Chapter 8

General conclusions and reflections

Section 8.1 presents the main research conclusions. In section 8.2, some directions for future research are indicated.

8.1 CONCLUSIONS

This study aims at the investigation of energy conservation options from an integrative approach which considers energy use in combination with the relations between economic processes. Since economic sectors which are related belong to the same production chains, the energy use in production chains is investigated. The consideration of whole production chains is possible by looking at the end of these chains. Households in their role as consumers of goods and services are located at the end of production chains. Therefore, the approach chosen starts from the household perspective by projecting all energy use in production and consumption processes to the households.

The first main research question (section 1.3) concerns the feasibility of such an integrative approach. Two energy analysis methods were adapted for the calculation of the energy requirements of households. It appeared to be feasible to calculate household energy requirements in a given year in a detailed way. Besides, the input-output method enabled the investigation of the development of household energy requirements over a 20-year period. Herewith, the first main research question is answered affirmatively.

Both methods enable the investigations of future energy requirements of households. The development of a sensitivity analysis makes the identification of relevant elements concerning household energy requirements possible. The sensitivity methodology developed offers tools for investigating the combined effects of changes in energy efficiency, changes in production structure and changes in consumption patterns. Herewith, the second main research question (section 1.3) is answered.

This study investigated the effect of changes in energy technology in production and consumption processes on household energy requirements. The implementation of all technological options presently known reduces household energy requirements with about 50% (assuming unchanging consumption). When estimations concerning volume growth in household consumption are taken into account, after 2000, the exponentially growing consumption will
overrule the energy efficiency improvements. In order to decrease energy use further, technical options only are not sufficient. Therefore, future research also involves changes in production structure and consumption patterns in the search for energy conservation options. This may lead to other conservation options or another priority of conservation options than options on the basis of sectoral studies.

The next sections discuss the conclusions of the methodological and empirical part of this study in more detail.

8.1.1 Conclusions of the methodological part
The methodological part (chapters 2-4) presents theoretical models for the calculation of household energy requirements and related CO₂ emissions based on two existing energy analysis methods: an input-output method and a hybrid method. The input-output energy analysis methodology was refined considering the aims of this study (chapter 3). In order to determine the CO₂ emissions related to household energy requirements, the input-output method has been extended to the calculation of CO₂ intensities. Furthermore, the input-output method had to be modified for the calculation of energy intensities over a longer time span. The main conclusions of the investigations concerning the refinement of the input-output method are:

• The system concerning the energy requirements of households includes all inputs in production processes and the capital goods in these processes. The consequences of excluding the capital goods and imports, competitive and non-competitive, from the input-output method were investigated. The calculations show that capital goods and imports cannot be excluded when calculating the energy intensities. The inclusion of the capital goods increases the 1990 indirect energy requirements of households with almost 20%. The exclusion of imports underestimates these indirect energy requirements with more than 70%.

• The input-output model for the calculation of the energy intensities of production sectors assumes that the monetary transactions in the input-output table are proportional to the physical transactions. Since there are large differences in the energy purchasing prices per sector, this assumption is certainly not valid for the deliveries of the energy sectors. Three solutions for this problem were compared by calculating the energy intensities for 1990 in three ways. Although the different calculation methods, in theory, should produce the same energy intensities for the non-energy sectors, this is not the case for 1990. A possible explanation is that the energy data used were derived in different ways. However, the different calculation methods identified the same sectors as energy-intensive sectors. On the basis of these
investigations, the ERE conversion method has been chosen for the empirical analysis.

- An uncertainty analysis by using Monte Carlo simulations showed that the uncertainties in the energy intensities are relatively small: about 7%. This result is very acceptable in comparison to the outcome of the analysis of a historical series of energy intensities. Possible differences between energy intensities of different years of more than 10% can thus not only be attributed to chance.

- A sensitivity analysis is used to investigate the effects of changes in the model parameters. Formulas were derived for the separate elements of the model parameters to determine the effects of changes in these elements on energy intensities and household energy requirements. With these formulas, important and less important elements can be distinguished for a specific consumption pattern. Important elements have a large influence upon the total energy use needed for that consumption pattern. These important elements deserve most attention in scenario studies.

The hybrid energy analysis method calculates household energy requirements by using energy intensities of consumption items (chapter 4). The reassessment of an existing hybrid method led to a revision of the calculation method for the energy intensity of the residual goods. The revised method gives a better treatment of the exclusion of the basic goods from the calculation. Further, an uncertainty analysis has been carried out for energy intensities of products. The uncertainties of the energy intensities based on a Monte Carlo analysis are about 13%.

A computer program, the Energy Analysis Program (EAP), has been developed in order to enable the application of the hybrid method to a large number of consumption items. EAP standardizes the application of the hybrid method on the basis of a common database. This database has been filled with a large amount of energy and CO₂ data concerning economic sectors, materials, means of transport, etc. It appeared to be feasible - with the diligence of a number of researchers - to calculate the energy intensities of about 350 basic consumption items covering all budget spending categories. The investigations in chapter 7 showed that EAP in combination with the analyses carried out with EAP is a useful tool for the assessment of options for energy conservation and CO₂ emission reduction. By extending the EAP database with key data of other greenhouse gases, the effect of household consumption on the emissions of these gases can also be considered.
8.1.2 Conclusions of the empirical part

The empirical part (chapters 5-7) describes the results of the calculations concerning energy requirements of households in the Netherlands. The description starts with a detailed analysis of the year 1990. After that, the period 1969-1988 is investigated and some predictions for the year 2015 are given. Some main conclusions concerning the 1990 investigations are:

- Many energy conservation programs consider only direct energy use. Sectors upstream in production chains show a high share of direct energy use in their total energy requirements. However, several downstream production sectors and the households show an indirect energy use that is higher than the corresponding direct energy use. Therefore, indirect energy use deserves more attention in energy policy, especially for downstream sectors.

- The energy requirements allocated to the 6.13 million households in the Netherlands amounted to 1650 PJ in the year 1990. Thus, the energy requirements per household were 270 GJ split up in 55% indirect energy use and 45% direct energy use. The difference in the outcomes for the 1990 energy requirements of households based on both the input-output method and the hybrid method is less than 5%. This difference is less than the uncertainty range in the energy requirements.

The energy intensities of the Dutch production sectors and the energy requirements of the households in the Netherlands have been studied for the period 1969-1988. The main conclusions can be summarized as:

- In the period 1969-1988, the energy intensity decreased for 40 of the 56 sectors, and 30 sectors showed a decrease of more than 10%. This points to a significant improvement in the energy efficiency for these sectors that was realized mainly in the years following the so-called oil crises.

- Since 1970 the energy requirements of the exports have grown faster than the energy requirements of the imports. In 1970, the exports were equal to the imports in energy terms. In 1988, the energy requirements of the exports were 28% higher than the energy requirements of the imports. The production system in the Netherlands shows more and more a concentration on energy-intensive exports.

- The annual energy requirements of households in the Netherlands increased in the period up to 1979. In the period 1979-1988, this quantity declined such that the 1988 value is close to the 1973 value. In household energy requirements the volume growth of consumption is compensated by a decrease in the energy intensities of the production sectors. Changes in the structure of household consumption play only a marginal role in the changes in the energy requirements.
During the growth in the number of households in the period 1969-1988 from 3.9 to 5.9 million both the direct and the indirect energy requirements per household decreased. The reduction took place in the period after the year 1979, and amounts to 8% for the direct energy requirements and 10% for the indirect energy requirements. The decrease in energy requirements per household is partly a result of a decline in the number of persons per household.

The methodology developed in chapter 7 enables the systematic study of parameters that exert strong (or weak) influence on the energy requirements of households. This issue has been studied through three approaches:

- a sensitivity analysis in the input-output formalism,
- an assessment of the influence of efficiency enhancing technologies as described in available databases on energy intensities, and
- an analysis of changes in values of key parameters in the resulting data base (by using the EAP program).

This has resulted in a procedure through which specific goods and services can be identified that require prime attention in energy efficiency enhancement programmes. The procedure follows the staged approach indicated above:

1) identification of relevant economic sectors,
2) assessment of the reduction potential of these sectors, followed by a ranking procedure of the reduction potentials,
3) detailed EAP-based analyses of goods and services that make use of contributions from the categories identified in step 2.

A full quantification of the impacts of this approach is beyond the scope of this study. Illustrative examples have been given, and these show a reduction potential of about 50% of the 1990 energy requirements and related CO$_2$ emissions of households in the Netherlands. Such potential gains will be offset completely if private consumption continues to grow along the lines of the last 40 years.

8.2 FUTURE RESEARCH

The investigations in this study are continued in a research project called 
(\textit{Evaluation of}) options for reduction of greenhouse gas emissions by changes in household consumption patterns, named \textit{GreenHouse} for short (Biesiot, 1994). The project consists of two main research lines. The first line concerns the integration of energy analysis and household analysis. The second line builds on the work carried out concerning the effect of changes in both production structure and consumption patterns on household energy requirements (chapter 7). The next two sections outline the main lines
mentioned.

Besides, the GreenHouse project considers the impact of household consumption on some other greenhouse gases: methane, chlorofluorcarbons and nitrous oxide. The investigations described in the previous chapters focus on energy requirements of economic activities in the Netherlands. One may wonder whether the results found for the Netherlands also hold for other countries. Therefore, some international comparisons will be carried out in the GreenHouse project.

8.2.1 Integration of energy analysis and household analysis
The energy analysis approach used considers a household as a black box consuming goods and services. The role of these goods and services in households is not considered. However, in searching for greenhouse gas reduction options it is relevant to open the black box. The processes inside the black box can be studied by using household analysis. From the perspective of household analysis, households try to reach a certain level of living by carrying out various activities by using household resources. The household activities can

![Figure 8.1](image_url)  
**Figure 8.1** Integration of energy analysis and household analysis (after Groot-Marcus et al., 1996; Resource extraction, Material production, Product manufacturing, Transport and trade, Waste disposal).
be grouped in activity categories like feeding, housing, etc. The reached level of living depends on the standard of living and the availability of household resources, such as time, money, and knowledge (Groot-Marcus et al., 1996).

In the energy analysis approach, the energy requirements of individual products are considered. From the perspective of household activities, combinations of products and the relations between products can be considered. Each household activity contains a number of products, which all have their own life cycle. By integrating household analysis and energy analysis, the energy requirements of household activities can be determined. For this purpose, the EAP analyses can be used as building blocks. Changes in household consumption within activity categories are investigated, since these changes may have consequences for the energy requirements of the activity categories. Changes in household consumption are limited by the availability of household resources. Therefore, household resources have to be taken into account in the integrated analysis. Figure 8.1 shows the integration of household analysis and energy analysis.

8.2.2 Changes in production structures and consumption patterns
Chapter 7 made a start with the investigations to possible changes in household energy requirements. This topic will be further investigated in the GreenHouse project. The research questions addressed are (the numbers correspond to the numbers in figure 8.2):

1 - what is the effect of technological changes in production sectors on the

![Diagram](attachment:image.png)

Figure 8.2 Relations between production structure, consumption pattern, energy requirements of households and greenhouse gas emissions.
energy requirements of households?
2 - what is the effect of changes in consumption patterns on the energy requirements of households?
3 - what is the effect on non-household sectors if all households choose a low-energy consumption pattern?

The analyses are carried out both at a meso level and at a macro level. The analyses on the meso level are carried out by using the database of the EAP computer program. The effect of changing basic data in the EAP database (corresponding with technology changes) on household energy requirements is investigated. The analyses at the macro level are carried out by using input-output analysis. By changing column elements in the technological matrix, available knowledge of technological innovations is implemented in the input-output framework. Besides, a sensitivity analysis is carried out in order to identify the most important elements in the technological matrix. These elements deserve most attention in searching for relevant energy and emission reduction options.

Changes in consumption patterns are investigated on the basis of the results from the other main line in the project: the integration of household analysis and energy analysis. The investigations concerning changes in both production structure and consumption patterns result in energy conservation options. The shift to low-energy production sectors may have effect on the production structure. Therefore, the overall effect of changes in production and consumption has to be considered.