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# Pursuing More Sustainable Consumption by Analyzing Household Metabolism in European Countries and Cities

*Henri C. Moll, Klaas Jan Noorman, Rixt Kok, Rebecka Engström, Harald Throne-Holst, and Charlotte Clark*

## Keywords

cross-national comparisons  
energy  
Energy Analysis Program (EAP)  
environmental load  
industrial ecology  
materials flow analysis (MFA)

## Summary

Bringing about more sustainable consumption patterns is an important challenge for society and science. In this article the concept of household metabolism is applied to analyzing consumption patterns and to identifying possibilities for the development of sustainable household consumption patterns. Household metabolism is determined in terms of total energy requirements, including both direct and indirect energy requirements, using a hybrid method. This method enables us to evaluate various determinants of the environmental load of consumption consistently at several levels—the national level, the local level, and the household level.

The average annual energy requirement of households varies considerably between the Netherlands, the United Kingdom, Norway, and Sweden, as well as within these countries. The average expenditure level per household explains a large part of the observed variations. Differences between these countries are also related to the efficiency of the production sectors and to the energy supply system. The consumption categories of food, transport, and recreation show the largest contributions to the environmental load. A comparison of consumer groups with different household characteristics shows remarkable differences in the division of spending over the consumption categories.

Thus, analyses of different types of households are important for providing a basis for options to induce decreases of the environmental load of household consumption. At the city level, options for change are provided by an analysis of the city infrastructure, which determines a large part of the direct energy use by households (for transport and heating). At the national level, energy efficiency in production and in electricity generation is an important trigger for decreasing household energy requirements.

## Address correspondence to:

H. C. Moll  
Center for Energy and Environmental  
Studies IVEM  
University of Groningen  
Nijenborgh 4  
9747 AG Groningen, The Netherlands  
<h.c.moll@fwn.rug.nl>

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## Introduction

The last decades have witnessed an enormous growth in production and consumption levels. Related to this production and consumption, environmental decay is occurring everywhere around the globe. The World Summit on Sustainable Development in Johannesburg (WSSD 2002) found that

Fundamental changes in the way societies produce and consume are indispensable for achieving global sustainable development. All countries should promote sustainable consumption and production patterns, with the developed countries taking the lead and with all countries benefiting from the process. . . Governments, relevant international organizations, the private sector and all major groups should play an active role in changing unsustainable consumption and production patterns. (WSSD 2002, Chapter III, point 14)

Quantification of the environmental load related to consumption is required to facilitate this process.

In the 1970s an approach to modeling the total energy use due to a household's consumption was developed by Bullard and Herendeen (see Bullard and Herendeen 1975; Herendeen and Tanaka 1976; Bullard et al. 1978). This approach takes into account both direct energy use, such as heating and motor fuel, and the indirect energy use required to produce the products and services consumed by a household. This approach was further extended in the Netherlands by Biesiot and Moll (1995) and by Vringer and Blok (1995). They analyzed the Netherlands household energy requirements of 1990 in detail, using data on energy use in the Dutch economy and on Dutch household expenditures. Studies have also been performed to determine the energy requirements and/or the CO<sub>2</sub> emissions related to household consumption in several other countries (Cohen et al. 2005; Pachauri 2004; Kim 2002; Bin and Dowlatabadi 2005; Munksgaard et al. 2000; Reinders et al. 2003; Lenzen 1998). In these studies, energy use (and the related greenhouse gas emissions) has been chosen as the most significant proxy indicator of environmental load.

All of these studies have demonstrated that the contribution of household consumption to the environmental load of the economy is substantial. The environmental load is partially caused by energy use within households, but a substantial remaining part of the environmental load is attributed to the consumption of goods and services by households. In total 70–80% of national energy use and greenhouse gas emissions may be related either to household activities directly or to activities required to deliver goods and services to households and to manage the waste flows generated by households.

These findings generate new research questions:

- What are the determining factors that may explain the environmental load due to household consumption?
- Which parts of household consumption patterns may be susceptible to environmentally relevant changes, and in what ways can the environmental load of consumption be diminished by changes at other levels?
- What advice can be given to individual households, to the government, and to the economic and institutional actors at each level of society to effect change in household consumption patterns toward a sustainable direction?

These questions are discussed and elaborated in the studies mentioned above, mostly at the level of a single country and using broad categories to describe household consumption. So the answers to these questions provided by these previous studies have a preliminary or incomplete status. In this article we present a cross-national comparison of the average household energy requirements of the Netherlands, the United Kingdom, Norway, and Sweden, and we analyze in greater detail within these countries the household energy requirements of some cities and of some household groups.<sup>1</sup> Our results, produced in the ToolSust project,<sup>2</sup> are useful in elaborating these three research questions.

First we present a framework for identifying the main determinants of the environmental load of households, and then we develop approaches for recognizing the triggers for diminishing this environmental load. The potential consequences

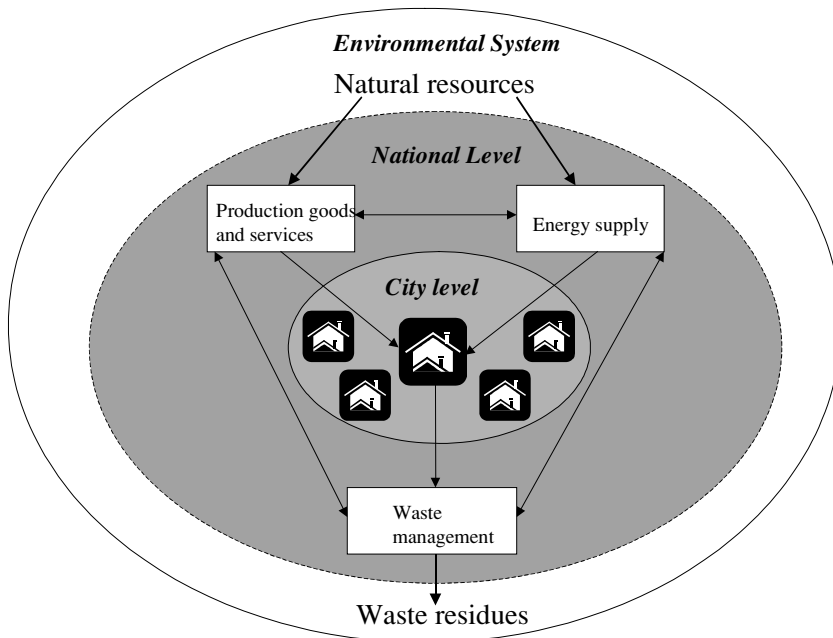
of following this methodology to perform this research are discussed, and findings relevant to these research questions are presented. Finally, we derive some conclusions about the determining factors and about the potential for change, and we discuss how this research may contribute to the development of sustainable consumption patterns.

### Conceptual Approach: Depicting the Household Energy Metabolism

The “industrial metabolism” concept refers to the flows of natural resources entering the production side of the economy and the flows of goods and services—to be consumed and/or exported—and of wastes and emissions to the environment leaving the production sectors. Seen from the consumer perspective the consumption of goods and services can be linked to patterns of inputs and outputs of the economy and, thus, to the associated environmental effects of economic activities. Because the major part of consumer activities takes place within households, households rather than individual consumers de-

termine a large part of resource consumption. The “household metabolism” concept refers both to the demand for resources (the direct flows of resources through households) and to the indirect requirements for resources—the flows of resources occurring elsewhere to accomplish household consumption (e.g., in mining, the production of materials, the construction of houses, the manufacturing of goods, and the handling of waste) (see Noorman and Schoot Uiterkamp 1998).

In figure 1 these energy flows are presented, relating the use of natural resources to consumption in households. Natural resources are extracted out of the environmental system and converted to energy carriers supplied directly to the households and to the production sectors supplying the households. The disposal of goods by the households also has effects on the indirect energy use by households. In this figure, two intermediate levels also are discerned between the environmental system and the households. National conditions mainly determine the energy supply system and factors related to the production of goods and services in the economic sectors. The city infrastructure partly determines the travel



**Figure 1** System description of household energy metabolism.

behavior of households and also influences the local energy supply to households.

Direct household energy consumption—energy that is literally consumed in households (electricity, natural gas, etc.) or via car fuels—composes a fraction of the national energy consumption (about 35%). Indirect energy flows, on the other hand, are very substantial. The indirect energy consumption of households is equal to the energy directly used for producing and distributing consumer goods and services and for handling consumer waste. The direct and indirect energy requirements are calculated as primary energy values. Primary energy use refers to the energy content of the resources required to deliver the final energy to be used (in forms such as electricity, motor oil, and heat) to the production sectors and to the households.

The total household energy requirement is calculated as the sum of the direct and indirect energy requirements. So the total household energy requirements are determined largely by the household spending pattern. This approach reflects the interdependency between industrial metabolism and household metabolism (see figure 1): Changes in the production processes of consumer items have a significant impact on the indirect household energy use, and changes in consumption patterns have effects on the structure of the production side of the economy.

This system description implies that determinants of the total household energy requirements may occur at several levels: the national level, the city level, and the household level. How relevant these levels are to understanding and to changing consumption patterns in the direction of sustainability is further researched in this article.

### **Methodological Approach: Hybrid Energy Analysis of Household Consumption**

The method we used, based on the household energy metabolism concept, projects the energy requirements in production, distribution, consumption, and waste processing for household consumption on household budget items. This analysis generates insights into the relationship between household spending patterns and the effects thereof (counted as direct and indirect en-

ergy requirements). This method, which assesses the energy requirements of budget items, is outlined in figure 2. In a hybrid approach elements of process analysis and input-output analysis are combined, building on the advantages of both methods. This approach requires statistical data concerning energy production and consumption, economic input-output matrices, household budget surveys, and goods and services price information. This method had been outlined by Bullard and colleagues (1978) and has been elaborated by Van Engelenburg and colleagues (1991) and Wilting (1996).

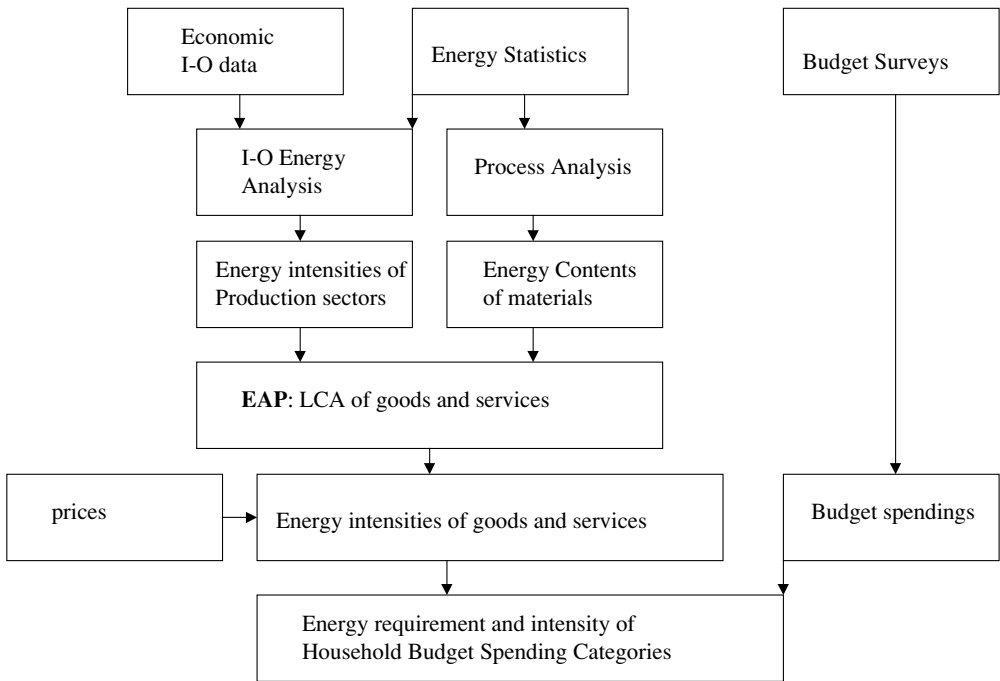
The combination of sector production data and energy data delivers data on the direct energy intensities of the various production sectors. Energy intensities are defined as the energy requirements divided by the monetary value (added), expressed in megajoules per Euro (MJ/Euro).<sup>3</sup> Process analysis is also used to determine the energy requirements (expressed in megajoules per kilogram [MJ/kg]) of a range<sup>4</sup> of (over 100) basic materials frequently used in the delivery and consumption of goods and services. The input-output energy analysis methodology is used to calculate the indirect energy intensities of the production sectors. The data sets are used in a simplified life-cycle assessment (LCA) of goods and services corresponding to the items included in the household budget surveys. The LCA results are calculated by and stored in a software program called the Energy Analysis Program (EAP) and its related database (Wilting et al. 1999). For a detailed description of the EAP methodology and calculations schemes we refer to work by Wilting (1996).

#### **The EAP Databases**

The EAP approach uses the following databases:

- energy requirements for basic materials;
- energy intensities of economic sectors;
- energy requirements of modes of transport;
- energy intensities of trade and services sectors; and
- energy requirements for waste processing.

Energy requirements for basic materials, transport modes, and waste processing are derived from



**Figure 2** Flowchart of the method for calculating energy parameters of budget spending categories (budget items). I-O = input-output; EAP = Energy Analysis Program; LCA = life-cycle assessment.

a variety of studies presenting process descriptions, energy statistics, and LCAs.

The energy intensities of the production, trade, and service sectors were calculated using country-specific energy data and economic data in the format of input-output tables.

The following economic data were used:

- an input-output table with intermediate deliveries, total production value, and net value added in basic prices;
- an input-output table with competitive and (where available) noncompetitive imports (competitive imports are imported commodities that are also produced domestically, whereas noncompetitive imports are not produced domestically);
- a data table of energy prices paid by the producing sectors; and
- a data table of the consumption of fixed capital (depreciation of capital goods).

In addition to economic data, the following energy data were used:

- energy consumption data per sector, categorized per fuel type; and
- energy data describing the losses in energy transformation processes (e.g., refining oil, generating electricity) determining the ratio between primary energy use and final energy use, expressed in the so-called energy requirement for energy (ERE) value.

### **EAP Analyses**

Once the EAP databases were available, EAP was used to calculate the energy intensities of products (i.e., budget items). The selection of budget items was based on the structure of the available household budget surveys. A separate EAP analysis has to be carried out to calculate the energy intensity each consumer item. For these EAP analyses, different types of information are needed:

- price information (i.e., consumer price of the product, including value-added tax);

- composition of the product (i.e., type and amount of the basic goods and type and amount of packaging materials);
- origin of the product (i.e., name of the manufacturer, names of the wholesale and retail trade, and transport distances); and
- how the consumer product is treated after it is used (i.e., waste processing, including recycling).

With help of these data, EAP calculates the energy intensity of each budget item. Dutch EAP analyses were used as a default in many cases where country-specific information was not available. The total energy requirement of the households was calculated by combining the information on energy intensities of the budget items with the expenditure data from the household budget survey.

The household energy requirements for the Netherlands were calculated following this approach for the year 1990 (Biesiot and Moll 1995) and 1996 (Kok et al. 2001). In the ToolSust project, for three other countries—the United Kingdom (UK), Sweden, and Norway—EAP country-specific databases were developed for the first time. Also, country-specific EAP analyses were performed of all of the items in each country's budget survey. The Dutch EAP database and Dutch budget items analyses served as a starting point, but as far as possible country-specific data were applied. Also, some methodological adjustments were made on the EAP approach in order to make it applicable in other European countries. The processes used to develop country-specific databases and analyses are found in Clark and colleagues (2003), Carlsson-Kanyama and colleagues (2002), and Throne-Holst and colleagues (2002).

### Evaluation of Determinants for the Total Household Energy Requirement

As mentioned earlier the total household energy requirement is determined by various factors related to the different levels—the national level, the city level, and the household level. Assessing the relevance of these factors is important for the identification of the triggers for changing

household consumption patterns in a sustainable direction.

Comparative analysis is necessary to measure the importance of these factors. For a full evaluation, comparisons are required between countries to examine the determinants related to the national level, comparisons are required within countries between national data and data from specific cities to examine locally determined factors, and comparisons are required between household groups within a country to examine the role of household characteristics.

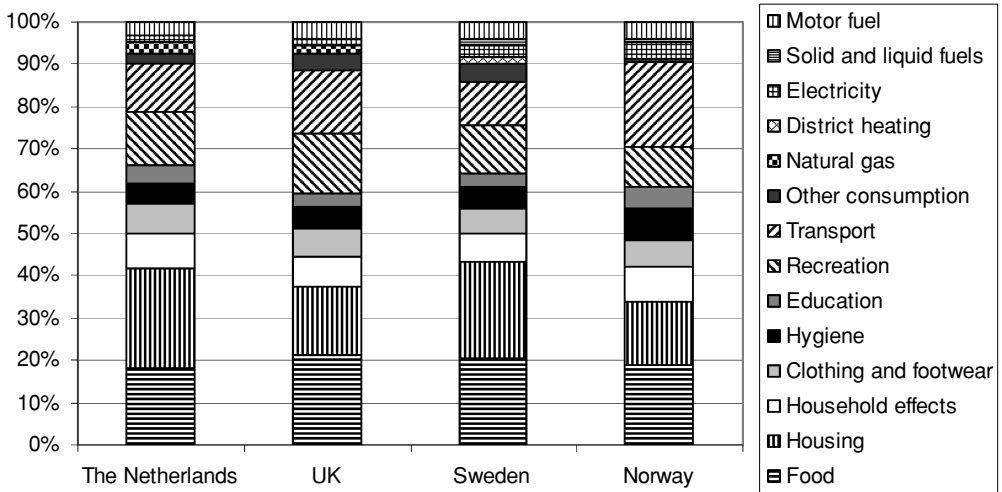
The results of the ToolSust project enable us to make some of these comparisons, indicating the most relevant determining factors as well as the levels at which these factors may be influenced. Here we present some results grouped around the comparisons made at the national level, the city level, and the household level.

### Comparisons of Household Energy Metabolism between Countries

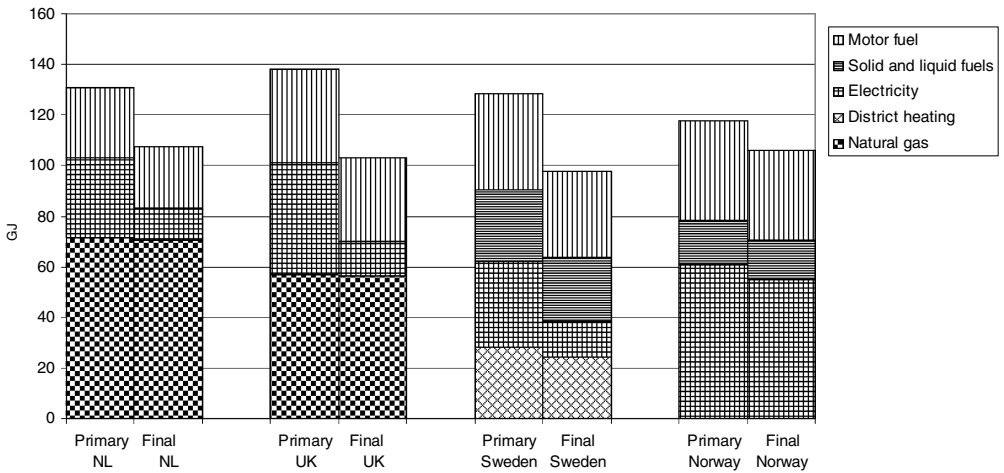
Household consumption patterns and the household metabolism of The Netherlands, the United Kingdom, Sweden, and Norway are compared here. See Kok and colleagues (2003) for the comparative results and Falkena and colleagues (2003), Clark and colleagues (2003), Carlsson-Kanyama and colleagues (2002), and Throne-Holst and colleagues (2002) for country-specific results.

Figure 3 shows the total expenditures of households and the division of the expenditures over budget categories. The total expenditure per household in Norway is the highest, with 27,900 Euro per year, followed by the United Kingdom with 25,500 Euro per year; the lowest are the Netherlands and Sweden with 21,400 and 20,300 Euro per year respectively. When looking at the relative importance of the different budget categories, the most important similarities (and differences) between the countries are the following:

- low expenditures on the aggregate of direct energy categories (motor fuel, solid and liquid fuels, electricity, district heating, and natural gas), ranging from 7 to 10%;
- high expenditures on the food category in all countries, ranging from 18 to 21%;



**Figure 3** Division of expenditures per budget category for an average household in the different countries.

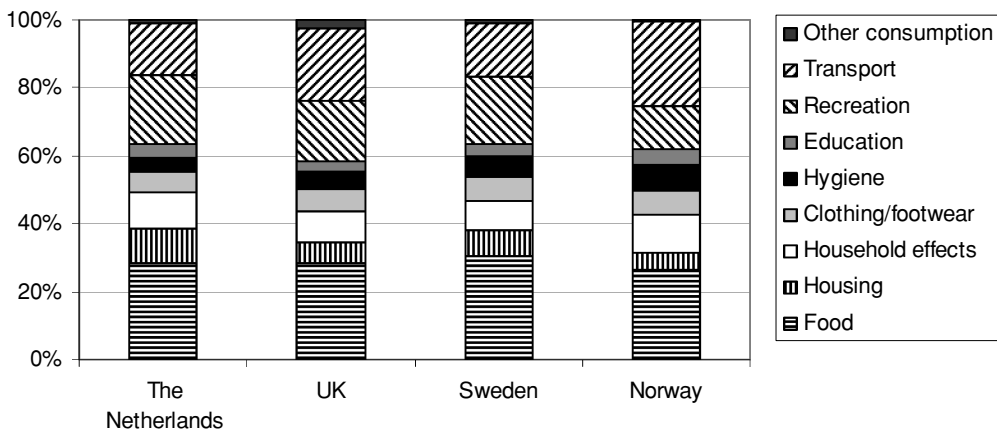


**Figure 4** Primary and final annual energy requirements in the different countries. Note: One gigajoule (GJ) =  $10^9$  joules (J, SI)  $\approx 2.39 \times 10^5$  kilocalories (kcal)  $\approx 9.48 \times 10^5$  British thermal units (Btu).

- high expenditures on the house category in all countries, ranging from 15 to 23%;
- high expenditures on the transport category (excluding motor fuels), ranging from 10 to 20%; (transport expenditures generally are relatively high in countries with high total expenditures, and are by far the highest in Norway);
- high expenditures on the recreation category, ranging from 9 to 14% (recreation expenditures in the United Kingdom and the Netherlands are relatively higher than in Sweden and Norway); and
- expenditures on other categories are relatively low and do not differ substantially between the different countries.

The first part of the total household energy requirement is the direct energy portion. The primary and final direct energy use of households in the various countries are given in figure 4. The primary household energy use is relatively low in Norway and is relatively high in the United Kingdom. For the final demand, though, the differences between the countries are small. So the differences between the countries in primary





**Figure 5** Division of indirect energy requirements over the budget categories in the different countries.

energy use by households are mainly caused by differences in the energy supply. The use of hydropower in Norway explains relatively low primary energy use, although the final energy use is high. For the United Kingdom the low efficiency due to the large shares of coal for electricity production explains high primary energy use by the United Kingdom. Comparing the division of the final energy demand, we observe a very high share of electricity in Norway and a high share of natural gas in the Netherlands. In the Netherlands the share for motor fuel is low compared to the other countries.

Figure 5 shows the total indirect energy requirement per household and the relative shares of the indirect budget categories for the countries. The indirect energy requirement is the highest in the United Kingdom, closely followed by Norway. The indirect energy requirements for Sweden and especially for the Netherlands are much lower. With regard to the division of indirect energy over the budget categories, we observe some striking similarities and some differences:

- The food category has the highest indirect energy requirement in all countries, ranging from 26 to 32% of the total indirect energy requirement.
- The transport and recreation categories are important in each country. Of these categories, transport has the highest energy requirement in Norway and in the United Kingdom, and recreation has the highest

energy requirement in the Netherlands, followed closely by the United Kingdom and Sweden;

- The house category has a low share of the indirect energy requirement (at most 10%), although the expenditures for houses are high (see figure 3).
- Other indirect budget categories have a minor share in the indirect household energy requirement.

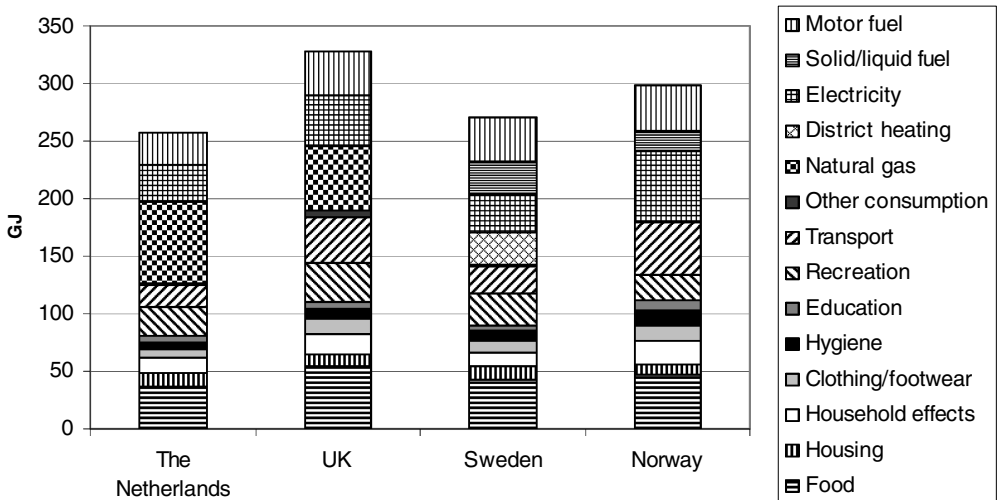
Differences between the countries with regard to the average indirect household energy requirements are partly explained by differences in the amounts of money spent. The differences of indirect energy intensities deliver another part of the explanation. In table 1 the energy intensities of the indirect budget categories and the total average indirect energy intensities are given for all countries. These figures clarify earlier-stated observations about the indirect energy requirements for the budget categories. The table demonstrates the following general pattern:

- The energy intensities of the food, transport, recreation, and household effects categories are high for all countries;
- Other indirect budget categories have low energy intensities.
- On average the indirect energy intensity is highest in the United Kingdom, followed closely by Sweden. Norway is in the middle,

**Table I** Indirect energy intensities of the different budget categories

Category	The Netherlands MJ/Euro	United Kingdom MJ/Euro	Sweden MJ/Euro	Norway MJ/Euro
Food	9.4	9.9	10.4	8.9
House	2.4	2.8	2.5	2.2
Household effects	7.7	9.0	8.8	8.8
Clothing and footwear	4.8	7.6	8.6	7.1
Hygiene	5.6	7.5	8.0	6.8
Education	5.3	6.9	8.2	5.9
Recreation	9.5	9.2	12.4	8.5
Transport	8.0	10.5	10.5	7.9
Other consumption	2.4	5.1	1.9	6.2
Total indirect energy intensity	6.4	8.0	7.8	7.1

Note: One megajoule (MJ) =  $10^6$  joules (J, SI)  $\approx$  239 kilocalories (kcal)  $\approx$  948 British thermal units (Btu).



**Figure 6** Total annual energy requirements and energy requirement per budget category for an average household in the different countries. Note: One gigajoule (GJ) =  $10^9$  joules (J, SI)  $\approx$   $2.39 \times 10^5$  kilocalories (kcal)  $\approx$   $9.48 \times 10^5$  British thermal units (Btu).

and the Netherlands has the lowest figures for the indirect intensities.

The total energy requirements of the countries are shown in figure 6. The important role of indirect energy requirements is demonstrated by this graph. The total energy requirement is highest for the United Kingdom and lowest for the Netherlands, just as for the indirect energy requirement portion alone.

Although expenditures on direct energy have only a minor share in the total household expenditures, direct energy use is responsible for a large share of the total energy requirement. Direct and indirect household energy requirements

are roughly of the same order of magnitude. Some summarizing results are presented in table 2. This table shows that the share of direct energy use in the Netherlands and in Sweden is around 50%, whereas the share in the United Kingdom and in Norway is around 40%.

### Comparisons of Household Energy Metabolism within Countries

Household consumption patterns and household metabolism are compared here within two countries, juxtaposing the national averages of the Netherlands and Sweden with the

**Table 2** Overview of the household metabolism results for the four countries

	<i>The Netherlands</i>	<i>United Kingdom</i>	<i>Sweden</i>	<i>Norway</i>
Expenditure (1,000 Euro)	21.4	25.4	20.3	27.9
Total energy requirement per household (GJ)	257	327	271	298
Total energy requirement per person (GJ)	112	135	123	130
Average total energy intensity (MJ/Euro)	12.0	12.9	13.3	10.7
Average indirect energy intensity (MJ/Euro)	6.4	8.0	7.8	7.1
Share of direct energy use (%)	51	42	47	40

Note: One megajoule (MJ) =  $10^6$  joules (J, SI)  $\approx$  239 kilocalories (kcal)  $\approx$  948 British thermal units (Btu). One gigajoule (GJ) =  $10^9$  joules.

**Table 3** Overview of household metabolism results for the Netherlands (on a national and a city level) and for Sweden (on a national and a city level)

	<i>The Netherlands</i>		<i>Sweden</i>	
	<i>National average</i>	<i>City of Groningen</i>	<i>National average</i>	<i>City of Stockholm</i>
Expenditures per household (in 1,000 Euro/yr)	21.4	14.1	20.3	20.9
Household size (persons)	2.3	1.5	2.2	1.8
Total energy requirement per household (GJ/yr)	257	168	271	246
Total energy requirement per person (GJ/yr)	112	111	123	137
Indirect energy requirement per household (GJ/yr)	126	83	142	151
Share of direct energy requirement (%)	51	50	47	39
Average indirect energy intensity (MJ/Euro)	6.4	6.4	7.8	7.7
Average total energy intensity (MJ/Euro)	12.0	11.9	13.3	11.8

Note: One megajoule (MJ) =  $10^6$  joules (J, SI)  $\approx$  239 kilocalories (kcal)  $\approx$  948 British thermal units (Btu). One gigajoule (GJ) =  $10^9$  joules.

city averages of Groningen (a Dutch city) and Stockholm (the capital of Sweden).

In table 3 results are given with regard to average household expenditures, household size, total energy requirement per household and per person, indirect energy requirement per household, the share of direct energy, and the total and indirect intensities of consumption.

The expenditures per household are lower in the city of Groningen than the national average for the Netherlands, but the expenditures per person in the city of Groningen are the same as for the Netherlands. For the total energy requirement, the same pattern may be observed. Although the energy requirements per person are the same, differences are found in the direct energy requirement, as follows:

- motor fuel use is lower in the city of Groningen, explained by the low car possession rate in the city;

- notwithstanding the smaller average size of the houses in the city of Groningen, natural gas use is higher in the city, mainly explained by climatic differences in the Netherlands.

The expenditures per household are a little bit higher in Stockholm than the average for Sweden, but the household energy requirement in Stockholm is lower than on average in Sweden. Due to the lower average number of persons per household in Stockholm, the total energy requirement per person in Stockholm is higher than on average in Sweden. For all indirect categories the energy requirements per person in Stockholm are higher than for Sweden, the energy requirement for heating and appliances is approximately the same, and the energy use for motor fuel is considerably lower in Stockholm.

**Table 4** Overview of the results for households of different income groups in the Netherlands

	First quarter	Second quarter	Third quarter	Fourth quarter
Total indirect energy intensity (MJ/Euro)	5.6	6.0	6.3	6.5
Total energy intensity (MJ/Euro)	13.4	12.7	12.2	11.5
Share of direct energy use (%)	62	57	53	48
Total energy requirement per household (GJ/yr)	141	204	263	347

Note: Four income classes; the first quarter refers to the lowest 25% income class, and the fourth quarter refers to the highest 25% income class. One megajoule (MJ) =  $10^6$  joules (J, SI)  $\approx$  239 kilocalories (kcal)  $\approx$  948 British thermal units (Btu). One gigajoule (GJ) =  $10^9$  joules.

**Table 5** Overview of the results for households of different income groups in the United Kingdom

	First quintile	Second quintile	Third quintile	Fourth quintile	Fifth quintile
Total indirect energy intensity (MJ/Euro)	7.8	7.9	7.9	8.2	8.2
Total energy intensity (MJ/Euro)	15.1	13.8	12.8	12.3	11.6
Share of direct energy use (%)	53	47	43	38	33
Total energy requirement per household (GJ/yr)	142	218	297	401	579

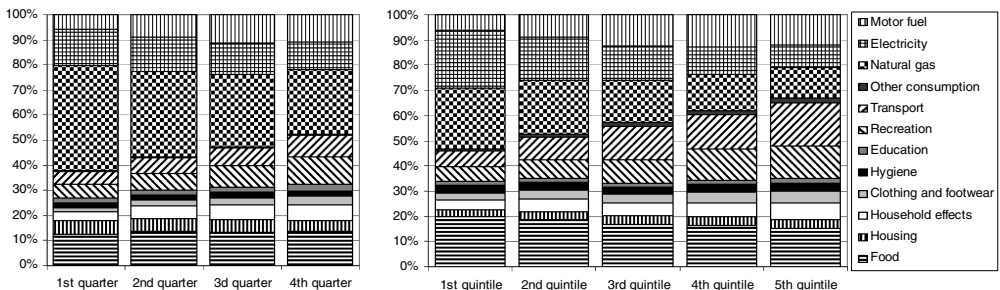
Note: Five income classes; the first quintile refers to the lowest 20% income class, and the fifth quintile refers to the highest 20% income class. One megajoule (MJ) =  $10^6$  joules (J, SI)  $\approx$  239 kilocalories (kcal)  $\approx$  948 British thermal units (Btu). One gigajoule (GJ) =  $10^9$  joules.

### Comparisons of Household Energy Metabolism within Countries at the Level of Consumer Groups with Different Household Characteristics

The dependence of household consumption patterns and household metabolism on the income variable, the household size variable, and the household composition variable is analyzed here for two countries: the Netherlands and the United Kingdom.

In tables 4 and 5 some results are given for the relationship between total household energy

requirement and income for the Netherlands and for the United Kingdom, respectively. A strong rising trend is observed in total energy requirements with increased income, although the relationship is not proportional (e.g., for the Netherlands the income ratio between the fourth and the first quarter is almost 3, whereas this ratio for energy requirements is about 2.5). For all individual budget categories, the energy requirements increase with income as well. The shares of the household total energy requirement for each of the budget categories are shown for the different income classes in figure 7. In the Netherlands



**Figure 7** Share of different budget categories in total annual energy requirements for households from different income groups in the Netherlands (left) and the United Kingdom (right).

**Table 6** Overview of results for households in the region of Groningen with various household sizes

	One person	Two persons	Three or more persons
Total indirect energy intensity (MJ/Euro)	5.8	6.4	6.7
Total energy intensity (MJ/Euro)	13.2	13.2	13.1
Share of direct energy use (%)	59	55	53
Total energy requirement per household (GJ/yr)	146	258	320
Total energy requirement per person (GJ/yr)	146	129	82

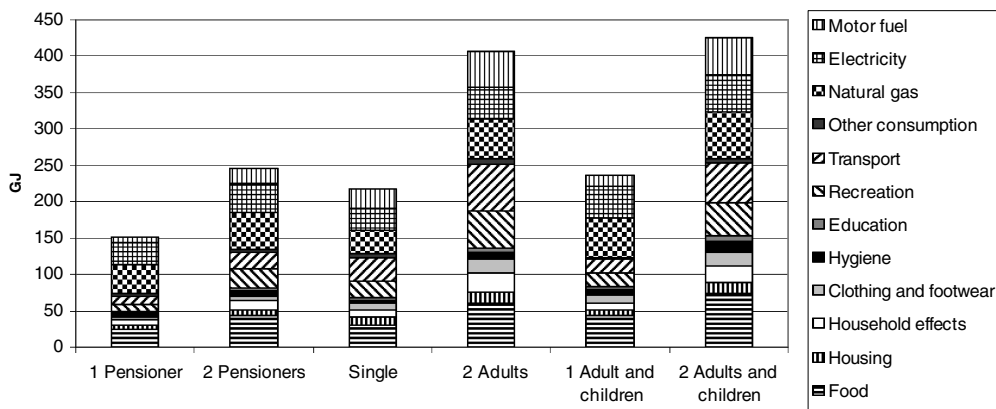
Note: One megajoule (MJ) =  $10^6$  joules (J, SI)  $\approx$  239 kilocalories (kcal)  $\approx$  948 British thermal units (Btu). One gigajoule (GJ) =  $10^9$  joules.

the shares for the categories of transport and recreation increases with income, whereas the shares for electricity and natural gas decrease with income. In the United Kingdom we see the same pattern, but the share of the food category also decreases. The share of direct energy use decreases with income from 62 to 48% in the Netherlands and from 53 to 33% in the United Kingdom. The decreasing share of direct energy explains the fact that the total energy intensity decreases with higher income. The average energy intensity of the indirect categories, on the other hand, increases with higher income. In both countries the increasing indirect energy intensity is mainly due to the heavily increasing categories of recreation and transport.

Table 6 shows the total energy requirements of households in the Netherlands for various household sizes. The energy requirements (just like the expenditure level) increase with grow-

ing household size. The average household size of a 3+-person household is 3.9 persons. Table 6 demonstrates that the total energy requirement per person for different household sizes decreases substantially with rising household size, especially for the 3+ person households. The share of direct energy use decreases slightly with rising household size. It turns out that the total energy intensity is the same for all households. The indirect energy intensity, however, is highest for the largest households, implying a more energy-intensive spending pattern.

Figure 8 shows the total energy requirements of households in the United Kingdom with different household characteristics, and in table 7 some quantitative findings are given. Between these households three characteristics can be identified: income, household size, and family phase. For the latter the distinction is relevant between pensioner households, households without



**Figure 8** Total annual energy requirements and energy requirement per budget category for households with different characteristics in the United Kingdom. Note: One gigajoule (GJ) =  $10^9$  joules (J, SI)  $\approx$   $2.39 \times 10^5$  kilocalories (kcal)  $\approx$   $9.48 \times 10^5$  British thermal units (Btu).

**Table 7** Overview of results for different household types in the United Kingdom

	<i>One Pensioner</i>	<i>Two Pensioners</i>	<i>Single</i>	<i>Two adults</i>	<i>One adult and children</i>	<i>Two adults and children</i>
Total energy intensity (MJ/Euro)	14.4	14.4	11.9	12.1	14.1	12.1
Total indirect energy intensity (MJ/Euro)	7.7	8.7	7.5	8.3	7.9	7.9
Share of direct energy use (%)	51%	45%	41%	36%	48%	39%
Total energy requirement per household (GJ)	150	246	217	406	237	426
Household size (persons)	1.0	2.0	1.0	2.0	2.8 <sup>a</sup>	3.8 <sup>a</sup>
Total energy requirement per person (GJ)	150	123	217	203	85	112

Note: One megajoule (MJ) =  $10^6$  joules (J, SI)  $\approx$  239 kilocalories (kcal)  $\approx$  948 British thermal units (Btu). One gigajoule (GJ) =  $10^9$  joules.

<sup>a</sup>Data on household sizes of these samples were not available. The household size is based on the fact that the average number of children in the United Kingdom is 1.8.

children, and households with children. For the income variable, the pattern as discussed above is valid, although the other characteristics may alter that pattern remarkably. For the household size variable the total energy requirement per household shows an increasing trend, as is also seen in the Netherlands when the three different family phases are considered case by case. The comparisons of all types together bring in additional factors (such as age). Single households have a higher energy requirement than one-pensioner households, as is also the case for two-adult households compared to two-pensioner households. Furthermore, households with one adult and children have an energy requirement much lower than that for two-adult households and a bit lower than that for two-pensioner households.

For each family phase, a few specific features are identified. Pensioner households have relatively low energy requirements for the categories of transport, recreation, and motor fuels, but have a high energy requirement for gas and electricity, explained by the relatively large amount of time spent at home and by relatively low incomes. For single and two-adult households, energy requirements for food, gas, and electricity are relatively low and energy requirements for recreation, transport, and motor fuels are relatively high. Households with children have relatively high energy requirements for food. The

two types of households with children have large differences. Households with two adults and children have relatively high energy requirements for recreation, transport, and motor fuel, whereas households with one adult and children have high energy requirements for gas and electricity. For the latter, this again can be explained by the large amount of time spent at home and the low expenditures.

The energy requirement per person decreases with increasing household size for pensioner households. For single and two-adult households the energy requirement per person is approximately the same. For households with children the energy requirement per person is the lowest compared to the other households, and the figures for households with one adult and children are lower than those for two adults and children.

## Discussion and Conclusions

The results for the four countries are strikingly similar. In all countries and for all household types, heating, electricity, food, transport, and recreation are the most important categories with regard to energy requirements. Apparently in these wealthy (north-) western European countries, consumption patterns and the resulting energy requirements are similar, but important differences do exist. Discussing these differences, we

try to identify determinants that may explain the environmental load due to household consumption.

The three main determinants of the differences in average household energy requirements between countries are the efficiency of electricity generation, the average levels of household expenditures, and the average indirect energy intensities. We learn from this analysis that reducing energy use in the economic sectors and especially in the electricity production sector is an important strategy.

The main determinant of the differences in average household energy requirements within countries is the average expenditure level of the household. We also observe, however, that in urban areas direct energy use, especially for motor fuels, is lower than in the corresponding national average data. This suggests that on the city level some triggers exist to decrease direct energy requirements: a traffic and transportation system that includes cycling and public transport, and a compact city structure in which local recreational facilities are available.

The quantitative differences between households with different characteristics (income, size of household, and so on) are mostly explained by the level of household expenditure. Other determinants are relevant as well. For a low-income household, the share of the household budget used for heating and electricity is high (together around 50% of the total energy requirement) and the share for motor fuel, transport, and recreation is low (together less than 20%). For a high-income household, the share for heating and electricity is low (together 25–35%) and the share for motor fuel, transport, and recreation is high (together 30–40%). Comparing households of differing size, we observe a remarkable difference with regard to the average energy requirement per person. A small household demonstrates a relatively high energy requirement per person. Similar results were found by Vringer and Blok (1995) and by Pachauri (2004).

The results presented in this article were generated by a specific method. This method enables us to study factors at the national level, at the local level, and at the household level together in a consistent methodological framework. Here we discuss briefly the most important source of

uncertainty influencing the significance of these results (see Kok et al. 2003 for a full discussion of uncertainties with regard to these results).

The Dutch EAP model was modified for application in other countries. For this purpose, databases describing other countries should be constructed and also country-specific analyses of products (i.e., budget items) should be performed. As much as possible, country-specific data were used for these modifications. We were not able, though, to fully replace the complete Dutch data set. Assessing this source of uncertainty, we conclude that the quantitative figures related to indirect energy use in the countries other than the Netherlands have a considerable margin of error. Because different assumptions have been made for each country, caution is required in comparing the absolute results describing the indirect energy use of these countries. Even so, the results do allow comparative conclusions within countries to be made to a fairly high level of certainty, and are therefore useful for our purposes. This is because the main uncertainties work in the same direction for all household types. So the conclusions about the determinants presented above are not affected by these sources of uncertainty.

The most important determinant explaining household energy requirements is the average level of household expenditure (or income). This was also found in other studies—in the Netherlands by Vringer and Blok (1995), in India by Pachauri (2004), and in Brazil by Cohen and colleagues (2005). But it would be socially and politically very difficult to reduce expenditures in order to achieve reductions in the environmental load. Other determinants are identified at the various system levels that are more susceptible to change and may serve better than those at the expenditure level as trigger points to affect decreases in the environmental load of production and consumption patterns. The relevant factors to affect change are as follows:

- At the (inter)national level, the structure of the economy and the structure and efficiency of the energy supply system determine the prices of goods and services and the energy intensity of consumer items.

- At the city level, the physical structure (such as the transport and energy infrastructure), the way in which buildings, houses, and other facilities are situated, the quality of the public transport system, and the (thermal) quality of dwellings all influence direct household energy requirements.
- At the level of individual households, the division of the budget among different consumption items and categories and the use of direct energy determine to a high extent the household energy requirements.

The identification of these determining factors is helpful for governmental, economic, and institutional actors in designing approaches and policies aiming at a decrease in the environmental load of household consumption. The consistent set of data describing production and consumption developed by the EAP is also useful in the following ways for the practical implementation of more sustainable production and consumption patterns: The calculated energy requirements and energy intensities of different consumption categories and more than 300 consumption items can offer help in daily environmentally motivated decision making about consumption. In several projects in the Netherlands such data were used fruitfully (for a discussion and evaluation of Dutch “sustainable consumption” projects, see Moll and Groot-Marcus 2002). In the ToolSust project these data were used in workshops with consumers, stakeholders, and governmental authorities to design images of everyday life in the future city (Carlson-Kanyama et al. 2003).

This article presents an analysis of average household energy requirements results. Such results are important for general communication with citizens, but are of limited use in addressing change in a specific household (Nonhebel and Moll 2001).

Finally, we would like to stress that the average household does not exist, so options based on average results have a general value but will not optimally fit the change potential of each individual household. Reasoning further along this line, one should advocate personalized energy advice to households addressing their consumption pattern. In a recent project (Wiersma et al.

2003) this approach was used experimentally for households in Groningen in a computer-aided information and feedback experiment. Based on the answers given to a questionnaire—filled in online—the direct and indirect energy use of the household of the participants was evaluated, and targeted advice about energy savings was provided instantly to the participants. Some months later a behavioral change was determined and the effects on direct and indirect energy were calculated and communicated to the participants. The evaluation of this experiment showed promising results: an average reduction in both the direct and indirect household energy requirements of more than 5% realized during the half-year. The EAP approach was used in this experiment to predict the effect of energy-saving options and to evaluate the results of behavioral change.

## Notes

1. For an analysis of household energy requirements in Sweden, see the article by Carlsson-Kanyama and colleagues (2005) in this issue of the *Journal of Industrial Ecology*.
2. The ToolSust project—with the full name *The involvement of stakeholders to develop and implement tools for sustainable households in the city of tomorrow*—was developed within the fifth framework programme of the EU, as a part of Energy, Environment and Sustainable Development, *Key action 4: City of Tomorrow and Cultural Heritage, 4.1.2 Improving the quality of urban life*. An important objective of this project is the development of tools to measure the impact of consumption and to develop approaches to direct consumption toward sustainability.
3. One megajoule (MJ) =  $10^6$  joules (J, SI)  $\approx$  239 kilocalories (kcal)  $\approx$  948 British thermal units (Btu).
4. One kilogram (kg, SI)  $\approx$  2.204 pounds (lbs).

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## About the Authors

**Henri C. Moll** is a professor of resource management for sustainable production and consumption,

**Klaas Jan Noorman** is an assistant professor, and **Rixt Kok** is a research fellow at the Center for Energy and Environmental Studies (IVEM), University of Groningen, the Netherlands. **Rebecka Engström** is a research fellow at the Center for Environmental Strategies Research—fms, KTH, Stockholm, Sweden. **Harald Throne-Holst** is a researcher at the National Institute for Consumer Research (SIFO), Oslo, Norway. **Charlotte Clark** is a research fellow at the Department of Psychology, University of Surrey, Guildford, UK.