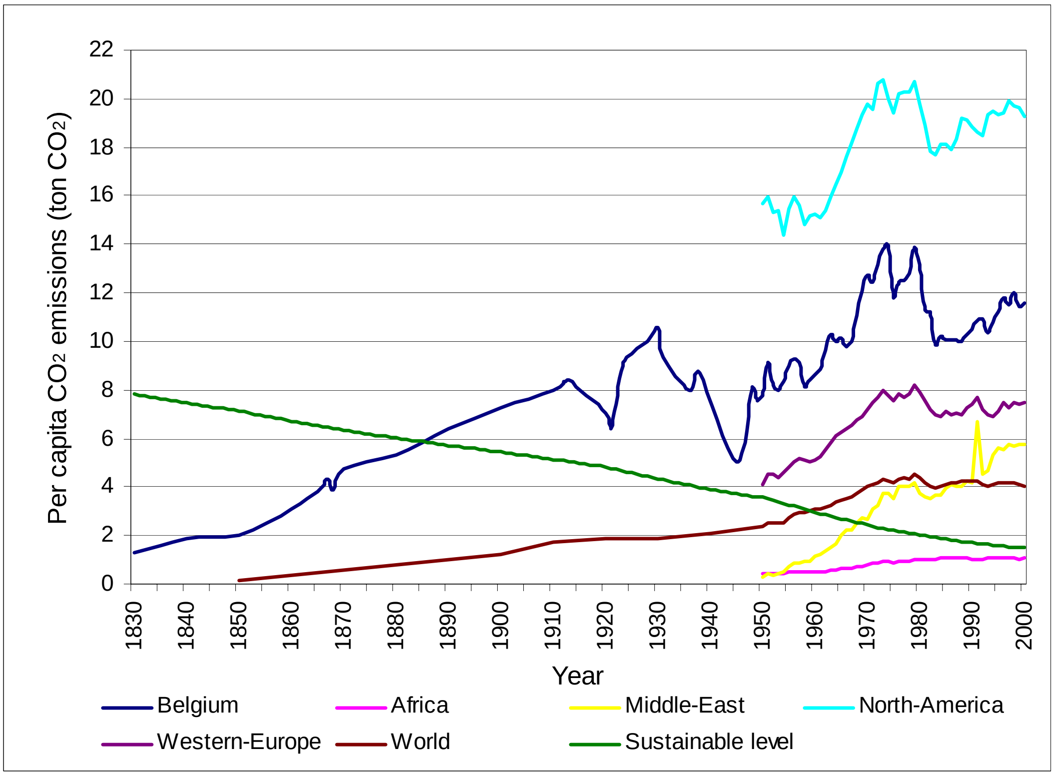
3.4.1.1. *Equitable rights to the absorption capacity of the atmosphere: Equal per capita emission rights?*

Agarwal and Narain (Agarwal & Narain, 1991) argue that since the atmosphere is a global resource, every citizen of planet Earth should have an equal entitlement to greenhouse gas emissions. As a fundamental principle of equity, developing countries should have the same per capita emission rights as the nations of the North. This egalitarian approach to equity has been claimed to be the only ethically justifiable method of allocating emission rights

(Agarwal & Narain, 1991; Grubb, 1995). It is, however, not without problems. There are a number of factors (Torvanger et al., 1996) in addition to population size that could be taken into account in order to allocate greenhouse gas emission rights on a national basis under a global limit. These include geographical as well as climatic conditions, and strength and energy intensity of the economy. It could also be argued that industrialised nations do not start from scratch, but have locked themselves into a fossil-based infrastructure.

Presumably at no time in the future will greenhouse gas emission rights ever be allocated strictly on an equal per capita basis. There will always be a political compromise. This will be acceptable to inter alia developing countries as long as the basic validity of the allocation rule is accepted. Equal per capita entitlements should be the moral guiding principle towards what could be called a solution of 'adjusted egalitarianism' (Ott & Sachs, 2000). In the further coarse of this work we will apply equal per capita emission rights as the standard against which to judge past emissions. The approach presented here could be adjusted to the 'adjusted egalitarianism' premise.

Figure 17 Per capita CO_2 emissions



3.4.1.2. A sustainable level of greenhouse gas emissions

The choice of a sustainable level of greenhouse gas emissions is not straightforward. It has already been discussed in the core research module (See §1.4.4.) in the context of the environmental space concept. It has been mentioned there that such a level is based on a selection of assumptions concerning the pressures nature can stand and estimations of what level of environmental pressures and risks a society is willing to accept.

The IPCC has estimated that a 60% global cut in greenhouse gas emissions below 1990 emission levels is necessary to stabilise the world's climate and to avoid the worst consequences of global warming (IPCC, 1995). This estimate of 60% reduction could be regarded as a “sustainable level” of worldwide greenhouse gas emissions; it is based on a ‘no regret policy’ and taking into consideration a considerable number of uncertainties. Emissions above that level can thus be regarded as contributing to the ecological damage of global climate change.

It may be clear that achieving sustainability will ideally be characterised by the fact that world per capita emissions get below the per capita sustainable level. Applying equal per capita emission rights which should not exceed the sustainable level implies that emission rights are based on a 60% reduction of 1990 emission levels, the 40% remaining being equally shared over all world citizens. Per capita CO_2 emission figures, presented in Figure 17 show historical and present inequalities between different regions and countries. The sustainable level is depicted in green; it decreases through time because of increasing world population; the intended 60% reduction in the year 1990 – the difference between the world average and the sustainable level – Is clearly visible.

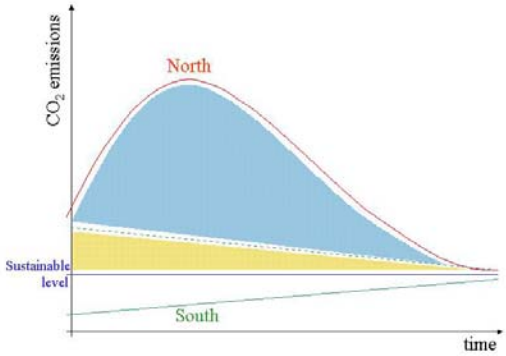
3.4.2. Operationalising the Carbon Debt concept: Historical and Generational Carbon Debt

In the core research (see §1.3.4.4.) it has been suggested that ecological debt may be seen as not only a matter between countries but also between generations. Two models were presented to illustrate the possibility of distinguishing between debt accumulated by one state towards another state and debt accumulated towards future generations.

We will briefly review this models and adopt them for the case of the carbon debt. In both models (see illustrations below), CO_2 emitters were divided in ‘the North’ (over-consumers of CO_2 absorption capacity) and ‘the South’ (under-consumers of CO_2 absorption capacity) and follow a path of contraction and convergence.

Model 1

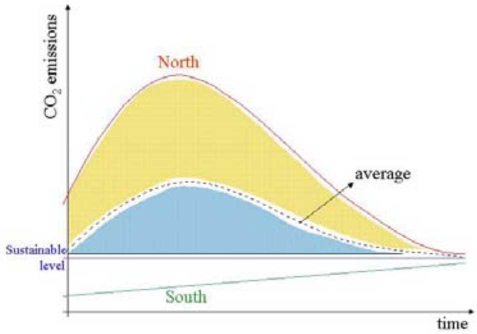
Here, it is argued that the North is in debt towards the South (intragenerational interstate debt; depicted in yellow) only in as much as the South is ‘underconsuming’ with respect to the sustainable level.



The rest of the Northern overconsumption (depicted in blue) is then regarded as debt towards future generations (intergenerational debt; indicated in blue).

Model 2

For the second model it is initially argued that over-*average*-consumers are in debt towards under-*average*-consumers (intragenerational interstate debt; depicted in yellow).



One could say that once this debt has been compensated for (supposing this is possible; see §3.4.3.1.: "The Historical Carbon Debt: a basis for allocating emission rights?") we are dealing with a notional average consumer ('this generation') who is over-consuming with respect to the sustainable level and thus could be regarded as being in debt towards future generations (intergenerational debt; indicated in blue).

Building on this, and in a next step towards operationalisation and quantification, we propose to split up the carbon debt into two different parts: the Historical Carbon Debt (HCD; the intragenerational interstate part of the carbon debt) and the Generational Carbon Debt (GCD; the intergenerational part of the carbon debt) which together make up the total Carbon Debt (CD). These concepts are worked out in detail for both models in the following paragraphs.

Where possible, analytic expressions will be given, presenting a way of calculating the HCD and GCD and thus the total CD of a country. These expressions will contain several parameters, such as the sustainable level discussed above and start and end years of accounting periods. These parameters are of course subject to discussion; they indeed leave open space for negotiation. It can be interpreted as a way of embodying uncertainty and relativity in these formulas. There is no such thing as an absolute level of sustainability, no absolute criterion for equity. As already indicated above, these will always be 'social constructs': uncertainties, differences in risk-perception and different viewpoints on equity can alter the results.

For Model 1 we will start from defining the total Carbon Debt, then indicating how it can be split up into a Historical and a Generational Carbon Debt; With Model 2, we will go the other way around, beginning with definitions for the HCD and GCD which taken together make up the total CD. It has to be noted that both models, apart from differing in the way they distinguish between the HCD and GCD, also differ slightly in the way the CD is interpreted. Also, definitions and expressions only apply for the model under which they are mentioned.

3.4.2.1. *Model 1*

The total Carbon Debt (CD)

Let us start with defining the total Carbon Debt for a country, i.e.

The ***Carbon Debt*** is the cumulative amount of CO_2 a country has emitted over time above the sustainable level.

In a more formal way, the carbon debt of a country *c*, CD_c, can be expressed as

$$CD_c = \sum_{i=\sigma}^{\varepsilon} \left[e_c(i) - \frac{Pop_c(i)}{Pop_w(i)} s_w(i) \right] \qquad (1)$$

where σ is the start year, ε the end year of accounting, $Pop_c(i)$ is country *c*'s population for year *i*, $Pop_w(i)$ is the world year *i* population, $e_c(i)$ is country *i*'s CO_2 emissions from year *i* and $s_w(i)$ is the world sustainable level for year *i*

The carbon debt can be positive or negative. Countries with a positive CD are debtors, those with a negative CD are creditors. Summing the CD_c over all countries gives the carbon debt of the world as a whole, CD_w, i.e.

$$\sum_c CD_c = \sum_{i=\sigma}^{\varepsilon} \left[\sum_c e_c(i) - \frac{\sum_c Pop_c(i)}{Pop_w(i)} s_w(i) \right]$$

which immediately gives

$$CD_w = \sum_{i=\sigma}^{\varepsilon} \left[e_w(i) - s_w(i) \right] \qquad (2)$$

The Historical Carbon Debt (HCD)

In this model, splitting the CD_c of a particular country in a HCD_c and a GCD_c is based on the $HCD_{debtors}/CD_{debtors}$ ratio of all debtor countries as a whole and the latter is determined as follows. Consider all carbon creditors, i.e. all countries which have a negative CD_c. According to model 1, these countries should be compensated for exactly the amount of carbon credit they total. Also according to model 1, this total amount of carbon credit equals the total amount of $HCD_{debtors}$ of all debtor countries together, i.e.

$$HCD_{debtors} = -\sum_{creditors} CD_{creditor}$$

In this way the $HCD_{debtors}/CD_{debtors}$ ratio is determined for all debtor countries as a whole. This ratio can than be used to determine the HCD_c for every individual debtor country; every debtor country thus having the same HCD_c/CD_c (=$HCD_{debtors}/CD_{debtors}$) ratio.

$$HCD_c = \frac{HCD_{debtors}}{CD_{debtors}} CD_c \qquad (3)$$

The Generational Carbon Debt (GCD)

The rest of a debtor country's CD_c is then regarded as carbon debt towards future generations, i.e. the GCD_c

$$GCD_c = CD_c - HCD_c$$

HCD_c being determined according to equation (3).

In this model, carbon creditors will have a negative HCD_c (credit) and no GCD_c; carbon debtors will have a positive HCD_c and a positive GCD_c adding up to a positive CD_c; the HCD_c/CD_c ratio of an individual country being determined by the $HCD_{debtors}/CD_{debtors}$ ratio of all debtor countries together. The sum of all HCD_c over all countries is of course equal to zero.

3.4.2.2. *Model 2*

The Historical Carbon Debt (HCD)

In this model, the HCD deals with over-emissions with respect to the world average per capita emissions. Following similar suggestions by Smith ('Natural Debt'; Smith, 1991, 1996) and Neumayer (2000) we define the concept of Historical Carbon Debt (HCD) as follows:

> The ***Historical Carbon Debt*** is the amount of CO_2 a country has emitted over time in excess of the world average per capita emissions which is still remaining in the atmosphere.

In a more formal way, the Historical Carbon Debt of a country *c*, HCD_c, can be expressed as:

$$HCD_c = \sum_{i=\sigma}^{\varepsilon} \left[r_c(i) - \frac{Pop_c(i)}{Pop_w(i)} . r_w(i) \right] \qquad (4)$$

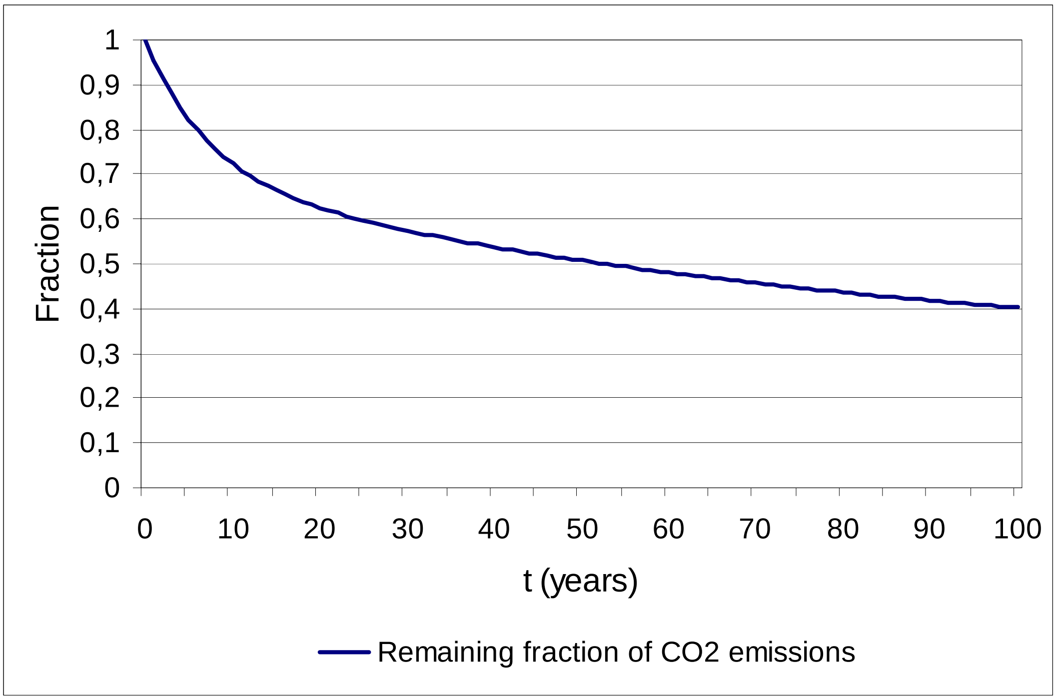
where σ is the start year, ε the end year of accounting, $Pop_c(i)$ is country *c*'s population for year *i*, $Pop_w(i)$ is the world year *i* population, $r_c(i)$ and $r_w(i)$ are country *i*'s and world CO_2 emissions from year *i*, which are still remaining in the atmosphere in the end year ε of accounting.

For this work we will use the Siegenthaler formula (Siegenthaler, 1983) to estimate the remaining CO_2, i.e. $CO_{2,remaining}$, in year t after the original CO_2 emissions, i.e. $CO_{2,original}$:

$$CO_{2,remaining} = CO_{2,original} .(0{,}3e^{(-t/7)} + 0{,}34e^{(-t/71)} + 0{,}36e^{(-t/815)}) \qquad (5)$$

This formula has to be regarded as a first estimate as it is an analytic expression substituting complex oceanic and biospheric model calculations of anthropogenic carbon uptake. Still, comparison with the widely used models (BERN Carbon Cycle Model HILDA used by IPCC (IPCC, 1994) and e.g. Joos et al., 1996) show that this formula gives reasonable results. Figure 18 shows the fraction of remaining CO_2 emissions as a function of time calculated according to the Siegenthaler formula. It shows that even after 100 years still 40% of the CO_2 emitted is remaining in the atmosphere.

Figure 18 Remaining fraction of CO_2 emissions according to the Siegenthaler Formula



The reason for taking the excess of CO_2 emissions remaining today instead of the total emitted from all past history for calculating the historical carbon debt is mainly the following. Consider the existent process between the emission of a greenhouse gas and the consequent effects such as temperature increase. The contribution of a gas to global warming is a result of earth's exposure to the gas, which in turn is a function of both the gas's atmospheric concentration and its residence time. This argues that responsibility of countries for the present situation is best indicated by the remaining total historical emissions, the HCD. From the standpoint of physical reality, this is a better measure of responsibility and thus for debt.

Also, in view of the definition which says that a country is in debt when it has emitted in excess of its per capita entitlements, it has to be considered that it is the remaining fraction of CO_2 in the atmosphere which is hampering other countries to take their equitable part, because the atmosphere is no longer considered as a free and unlimited resource for carbon uptake.

It should also be mentioned that the HCD can be positive or negative. Countries with a positive HCD are considered to be in debt with countries that have a negative HCD. Note that the sum of HCD over all countries is equal to zero.

The Generational Carbon Debt (GCD)

The Generational Carbon Debt concerns that part of over-emissions with respect to a sustainable level that does not fall under the historical carbon debt. It is defined as follows:

> The ***Generational Carbon Debt*** is the cumulative amount of CO_2 a country has emitted over time above the sustainable level, taking into account only that part of

CO_2 emissions that does not overshoot the world average per capita emissions (as that part is contained in the HCD).

In a more formal way, the Generational Carbon Debt of a country *c*, GCD_c, can be expressed as

$$GCD_c = \sum_{i=\sigma}^{\varepsilon} GCD_c(i) \qquad (6)$$

with:

$$GCD_c(i) = 0 \qquad \text{if} \qquad e_c(i) < \frac{Pop_c(i)}{Pop_w(i)} e_{sust}(i) \text{ or } e_w(i) < e_{sust}(i)$$

$$GCD_c(i) = e_c(i) - \frac{Pop_c(i)}{Pop_w(i)} e_{sust}(i) \qquad \text{if} \qquad \frac{Pop_c(i)}{Pop_w(i)} e_{sust}(i) \le e_c(i) < \frac{Pop_c(i)}{Pop_w(i)} e_w(i)$$

$$GCD_c(i) = \frac{Pop_c(i)}{Pop_w(i)} \left(e_w(i) - e_{sust}(i) \right) \qquad \text{if} \qquad \frac{Pop_c(i)}{Pop_w(i)} e_w(i) \le e_c(i)$$

where σ is the start year, ε is the end year of accounting, $Pop_c(i)$ is country *c*'s population for year *i*, $Pop_w(i)$ is the world year *i* population, $e_c(i)$ and $e_w(i)$ are country *i*'s and world CO_2 emissions from year *i*, and $e_{sust}(i)$ is the sustainable level for year *i*.

The reason why, contrary to the HCD, the cumulative amount of actual excess emissions are taken into account is because it is of course supposed that the sustainable level intrinsically takes into account the causal process of CO_2 emissions leading to atmospheric concentrations resulting in impact. Note that in this model, no GCD can be incurred as long as the world average emissions do not exceed the sustainable level.

The total Carbon Debt (CD)

The total Carbon Debt of a country, CD_c, is of course determined by the sum of the HCD and GCD, i.e.

$$CD_c = HCD_c + GCD_c$$

Note once again that the CD calculated according model 2 will differ in magnitude from the CD of model 1; the difference due to the fact that the HCD of model 2 is determined by the excess of CO_2 emissions remaining today whereas both the HCD and GCD of model 1 are based on the total excess emissions from all past history.

3.4.2.3. *Historical accountability*

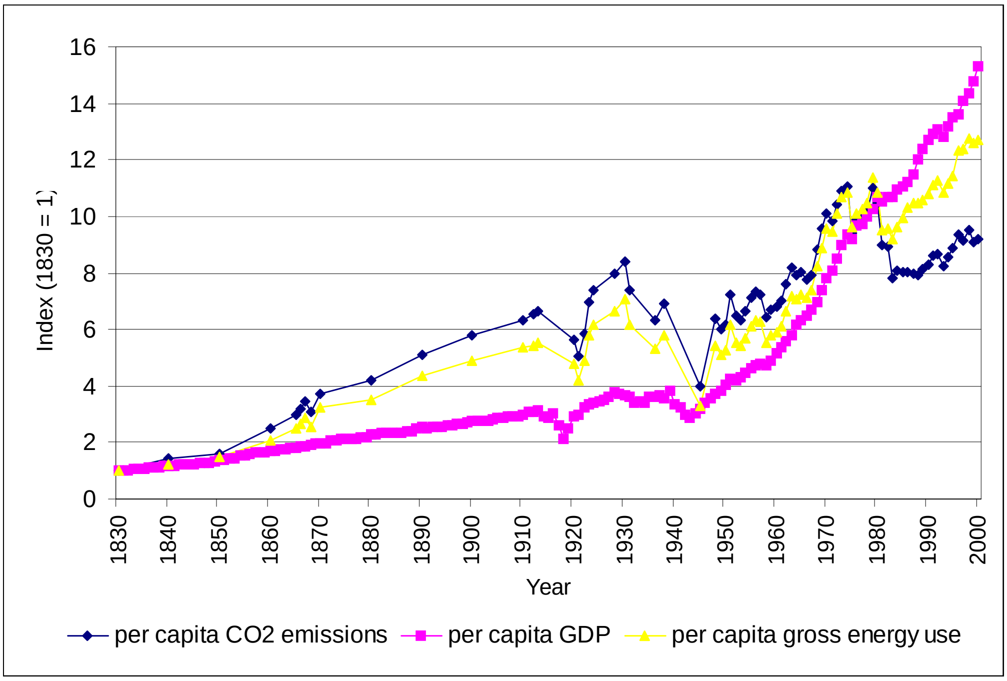
The words 'over time' in the general ecological debt definition already explicitly refer to the principle of historical accountability. In this paragraph we want to discuss some specific arguments in defence of historical accountability in the climate change issue. It will certainly be a crucial point in the upcoming negotiations for the second commitment period of the Kyoto Protocol, which should start no later than 2005. Neumayer (Neumayer, 2000) explicitly mentions three reasons in favour of historical accountability in the climate debate: to not ignore the physical laws that give rise to the environmental problem of global warming, to not give a retrospective licence to past emitters and, to not privilege those who lived in the past with the opportunity to benefit from emissions.

First of all, it is indeed undisputed that global warming is a consequence of the increased concentration of greenhouse gases in the atmosphere, which is a function of emissions that accumulated over time. The United Nations Framework Convention on Climate Change explicitly acknowledges the fact that emissions, once produced, have a long lifetime (over hundred years for CO_2; see Figure 18) and a long-time effect resulting in additional warming of the Earth's surface and atmosphere which may adversely affect natural ecosystems and humankind.

Secondly, historical accountability is buttressed by the polluter-pays principle which has been embraced by the OECD countries in 1974 (OECD, 1974). Those who caused the environmental damage in the first instance have to compensate for it.

Third, historical accountability is supported by the principle of equality of opportunity. The natural absorptive capacity of the planet earth that allows for the decay of a certain amount of greenhouse gas emissions belongs to nobody and should therefore be assigned to everybody in an equitable way in order to give everybody the opportunity to benefit from emissions. To account for historical emissions ensures equality of opportunity to use the global resource atmosphere, no matter where or when he or she happens to live.

Figure 19 Per capita GDP, gross energy consumption and fossil CO_2 emissions



Additionally, it could be argued that the carbon debt is built by borrowing assimilative capacity of the atmosphere from other countries and future generations, the latter through the release of greenhouse gases faster than they can be naturally removed. Just as with a national (financial) debt, borrowing on the carbon debt has allowed nations to build up their infrastructure and economic wealth faster than would have occurred otherwise. This is confirmed by the observation of a significant relationship between GDP for a country and its relative contribution to the carbon dioxide concentration rise by fossil fuel combustion (See e.g. (Janssen et al., 1992) and (Tucker et al., 1995)). Figure 19 shows how gross energy consumption, CO_2 emissions from fossil fuel combustion and GDP have evolved for Belgium.

This also refutes the common objection against historical accountability, i.e. that present generations must not be held responsible for something that was caused not by themselves but by individuals who are long since dead. Current developed countries readily accept the benefits form past emissions in the form of their high standard of living and should therefore not be exempted from being held accountable for the detrimental side-effects with which their living standards were achieved. Historical accountability is not about blame or collective moral guilt, not even about awareness of harm caused, but about assigning an equal share of the beneficent existence of the absorptive capacity of nature to every individual, independent of his or her place in either space or time.

It should certainly be added that the Principle of Common but Differentiated Responsibilities, explicitly mentioned in the UN Convention on Climate Change, strongly buttresses historical accountability (See also §2.1.1.2. of the modular research on MEA for more details). It was already incorporated into the 1987 Montreal Protocol and it underlies the dual standard of commitments for developed and developing countries established by the Climate Convention. It is widely recognized that all states contribute to climate change and that all states may, to different degrees, suffer from it. But the industrialized states developed their economies over the past 150 years in part by treating the atmosphere as a free and unlimited resource, and they continue to generate the greatest quantity of greenhouse gases. Developing countries are now attempting to industrialize at a time when the atmosphere is no longer considered as free and unlimited. In addition, they still make a smaller contribution to climate change (although it will increase in the decades to come). Therefore, developed countries should take the lead in combating climate change. The concept of the HCD, as proposed here, could be regarded as an operationalisation of this principle: the HCD should then be interpreted as a basis for attributing responsibility in combating climate change. In the next paragraph it will be shown how the HCD could be used as a basis to allocate emission rights.

3.4.3. The Carbon Debt: elements for implementation

Regarding the HCD, which is conceived as an intragenerational interstate debt, we will present elements on how the compensation of this debt could be embodied in an emission rights allocation system. The basic idea behind this settlement is that countries which have in the past emitted in excess of an equal per capita allocation should have less than their equal per capita allocation of emission rights in the future, and vice versa for countries which have in the past emitted less than their equal per capita allocation. This way of debt compensation seems more realistic than aiming at financial compensation as the latter requires the financial valuation of ecosystems services[8]. Moreover, such an emission rights allocation system might encourage all countries to take part, as e.g. developing countries which have been under average CO_2 emitters will be entitled to increase their CO_2 emissions. Besides, we are

[8] Although this can indirectly take place via the buying of emission entitlements from countries which are HCD creditors.

convinced that climate change related issues, to be effective and efficient, should be treated within the existing United Nations Framework.

A rather general rule for allocating greenhouse gas emission rights will be proposed based on historical accountability and working with the HCD concept proposed here[9]. It is in the same spirit of the well-known Brazilian Proposal (BP, 1997) which aims at a reduction towards an overall emission ceiling for all UNFCCC Annex I Parties (developed countries) to be shared among individual Annex I Parties proportional to their relative share of responsibility for climate change; the latter being based on the impact of a country's historical CO_2 emissions on the world average temperature.

As the GCD is conceived as an intergenerational debt, it could be the basis for the creation of a fund aimed at assisting people in the future to overcome the real impacts of climate change. This will be briefly discussed in §2.4.3.2.

3.4.3.1. *The Historical Carbon Debt: a basis for allocating emission rights?*

As already mentioned above, discussing the notion of historical accountability, the HCD concept may open the possibility to implement 'the principle of common but differentiated responsibilities'. Countries which have in the past emitted in excess of an equal per capita allocation are considered to be in debt and vice versa for countries which have in the past emitted less than their equal per capita allocation. Countries with a positive HCD are considered as debtors, and those with a negative HCD are considered creditors.

Then, supposed an agreement on the HCD accounting period (i.e. parameters *s* and *e* in formulas (1) (model 1) and (4) (model 2)) is reached, how could the compensation of the HCD be applied to allocate future emission entitlements? First of all, the time period over which the compensation should take place has to be decided. Assume for simplicity that countries agreed on N, the number of years during which compensation takes place, and that compensation takes place according to the following rule:

$$C_c = HCD_c / N \qquad (4)$$

Then, the rule which allocates emission rights below an overall emission ceiling on an equal per capita basis with historical accountability can formally be defined as follows:

$$x_c^t = \frac{Pop_c^b}{Pop_w^b}.w^t - C_c \qquad (5)$$

where x_c^t are a country *c*'s emission entitlements and w^t world target emissions for each target year *t*; Pop_c^b is country *c*'s base year population and Pop_w^b is base year world population[10]. Countries with a positive HCD_c will thus have less than their equal per capita allocation of world target emission rights in the future and vice versa for countries with a negative HCD_c.

[9] Partly based on Neumayer, 2000

[10] Instead of base year population figures future projected populations could be used as reference points, the formula only needing slight modifications.

3.4.3.2. *Compensating the Generational Carbon Debt: assisting future generations to cope with the impacts of climate change*

As mentioned, one could think of a fund, fed by the 'repayment' of the GCD, aimed at assisting future generations to cope with the real impacts of climate change. These funds should be attributed to those people who are effectively confronted with the impacts of climate change. In this respect it might be noteworthy to add that the impacts of climate change will fall disproportionately upon developing countries (IPCC, 2001), which are less responsible for the problem. Moreover, they will, by and large, be less equipped to deal with its results, and more vulnerable to disruption of their ability to meet the basic needs of their people.

Establishing such a fund will again raise the difficult question of putting a price on CO_2, already discussed in the core research module (See §1.4.6.). Different estimates were presented for different market segments of the carbon market, ranging from $4.88 (end of 2003) to $5.52 (mid-2004) in the CDM/JI segment, to between 6 € per ton CO_2 equivalent (tCO_2e) and 12 €/tCO_2e under the European Trading Scheme (ETS). A much higher price is mentioned by Alier et al. (Alier et al., 2002) who refers to the amount proposed by the European Commission for whose emissions surpass their entitlements. This fine is 100 € per ton of CO_2 equivalent. The Brazilian Proposal (BP, 1997) contains a penalty mechanism for non-compliance on the basis of 10 US$ per ton carbon, i.e. 2.73 US$ per ton CO_2.

3.4.4. The Carbon Debt: figures and international comparison

The formulas and expressions given above allow to calculate any country's carbon debt (or credit) according to both model 1 and 2 given its historic emission profile. For the moment resulting extra emission reductions (C_c via the HCD) and fund payments (GCD) for different scenario's can only be calculated for model 2; the determination of HCD/CD for model 1 requires the calculation of the HCD_c for all world countries which is an enormous and difficult task out of the limited scope of this project. Based on the figures presented in §2.2. we will calculate the Belgian carbon debt for the 1900-2003 period and make an international comparison for the 1950-2000 period making use of CO_2 emission data provided by CDIAC, the Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory (CDIAC, 2004) .

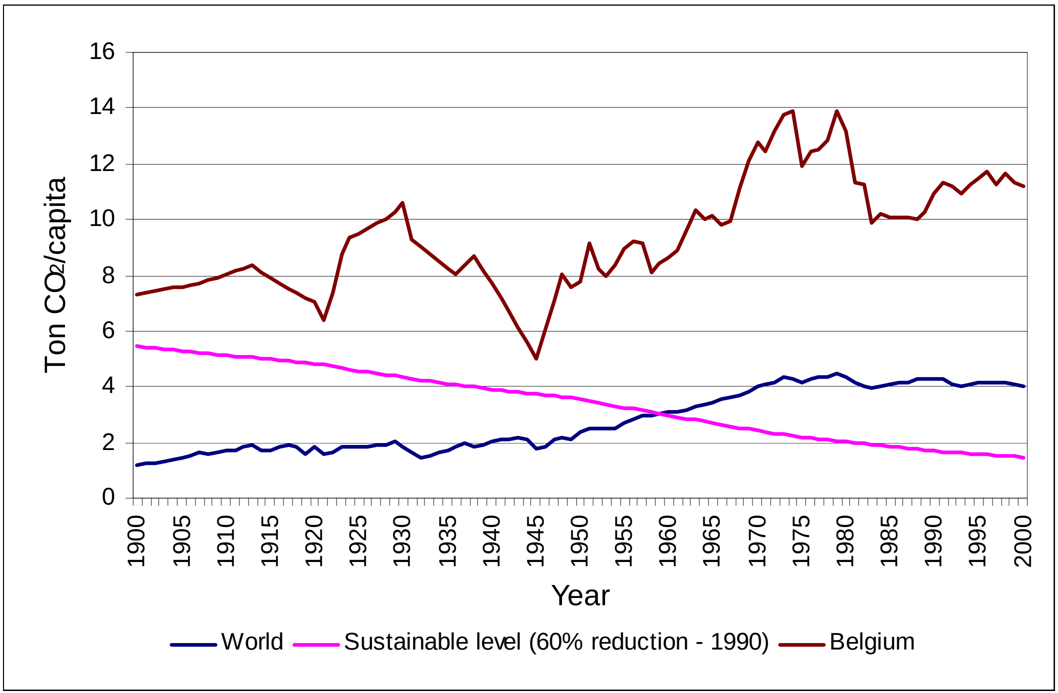
3.4.4.1. *The Belgian Carbon Debt*

For practical reasons, the start year of accounting was set at 1900 because of lack of data points concerning world average emission data and world population data for the pre-1900 period. An estimate made clear that a maximum difference of 15 % results from omitting the pre-1900 period. 2003 was taken as end year. For the calculations the sustainable level was set at a 60% reduction of the world 1990 emission level (see Figure 20).

The calculation according to model 1 results in a Belgian CD(1900-2003) of 5787 million tons of CO_2.

Model 2 gives a Belgian HCD(1900-2003) of 3389 million tons of CO_2, a GCD(1900-2003) of 845 million tons of CO_2. This gives a total CD(1900-2003) of 4234 million tons of CO_2.

Figure 20 Comparison of world and Belgian CO_2 emissions and the sustainable level adopted



Still according to model 2, equations (4) and (5) teaches us that if the HCD(1900-2003) was to be compensated in e.g. the 2004-2050 period, this would imply an annual extra emission reduction (apart from the emission reductions needed to maintain emission levels under the world target emissions w^t) of 73 million ton CO_2 (about 7.2 ton /capita in 2004).

3.4.4.2. International comparison

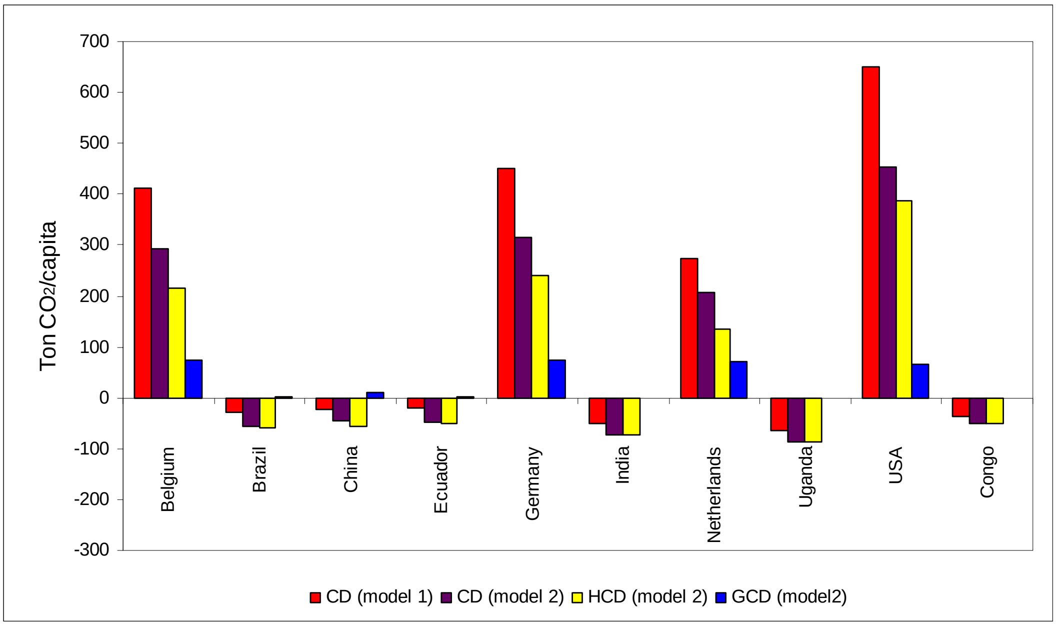
Based on historic National CO_2 Emission data from fossil fuel burning provided by CDIAC (CDIAC, 2004) the CD according to model 1 and 2 and the HCD and GCD according to model 2 have been calculated for a selected set of countries for the 1950-2000 period (so not 1900-2000 as in the previous paragraph). The results are listed below in Table 4.

Table 4 The carbon debt: international comparison

1950-2000	Model 1 CD (10^6 ton)	Model 2 CD (10^6 ton)	Model 2 HCD (10^6 ton)	Model 2 GCD (10^6 ton)
Belgium	4231	2993	2222	771
Brazil	-4941	-9648	-9886	238
China	-30105	-57776	-69667	11890
Ecuador	-271	-605	-636	30
Germany	37010	25918	19763	6154
India	-50530	-72313	-72313	0
Netherlands	4320	3278	2155	1123
Uganda	-1318	-1809	-1809	0
USA	183942	128471	109766	18705
Congo	-2688	-3777	-3777	0

A per capita comparison is given in Figure 21 where respectively the country's per capita CD (model 1), CD (model 2), HCD (model 2) and GCD (model 2) are depicted.

Figure 21 Per capita carbon debt for selected countries 1950-2000



3.4.4.3. *Monetary valuation*

As already discussed in §1.4.5. of the core research monetary quantification in general and monetary valuation of CO_2 emissions in particular (see §2.4.3.2.) is not straightforward. Taking all estimates based on market prices, proposed non-compliance penalty mechanisms etcetera into consideration, it seems reasonable to suggest a value ranging from 1€ up to 100€ per ton CO_2 emitted.

Monetary estimates for the carbon debt can thus easily be deduced from the data presented above. According to model 1, the Belgian carbon debt for 1900-2000 amounts to a figure between 5,8 and 579 billion €; according to model 2, the figure is somewhere between 4,2 and 423 billion € .

Taking by way of example a very reasonable price of 10 € per ton CO_2, yields a Belgian carbon debt of 58 billion € (model 1) or 12 billion € for the period 1900-2000.

When using figures for 1950-2000 (see table 4) and using the same 10 € per ton CO_2, it becomes possible to calculate debts and credits for other countries. Depending on the model, the credit to e.g. India amounts to 505 or 723 billion €, the credit for Congo to 27 or 38 billion €.

3.5. Conclusions

In this modular research, the concept of ecological debt has been elaborated on a conceptual as well as a methodological level for the issue of the Belgian energy system with special attention to the use of fossil fuels and the resulting CO_2 emissions.

In a first step, a detailed picture has been drawn of the Belgian energy supply throughout the 1830-2000 period. Figures on annual amounts of coal, oil and gas imported, exported and consumed and on the resulting CO_2 emissions were compiled and internationally compared. Also, the geographical origin of all fossil fuels imported was retrieved. Based on these data, the evolution of the Belgian energy system has been interpreted in terms of social, economic, cultural and technological factors.

A first important conclusion that arises from this historical picture is that in 170 years time, the Belgian gross energy consumption has exponentially increased from 1,7 million TOE up to 58,3 million TOE. A per capita approach shows an increase by a factor 12 in the same period, from 0,5 TOE in 1830 to 5,7 TOE in 2000, the latter being almost four times the world average per capita consumption in 2000. Contrasted with figures on proven fossil fuel reserves, our findings show that if the current Belgian level of fossil energy consumption was adopted worldwide, this would lead to the depletion of these stocks in 40 years time.

It has also been made clear that during its 170 years of existence, Belgium has evolved from being 100% self-supporting in its energy needs, mainly by coal, to being almost 100% dependent on imports of energetic resources, mainly fossil fuels complemented with nuclear fuel. In this way, Belgium has exported all social and environmental pressure associated with the extraction process of coal to countries as Russia, Algeria and South-Africa, from where it imports significant amounts of respectively oil, natural gas and coal.

Regarding the CO_2 emissions due to fossil fuel combustion our calculations show that Belgium's CO_2 emission level has increased from 5 million tons of CO_2 in 1830 up to 115 million tons in 2000 reaching a maximum of 137 million tons in 1979. On a per capita basis this shows that since 1900 Belgium has constantly emitted two to three times the world average amount and from 1975 on its CO_2 emissions have exceeded by a factor five the sustainable level suggested by the IPCC for all greenhouse gasses together,.

Finally, it has to be mentioned that in this quantitative picture renewable energy sources do not play a significant role at all. Finite fossil fuels have remained the main energy source, depleting them at the expense of others and future generations. Nuclear fuel is the only non-fossil energy resource used is significant amounts, but nuclear energy generation, although it may seem advantageous on a short term in the climate change issue, comes with a potentially disastrous impact on future generations and can therefore hardly be viewed as a valuable alternative.

In accumulating wealth, countries cause ecological damage elsewhere and increasingly put pressure on ecosystems and ecosystems services at the expense of the equitable rights of others. These two processes, which we believe make up the core of the ecological debt concept are clearly present in the quantitative picture this research project has drawn from the Belgian energy system. Belgium has built part of its wealth, which is based on a high level of energy consumption, by appropriating ecological carrying capacity belonging to other countries and future generations and has thus incurred an ecological debt with them.

By switching to imported energy carriers, Belgium has accumulated ecological debt by passing the ecological damage from the extraction process onto other countries. Belgium's high level of fossil energy consumption contributes to the depletion of this finite resource and this happens at the expense of the equitable rights to these resources not only of other countries but also of future generations by depriving them of the possibility to benefit from the use of these resources.

The combustion of fossil fuels results in significant amounts of CO_2 emissions which in turn cause climate change and thus ecological damage. But there is more. As the build-up of CO_2 in the atmosphere leads to climate change, the CO_2 absorption capacity of the atmosphere has to be viewed as a finite 'resource' which has to be divided in an equitable way. Also in this respect, Belgium has accumulated ecological debt by overusing this ecosystem service.

Both aspects of ecological debt due to CO_2 emissions, causing ecological debt and overusing the absorption capacity of the atmosphere, make up the so-called 'carbon debt'. Important choices are involved regarding the point at which carbon debt begins to build up and imply the evaluation of emission levels against normative standards. What is a sustainable level of greenhouse gas emissions and what is meant with 'equitable rights to the absorption capacity of the atmosphere'. What a society perceives as sustainable and equitable will always be a 'social construct', subject to scientific uncertainties, differences in risk-perception and different viewpoints on equity. In this research, two simple models have been used to split up the total carbon debt in an intragenerational interstate debt, the 'historical carbon debt', and an intergenerational debt towards future generations, the 'generational carbon debt'. Also, this splitting up is not straightforward and is subject to discussion and interpretation; other models are conceivable.

Analytic expressions are given for both models, presenting a way of calculating the historical and generational carbon debt and thus the total carbon debt of a country, given its historic emission profile. The Belgian total carbon debt, accounted over the period 1900-2003, amounts to 4234 million tons of CO_2 according to one model, 5787 million tons according to the other, to be compared to a total CO_2 emission of 115 million ton CO_2 in 2001. Valuated at a reasonable 10 € per ton CO_2 this gives a total carbon debt between 42 and 58 billion € for 1900-2000. Adopting the same calculation method, but using the period 1950-2000, results in a carbon credit of between 505 and 726 billion € for India and between 27 and 38 billion € for Congo.

A preliminary proposal on how these concepts could be brought into practice has been elaborated including an emission rights system which embodies compensation for the historical carbon debt. In this proposal, 'debtors' compensate 'creditors' by realising extra emission reductions giving creditors extra emission rights. Such an emission rights system might encourage developing countries to accept binding emission targets as it takes into account the historical accountability of a country in causing climate change. Industrialised countries, which have been the main contributors to climate change so far, would take the lead in combating climate change, whereas most developing countries, which have not exceeded the sustainable level in the past, would temporarily get the opportunity to foresee in their necessary development with fossil fuels.

This investigation of the Belgian energy system has clearly illustrated that ecological debt is a strong concept revealing in a convincing way a problematic characteristic of the process of wealth creation in industrialised countries. Through their consumption and production patterns, they have appropriated ecological carrying capacity that belongs to others and future generations. Moreover, the concept of ecological debt readily shows two spheres of action: the compensation of ecological debt historically accumulated and avoiding the build-up of ecological debt in the future.

Regarding compensation of the carbon debt, Belgium could recognise that it has an important historical responsibility in causing climate change. In a more explicit way, Belgium could adopt a constructive attitude in those cases, where representatives of southern countries and/or civil society organisations bring the concept of historical accountability into the debate during the climate negotiations and support proposals which, as our preliminary proposal does, divide future emission rights based on historical accountability. To avoid future build-up of carbon debt, the sustainability of the Belgian energy system as a whole has to questioned. Apart from working towards a more sustainable energy supply by developing renewable energies, the scope has to be broadened paying more attention to demand side management. We need to rethink how the needs of people can be fulfilled in a less energy-intensive way. This of course implies a mental and behavioural change: it is imperative that the idea that availability of cheap energy is a fulfilment of a modern human need is abandoned. People do for instance not need cheap petrol; what they do need is mobility. The question then comes down to providing mobility in a sustainable way. This way of thinking, however, has not yet received due attention.

References

Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm

Mineco 1, 2004: http://ecodata.mineco.fgov.be/

Statistisch Jaarboek, 2004: Statistisch Jaarboek 1830-2004

Mineco 2, 2004: Jaarlijkse uitgave 'De economie in België in 19..' van het Ministerie van Economische zaken 1951-1985

Petrolfed, 2004: Jaarverslagen Belgische Petroleum Federatie (BPF) 1980-2004

Jaarboeken buitenlandse handel van de BLEU, 2004: Jaarboeken buitenlandse handel van de Belgisch-Luxemburgse Economische Unie 1953-1973

FIGAS, 2004, Jaarverslagen Belgisch Verbond der Gasnijverheid (FIGAS) 1960-2004

Paredis et al., 2003, 'Elaboration of the Concept of Ecological Debt' Interim Report December 2003

Podobnik, 2002, "Global Energy Inequalities: Exploring the Long-Term Implications," *Journal of World-Systems Research*, vol 8(2), pp. 252-274.

Fraunhofer, 2003, Beheer van de energievraag in het raam van de door België te leveren inspanningen om de uitstoot van broeikasgassen te verminderen, Karlsruhe, Fraunhofer, 2003

Belgium's Greenhouse Gas Inventory: National Inventory Report submitted under the United Nations Framework Convention on Climate Change: http://www.environment.fgov.be/Root/tasks/atmosphere/klim/pub/natcom/main_nl.htm

IPCC, 2001, Intergovernmental Panel on Climate Change, Third Assessment Report

Agarwal, A., Narain, S., 1991. Global Warming in an Unequal World. Centre for Science and Environment, New Delhi.

Grubb, M., 1995. Seeking fair weather: ethics and the international debate on climate change. Int. Affairs 71, 463-496.

Torvanger, A. et al., 1996. Exploring Distribution of Commitments – A follow-up to the Berlin Mandate; CICERO Report No. 3.

Ott, H. E., Sachs, W., 2000. Ethical Aspects of Emissions Trading; Wuppertal Papers Nr. 110

IPCC, 1995. Intergovernmental Panel on Climate Change, Second Assessment Report

Paredis, E., Goeminne, G., 2003. Elaboration of the Concept of Ecological Debt. Interim Report October 2003

Smith, K. R., 1991. Allocating responsibility for global warming: the natural debt index. Ambio 20(2), 95-96.

Smith, K. R., 1996. The Natural Debt: North and South. In: Giambelluca, T. W., Henderson-Sellers, A. (Eds.), Climate Change: Developing Southern Hemisphere Perspectives. John Wiley & Sons, Chicester, 423-448

Neumayer, E., 2000. In defence of historical accountability for greenhouse gas emissions. Ecological Economics 33 (2000) 185-192

IPCC, 1994. Radiative forcing of climate change. In: Climate Change, 1994. Cambridge University Press.

Joos F., et al., 1996. An efficient and accurate representation of complex oceanic and biospheric models of anthropogenic carbon uptake. Tellus (1996) 48B, 397-417

OECD, 1974, Recommendation on the Implementation of the Polluter-Pays Principle, C(74)223. OECD, Paris.

Janssen, M. A., et al., 1992. Allocating CO_2-emissions by using equity rules and optimization. RIVM, Report no. 222901012. Dutch National Institute for Public Health and the Environment, Bilthoven.

Tucker, M., 1995. Carbon dioxide emissions and global GDP. Ecological Economics 15 (1995) 215-223

BP, 1997. The Brazilian Proposal. FCCC/AGBM/1997/MISC.1/Add.3

Alier, J. M., et al., 2002. Ecological Debt, Who owes Who ? l'Observatori del Deute en la Globalització, Universitat Politècnica de Catalunya

CDIAC, 2004. http://cdiac.esd.ornl.gov/home.html