Summary

Introduction
All economic activities use energy in more or less extent. History shows that increasing economic activities often involve a rise in energy use. Therefore, energy is once called the engine of the economy. About 90% of world energy use is derived from finite fossil energy sources such as coal, oil and natural gas. The use of these energy sources causes several problems. With the current growth-rate of energy use, the depletion of the presently known global resources will probably become reality sometime in the next century. Further, the combustion of fossil energy involves the emission of carbon dioxide (CO₂). CO₂ is one of the greenhouse gases, so-called since they contribute to the enhanced greenhouse effect. This enhanced greenhouse effect is the possible global warming of the earth which may cause climate changes. Finally, extraction, transport and conversion of fossil energy carriers cause local environmental problems. The problems mentioned above have to be solved. A solution is a switch to renewables, but this switch takes time. Therefore, a first step is a more saving use of fossil energy carriers.

The growing awareness of the consequences of the use of fossil energy led to several energy conservation measures in various economic sectors. However, an energy conservation measure in an individual sector not always leads to an overall saving. A household e.g. can save natural gas by insulating the house. If more energy is required for the production of the insulators than is saved in the house, the insulation measure results in an overall increase in energy use. So, in the search for energy conservation options, it is essential to consider not only the energy use in the sector itself (direct energy use), but also the energy use in other sectors (indirect energy use).

This research aims at the energy use of all sectors in the economy. The search for energy conservation options takes into account both the energy use in economic sectors and the coherence between economic sectors. Starting-point in this approach is the household sector. Households themselves use energy for activities as heating (natural gas), lighting (electricity) and transport (motor fuel). Moreover, households purchase all sorts of goods and services which are delivered by the economic production sectors. The energy use for the production and delivery of these goods and services is indirect energy use of the households. Assuming that the economy is based on this supply of goods and services, the total energy use in the production sectors can be allocated to the households. The sum of the direct and indirect energy use of households is called the energy requirements of households. This study takes the Netherlands
as an example, although the chosen approach is generally applicable.

Methodology
The energy requirements of households were determined by using methods from energy analysis (chapter 2). Energy analysis has been developed since the early 70s when the interest in energy problems increased strongly. Energy analysis considers the energy use in the whole production chain and consumption chain (life cycle) of a product. Energy requirements are expressed in primary energy terms. Primary energy is energy in the form in which it appears in nature. So, when a process uses electricity, the energy use for production and distribution of the electricity is also taken into account. Electricity production requires e.g. extraction, transport and combustion of coal. An energy analysis can be carried out from both a technical point of view (process analysis) and an economic point of view (input-output analysis).

Process analysis starts from a description in physical terms of the life cycle of a product. The energy use in the different processes is determined in detail. The energy use in e.g. the bakery, at the farm and at the fertilizer plant contribute to the energy requirements of a bread. So, process analysis is an accurate, but also a laborious method.

Input-output analysis, which has its origins in economics, is based on input-output tables. An input-output table of an economy contains the transactions between economic sectors in financial units. Input-output tables only contain the direct transactions between economic sectors, but by using a mathematical formalism the indirect deliveries between sectors can be determined. In the example of the bread, the deliveries of the fertilizer sector and agriculture are indirect deliveries for the bakeries. One of the applications of input-output analysis concerns the projection of primary factors, such as labour and capital, on final demand given, e.g. household consumption. Input-output energy analysis projects the primary factor energy. Input-output analysis is a fast calculation method, but less detailed due to the use of sectoral input-output tables. The bakeries e.g. belong to the flour-processing industry which also produces biscuits. A combination of elements of process analysis and input-output analysis results in a so-called hybrid analysis.

This study determined the energy requirements of households in two ways: by using an input-output energy method (chapter 3) and by using a hybrid method (chapter 4). Both the input-output method and the hybrid method are existing methods. The methods were evaluated extensively and were adapted for the calculation of the energy requirements of households. One of the steps in the hybrid method was improved. Moreover, attention was paid to uncertainty analysis and sensitivity analysis. The hybrid method was standardized in a
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computer program: the Energy Analysis Program (EAP). The program consists of a common database comprising basic data about energy and CO₂ requirements of materials, economic sectors, means of transport, etc. The program enables a relative fast calculation of the energy and CO₂ requirements of goods and services.

By using input-output analysis the energy intensities of 57 economic sectors were determined. The energy intensity of an economic sector gives the total amount of energy that a sector requires for the production of one financial unit of output. The sectoral energy intensities combined with the household consumption per sector give the energy requirements of households. The hybrid method determines the energy requirements in the different stages of the life cycle of a consumption item. This calculation was carried out for about 350 consumption items from all consumption categories (food, house, clothing, etc.). Household energy requirements were calculated by combining the energy requirements of consumption items with spendings on these consumption items of all households in the Netherlands. Uncertainties in the energy intensities of both sectors and consumption items were determined by using Monte Carlo simulations.

A time series was investigated to get insight in changes in household energy requirements. The period 1969-1988 was chosen, since the availability of a consistent data set. Considering the extent of the calculations, the input-output method was used.

There are several ways to decrease household energy requirements: improvements in the energy efficiency of production and consumption processes, changes in the production structure, and changes in volume and pattern of household consumption. The methods used enable the investigation of these ways. Technological improvements in energy efficiency were investigated by using data on energy conservation options in production and consumption sectors. Two existing databases containing technological energy conservation potentials for the year 2015 were used for this purpose. In order to investigate changes in the production structure of the economy, a sensitivity analysis was developed for the identification of relevant economic sectors. Besides, a method was developed for analysing future energy requirements by using the hybrid method. The effect of efficiency changes on energy intensities of products can be studied on the basis of changes in the key parameters in the EAP program.

A part of the energy requirements of households in the Netherlands concerns energy use in foreign countries. Furthermore, the Dutch production sectors use energy for household consumption abroad. Therefore, domestic energy use does not equal energy requirements of the households in the Netherlands. To get insight in the energy requirements of the flows of goods
through the Dutch economy an energy balance for the Netherlands was made.

**Results and discussion**

In order to evaluate and to compare the energy analysis methods, both methods were applied extensively for the Dutch economy in 1990 (chapter 5). This gave a detailed picture of the energy requirements of households in that year. Several input-output methods for the calculation of energy intensities were compared. The differences concern the treatment of the problem that not all sectors pay the same energy prices. The energy intensities were calculated with three methods which are different in the treatment of the price problem. The three methods did not show significant differences in the outcomes. The effect of including imports and capital goods in the calculation was investigated too. The exclusion of imports and capital goods gave a significant underestimation of the energy intensities. On the basis of the investigations, one method was chosen for the calculation of the energy intensities of the economic sectors. These energy intensities lie between 1 and 30 MJ per Dutch guilder production. The uncertainties in the energy intensities are about 7%.

The energy intensities of the consumption items were calculated with the hybrid method. These energy intensities lie between 0 and 60 MJ/Dfl with an uncertainty of about 13%. This uncertainty is mainly the result of uncertainties in prices. The energy requirements of all 6.13 million households in the Netherlands in 1990 are about 1650 PJ. The energy requirements per household are about 270 GJ. About 55% of the energy requirements concerns indirect energy use of the households. This shows the importance of the indirect energy requirements of households. The energy requirements calculated with the input-output method are little higher than those calculated with the hybrid method. The difference lies between the uncertainty boundaries.

In the period 1969-1988, the energy intensities of 40 sectors out of 56 decreased (chapter 6). 30 sectors showed a decrease of more than 10%. The decline of the energy intensities mainly took place in the period 1977-1982. The decrease in the energy intensities seems to be a combination of a delayed effect of the first oil crisis in 1973, and an effect of the second oil crisis in 1979. The decrease in the energy intensities corresponds to a rise in the energy price. Herewith, the energy price seems to be one of the explaining factors of the development of the energy intensities of the production sectors.

In the period 1969-1988, the volume of household consumption rose strongly, partly caused by a 50% increase in the number of households. The energy requirements of all households in the Netherlands increased with about 30% in the period considered. So, energy efficiency improvements in production and consumption processes partly compensate for the volume growth of
consumption. In the consideration of the energy requirements per household, the
decline in the number of persons per household plays a role. The energy
requirements per household decreased with about 10% in the period 1969-1988.

The energy requirements of imports and exports are of the same
magnitude as household energy requirements. In the period 1969-1988, the
energy requirements of exports increased faster than those of imports as a result
of the rise of the energy intensive basic industry. In 1970, the energy
requirements of the exports equalled the energy requirements of imports. In
1988, the energy requirements of exports were 28% higher than those of
imports. With regard to goods and services, the Netherlands has become a net
exporter of energy.

Conclusions
The consequences of possible future developments in energy efficiency for
household energy requirements were investigated (chapter 7). Since the energy
conservation potentials for the households are higher than those for the
production sectors, the share of indirect energy in household energy
requirements will increase. The implementation of all technological options
presently known reduces energy requirements of households with about 50%
assuming unchanging consumption. The expectations are a further increase in
the volume of household consumption as a result of growth of population and
purchasing power. When estimations of the Central Planning Bureau concerning
volume growth in household consumption are taken into account, households
energy requirements in 2015 will be of the same magnitude as the 1990 energy
requirements. The decrease in energy requirements as a result of technological
improvements will be completely neutralized by the growth of consumption.
Especially after 2000, the exponentially growing consumption will overrule the
energy efficiency improvements. For a further decrease in energy use,
technological options only are not sufficient. Therefore, effects of changes in
production structure and in consumption patterns have to be investigated too.
These investigations will be carried out in a new project, the so-called
GreenHouse project.