"Balance of energy and greenhouse gas emissions throughout the life cycle of natural gas and heating oil as fuel for domestic heating"

Synopsis

I.1. OBJECTIVE OF THE STUDY

The objective is to provide an answer to the following question: "*What are the emissions of greenhouses gases (GHGs) and the consumption of non-renewable energy resources relative to the use of a domestic gas*[1] *or heating oil boiler purchased in 2005, with a life of 20 years?*"
More generally the question is: "*Should preference be given to gas boilers to reduce the risk of climatic change caused by the greenhouse effect and to reduce consumption of energy resources?*"
The purpose of this report is therefore to answer these questions by establishing the balance of energy and GHG emissions throughout the life cycle of the two main sources of domestic heating energy, namely heating oil and natural gas.
To guarantee the impartiality and reliability of the study and its conclusions, a Critical Review Committee, composed of five professors, re-read the report, commented on it and suggested improvements, which were taken into account in drafting the final version of the report, published in June 2004.

Author's note: The changes made to the study in this version have not been subjected to critical review.

The main changes involve:

- Gas and heating oil boiler efficiency.
- Marginal mix hypotheses for natural gas.

[1] In this report, the expressions "gas heating boilers" and "gas" are used to refer to "natural gas heating boilers" and "natural gas".

I.2. SCOPE OF THE STUDY

In this study we shall consider:

- **Two types of fuel** as domestic heating energy:
  - Heating oil (with a sulphur level of < 50 ppm)
  - Natural gas (including that imported in the form of LNG)
- Three types of **domestic gas boilers** (nominal heat input ≤ 70 kW):
  - Traditional boiler (HE+): useful efficiency of between 81.9 % and 88.6 %
  - Low-temp. boiler (HE+): useful efficiency of between 86.7 % and 88.9 %
  - Condensing boiler (HE TOP): useful efficiency of between 94.5 % and 106.9 %
- Two types of **domestic heating oil boilers** (nominal heat input ≤ 70 kW):
  - Traditional boiler: useful efficiency of between 81.9 % and 91.9 %
  - OPTIMAZ boiler: useful efficiency of between 86.7 % and 93.2 %

The environmental impacts created by the exploration of new deposits, and by the manufacture and elimination of production or transport equipment are seen as negligible and were consequently not taken into account.

I.3. METHODOLOGY

I.3.1. General methodology

The methodology used enables us to estimate emissions throughout the cycle of the fuel: from extraction to combustion in the boiler. This methodology, known as “Life Cycle Assessment” (LCA), is governed by international standards: ISO 14040-14043, which describes the various stages of an LCA:

- Purpose and scope of study (ISO 14040)
- Inventory calculation and analysis (ISO 14041)
- Impact assessment (ISO 14042)
- Interpretation of results (ISO 14043)

In the strict sense of the definition given in ISO 14040, this study does not involve an LCA since not all the impact categories were studied. Nevertheless, the notion of life cycle and the methodological principles of an LCA have been applied.

I.3.2. Detailed presentation of the results on the greenhouse effect

The IPCC[2] gives an equivalence factor with CO_2 emission (Global Warming Potential) for greenhouse gases (GHGs). Using these factors allows us to calculate the contribution of these gases to the greenhouse effect expressed in g-equivalent CO_2 over 20, 100 or 500 years. The Kyoto Protocol defined its goals by considering the consequences of GHG emissions over a period of 100 years.
These data aggregated over 100 years give a mean impact over the entire period without taking account of the differences between short-, medium- and long-term effects.
Because of the major importance of methane emissions in this study, it is useful to present the results over the next 100 years not merely with a mean but year by year. In this way the results are much more extensive.

I.3.3. Taking account of the marginal energy mix

According to numerous observers, including the European Commission, if gas is to be favoured, the surplus energy consumption at European level will be met by an increase in imports of natural gas from Russia and the Caspian Sea region, and by an increase in imports of LNG[3]. As regards heating oil, the future sources of supply are the Middle East and Russia[4]. The reduction in consumption will involve the above sources. This reduction will also involve a change in the proportions of the various fractions produced during refining. Modelling has been carried out for the implications of this change in the refining process.

We have therefore considered as the energy mix hypothesis that:

- the surplus consumption of gas will be provided for by natural gas at a rate of 75 % and by LNG at a rate of 25 % via the following sources of supply:
  - Natural gas (NG): 75 % from Russia and 25 % from the Caspian Sea region
  - Liquefied natural gas (LNG): 50 % from Algeria and 50 % from the Middle East
- For heating oil: 50 % from the Middle East and 50 % from Russia.

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2 "Climate Change 2001: The Scientific basis"
3 LNG will retain its strategic importance in facing up to peak demand and assuring security of supply.
4 In contrast to natural gas, the variability of impacts according to supply sources is very limited given that the "extraction + transport" stages only represent 4% of the total impacts.

I.3.4. Allocation method for refining

We have taken into account the “marginal production” emissions of heating oil, i.e., the evolution (delta) of a refinery's emissions in the event of a decrease in the consumption of heating oil and the consequent abandonment of the more energy-greedy production systems put in place to satisfy the high demand for heating oil and diesel.

I.3.5. Identification of key processes

Based on data found in the literature and the GEMIS 4.1, ETH and BUWAL databases, we were able to identify those processes that have the greatest impact on the results for the two systems studied (the contribution of the processes of each system to the increase in global warming over 100 years is presented in the graphs below).
We then refined the most sensitive data for the key processes directly with the petroleum companies (TOTAL, BP, ESSO, etc.) or the authors of the most relevant publications.

I.4. KEY DATA AND HYPOTHESES

The calculation functionalities of the RangeLCA software allowed us to identify the key parameters that most influence the results:

- Important parameters with low uncertainty:
  - Self-consumption during the transport of Russian gas (over 7,000 km): 21 %
  - Self-consumption during the liquefaction and transport of LNG: 17 %
  - Emissions for the marginal production of heating oil: almost double the emissions of the Antwerp refinery if we consider current heating oil production.
  - Difference in CO_2 emissions for the combustion of 1 kWh of natural gas and heating oil: gas emits 21 % less CO_2 than heating oil
- Important parameters with high uncertainty:
  - Losses of gas (methane) during extraction and on the Russian transport network.
    In this study, we took account of this uncertainty by taking as a value for emissions of methane during the transport of Russian gas a variable between 1 and 3.6 % of the quantity delivered. This variable takes the form of a normal log type with a mean of 2 %[5]. This mean value of 2 % corresponds to the most likely estimation made on the basis of direct measurements of methane in the atmosphere, the method we felt was the most reliable given the lack of data for the production of a mass balance.

[5] For a transport distance of 7,000 km.

- Losses of gas (methane) during the extraction of Algerian gas.
  For losses of methane during the extraction of Algerian gas, there are no reliable estimations based on in-situ measurement programmes. Given the potential for improvement over the next few years, we retained the low hypothesis (0.8 % of gas extracted) while other sources estimate losses of up to 6 % of gas extracted.
- Boiler efficiency
  With regard to boiler efficiency, we have applied a corrective factor to the theoretical useful efficiencies so as to take account of the oversizing phenomenon observed for households (this corrective factor has the same effect for gas and heating oil). Taking into account market share and the variation in theoretical useful efficiency (according to conditions of use and the corrective factor due to oversizing), the following mean useful efficiencies are obtained:
  - *Gas boilers: 76.83 %*
  - *Heating oil boilers: 76.70 %*

I.5. RESULTS

I.5.1. Contribution of life cycle stages to the greenhouse effect

The figures below present the contribution of the life cycle stages of natural gas and heating oil to the greenhouse effect over 100 years. We can see that over the entire life cycle of the two fuels, GHG emissions upstream from the boiler are relatively higher for gas (30.8 %) than for heating oil (14.3 %).

Figure 1: Contribution of the processes of the “natural gas system” to the greenhouse effect

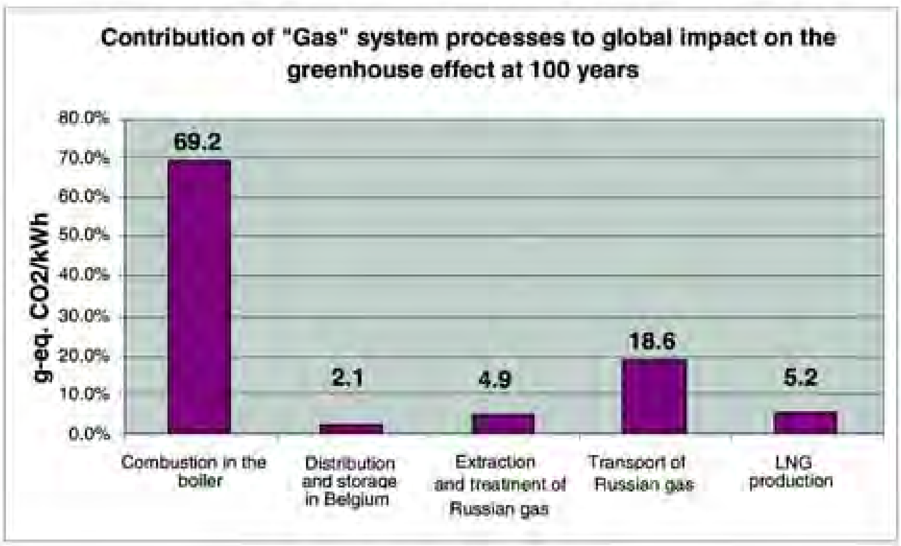
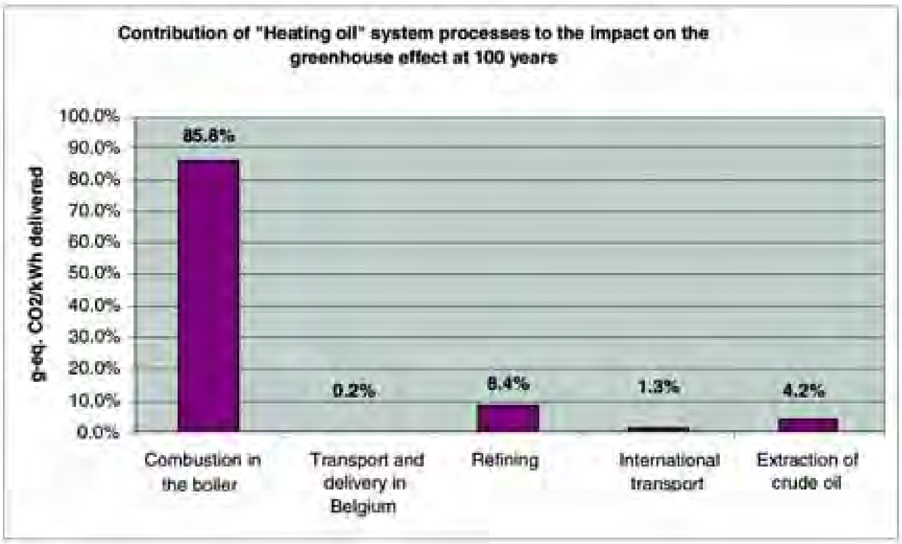


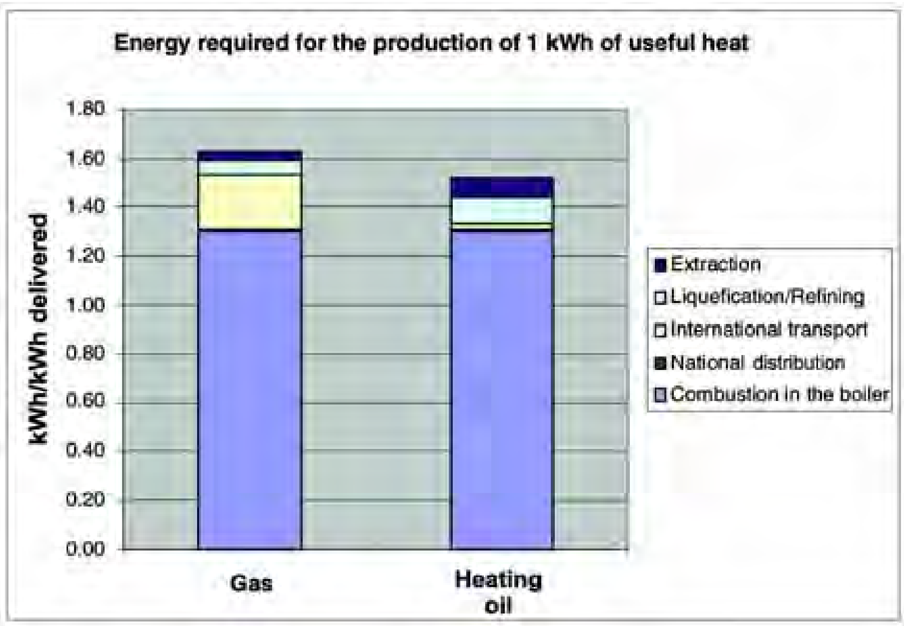
Figure 2: Contribution of the processes of the "Heating Oil" system to the greenhouse effect



I.5.2. Energy consumption

The consumption of energy resources (direct losses + self-consumption) required for the delivery of 1 kWh of heat in a building via a gas and heating oil boiler is shown in the graph below.

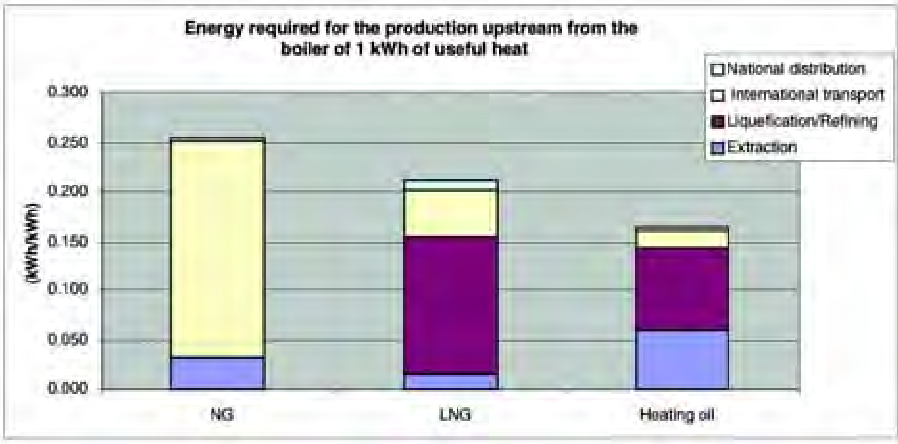
Figure 3: Consumption of energy resources by Gas and Heating Oil systems



For the entire life cycle, on average, the production of 1 kWh of useful heat via a gas boiler consumes 7.0 % more in energy resources than a heating oil boiler.

As shown by Figure 3, this over-consumption of energy resources for gas is mainly due to the stages upstream from combustion in the boiler.

Figure 4: Consumption of energy resources upstream from the boiler



I.5.3. Emissions of greenhouse gases

The results for GHG emissions were calculated year by year for a 100-year period from 2005, i.e., up to 2105.

Figure 5: GHG emissions from gas or heating oil boilers operating for 20 years presents, year by year, the quantity of greenhouse gases (expressed in g-eq. CO_2) present in the atmosphere after a gas boiler and a heating oil boiler are used for 20 years (from 2005 to 2025). It is thus observed that, per useful kWh per year produced from 2005 onwards, a natural gas boiler will cause 9,829 g-eq. CO_2 in 2025 compared to 8,285 for a heating oil boiler, i.e., an increase of 16 %. This difference then abates gradually (as the methane oxidises into CO_2), but over 45 years the quantity of GHGs present in the atmosphere remains greater for a gas boiler. It is only from 2050 that the situation is reversed.

Figure 5: GHG emissions from gas or heating oil boilers operating for 20 years

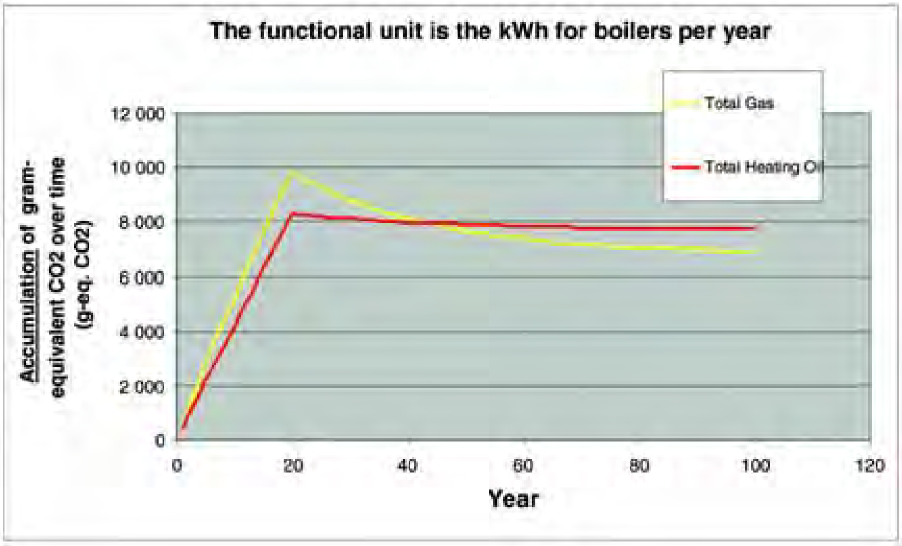
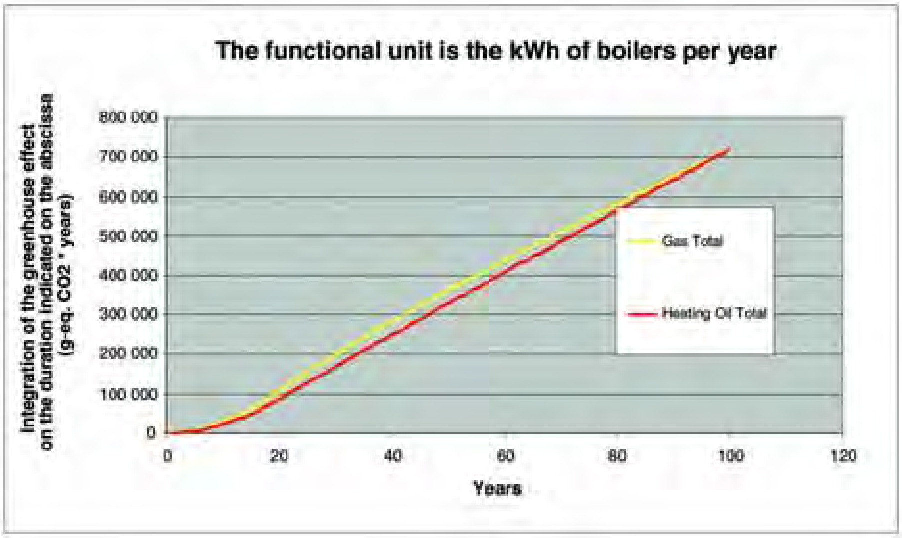


Figure 5 shows the mean of the difference in GHG levels over the next 100 years as typically calculated on the basis of factors defined by the IPCC ("23" for methane at 100 years).

Figure 6: Contribution to the greenhouse effect of gas and heating oil boilers operating for 20 years



In order to understand this graph correctly, LCA assessments typically present only the points for 100 years, and possibly for 20 years, of this figure. Over the next 100 years, the mean quantity of GHGs (present in the atmosphere after a boiler is used for 20 years) will be 0.1 % higher for a gas boiler.

I.5.4. Conclusions

Conclusion 1:
Switching from a heating oil boiler to a gas boiler in Belgium in 2005 does not bring about a relative decrease in GHG emissions[6] (over 100 years)

Considering the entire life cycle of the two fuels, from extraction to combustion in a domestic boiler purchased in 2005 and operating for 20 years, the mean quantity of GHG in the atmosphere over the next 100 years will be very slightly higher (+0.1 %) for a gas boiler, based on the model considered as the most relevant by the authors.

At present, there is therefore no relevance in applying policies that favour gas boilers based on the balance of GHG emissions and on the consumption of non-renewable energy resources.

Conclusion 2:
For gas, emissions due to processes upstream from combustion contribute significantly to the GHG balance

In the case of gas, around 2/3 of GHG emissions (69.2 %) are released during combustion in the boiler. The remaining third (30.8 %) results mainly from extraction, transport (consumption by gas pipelines and liquefied natural gas tankers) and the liquefaction/evaporation of LNG.

In the case of heating oil, a greater proportion of GHG emissions are released during combustion in the boiler (85.8 %). The remainder (14.2 %) result mainly from refining (8.4 %) and extraction (4.2 %).

The proportion of GHG emissions upstream of the boiler is therefore greater for gas (30.8 %) than for heating oil (14.2 %).

Conclusion 3:
The time distribution of the impacts of GHG is stable for heating oil and more concentrated over the first 50 years for gas

In the short term, natural gas has a much greater impact on the greenhouse effect than heating oil (+30 %); it remains higher for 50 years and then becomes less (–11 % in 2105). In contrast to the normal presentation of results for GHG emissions, which only show the mean over 20 years, 100 years or 500 years, a year-by-year presentation enables us to get a better idea of the short-, medium- and long-term effects of each fuel on the greenhouse effect (cf. Figure 5: GHG emissions from gas or heating oil boilers operating for 20 years).

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[6] Expressed in g-eq. CO_2

Conclusion 4:
The use of high-efficiency boilers presents considerable margins in the reduction of large-scale GHG emissions in contrast to changing fuel

This was demonstrated by the sensitivity analysis for emissions vis-à-vis efficiency presented in the final report. A few key figures complete the basis of this analysis:

- The market share for traditional boilers remains high, while the difference in efficiency with HE+, condensing or Optimaz boilers amounts to between **5 and 20 %**[7].
- Correct sizing, and the installation of two-speed or modulating burners or the installation of boilers in a cascade so that they are able to operate at a high load level (in order to keep real efficiency close to theoretical efficiency) are factors that allow a gain in efficiency of between **10 and 30 %.**
- Switching from a heating oil to a gas boiler does not lead to a reduction in GHG emissions.

These considerations show that improving the efficiency of boilers is a solution with greater potential than changing fuel and should therefore be applied as a priority.

[7] Depending on installation and maintenance conditions.