An Input-Output Based Methodology for the Evaluation of Technological and Demand-Side Energy Conservation Options

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Abstract

Analysis of the energy requirement of households demonstrates that future household consumption based on fossil fuels is far from sustainable. Both technology and lifestyle offer options for reducing fossil energy use. This paper presents a methodology for implementing technological and demand-side energy conservation options in an input-output model for calculating the energy requirement of households. The energy consequences of conservation options are calculated and related with total present and future household energy requirement. The implementation of a set of technological energy conservation options shows a 55% decrease in present household energy requirement. The implementation of a set of demand-side options decreases present household energy requirement with 9%. The combined effect of technological and demand-side options results in a decrease of 59% (some of the options are cancelled out). Relating the options to a scenario for 2020 allowing for economic and demographic developments shows that the 2020 target directed to sustainable household consumption in 2050 is not achieved.

Keywords: Input-output analysis, energy conservation, households, The Netherlands.

Introduction

In studying energy use in relation to production and consumption, the concept of the energy requirement of households has shown to be useful (Vringer and Blok, 1995; Wilting, 1996). Households can be seen as end-users of goods produced and services delivered by economic production sectors. In such an approach, energy used along entire production-consumption chains is attributed to household expenditures. By using the household energy requirement both energy use in households itself and in production sectors can be studied.

At present, 90% of world commercial energy use originates from fossil fuels such as coal, oil and natural gas (IEA, 1996). Energy use based on fossil fuels is accompanied by important environmental drawbacks like the risk of an enhanced greenhouse effect and environmental degradation at the mining of fossil fuels. Furthermore, with the current growth-rate of energy use, an depletion of fossil energy resources will probably become reality sometime in the next century (Mulder and Biesiot, 1998). A first step in the direction of a more sustainable use of energy is energy conservation. Traditionally, searches for energy conservation started from a technological view. Although technological energy conservation measures lead to reasonable savings in energy use per unit product, these savings are often cancelled out by the ongoing growth in consumption. Therefore, the interest in lifestyles and consumption patterns as a second source for energy conservation grew (Bruggink, 1995). In this paper, the energy requirement of households concept is used to assess both types of energy conservation options.

Input-output analysis is a convenient tool for calculating the consequences of household consumption with regard to natural resources and environment (Duchin, 1996). The use of input-output analysis for calculating the energy requirement of households is described in more detail in (Wilting, 1996). In this study, we use an input-output model for developing a methodology which enables a combined investigation of energy conservation by technological innovation and by changes in consumption patterns. Both types of energy conservation options, technological and demand-side, are implemented in the input-output model by coupling them to the model parameters. The methodology is used for assessing individual energy conservation options as well as sets of energy conservation options. First, individual options and sets of options are evaluated by calculating the energy consequences for present Dutch household energy requirement. After that, sets of options are combined with economic scenario studies in order to investigate if a decrease in energy requirement directed in long-term sustainability in 2050 is achievable.

Calculating the energy requirement of households

Households use energy not only in a direct way, e.g. by using electricity, motor fuels and natural gas, but also in an indirect way by buying goods (food products, clothes, etc.) and using services (insurances, public transport, etc.). The manufacturing and delivery of these goods and services requires energy in economic production sectors. Energy use of manufacturing and service industries can be considered as indirect energy use of households. Figure 1 shows the distinction between direct and indirect energy use of households. The total energy use of households, direct and indirect, constitutes the household energy requirement.

Energy analysis provides methods for calculating the energy requirement of households. Main energy analysis methods are process analysis and input-output analysis (IFIAS, 1974). Process analysis is an accurate, but also labourious method and for that reason less appropriate for calculating the household energy requirement. Input-output analysis is a much faster calculation method. Therefore, it is a convenient methodology for the determination of energy use associated with consumption patterns. We used the following static open input-output model for the calculation of the energy requirement of households:

$$E = \mathrm{r}\,\{\mathrm{D}^{\mathrm{p}}\,(\mathrm{I}-\mathrm{A})^{-1} + \mathrm{D}^{\mathrm{c}}\}\,\mathrm{y} \qquad (1)$$

where

E the energy requirement of households

r vector with energy requirements of energy (ERE) values per energy carrier

D^{p} matrix with direct energy intensities of economic sectors per energy carrier

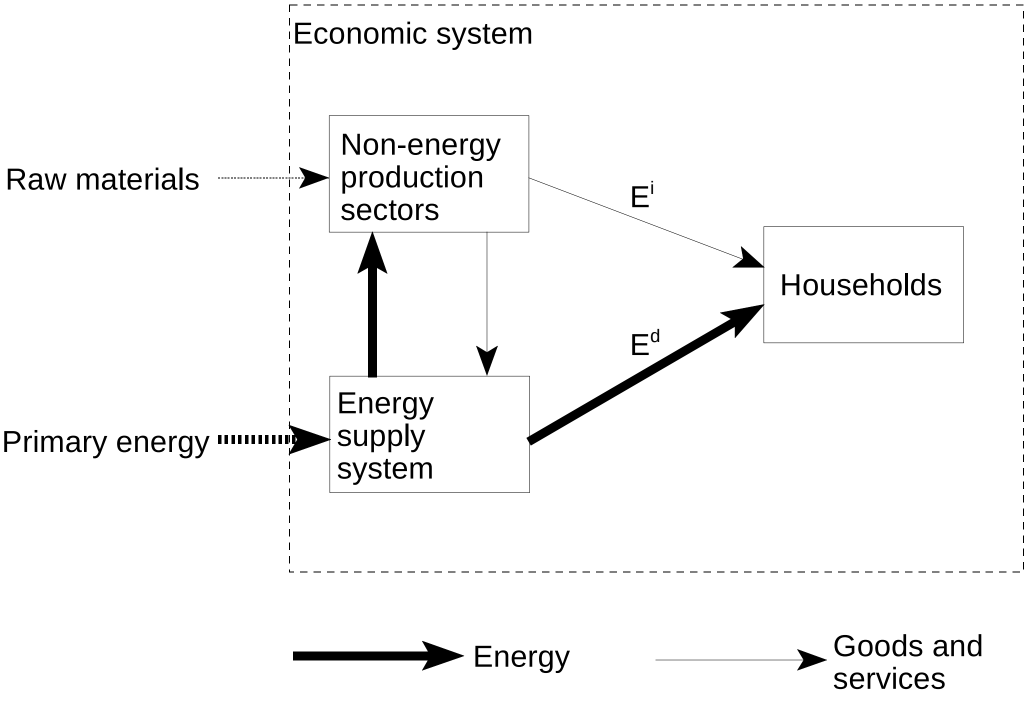

Figure 1 Direct (E^d) and indirect (E^i) energy requirements of households.

(direct energy intensities of energy sectors are zero)

I	unit matrix
A	technological matrix
D^c	matrix with direct energy intensities of household consumption per energy carrier
y	household consumption vector

The right-hand side of expression (1) deals with the separate actors in figure 1. Vector **r** corresponds with the conversion of energy in the energy supply system (ESS), the part $\mathbf{D^p}\ \mathbf{(I\text{-}A)^{-1}}$ corresponds with the energy efficiency and production structure of production sectors, and matrix $\mathbf{D^c}$ and vector **y** correspond with household consumption.

The model for calculating the household energy requirement assumes that monetary transactions in input-output tables are proportional to physical transactions. Since there are large differences in energy prices per sector, this assumption is certainly not valid for energy deliveries. To solve this problem, we computed, for each non-energy sector, primary energy use on the basis of final energy use and ERE values of energy carriers. The ERE (energy requirement of energy) value of an energy carrier is the total amount of energy needed for the production of that energy carrier, e.g. by extraction, conversion or distribution of the energy carrier. The energy use of the energy sectors was set to zero to avoid double counting (Van Engelenburg et al., 1991).

Intermediate goods and services used in production processes partially concern imports which required energy abroad. We assumed for competitive imports (which concern products that are also produced domestically) that foreign production structures are similar to the production structure in the Netherlands[1]. We used for the determination of the energy requirements of non-competitive imports (which are goods that are not produced domestically) additional information concerning the production of these goods abroad, which was comprised in the input-output table used. The household energy requirement also allows for energy required for producing capital goods in the past. These requirements were assigned to production during the whole life time of the capital goods. The annual contribution of energy embodied in the capital goods was determined by using the depreciation of these capital goods. Since the input-output tables used do not specify depreciation for type of capital goods, we used new investments for the determination of the composition of the depreciations.

In input-output analysis, the accuracy of the outcomes depends on the aggregation level of the input-output tables used. We used for the calculations a so-called homogeneous input-output table containing about 250 goods and services. The rows and columns in homogeneous input-output tables correspond to commodities which can be seen as collections of goods which are produced as much as possible in the same way. The column corresponding to a commodity can be seen as a representation of the production process of that commodity. Konijn (1994) gives an extensive description of the compilation of homogeneous input-output tables on the basis of make and use tables. The first homogeneous table for the Netherlands was compiled for 1987. By now, the CBS also published a homogeneous input-output table for 1990 (Konijn and De Boer, 1993).

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[1] Recently, Battjes et al. (1998) showed that there are differences in energy intensities per country.

The Dutch household energy requirement in past and future decennia

The input-output model was used for an investigation of developments in the energy requirement of Dutch households in time. A historic time series concerning the period 1969-1988 (chosen due to the availability of a consistent data set) has been investigated before[2] (Wilting, 1996). Figure 2 shows the historic trend in the (direct and indirect) energy requirement of households in the Netherlands. The indirect energy requirement of households turns out to be higher than the direct energy requirement. In the period 1969-1988, the share of the direct energy requirement in the total energy requirement fluctuated between 0.39 and 0.44. Both the direct and indirect energy requirement rose during the seventies with a slight fall in 1974 after the first oil crisis. During the 1980s the direct energy requirement of households remained at the same level. The indirect energy requirement of households increased slightly in the period 1984-1988. In 1988, the total energy requirement of households had returned to the level of 1973.

Figure 2 also shows direct energy use of households per energy carrier. The energy required for the production and distribution of energy carriers, which is calculated with ERE values, is included in the direct energy, although it is indirect from the households' perspective. Natural gas, which is mainly used for heating, has a large share in the direct energy use of households. The figure also shows a shift from oil products to gas and electricity. The direct electricity use doubled in the period 1969-1988. Indirect energy consumption is not shown per

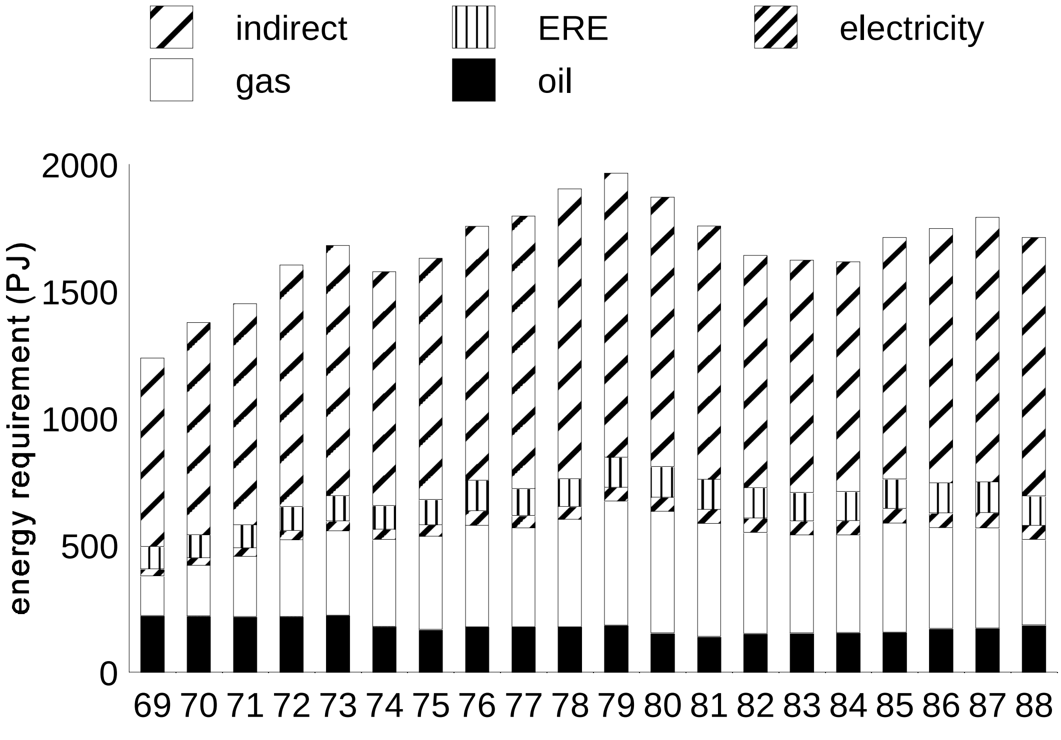

Figure 2 Direct (specified per energy carrier) and indirect energy requirements of Dutch households in 1969-1988 (Wilting, 1996).

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[2] This time series was calculated with sectoral input-output tables discerning 57 economic sectors (CBS, several years).

energy carrier, since the division is rather uncertain due to lack of reliable data series. Part of indirect energy consumption takes place abroad with possibly a quite different fuel mix. Besides, the output of production sectors is rather heterogeneous and only a part, with possibly a fuel mix deviating from the average, is aimed at households.

On the basis of expected growth in household consumption and improvements in energy efficiency, the energy requirement of households will further rise in the next decennia. We demonstrate these expectations by using three economic scenarios for the period 1995-2020 developed by the Netherlands Bureau for Economic Policy Analysis (CPB, 1996). The *Divided Europe* (DE) scenario assumes a low economic growth for Europe in relation to Japan and the US. The growth in the Dutch GNP in the DE scenario is the lowest for the three scenarios (1.5% per cent annually). The rise in the number of households (from 6.5 million households in 1995 to 7.5 million households in 2020) is also inferior to the other scenarios. The second scenario, the *European Coordination* (EC) scenario, can be seen as the mid-scenario. This scenario assumes a growth in GNP of 2.7 per cent annually and a rise in the number of households to 7.8 million in 2020. The *Global Competition* (GC) scenario shows the strongest economic growth: a 3.3 per cent annually growth in the GNP. Due to further individualization of society assumed in the GC scenario, families will be smaller resulting in 8.1 million households in 2020.

By using the parameters of the three scenarios concerning developments in household consumption patterns and energy efficiency, household energy requirements for the year 2020 were calculated. Figure 3 shows the possible developments in the energy requirement of

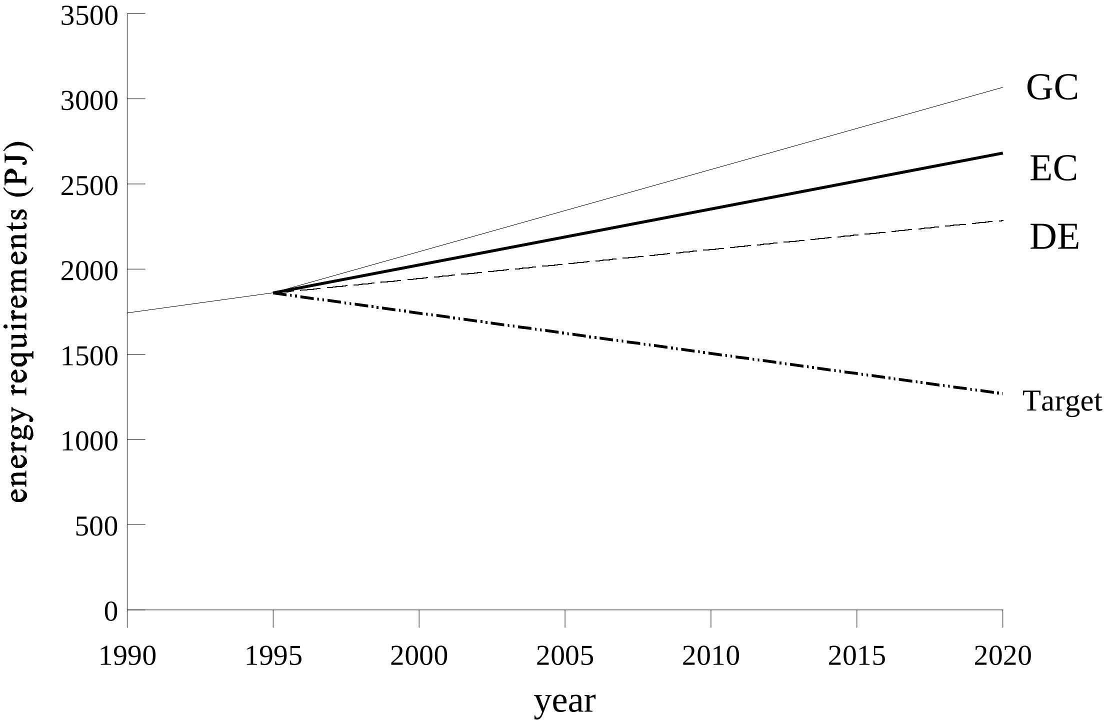

Figure 3 Four scenarios concerning the development of the household energy requirement in the period 1995-2020.

households for the three scenarios[3]. In the three CPB scenarios, the improvements in energy efficiency, which vary between 0.7% and 0.9% annually, are more than cancelled out by the growth in consumption. The 2020 energy requirement of households is 23-65% higher than that in 1995. The possible developments in the household energy requirement are downright opposite to a trend in the direction of sustainable energy consumption in 2050 (the lowest line in figure 3). Mulder and Biesiot (1998) derived a long-term target (about 70% reduction in household energy requirement in the year 2050 compared to 1995) from estimates concerning the global capacity of renewable energy production and population developments. The ratio of about 10-12 TW installed renewable capacity and about 8-10 billion of world citizens delivers 1-1.5 kW/caput by the year 2050 as an average long-term target value, about four times as low as the current per capita energy requirement in the Netherlands (Noorman et al., 1998). The 2050 long-term target corresponds with a reduction of 32% in 2020.

Methodology for evaluating energy conservation options

The energy-efficiency improvements assumed in the CPB scenarios are far from sufficient for sustainable household consumption. Therefore, we investigate to what extent extra energy conservation options can contribute to bridge the gap in the household energy requirement. This section presents a methodology for evaluating the effects of energy conservation options on the household energy requirement.

Energy conservation options are available at the level of individual sectors. An improvement in energy-efficiency in a certain sector decreases energy use in that sector. A shift in consumption to a less energy-intensive product may change energy use in several production sectors, even in other countries. Each energy conservation option is coupled with one or more elements of the five parameters of the input-output model. Technological options concerning energy efficiency improvements in both conversion and end-use of energy are implemented in the input-output model by changing the parameters $\mathbf{R}$, $\mathbf{D}^p$, and $\mathbf{D}^c$. Other options concerning changes in production processes in order to save energy, e.g. substitution of materials or changes in productivity, are implemented in the input-output model via parameter $\mathbf{A}$. The implementation of changes in the consumption pattern of households in the model is performed via the parameter $\mathbf{y}$. As an example, figure 4 shows the elements in the parameters $\mathbf{A}$ and $\mathbf{y}$ which are changed as a result of a reduction option concerning a shift from plastic to wooden furniture. The coefficients in the production column of furniture corresponding with the use of plastic and wood are changed[4]. Furthermore, the consumption of furniture may change as the result of price differences between plastic and wooden furniture and likely a longer lifetime of wooden furniture.

In order to determine if the long-term target can be reached, sets of energy conservation options have to be studied. Sets of options are implemented in the input-output model by

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[3] Since 1990 is the most recent year for which detailed input-output tables are available, this year served as starting-point in the calculations. In order to bring the 1990 household energy requirement in line with the CPB scenarios, we extrapolated the 1990 figures to 1995, the base year of the economic scenario studies. The rise in the household energy requirement in the period 1990-95 was almost 7%.

[4] A more detailed input-output table may consist of separate rows and columns concerning plastic and wooden furniture. In that case, the implementation of the option concerns a shift in the corresponding elements of the consumption vector.

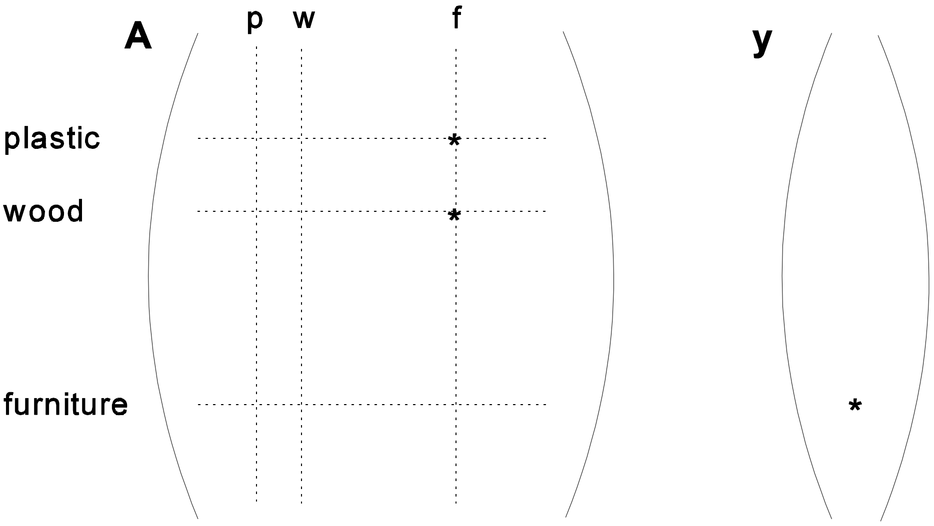

Figure 4 Elements of the technological matrix **A** and the consumption vector **y** that are changed in case of a shift from plastic furniture to wooden furniture.

changing several elements of the five model parameters simultaneously. The combined effect of all individual options determines the over-all effect on the household energy requirement with regard to the given set of options. The combined effect of a set of reduction options may be lower than the sum of the effects of the individual options. E.g. technical energy conservation options in greenhouse horticulture may decrease energy requirements of vegetables considerably. The same holds for a shift from greenhouse vegetables to season vegetables grown in open ground. However, the effect of combining both options will be less than the sum of the effects of the individual options.

Effects of energy conservation options

We illustrate the methodology by calculating the effect of conservation options described in the literature on the 1990 household energy requirement. We obtained technical energy conservation options from a database, named Icarus, containing data concerning several hundreds of technical energy conservation measures of all production sectors and of households realizable in a 25-year period (De Beer et al., 1994). A set of 20 demand-side energy conservation options concerning shifts between consumption categories and within consumption categories was obtained from Vringer et al. (1993, 1995), Brouwer (1998), Kramer (1998), Uitdenbogerd (1998) and Vringer (1998).

The 1990 household energy requirement, calculated with expression (1), is 1744 PJ of which 707 PJ (41%) is related to direct energy use in the households itself. Figure 5 gives an overview of the savings in the household energy requirement as a result of technological improvements in several economic sectors. The combined application of all technological options from the Icarus database results in a 55.0% decrease in the 1990 household energy requirement. Almost half of the savings can be attributed to households themselves: more efficient houses, appliances and private cars. The other savings are mainly accomplished by measures in industrial and service sectors. Figure 5 also shows the effect of measures in the energy supply system (ESS), e.g. improvements in efficiency in electricity production, on the household energy requirement. These savings (5.9%) concern the savings in the ESS without the implementation of measures in the other sectors. After implementing all measures in the production sectors, the savings in the ESS are 3.7%.

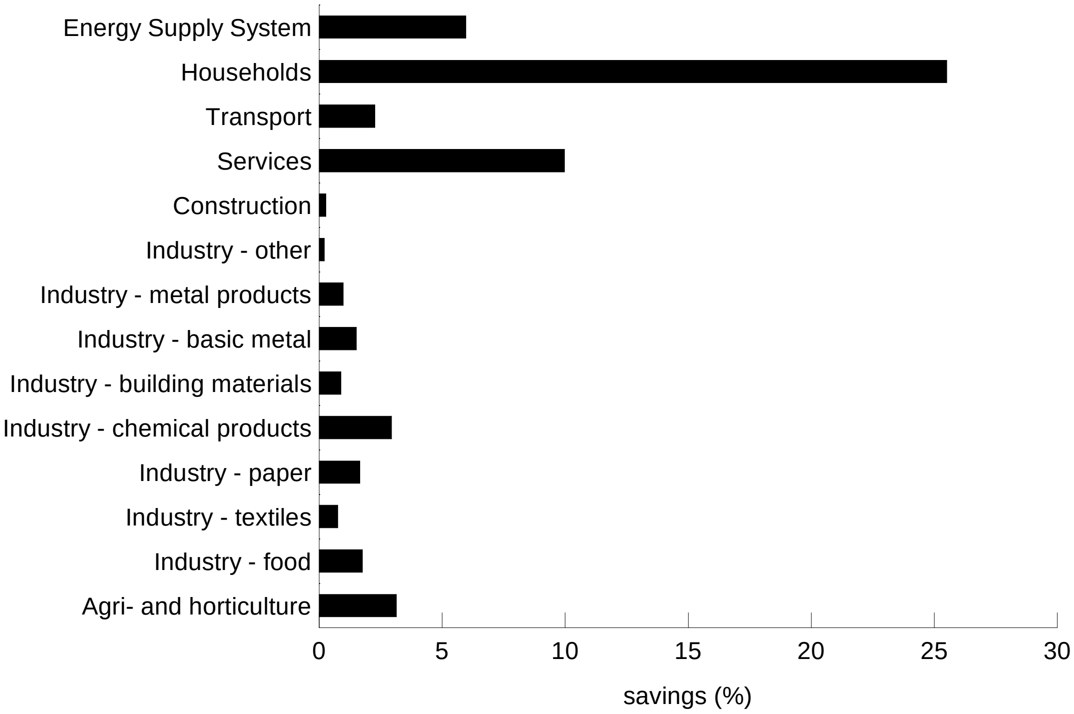

Figure 5 Savings in the household energy requirement (%) as a result of implementing technical energy conservation options in production and consumption sectors.

The demand-side options used concern several household consumption categories: food, clothing and maintenance of clothing, household effects, recreation, holidays and transport. For each demand-side option, the corresponding parameters in the model were adapted. Figure 6 shows the individual effects of the demand-side options on the household energy requirement. Options with a more than 1% change in the household energy requirement are in the category of holidays. The sum of the savings as a result of implementing the 20 demand-side options listed in figure 5 is 10.4%. However, the implementation of the demand-side energy conservation options resulted in a reduction in the household energy requirement of 9.3%. The reduction based on combining both technological and demand-side options is 59.2%. Since this figure is somewhat smaller than the sum of the potentials based on both sets separately (64.4%), the

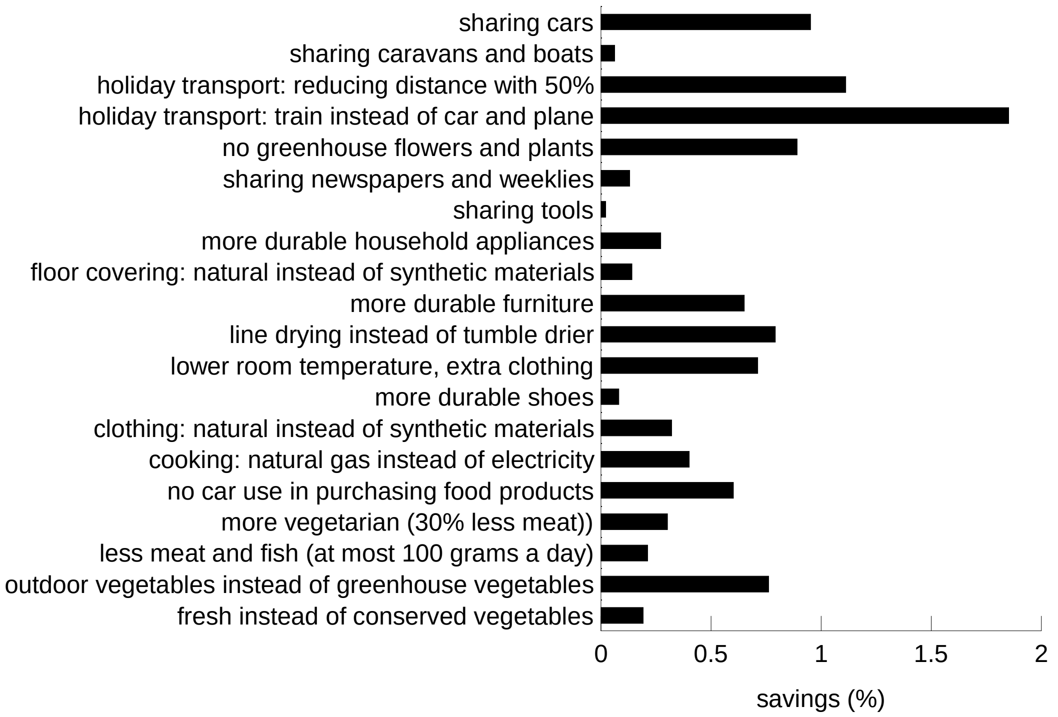

Figure 6 Savings in the household energy requirement (%) as a result of implementing demand-side energy conservation options.

combined effect of options is diminished. The 1990 household energy requirement decreases to 780 PJ. The direct energy use of households is more affected with energy conservation options than indirect energy use. The share of the direct energy requirement in the total energy requirement of households decreases to 33%.

We now combine the reduction options with the EC scenario (as the mid-scenario) allowing for economic and demographic developments in the coming decennia. Without reduction options, the EC scenario results in a growth of 44% in the household energy requirement in the period 1995-2020. Figure 7 shows the effects of implementing technological and demand-side conservation options on the 2020 energy requirement of households. The application of all technological options from the Icarus database results in a decrease in the household energy requirement of 37% compared with the EC scenario. This figure is lower than the effect on the 1990 household energy requirement, since the EC scenario also allows for energy-efficiency improvements (0.9% annually). Combining technological and demand-side energy conservation options results in a total reduction in household energy requirement of about 43% compared with the EC scenario. This figure is still 10% less than the 2020 target reduction[5]. In order to reach this long-term target, more extreme demand-side energy conservation options have to be implemented. Besides, the implementation of technological and demand-side options also affects total household expenditures which are about 3% lower than in the EC scenario. In case this saved money is spent on other consumption items, the household energy requirement

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[5] In case of the DE scenario, the 2020 target will be achieved.

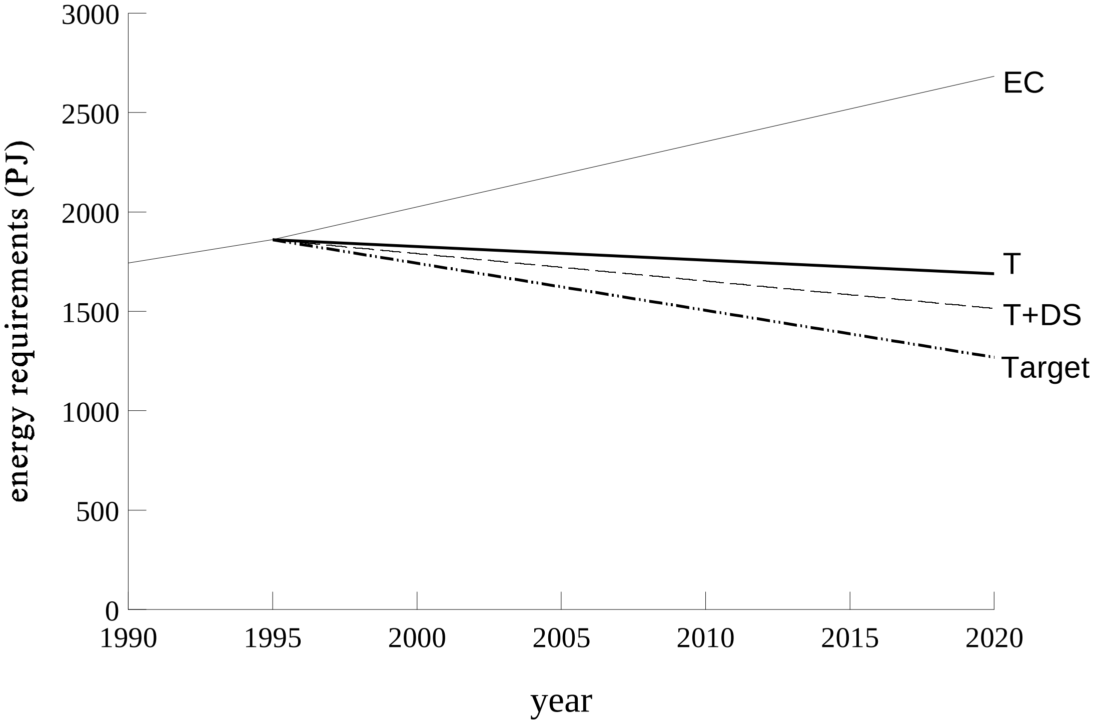

Figure 7 The 2020 energy requirement of Dutch households in the EC scenario, after implementing extra technological options (T), and both technological and demand-side options (T+DS). The target line indicates the direction to sustainable household consumption in 2050.

will be higher.

Discussion and conclusions

The research described in this paper is a first step in evaluating the effects of energy conservation options by using input-output analysis. We presented a methodology for evaluating technological and demand-side energy conservation options based on an input-output model for the calculation of the energy requirement of households. The case study concerning the savings in the Dutch household energy requirement showed the applicability of the methodology. The input-output framework enabled an easy investigation of the effects of both individual options and sets of options on the household energy requirement. Besides, the use of input-output analysis enables (future) research directed on the effects of these options on several economic parameters. The implementation of the demand-side energy conservation options particularly effects the economy, e.g., on the size of economic sectors, GDP and employment, etc. The evaluation of individual energy conservation options may result in a ranking of energy conservation options concerning the effect on energy use and economic parameters. The outcome of such considerations clarifies the social significance of separate energy conservation options.

The savings achieved in the household energy requirement depend on the set of energy conservation options used. Especially the choice of demand-side options, e.g., the reduction of holiday transport (50%) or the reduction of meat consumption (30%), is arbitrary. So, savings may be determined for different sets of options, e.g., a moderate set against a more extreme set of options. The choice for a set of reduction options may be based on the economic feasibility of technical energy conservation options or the willingness of households to accept shifts in consumption. In choosing a set of demand-side options other household constraints, e.g. time and money, have to be taken into account. The methodology does not give directions on how to implement the energy conservation options in practice.

The approach described is generally applicable, but considering the easy access to data, the Netherlands was taken as an example. So, we restricted to the energy requirement of Dutch households. The energy requirement does not correspond with energy use in the Netherlands. The energy use in the economic production sectors is also aimed at, e.g., exports and investments. Vice versa, in other countries, energy is used for the production of goods and services for Dutch households. So, the reduction potential of Dutch energy use will be different from that of the household energy requirement.

The case study showed that the implementation of both technological and demand-side energy conservation options may bring about a reasonable reduction in the household energy requirement. The implementation of known technological options reduced the 1990 household energy requirement with 55%. The implementation of the set of demand-side options resulted in a decrease of 9%. The combined effect of both types of options was smaller than the sum of the effects of the separate options. Obviously, the effect of some energy conservation options is diminished by combining them. Since the set of energy conservation options considered has more impact on the direct energy requirement than on the indirect energy requirement, the share of the direct energy requirement in the total household energy requirement declined from 41% to 33%.

According to three economic scenario studies, the energy requirement of Dutch households will rise in the coming decennia (23-65% increase related to the 1995 value). The implementation of technological and demand-side options decreases the 2020 household energy requirement (EC scenario) with 43%. This decrease is not sufficient to bridge the gap to a scenario directed on sustainable household consumption in 2050.

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