Chapter 1

Introduction

History shows the importance of the role of energy in economic activities. Nowadays, almost all energy use originates from fossil fuels. Since there are (future) constraints on the use of fossil energy, the present energy use is not sustainable. This chapter presents an integrative approach which may contribute to the search for energy conservation options.

1.1 ECONOMIC ACTIVITIES AND ENERGY USE

The importance of the role of energy in economic activities is undeniable. All economic activities require more or less energy. In the twentieth century, people have become more aware of the importance of energy in production and consumption processes. In 1926 already, Soddy wrote (p. 56):

"If we have available energy, we may maintain life and produce every material requisite necessary. That is why the flow of energy should be the primary concern of economics."

So, energy seems to be indispensable in the economic activities of men. For illustration, figure 1.1 shows the relationship between the total energy use and the gross domestic production (GDP)¹ in a densely populated and highly industrialized Western country like the Netherlands during the period 1946-1992 (Noorman, 1995). Both the economic activities and the demand for energy show an increasing trend².

Economic analyses take human needs and wants as a starting-point. In general, economic theories do not take into account physical constraints. However, the underlying processes of consumption and production are physical and are therefore subjected to physical constraints. Physical constraints on energy use are e.g. the impending depletion of fossil fuel stocks, the related

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¹ GDP is a common indicator for economic activities.
² In the post-war period of reconstruction, both indicators were closely matched. For the period 1967-1990, this match between energy use and GDP was disturbed, since policy in the Netherlands attracted energy-intensive industries with long-term contracts for the delivery of cheap natural gas. In that period, the petrochemical and basic metal industry grew considerably.
impacts on the environment, and thermodynamical limitations. This study considers economic activities from a physical perspective. Therefore, the study belongs to the field of Natural Capital Accounting (NCA). NCA takes into account the interdependency between economic activities and the available physical resources. NCA links economics and the environment by investigating the physical flows across the ecosystem-economy boundaries. Furthermore, NCA obeys the thermodynamic laws. Noorman (1995) gives an overview of the application of physical laws in economic activities.

1.2 CONSTRAINTS ON THE USE OF ENERGY

At present, more than 90% of world commercial energy use originates from fossil fuels such as coal, oil and natural gas. The report Limits to growth (Meadows et al., 1972) and the first oil crisis, in 1973, emphasized the finite availability of these fossil fuels. So, the depletion of these fuels poses a real challenge. With the current growth-rate of energy use, the depletion of the presently known global resources which are economically available will probably become reality sometime in the next century (Mulder, 1995).
Another problem of fossil energy use, which is possibly even more important, is the emission of carbon dioxide (CO₂) from the combustion of fossil fuels (a.o. Graedel and Crutzen, 1993). CO₂ is one of the greenhouse gases, so-called as they contribute to the enhanced greenhouse effect. The enhanced greenhouse effect is the possible global warming of the earth due to an increased concentration of greenhouse gases in the atmosphere. The effects of global warming on the earth climate are not yet precisely known. Therefore, the different aspects of the greenhouse effect and possible solutions have to be studied (Houghton et al., 1996).

There also are problems due to fossil energy use with a more local character. These local problems occur at extraction, transport and conversion, and use of fossil fuels. A transition to electricity from nuclear power stations is controversial since there are still problems concerning reactor safety, security and radioactive waste. Furthermore, there are limitations on the amounts of uranium ores used in light water reactors. A transition to fast breeder reactors which is a necessary condition for a stable nuclear energy supply meets large technological difficulties (Biesiot and Dwarshuis, 1993).

1.3 AN INTEGRATIVE APPROACH

Future prospects show a further increase in economic activities (a.o. CPB, 1992). According to the match between energy use and economic activities, the present energy supply based on fossil fuel is not sustainable. A solution is a switch to renewable energy carriers. Since this switch takes time, a first step is a more saving use of fossil energy carriers.

The awareness of the necessity of energy conservation led to several energy conservation programs (a.o. Ministry of Economic Affairs, 1990). Most of these programs only consider the energy use of processes in individual sectors, e.g. the energy use for the production of fertilizer or the energy use for the production of agricultural products. This has led to several databases with technical options for energy conservation (e.g. Melman et al., 1992; Beer et al., 1994). However, the consideration of relations between processes may also result in energy conservation options. E.g. agriculture uses lots of fertilizer. The energy use of the production of fertilizer is as it were indirect energy use of the agricultural sector. So, a reduction of the use of fertilizer in the agricultural sector indirectly leads to energy conservation.

The relation between the production of fertilizer and the production of

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3 Some other important greenhouse gases are methane, nitrous oxide, chlorofluorocarbons and ozone.
agricultural products is straightforward. However, there exist relations along the production chains of goods and services which are far more complicated. Most energy conservation programs do not take into account the relations between processes in production chains. The inclusion of these relations in the search for energy conservation options may lead to new insights. Therefore, the first main research question in this study concerns the feasibility of an integrative approach which considers total energy use in combination with the relations between production processes.

The consideration of whole production chains is possible by looking at the end of these chains where the activities of end-users are. Total energy use in the production chains is projected at these activities. The concept of activities of end-users enables the investigation of changes in these activities and the effects of these changes on energy use. This enables the combined investigation of technological and behavioural options for energy conservation. The integrated search for energy conservation options is more complex than the search in individual sectors. Therefore, the second main research question in this study concerns the development of a methodology for identifying energy conservation options in the integrative approach.

1.4 ENERGY REQUIREMENTS OF HOUSEHOLDS

The chosen approach starts from the economic theories which split up economic activities in production and consumption. Assuming that production takes place in favour of consumption implies that all energy use in an economy can be allocated to consumption. A main consumption sector is formed by the households. Households have many categories of expenditures; they buy products (food, clothes, etc.) and use services (insurances, public transport, etc.). The whole economy is based on this consumption of goods produced by industry, and services delivered by service industry. The direct energy use of the production sectors can be considered as indirect energy use of the households. Thus households do not only use direct energy, e.g. electricity, motor fuels and natural gas, but also indirect energy by purchasing goods and services. The total energy use of households, direct and indirect, is called cumulative energy requirements of households.

Figure 1.2 shows the division of household energy requirements in

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4 The concept of household energy requirements corresponds to the formulas given by Mulder (1995) in which total energy use is considered as the product of population size, the material wealth level per capita and the energy required per material wealth unit.

5 This study uses the term 'energy requirements' to mean 'cumulative energy requirements'.
direct and indirect energy requirements. The direct energy requirements of households contain both the energy use of households and the energy use of the energy supply system needed for the direct household energy use\(^6\). The indirect energy requirements of households consist of the energy required for the production of goods and services and the energy needed by the energy supply system for the production of this energy from primary energy. So, the energy use of the energy supply system is divided over the direct and indirect energy requirements of households.

The approach described is generally applicable, but considering the access to data, this study takes the Netherlands as an example. So, this study is restricted to the energy requirements of households in the Netherlands related to the consumption of goods and services\(^7\). However, the energy requirements of households in the Netherlands are not equal to domestic energy use. The energy use in the economic production sectors is also destined for e.g. exports\(^8\).

\(^6\) Although, the direct energy use of the energy supply system is indirect energy use of the households, it is directly related to the direct energy use of households. Therefore, this study includes it in the direct energy requirements of households.

\(^7\) Energy requirements of government consumption are not attributed to households.

\(^8\) These exports are consumer goods or intermediate goods for use in production sectors which on their turn produce for consumption.
and investments. In other countries, energy is used for the production of goods and services for the households in the Netherlands. Therefore, household energy requirements are investigated in relation to other, direct and indirect, energy flows in the economy of the Netherlands including imports and exports.

1.5 SCOPE OF THIS STUDY

Changes in household energy requirements can be investigated from different perspectives. E.g. in the HOMES research program (Noorman and Schoot Uiterkamp, 1996), the potential for changes in the material use and energy use of households is investigated from four perspectives (figure 1.3). Jager et al. (1992) combined three perspectives, the technological, social and institutional perspective, in order to determine the potential for energy conservation. This study investigates household energy requirements from a physical/technological perspective. For this purpose, the energy analysis methodology is used which has been under study since the early 70s.

The energy requirements of households are calculated at a sectoral level and at a product level by using two energy analysis methods (figure 1.4). At the sectoral level, household energy requirements are determined on the basis of input-output tables. Input-output energy analysis determines the energy intensities of economic sectors. By combining these intensities with the

Figure 1.3 Different sets of constraints determine the potential for change (Noorman and Schoot Uiterkamp, 1996).
consumption of households, which is also derived from input-output tables, household energy requirements are calculated. The second way to determine the energy requirements of households takes place at the product level. Household energy requirements are determined with data from budget surveys. A budget survey lists expenditures of households on consumption items. For all consumption items in the budget survey, energy intensities are determined by using a hybrid energy analysis method. With the energy intensities for all consumption items and the household expenditures on these consumption items, household energy requirements are calculated. The energy related CO₂ emissions of households are also determined with both methods by using data of CO₂ emissions of energy carriers.

The calculation methods give several starting points in order to decrease household energy requirements. Changes in household consumption concern both changes in structure and volume of consumption. The energy requirements per consumption unit depend on the production structure and the energy efficiency of the economy. So, changes in the energy intensities have both a structural and a technical component.

In order to serve the aims of this study, the following steps are carried out:

1) Extension and application of the input-output energy analysis
methodology which is used for the calculation of the energy intensities of economic sectors. In order to assess the outcomes of the calculations an uncertainty analysis is carried out. A sensitivity analysis is developed to identify the most important model parameters.

2) Reassessment and improvement of a hybrid energy analysis method for the calculation of the energy requirements of consumption items, especially the method for calculating the energy intensities of residual goods.

3) Formalization and simplification of the hybrid method in a computer program. This computer program enables the calculation of the energy requirements and CO₂ emissions of large amounts of consumption items in a standardized way. Selection of appropriate energy data and CO₂ data for the database of this computer program.

4) In order to compare and evaluate the energy analysis methods, both methods are applied extensively to the situation in the Netherlands for the base year 1990. This results in a detailed picture of the direct and indirect energy requirements of households.

5) An analysis of structural trends and short term fluctuations through a study of a time series over 20 years of the energy and CO₂ intensities of Dutch economic sectors in order to get insight in changes in household energy requirements and CO₂ emissions, and their main determinants.

6) Survey of the consequences of possible future technological developments in energy requirements and CO₂ emissions of households by means of the scenario approach.

Figure 1.5 depicts an overview of the structure of this study. The study consists of both a methodological part and an empirical part. Chapters 2-4 form the methodological part. First, chapter 2 discusses the general concepts of energy analysis. Chapters 3 and 4 present the two methods used for calculating the energy requirements of households. The first method, in chapter 3, is based on economic input-output analysis. The second method, in chapter 4, combines two types of energy analysis: process analysis and input-output energy analysis. Chapter 4 also presents the computer program EAP in which the hybrid method has been implemented.

The empirical part (chapters 5-7) uses both methods to calculate energy requirements and CO₂ emissions of households. Chapter 5 investigates one year, 1990, thoroughly. Some topics concerning methodology are illustrated on the basis of the situation in the Netherlands. To assess changes in energy requirements of households in the Netherlands, chapter 6 studies historical trends over a period of twenty years, namely 1969-1988. This period overlaps
to a large degree with the period in which GDP and energy use were decoupled (figure 1.1). The period 1969-1988 is characterized by two oil crises, in 1973 and 1979, resulting in sharp hikes in the crude oil price. Therefore, this period is also suitable for an investigation of the effect of price changes on energy intensities. Chapter 7 examines household energy requirements in the year 2015 by implementing improvements in energy efficiency and volume changes in household consumption assuming production structure and consumption pattern remain unchanged. The improvements in energy efficiency are based on technical energy conservation potentials from studies which centre on the possibilities of decreasing direct energy use in production and consumption sectors. Finally, chapter 8 discusses the main conclusions and it also gives a perspective on future research.